Noble Liquids for WIMP Searches

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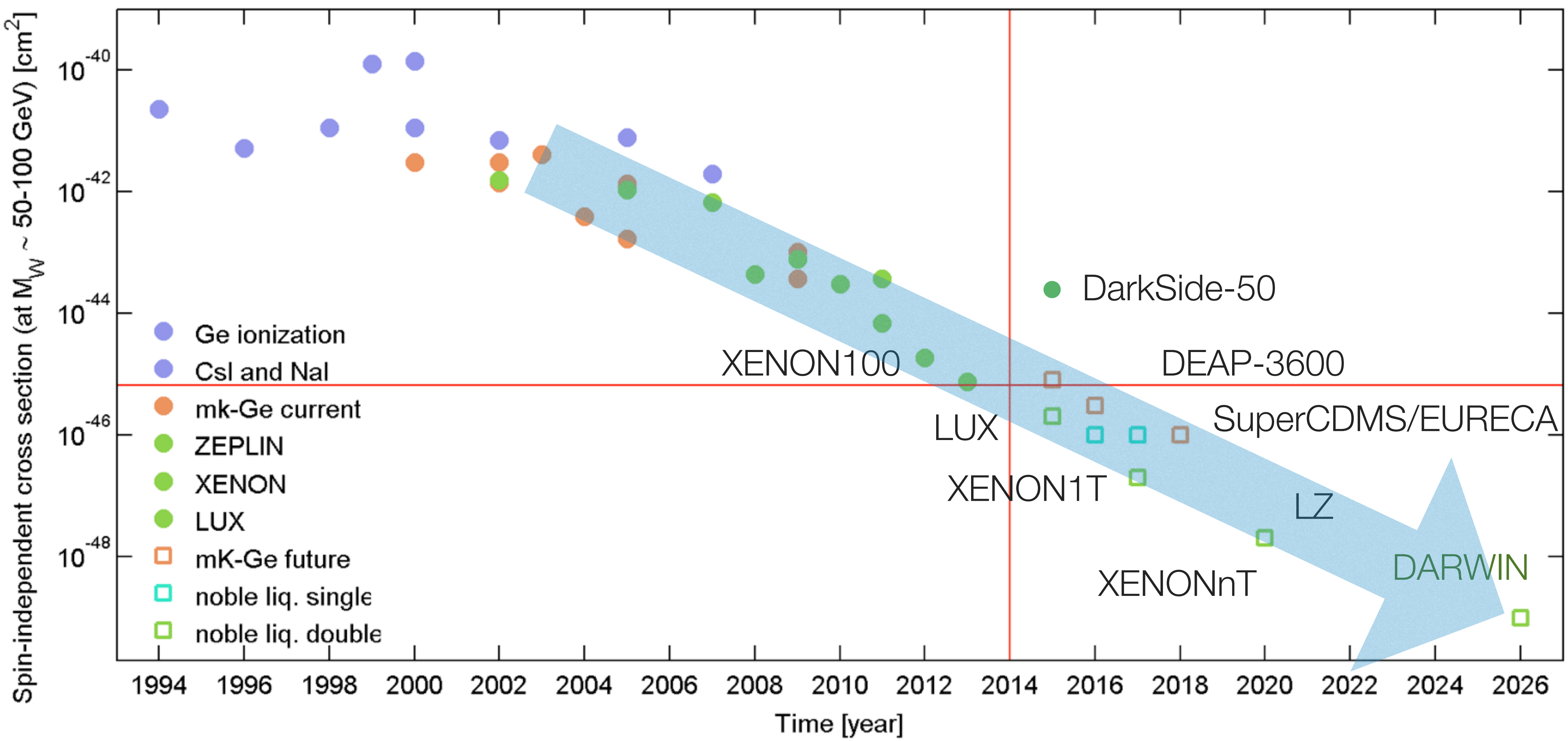
May 3, 2018

WIMP-nucleon cross section versus time

- About a factor of 10 increase every ~ 2 years
- Progress led by searches using **noble liquids**



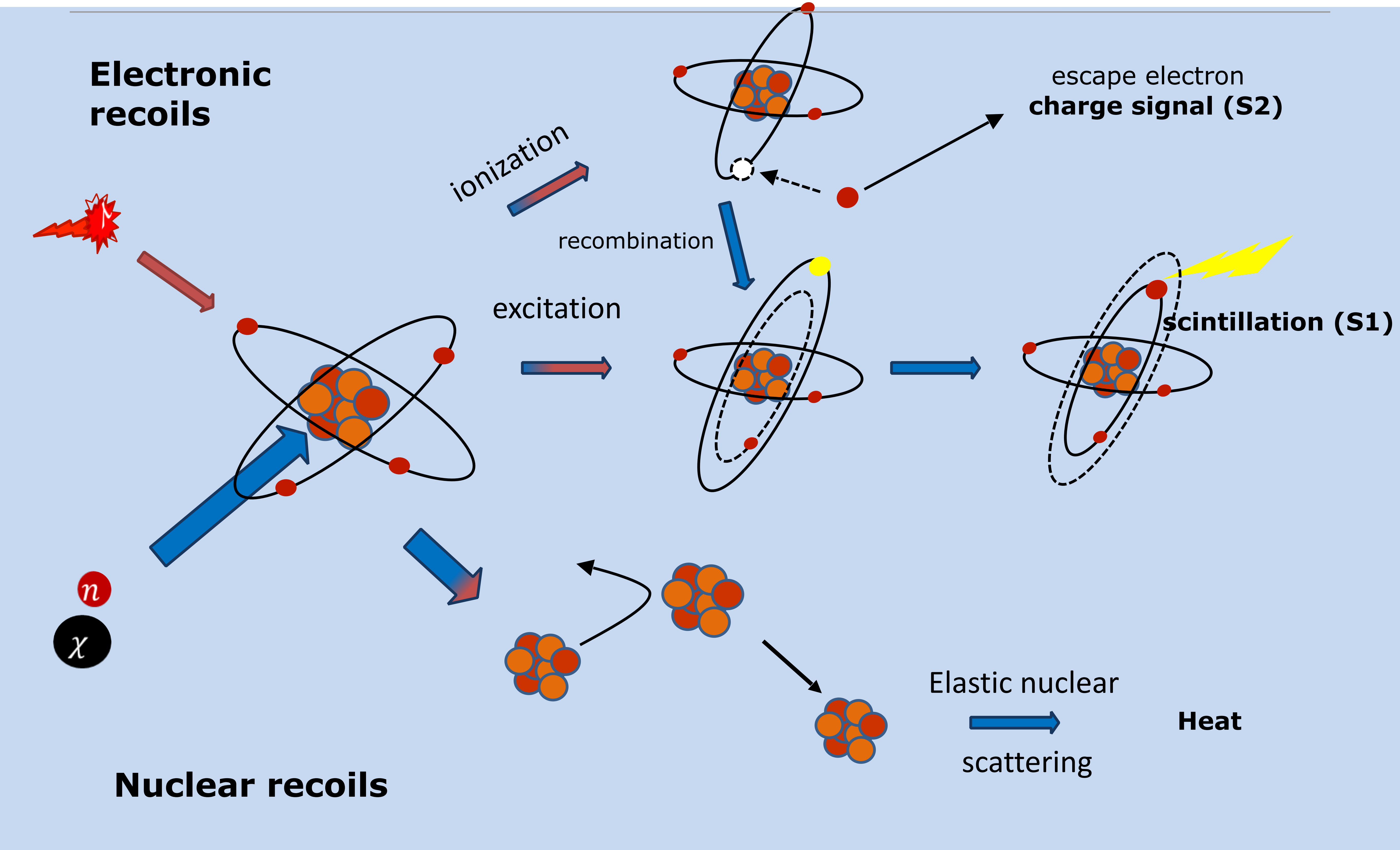
LB, Physics of the Dark Universe 4, 2014

Noble Liquids: some properties

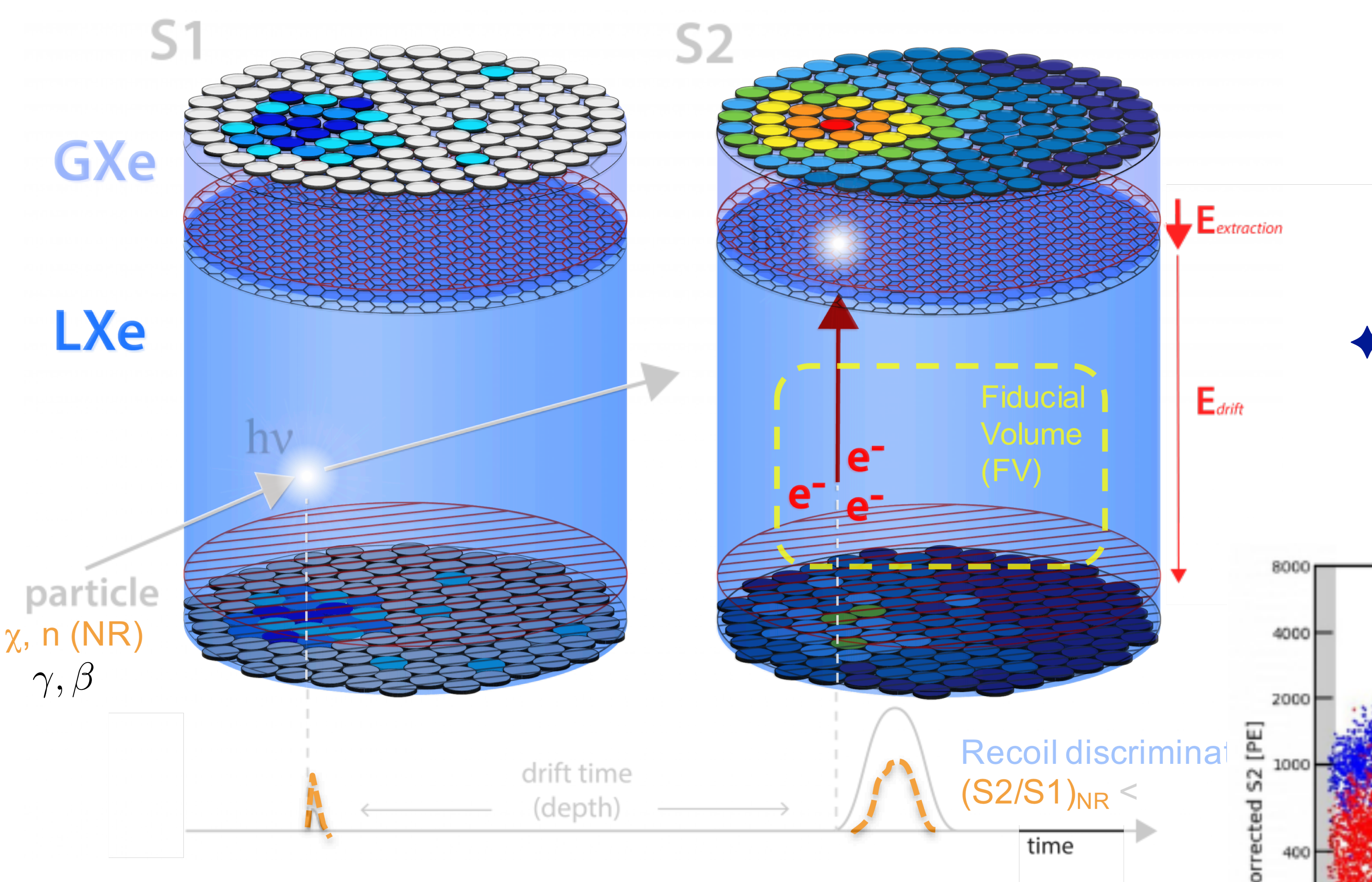
- ➡ large volume, homogeneous targets and detectors
- ➡ high density and Z enable effective self-shielding
- ➡ do not attach electrons; transparent to own light; not flammable, excellent dielectrics
- ➡ commercially easy to obtain and purify; moderate cryogenics
- ➡ high scintillation and ionization yield

Element	Z (A)	BP (T_b) at 1 atm [K]	liquid density at T_b [g/cc]	ionization [e^-/keV]	scintillation [photon/keV]
He	2 (4)	4.2	0.13	39	15
Ne	10 (20)	27.1	1.21	46	7
Ar	18 (40)	87.3	1.4	42	40
Kr	36 (84)	119.8	2.41	49	25
Xe	54 (131)	165	3.06	64	46

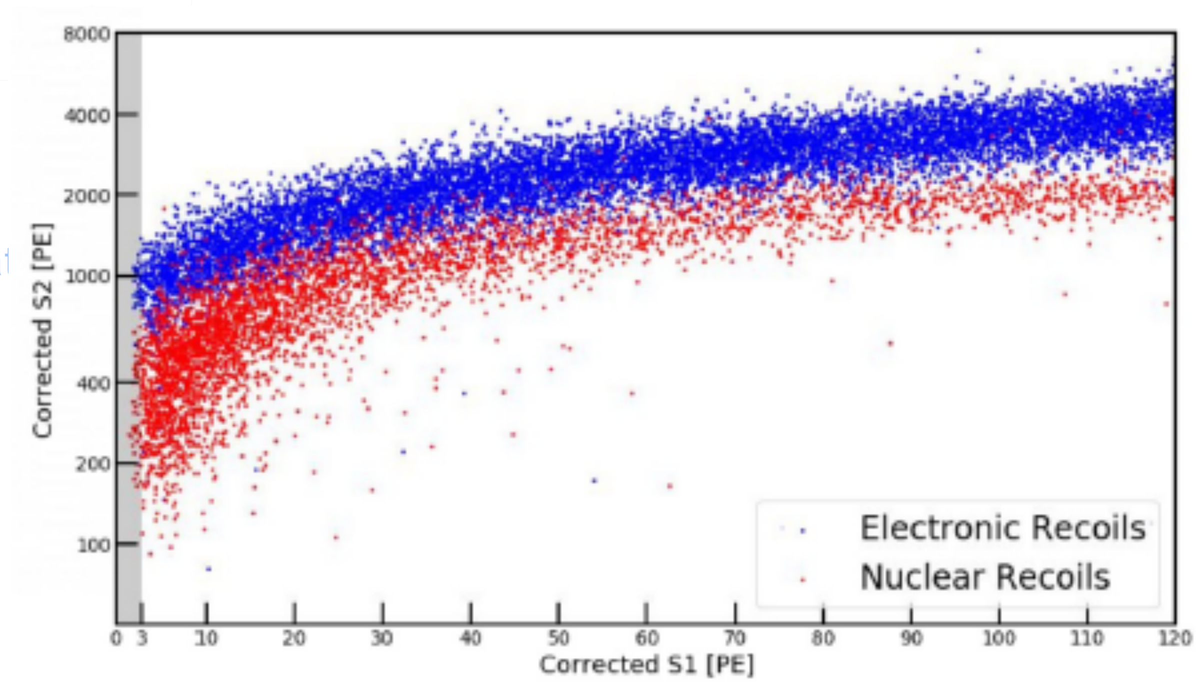
Signals in Noble Liquids



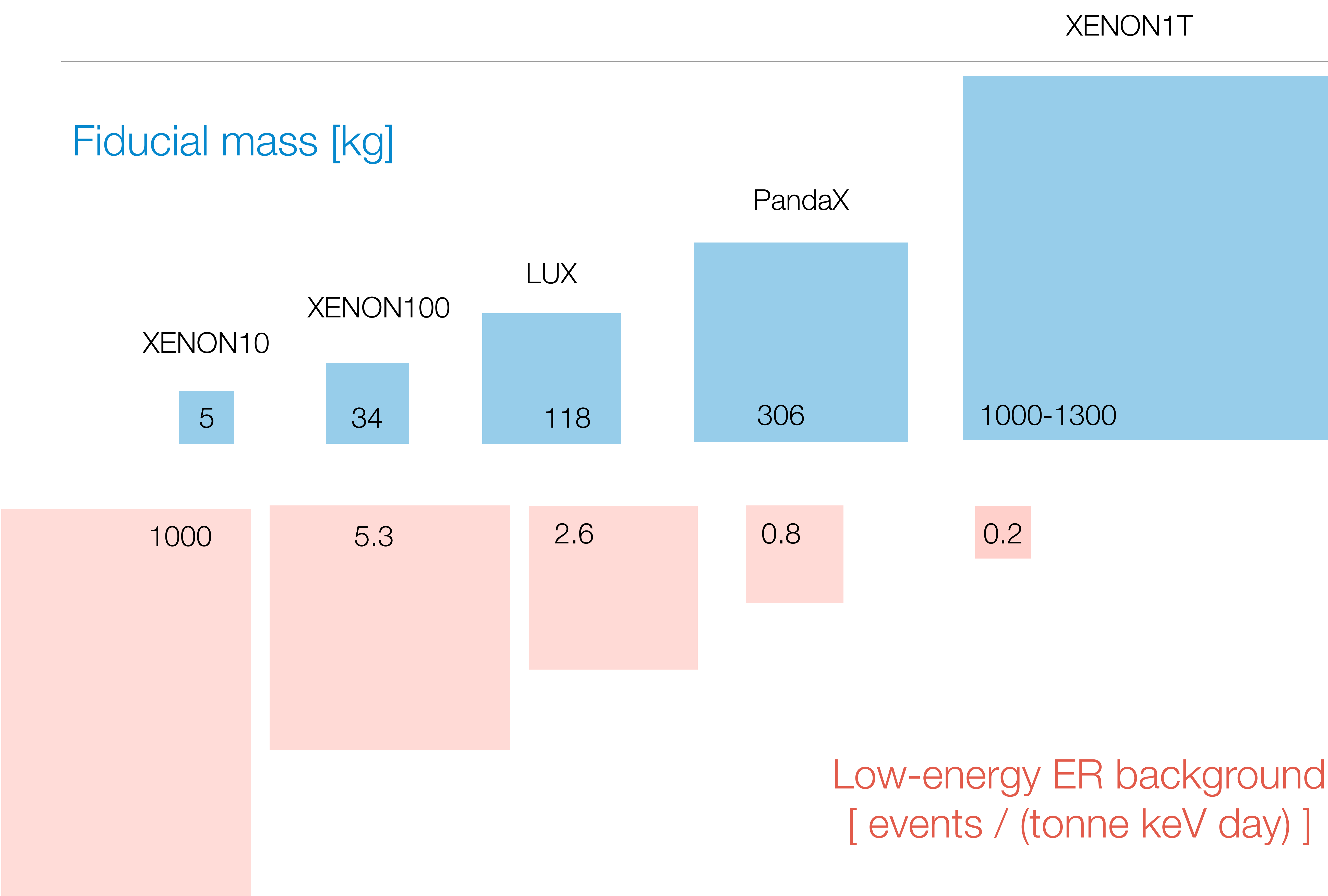
Two-phase Xe Time Projection Chamber as WIMP detector



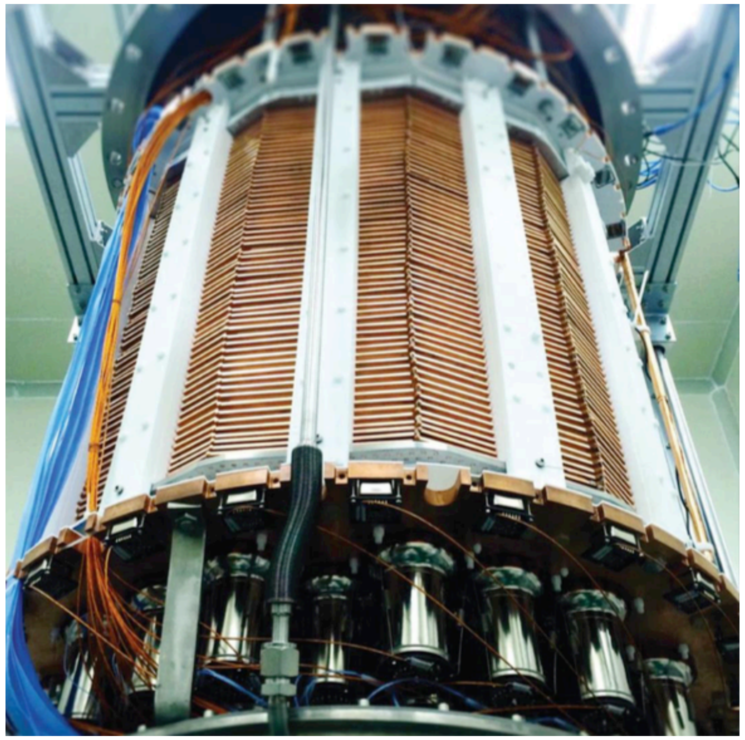
- two signals for each event:
  - Energy from S1 and S2 area
  - 3D event imaging: x-y (S2) and z (drift time)
  - self-shielding, surface event rejection, single vs multiple scatter events
- Recoil type discrimination form ratio of charge (S2) to light (S1)



The impressive evolution of LXeTPCs as WIMP detectors

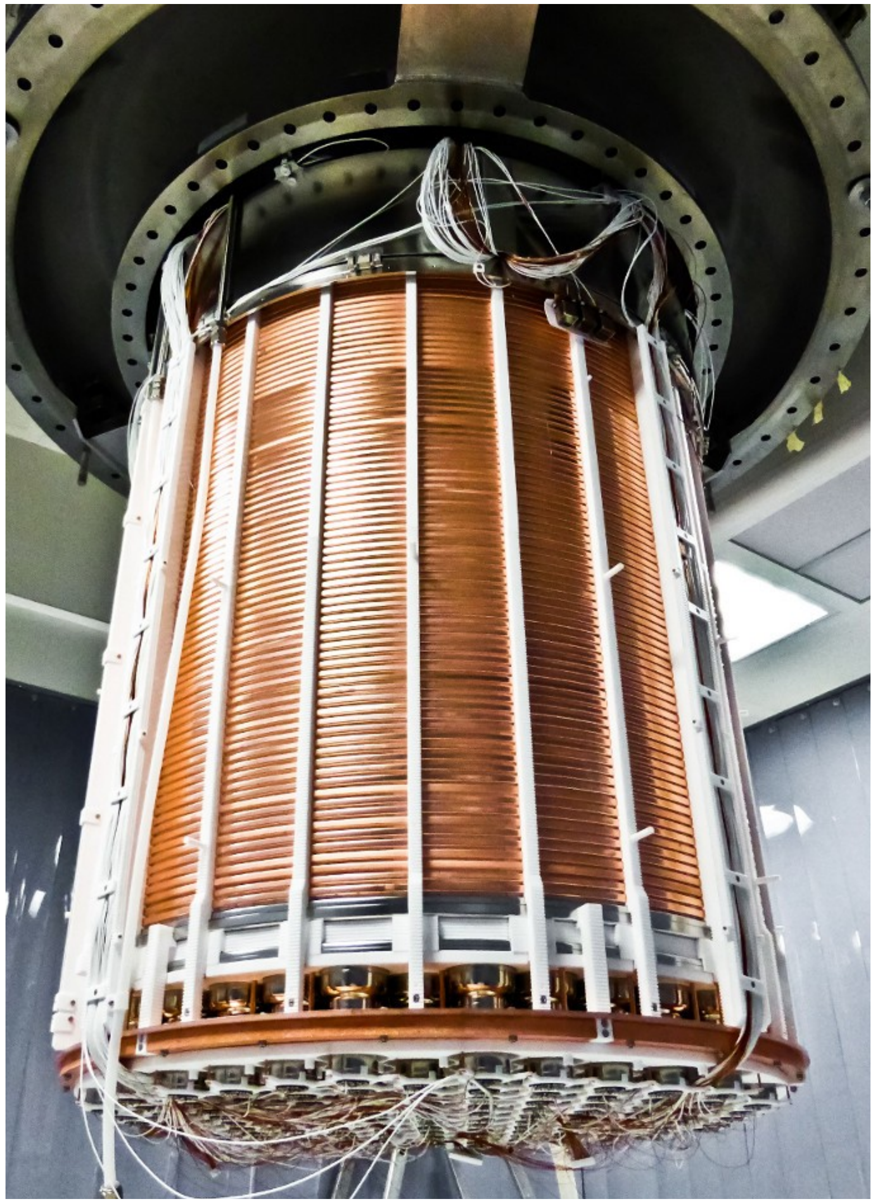


Liquid Xenon Detectors: in operation (till 2018)



PandaX-II @ CJPL

580kg of LXe



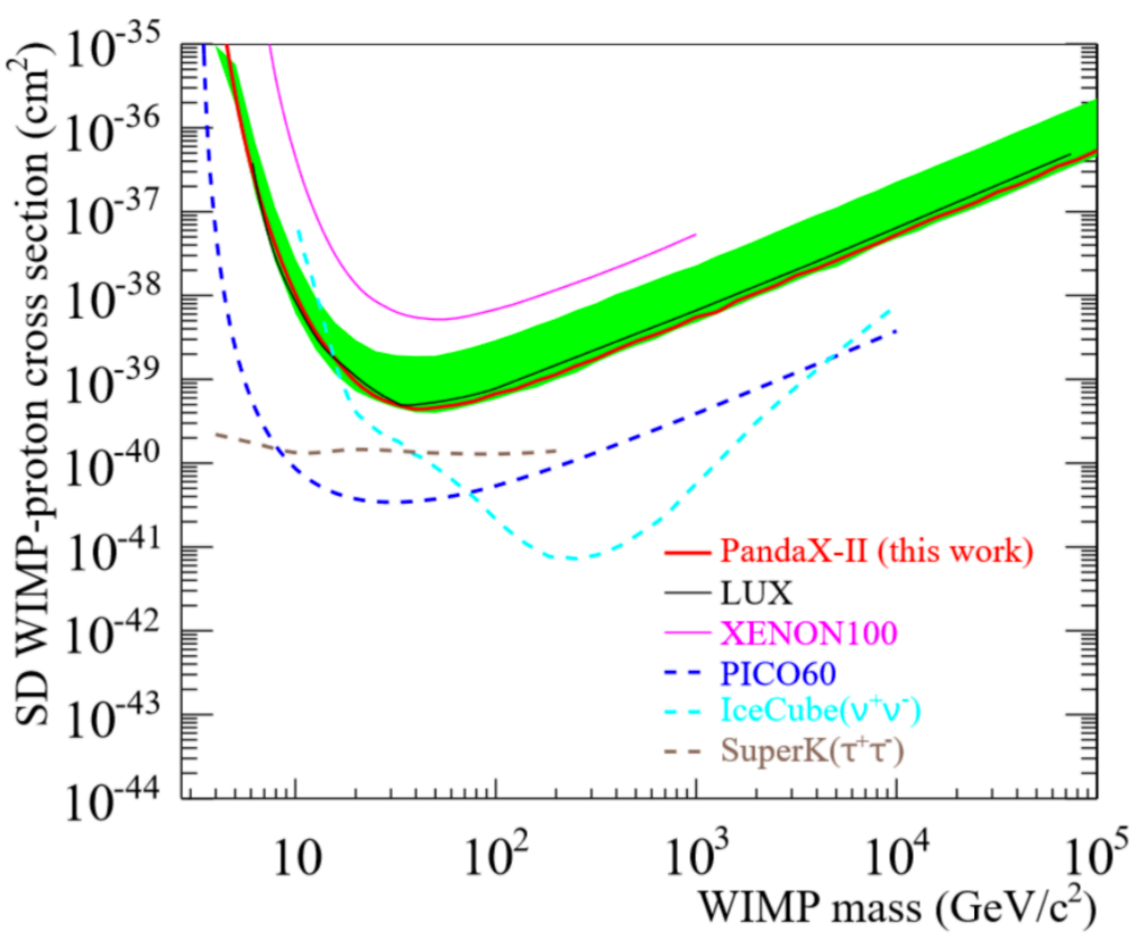
XENON1t @ LNGS

2000 kg of LXe

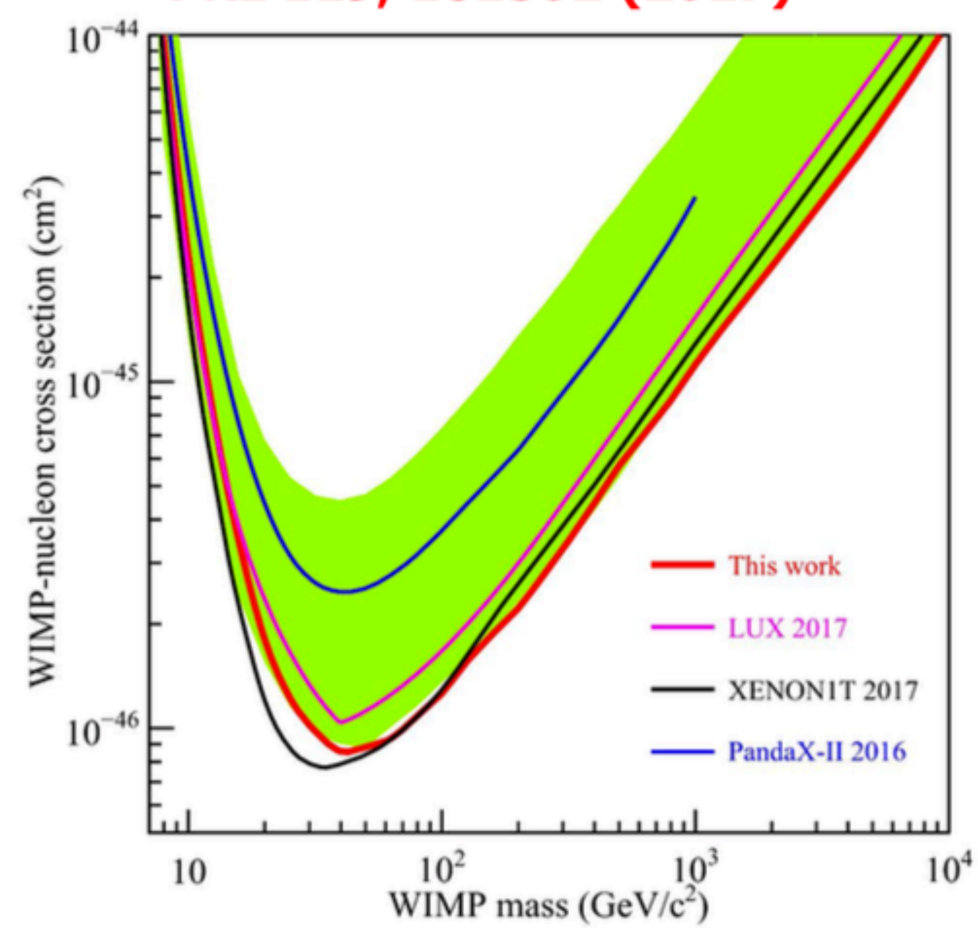
PandaX-II Dark Matter Search Results

	ER	Accidental	Neutron	Total Fitted	Total Observed
Run 9	376.1	13.5	0.85	390 ± 50	389
Below NR median	2.0	0.9	0.35	3.2 ± 0.9	1
Run 10	172.2	3.9	0.83	177 ± 33	177
Below NR median	0.9	0.6	0.33	1.8 ± 0.5	0

- Both Run 9,10 have downward fluctuation of background
- Similar limit to XENON1T 30-day result, but slightly worse sensitivity

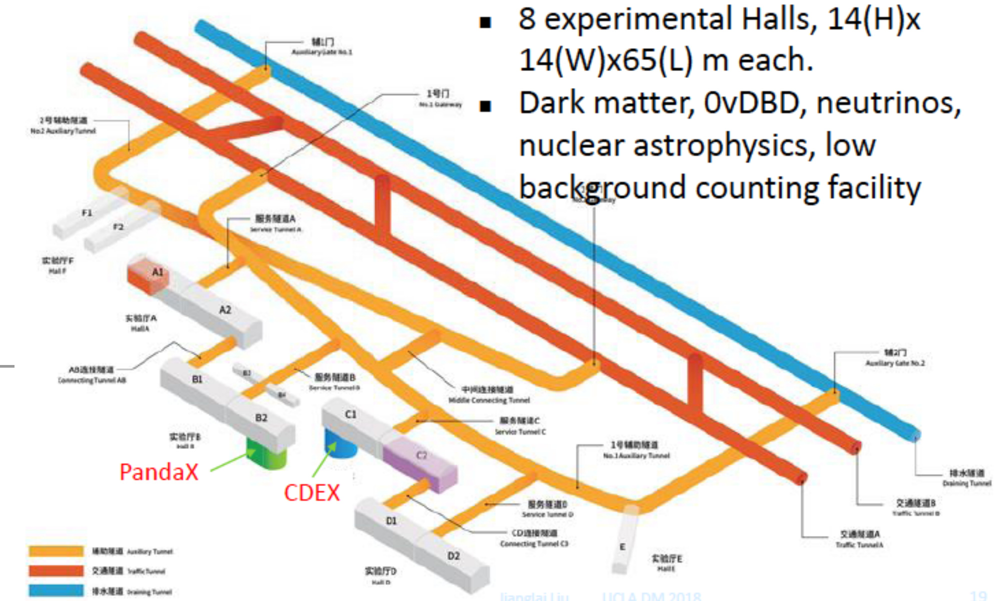


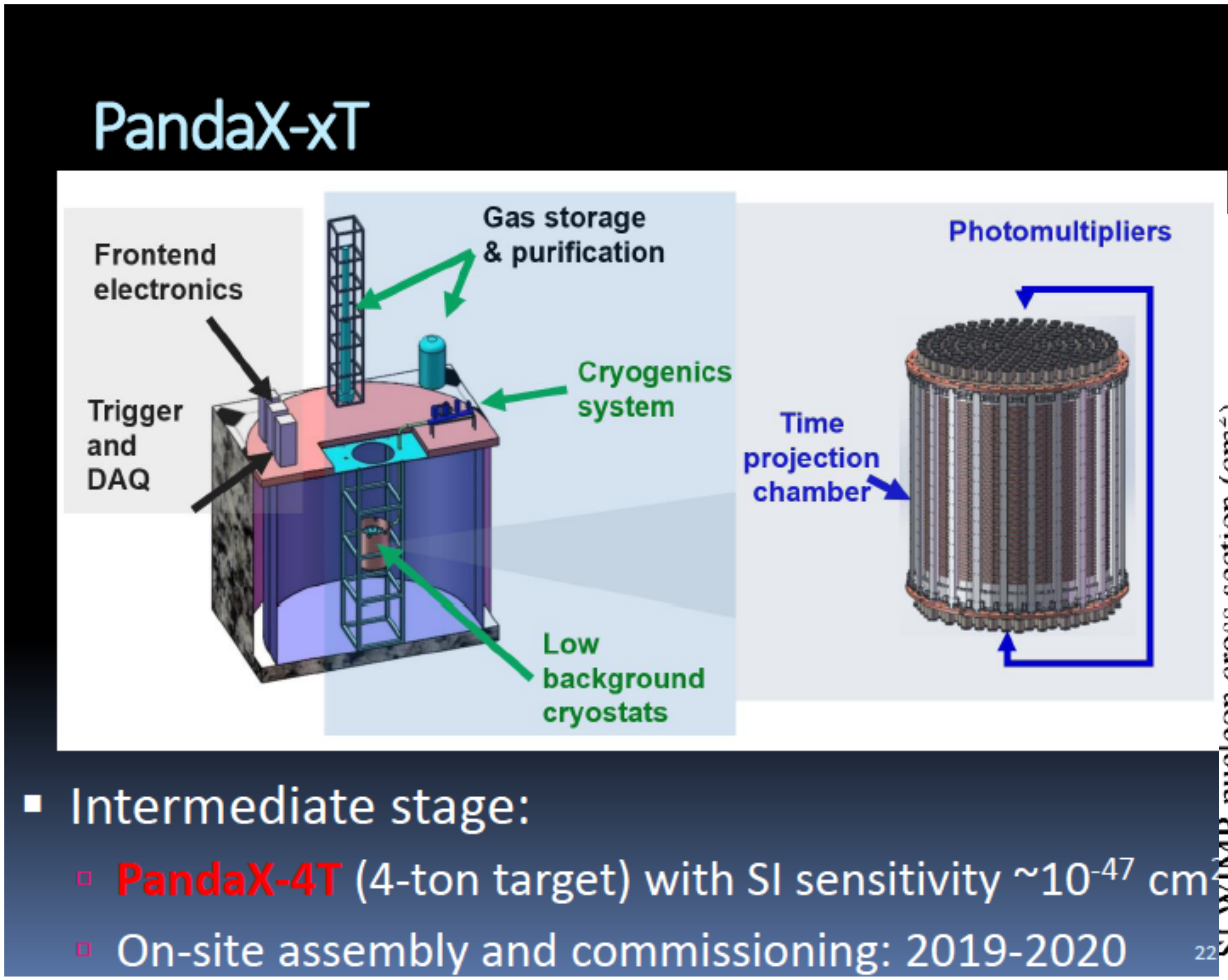
PRL 119, 181302 (2017)

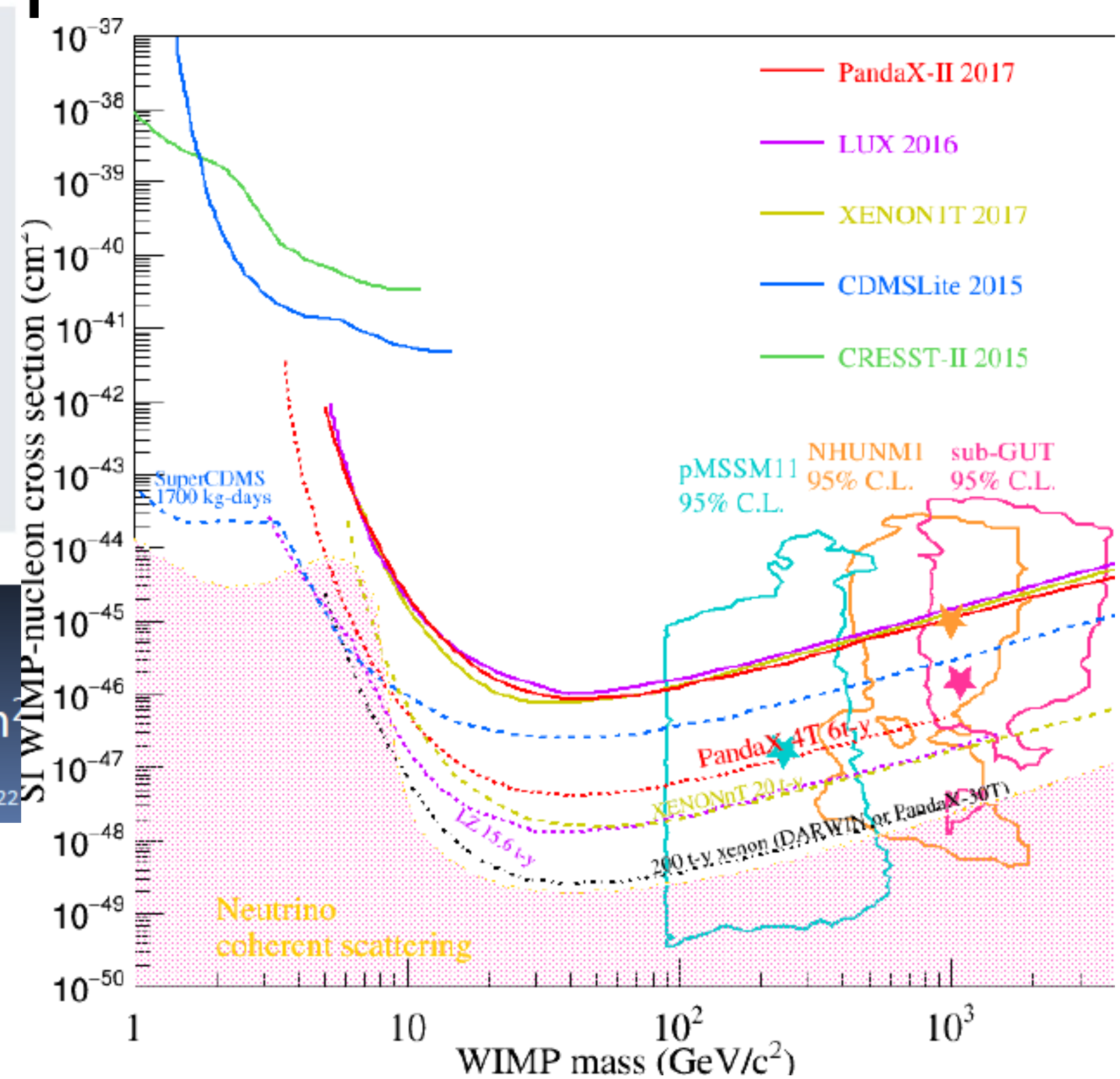


PandaX Future @ CJPL-II

- 8 experimental Halls, 14(H)x 14(W)x65(L) m each.
- Dark matter, 0vDBD, neutrinos, nuclear astrophysics, low background counting facility



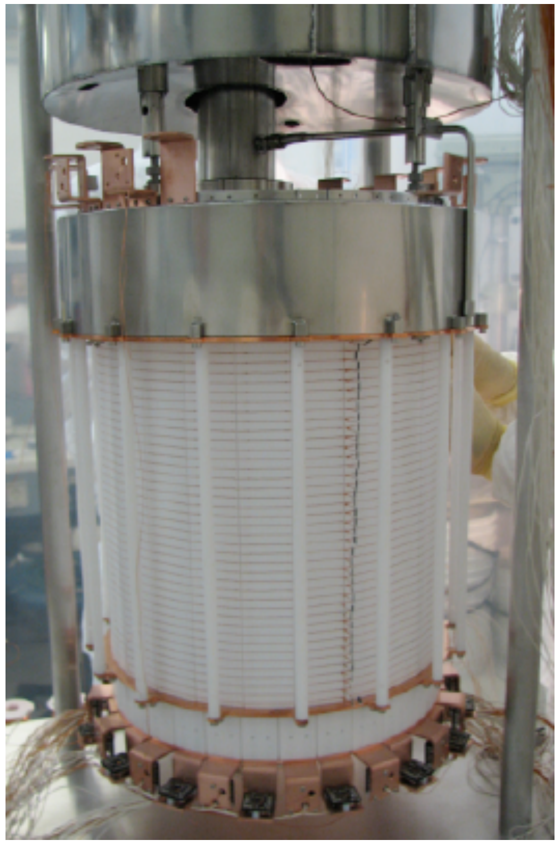


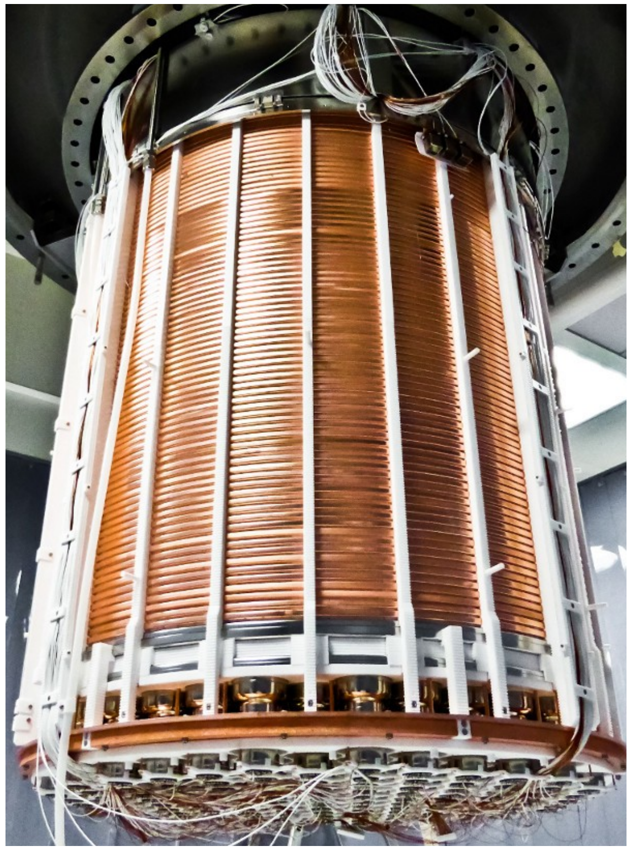


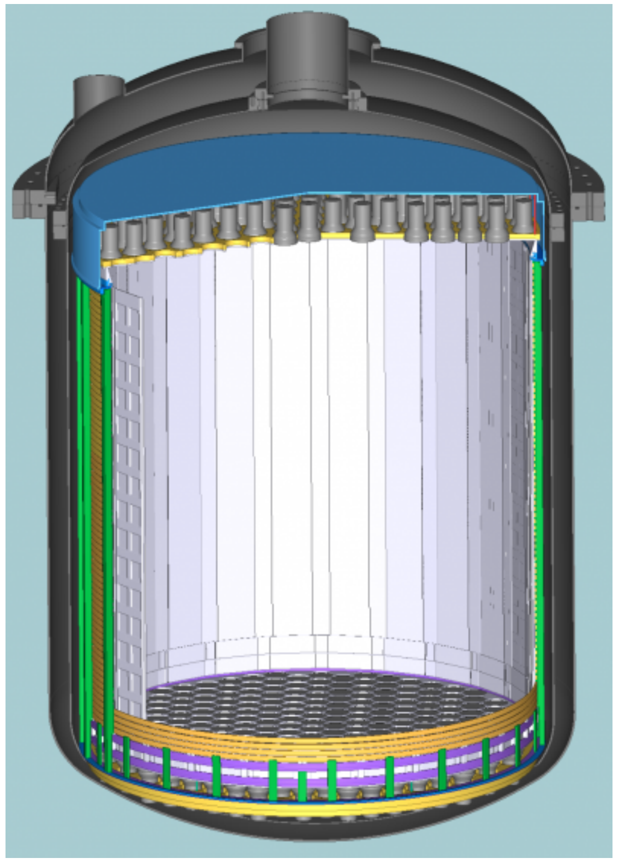
Jianglai Liu UCLA DM 2018

The phases of XENON

XENON10 XENON100 XENON1T XENONnT







2005-2007	2008-2016	2012-2018	2019-2023
25 kg - 15cm drift	161 kg - 30 cm drift	3.2 ton - 1 m drift	8 ton - 1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

XENON1T Overview

EPJ C 77, 881 (2017)

Water tank and
Cherenkov muon veto

Cryostat and support
structure for TPC

Time Projection
Chamber / Feed
Pipe

Cryogenics/
Purification/
Calibration sources

Electronics/
Data acquisition/
Slow Control

Xenon Storage/
Recovery
Kr-distillation column
Gas handling/
analytics

The XENON Collaboration: ~170 scientists

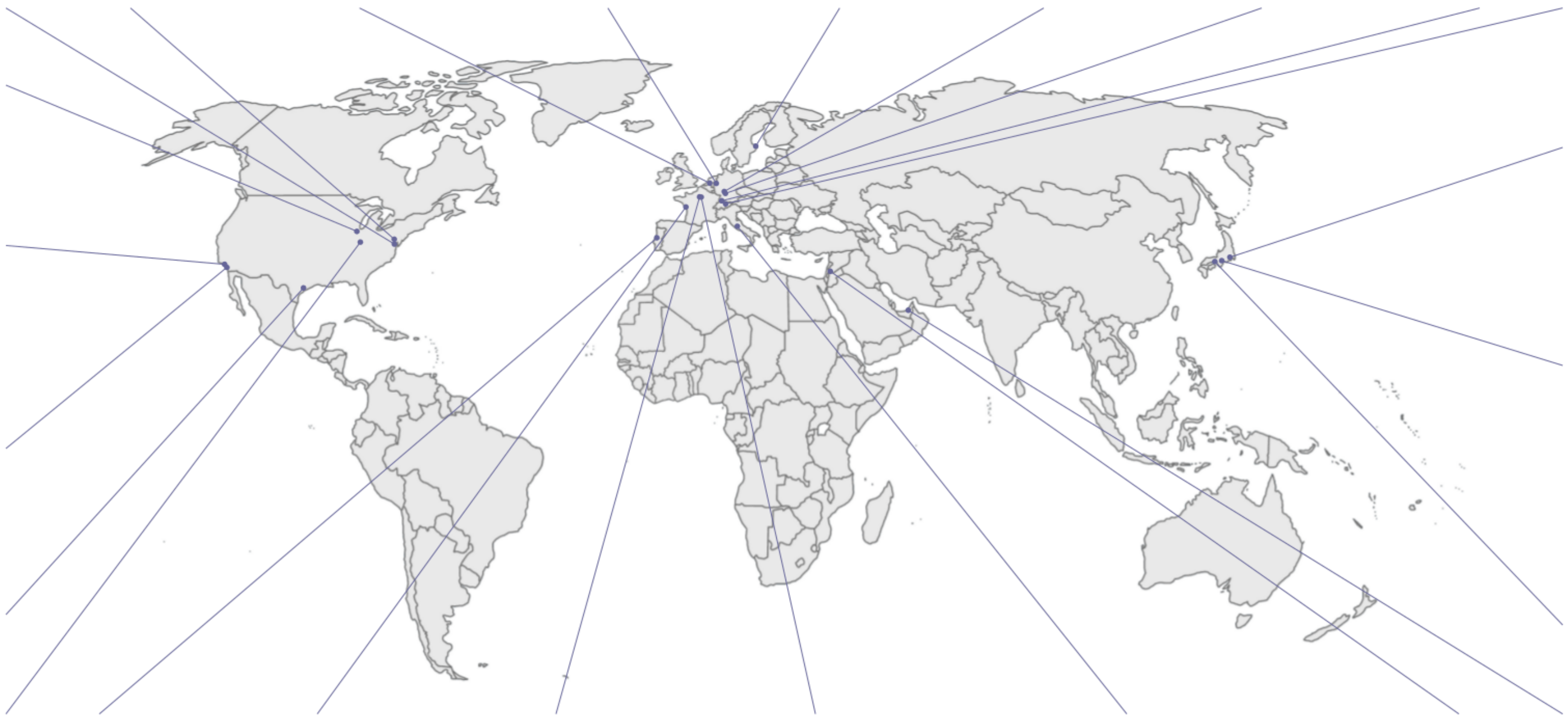
Columbia | RPI | Nikhef | Muenster | Stockholm | Mainz | MPIK | Freiburg | Zurich

Chicago

UCLA

UCSD

Rice



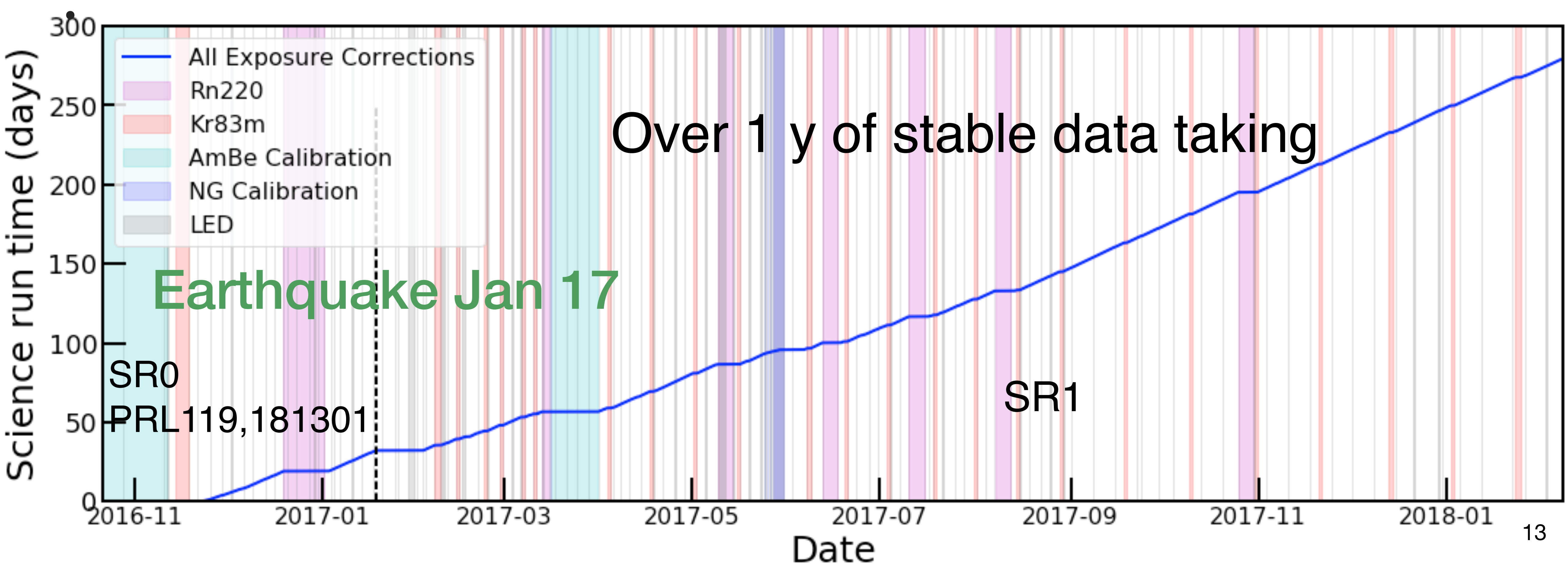
Tokyo

Nagoya

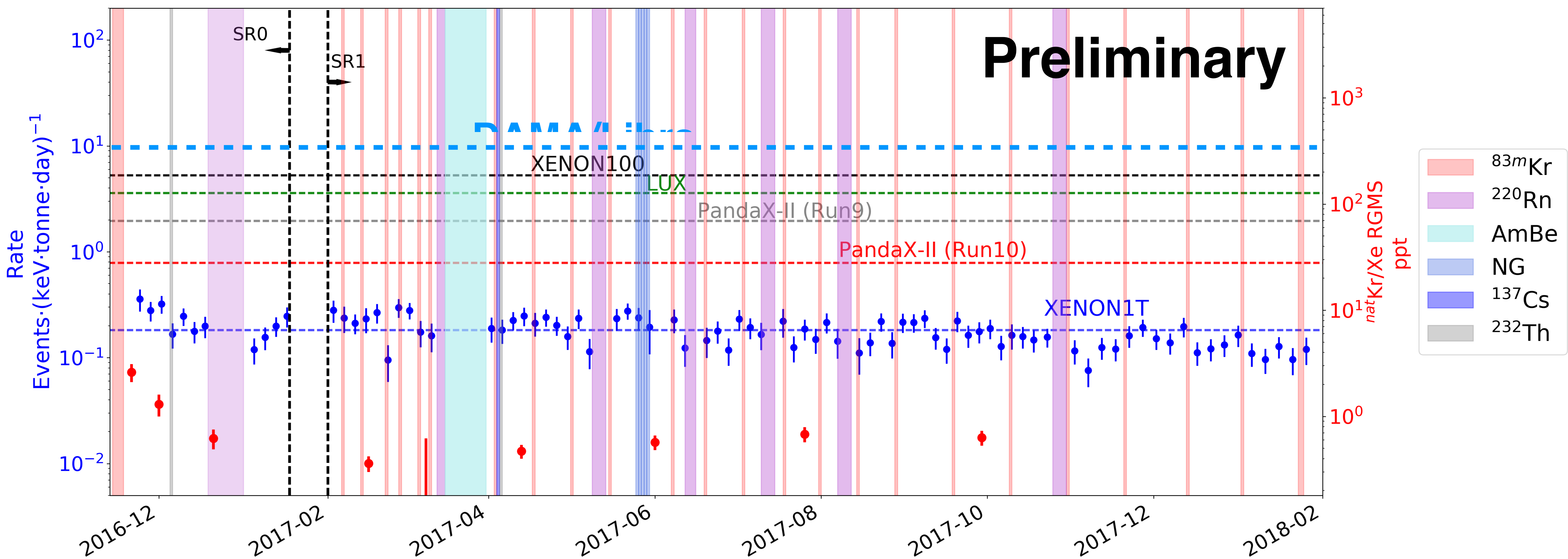
Kobe

XENON1T Data overview: science and calibration

- Detector still running smoothly and taking data with high efficiency
- SR0 (34 days): best SI limit 7.7 x 10^{-47} cm^2 at 35 GeV/cm^2 (PRL 119, 2017)
- SR1 (247 days): improved detector stability - calibration statistics - refined analysis
- Result from combined 1 ton x year exposure (1.3 ton fiducial mass) within this month



ER Background: Data



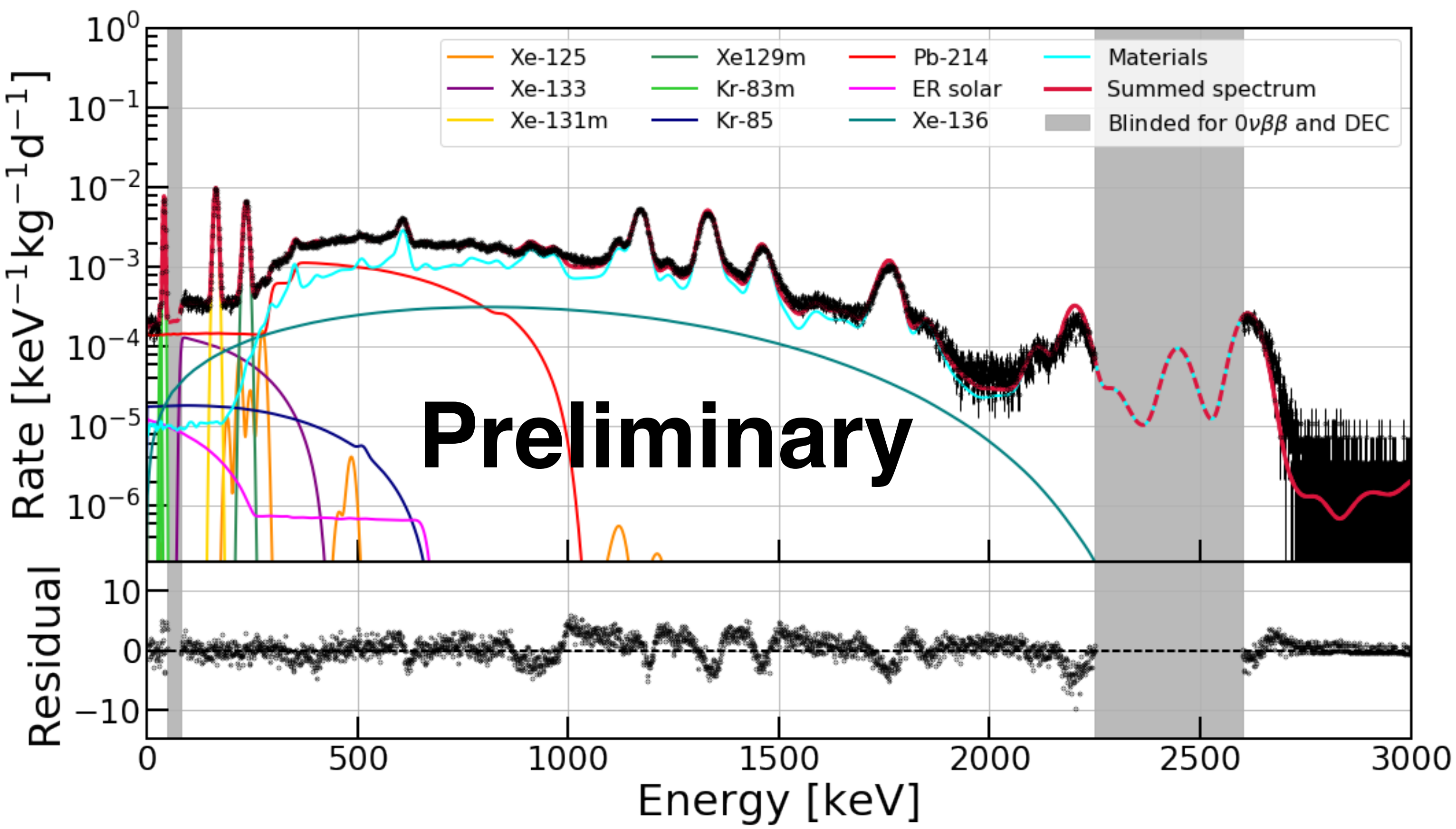
Measured in SR1: (1.7 +/- 0.25) 10^{-4} events / (kg day keV) in 1300 kg FV and 5-40 keVnr

Predicted for SR1 (considering the average 0.45 ppt of Kr): (1.9 +/- 0.2) 10^{-4} events / (kg day keV)

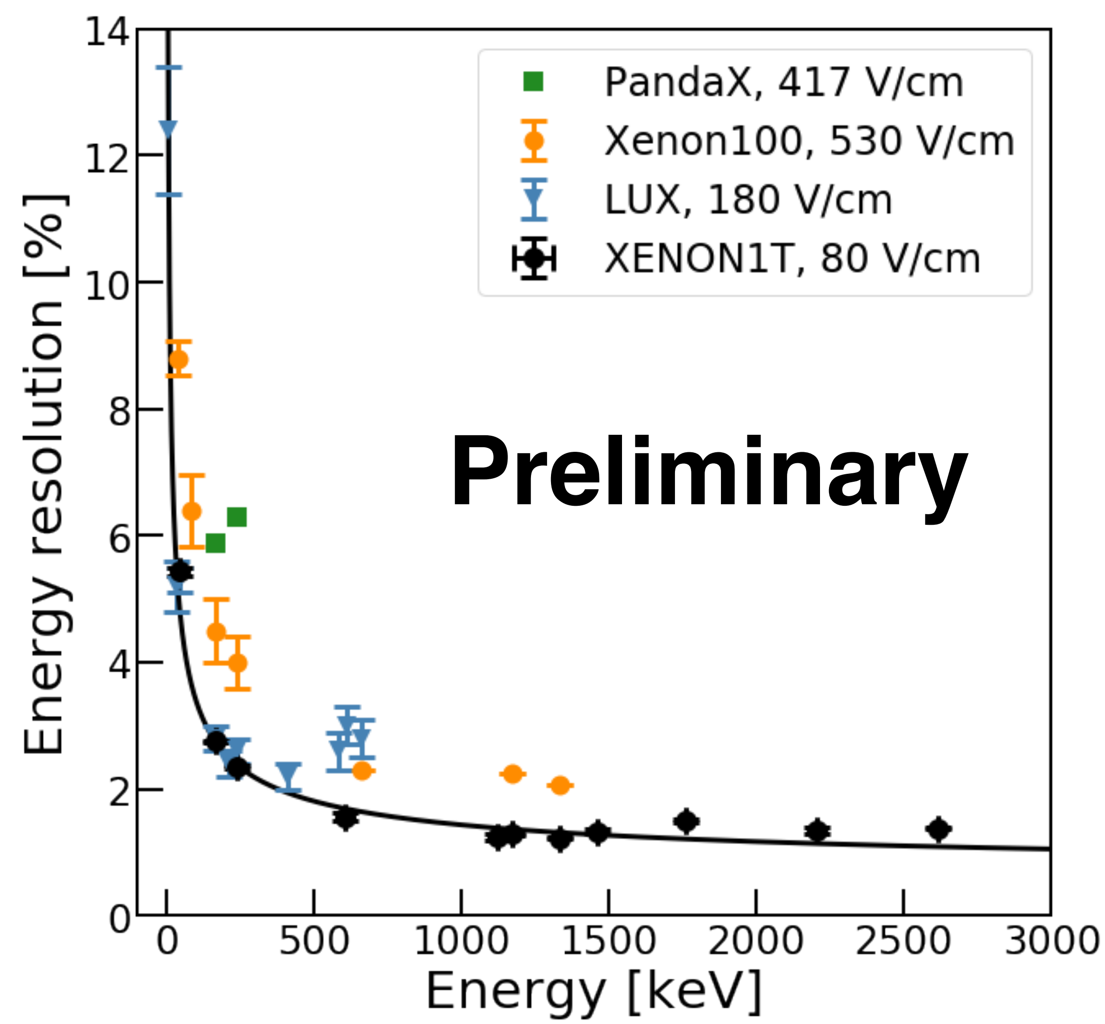
Lowest ER background ever achieved in a DM detector !

Dominated by Pb214 from Rn222.

Background Data: Energy Spectrum and Energy Resolution

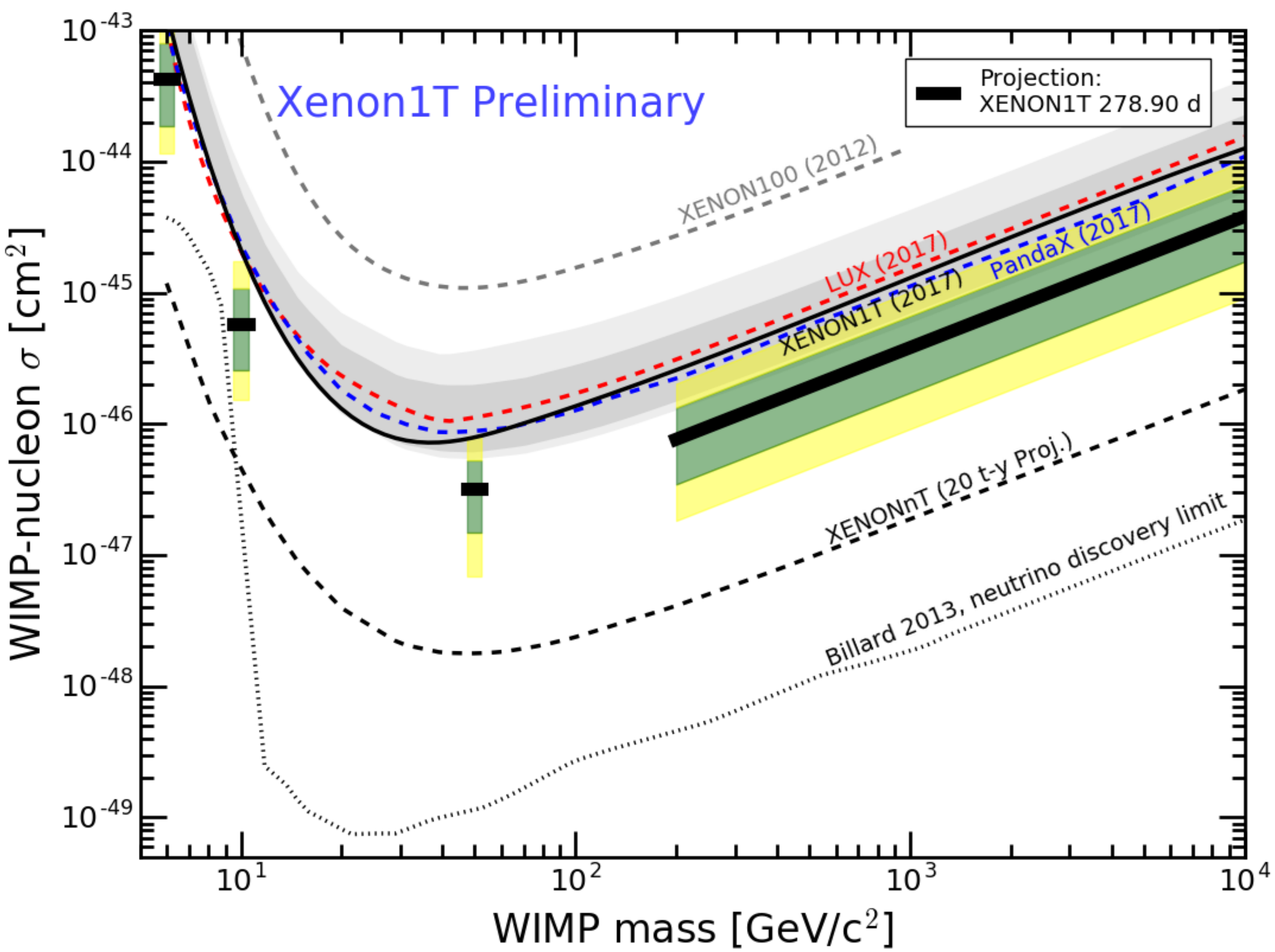


- Excellent energy resolution measured with a large LXeTPC
- ~1.6% resolution (sigma) at 2.5 MeV



- Good agreement between predicted and measured background spectrum
- Kr: ~0.45 ppt; Pb214: ~ 10 uBq/kg
- Gammas based on screening measurements

XENON1T Sensitivity Projection



- Given injected signal with cross-section right below our first-results limit, the chance to see a 3-sigma excess in full exposure is ~ 50%
- Expected sensitivity at 4 typical WIMPs masses: 6, 10, 50, 200 GeV
- A factor of ~3 median sensitivity increase compared to SR0

The next step: XENONnT

Aprile et al., Eur. Phys. J. C (2017) 77: 881. *XENON1T sub-systems*

Aprile et al., JCAP 77 (2016), 358. *online Rn-removal*

Aprile et al., Eur. Phys. J. C (2017) 77: 275. *online Kr-removal*

Aprile et al., JCAP 4 (2016), 27. *sensitivity*

Minimal Upgrade

The XENON1T infrastructure and sub-systems were originally designed to ***accommodate a larger LXe TPC***.

Fiducial Xe Target

XENONnT TPC

features:

total Xe mass = 8 t

target mass = 5.9 t

fiducial mass = ~4 t

Background

Record low-back levels in XENON1T dominated by ^{222}Rn-daughters.

Identified strategies to effectively ***reduce ^{222}Rn by ~ a factor 10***.

Fast Turnaround

Use ***XENON1T sub-systems,*** already tested

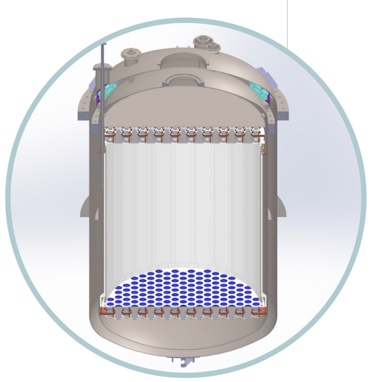
Fast pace:

Installation starts in 2018

commissioning in 2019

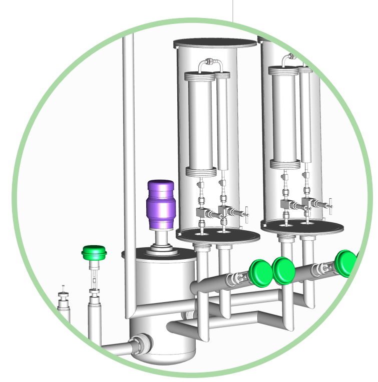
XENON1T Facilities and sub-systems (already operative)

Aprile et al., Eur. Phys. J. C (2017) 77: 881



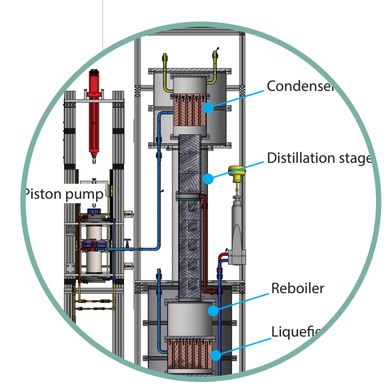
New TPC

5.9-ton Time Projection Chamber



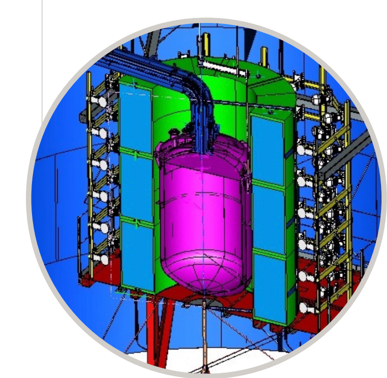
LXe Purification

To achieve fast cleaning of the large LXe volume (5000 SLPM)



Radon Distillation

To online remove the ^{222}Rn emanated inside the detector



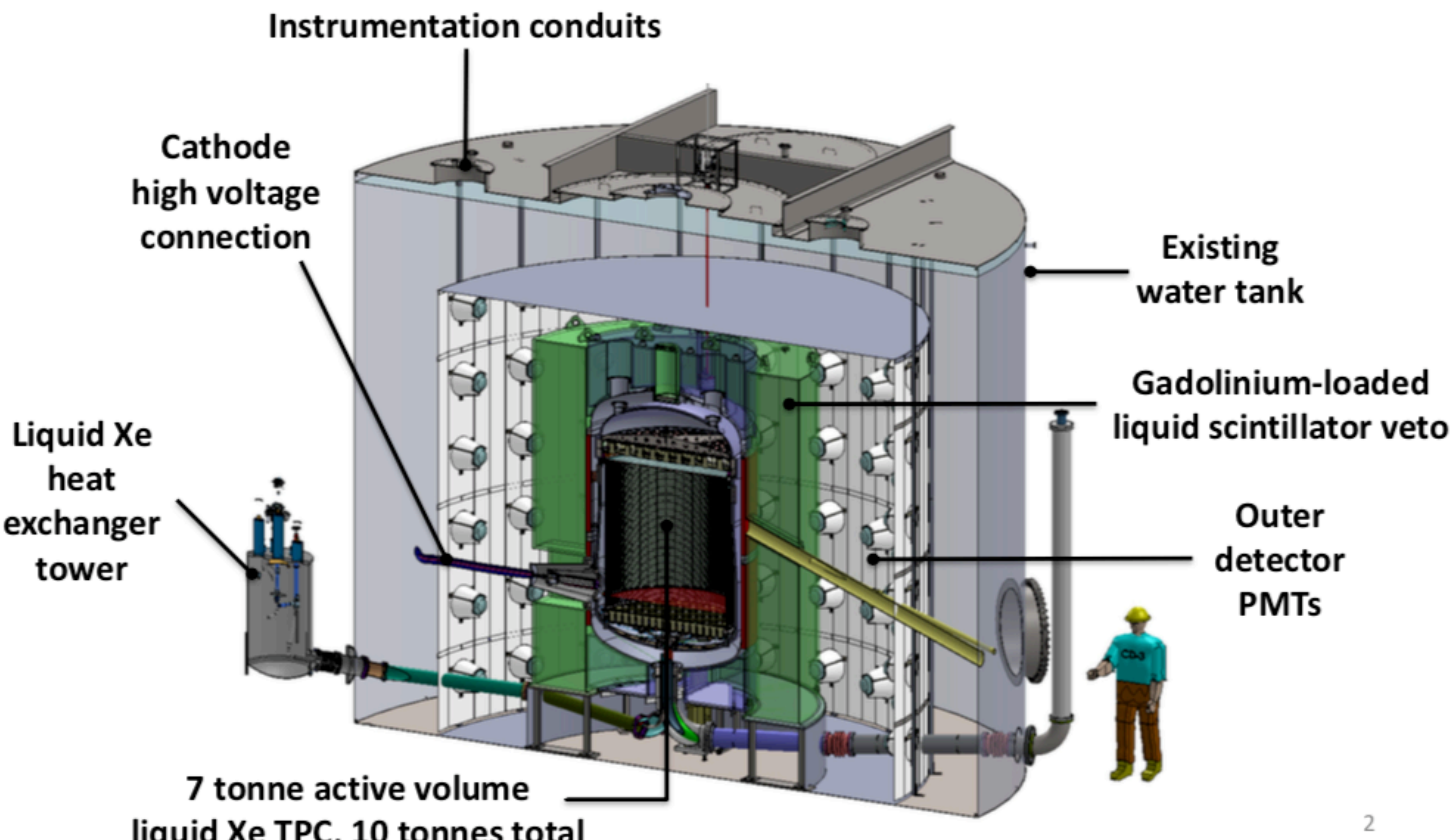
Neutron Veto

To tag and measure in situ neutron-induced background

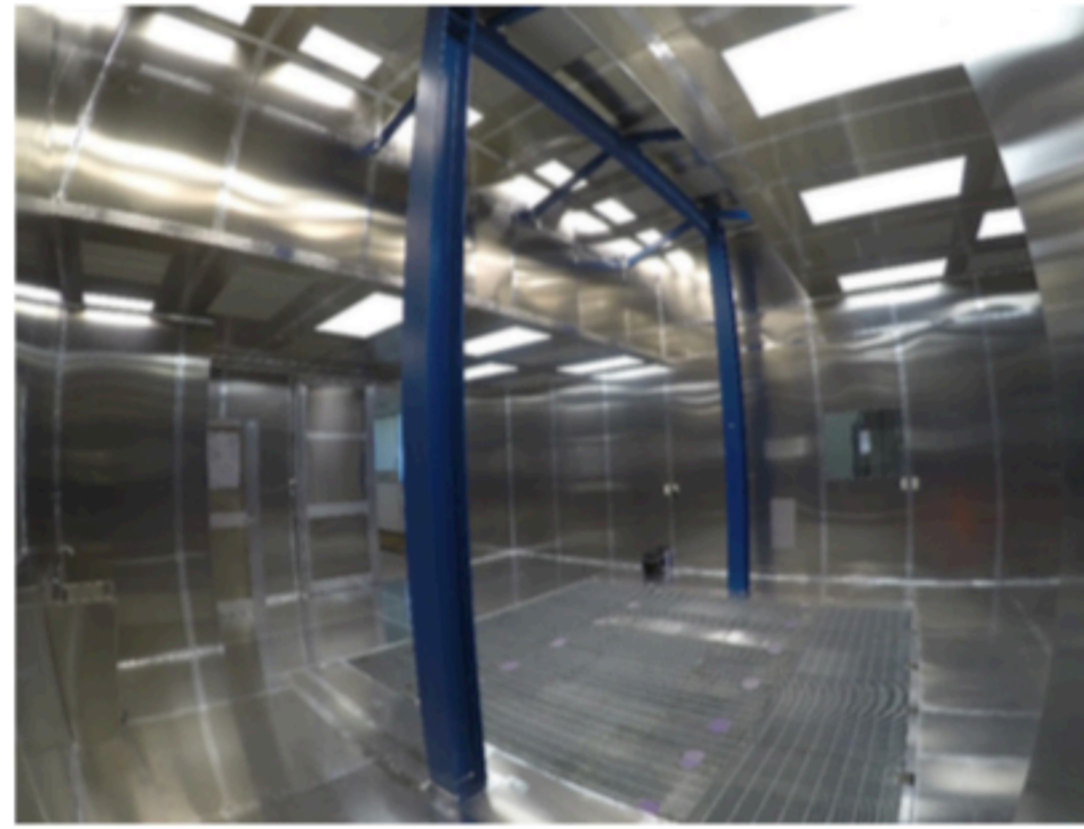
LUX-ZEPLIN (LZ)

- LXe-TPC: ×50 scale up of LUX
- 1 mile underground (4300 m w.e.) at SURF
- **Underground installation 2019**
- **Physics data taking 2020**

LZ Detector Overview

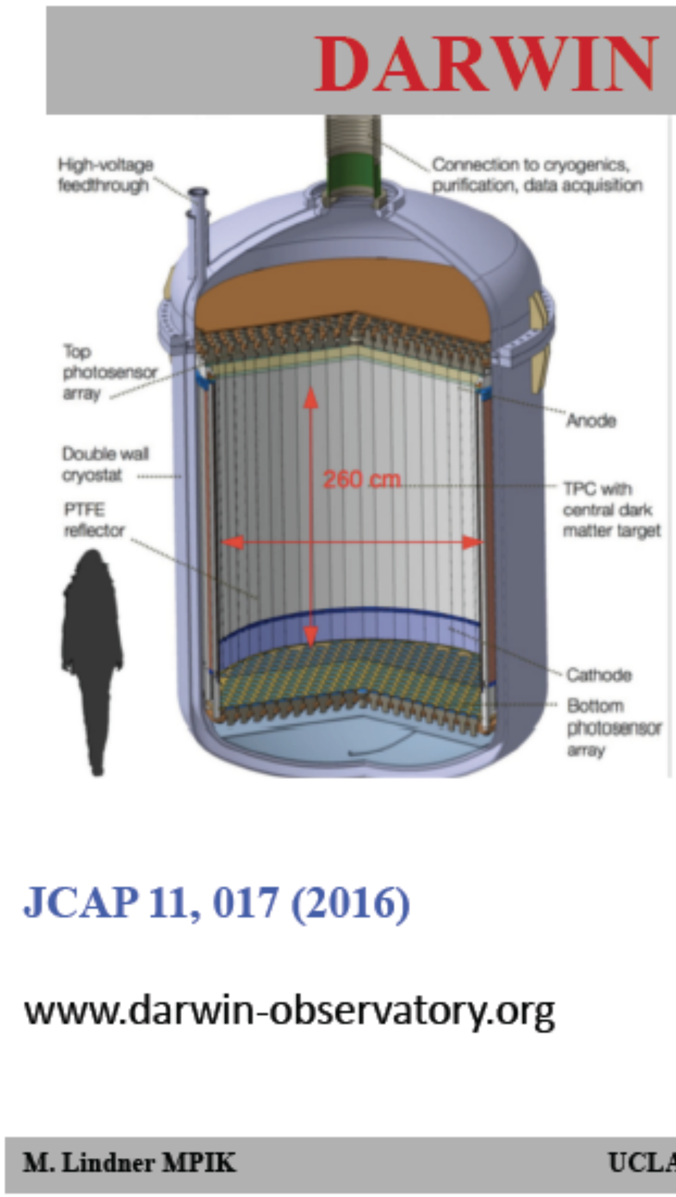


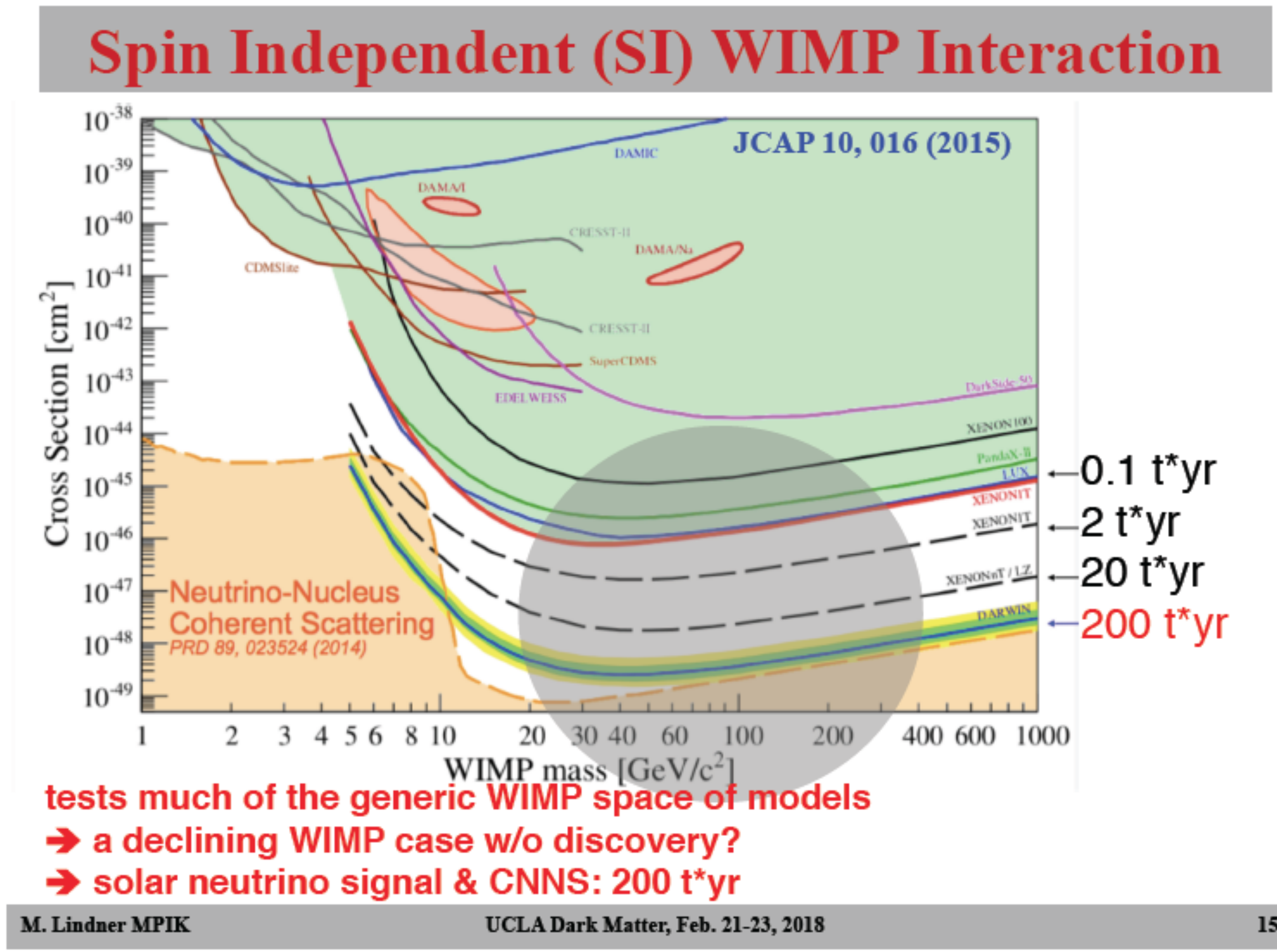
On Site Facilities



- Low radon, class 100-1000 cleanroom ready at SURF for first parts
- Radon reduction system installed
- Underground improvements started, to finish by May

Beyond XENON: DARWIN



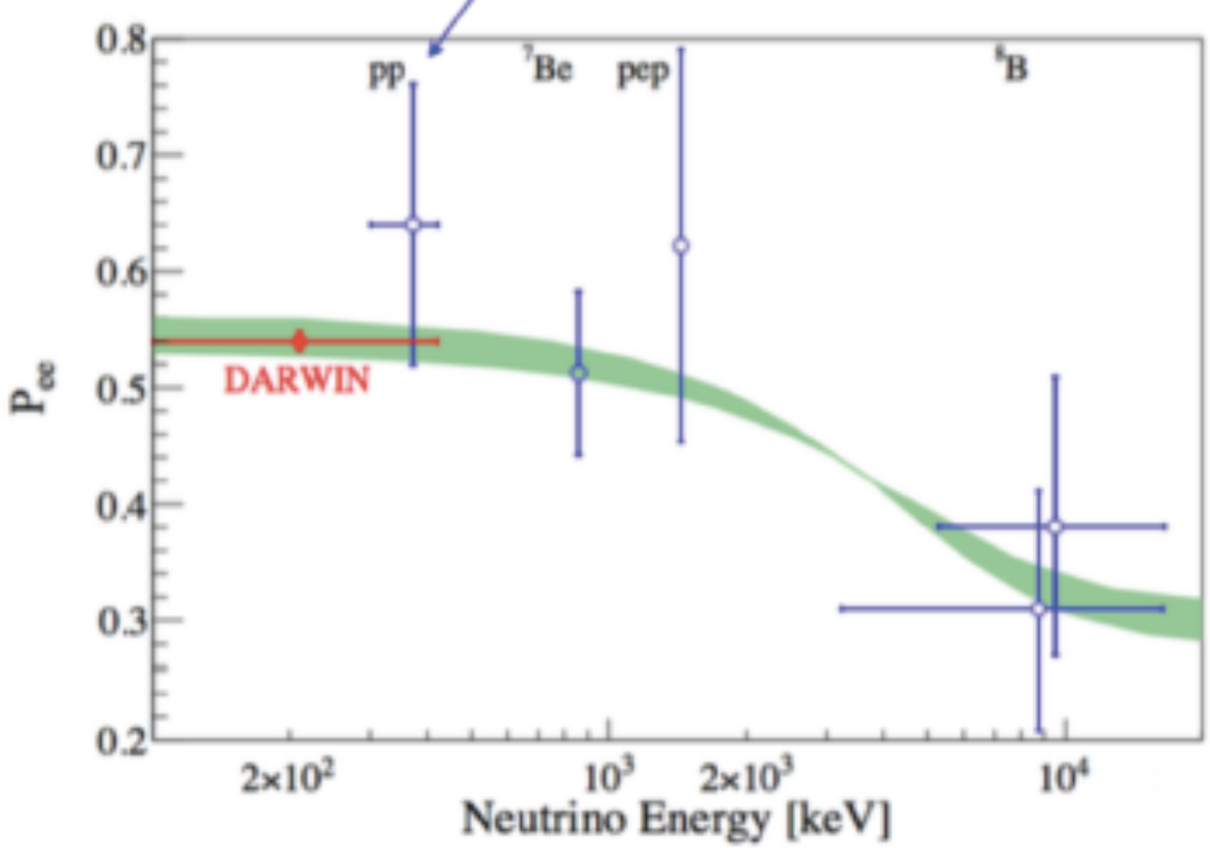


Neutrino Physics with DARWIN

➔ **Coherent Neutrino-Nucleus Scattering (CNNS)**
200 t*yr ➔ ca. 200 (25) events for > 3 (4) keV_{NR}

➔ **Low energy solar neutrino signal: pp, ^{7}Be** JCAP 01, 044 (2014)
~1% statistical uncertainty for 100 t*yr ➔ solar models & ν properties

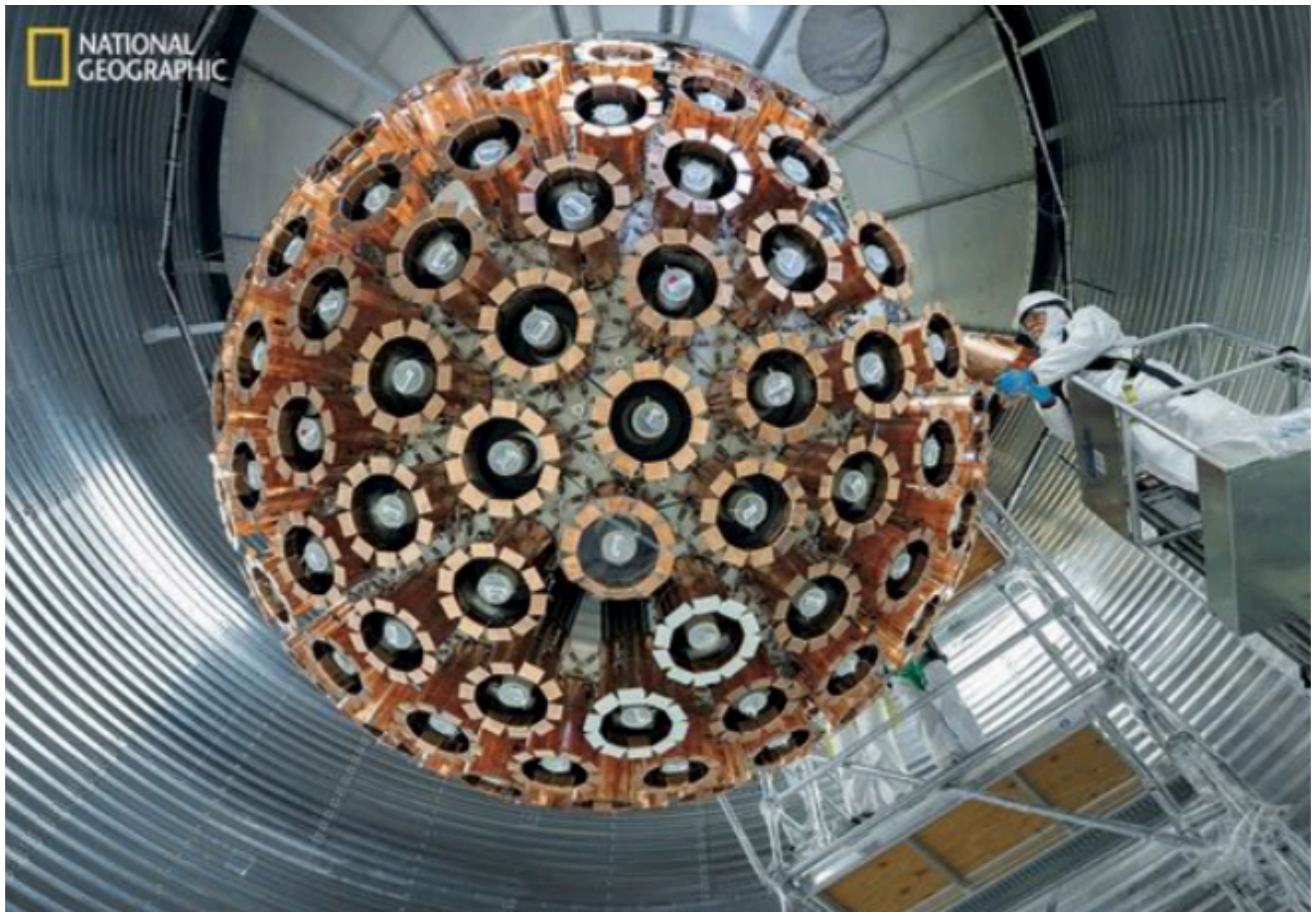
Borexino (Nature 512, 383-386, 2014)

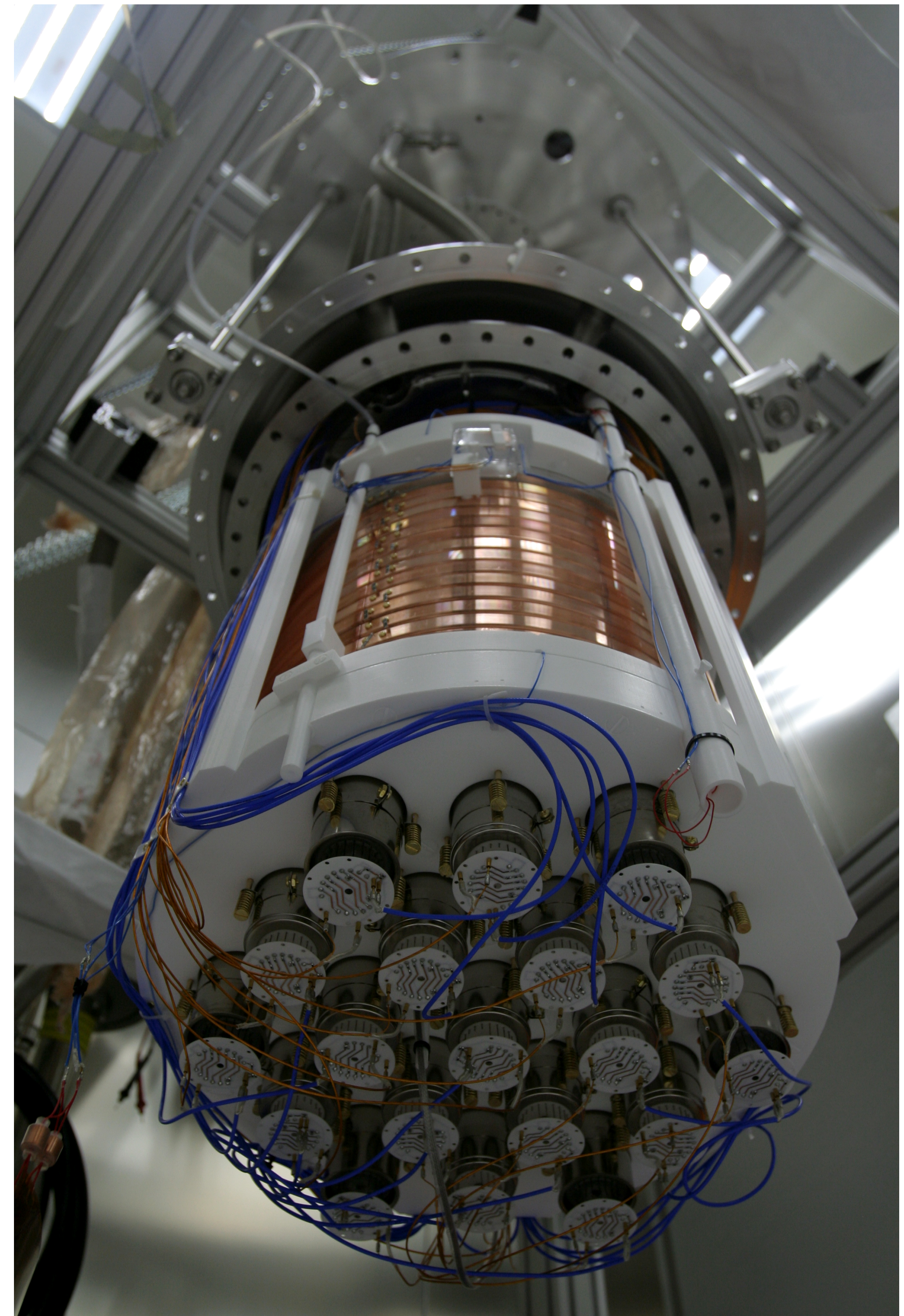


real-time measurement of the solar neutrino flux:
→ 7.2 events/day from pp
→ 0.9 events/day from 7Be

➔ **Supernova neutrinos:**
→ 5σ sensitivity for a 27M⊙ SN progenitor at 10 kpc (~700 events)
→ flavor-insensitive neutrino energy measurement Phys. Rev. D 94 (2016)

Liquid Argon Detectors: in operation

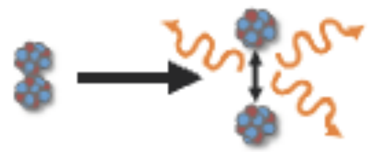




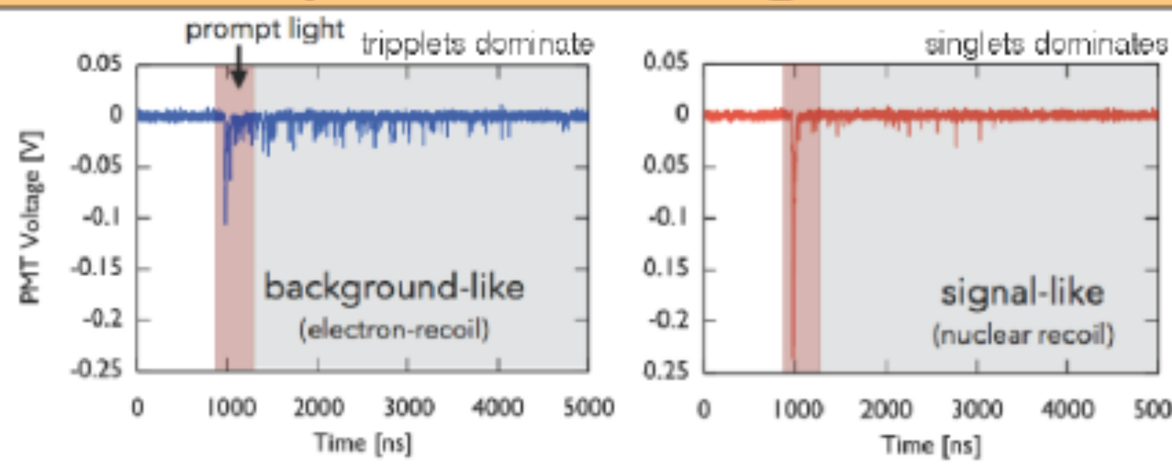
- Single Phase: DEAP3600 @ SNOLAB
- Dual Phase TPC: DarkSide-50 @ LNGS

Experimental Signatures

Ar scintillation:
- excimers are create



- singlet: 6 ns
- tripplet: 1500 ns
- wavelength: 128 r

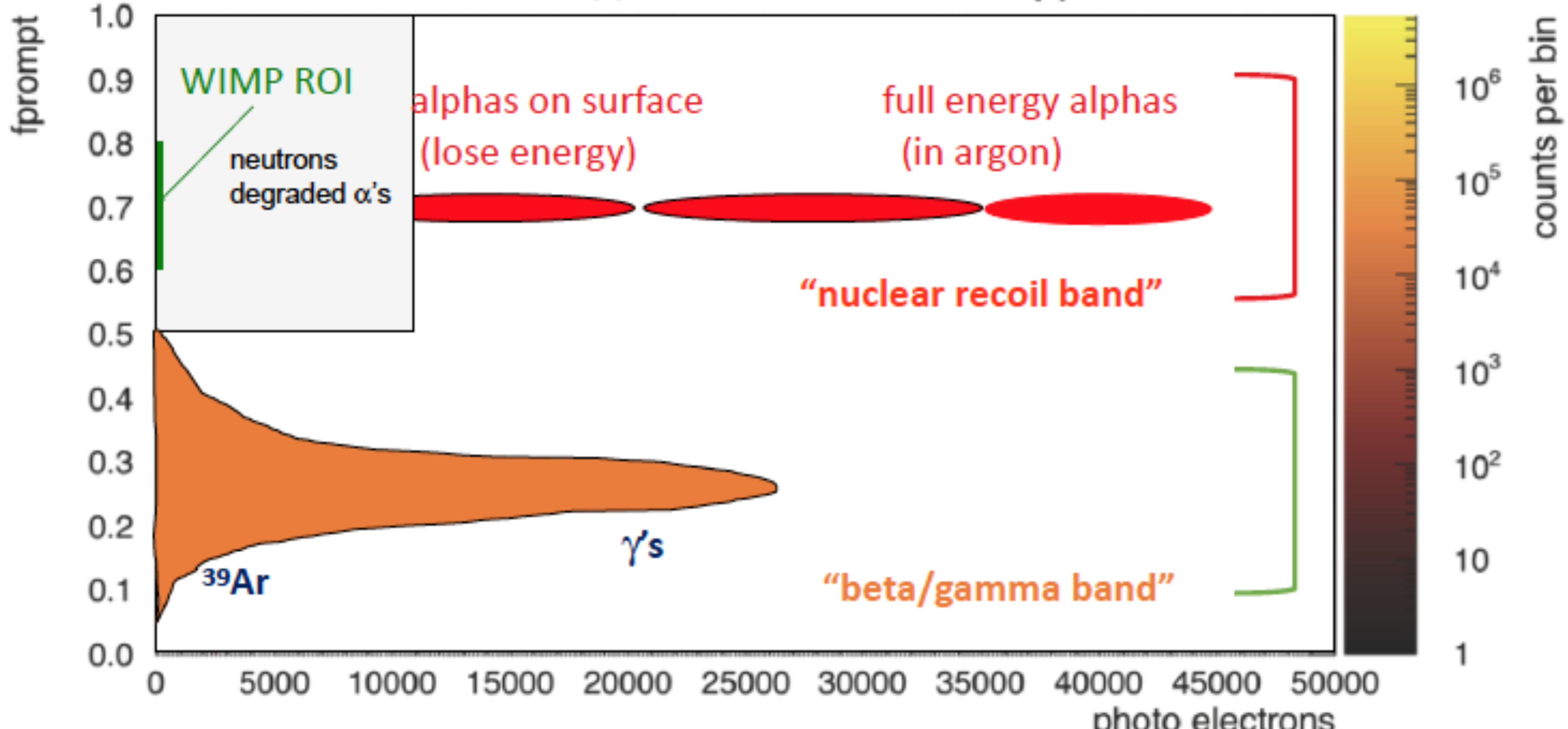


Pulse shape discrimination (PSD) parameter:

fprompt =

$$\frac{\textbf{prompt light (150 ns)}}{\textbf{total light (10000 ns)}}$$

overview of backgrounds: see Bjoern Lehnert R1-5

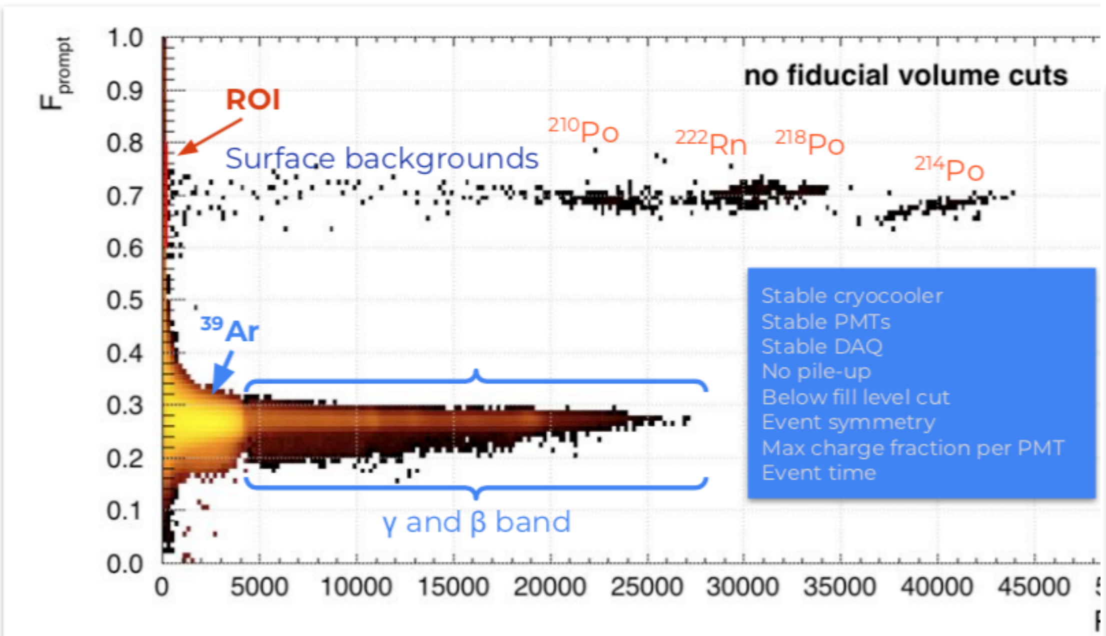


DEAP 3600 commissioning data

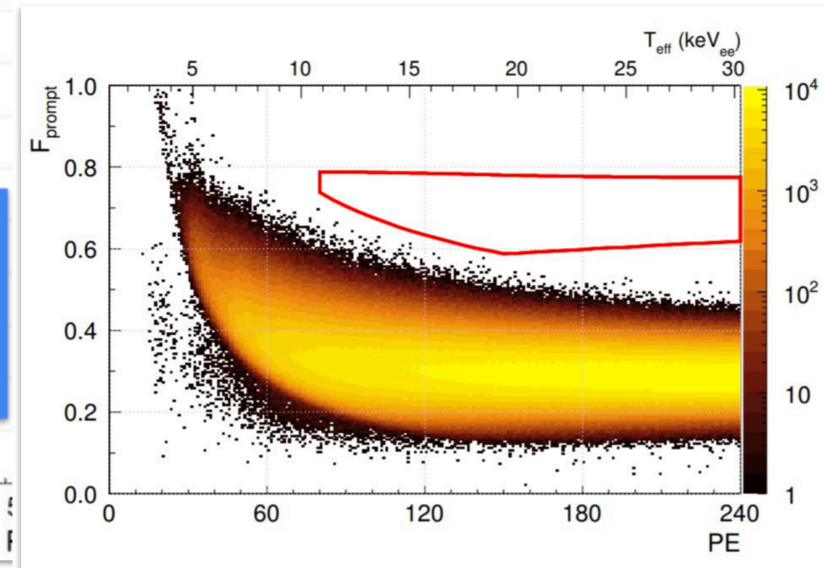
Slide from MG Boulay – TAUP 2017, Sudbury

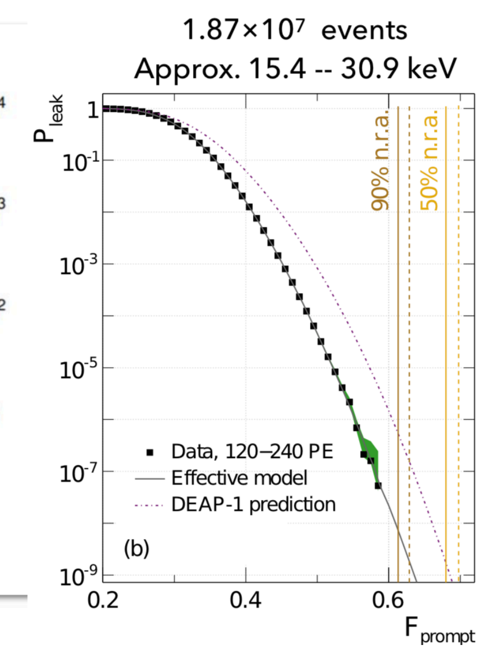
DEAP3600: First Result & Projected Sensitivity

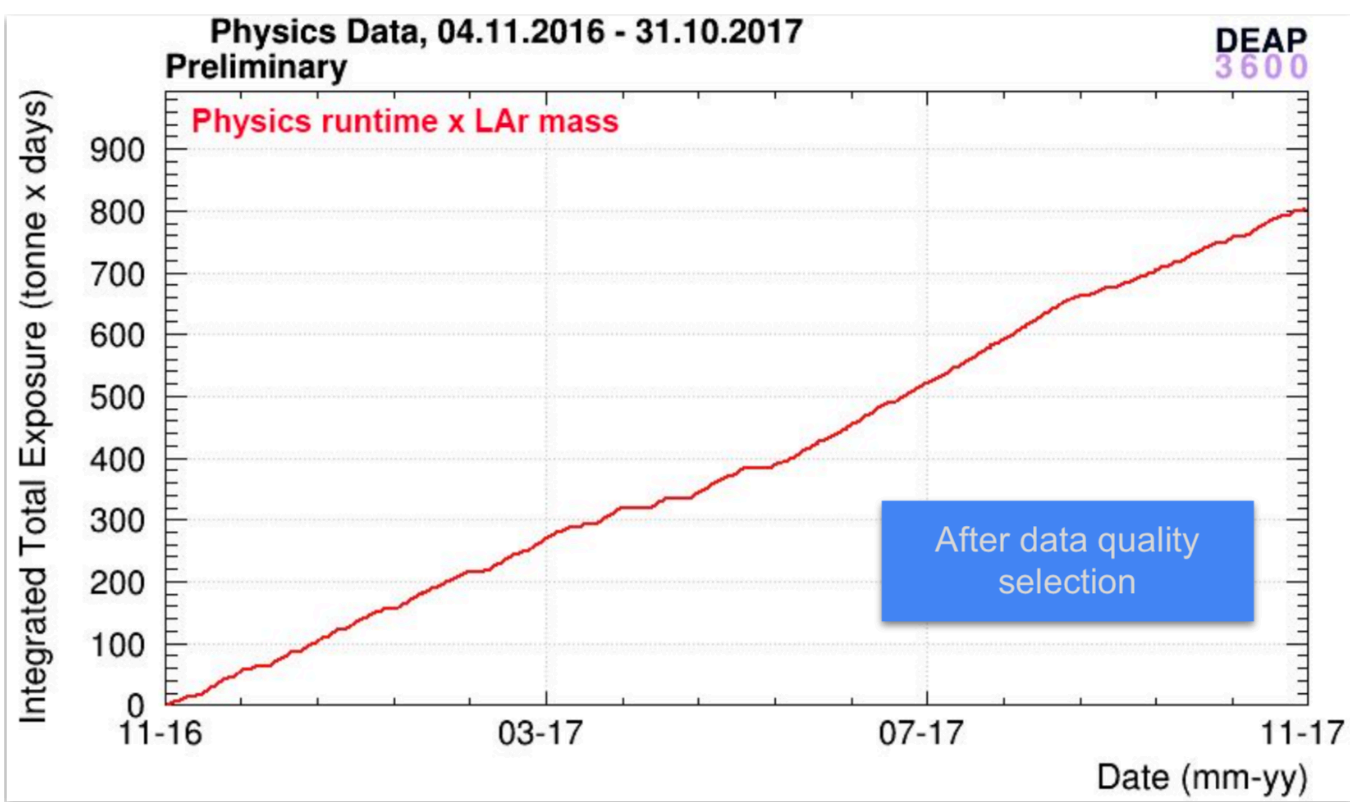
First paper dataset (4.4 d), partial cuts

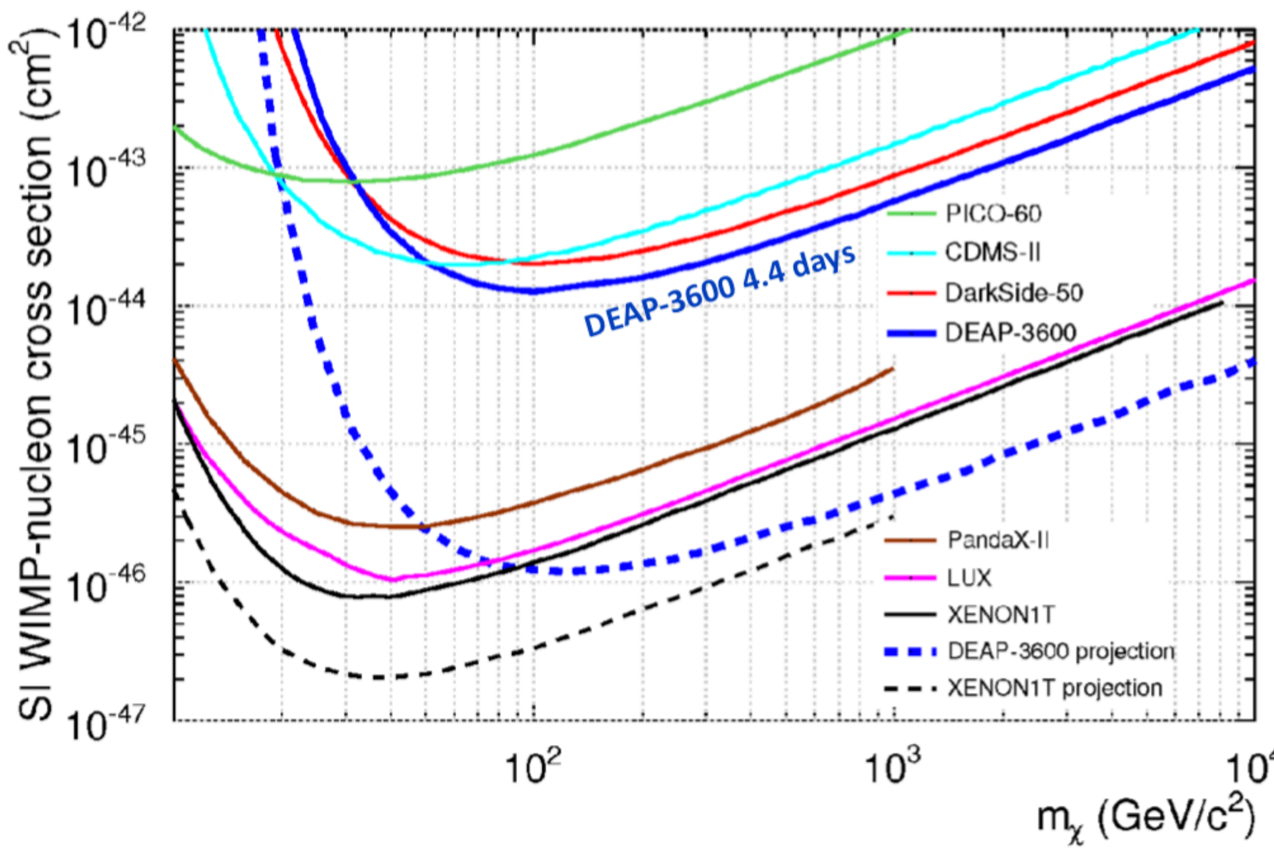


In the region of interest, after all cuts



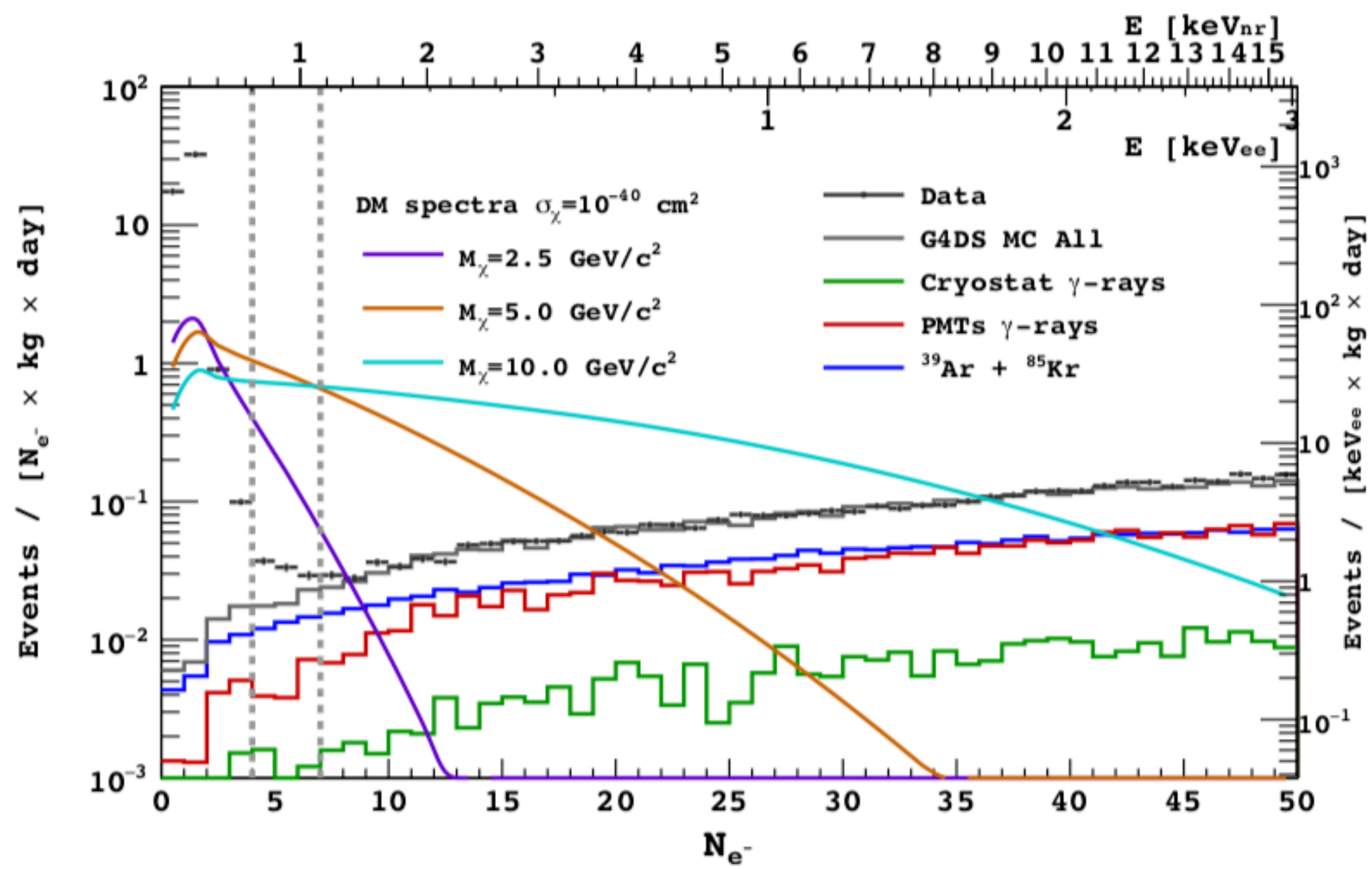


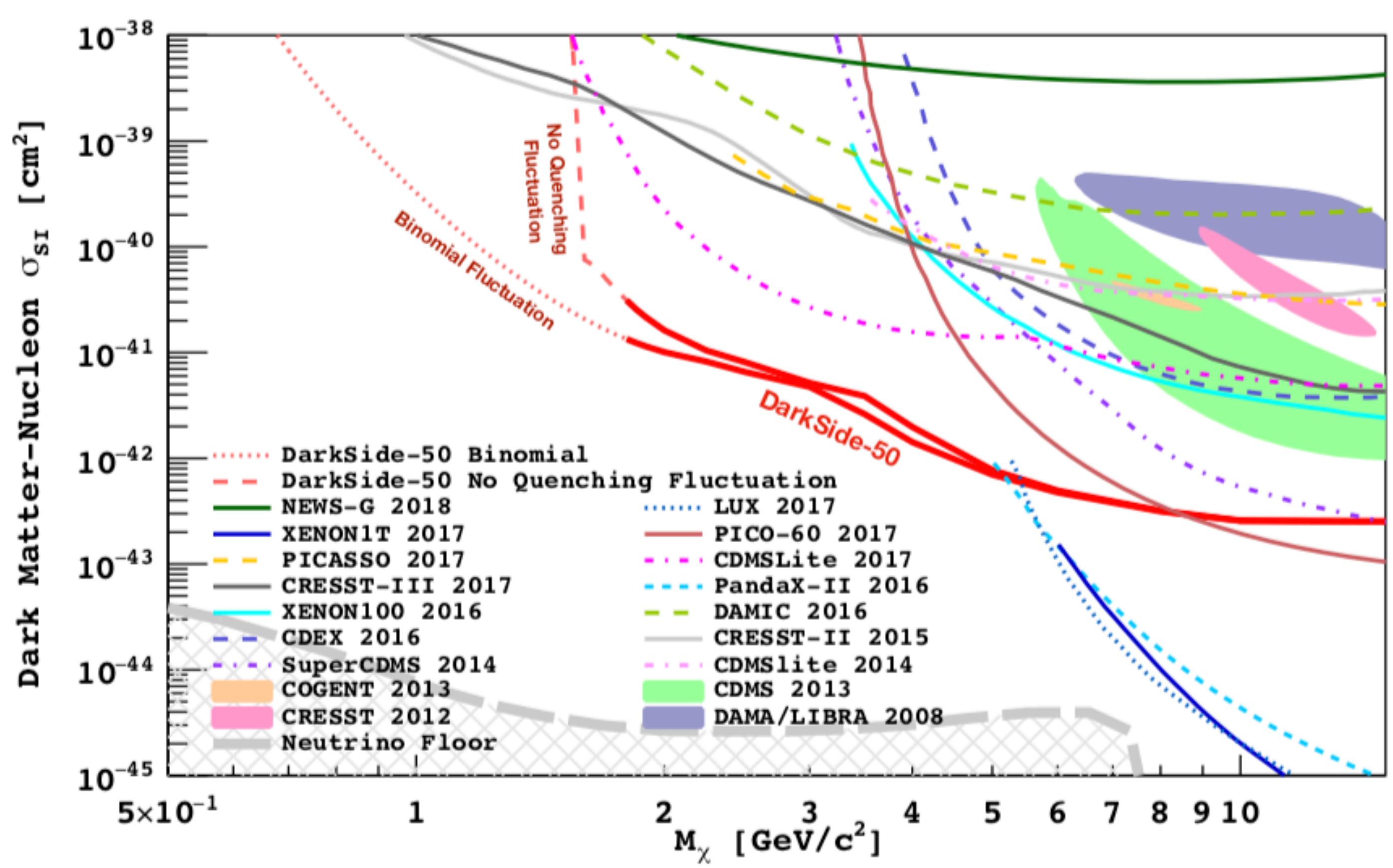




DarkSide-50: S2-only Analysis

- Conservative Qy is used to calculate expected WIMP signal
- Best limit in the mass range of 2-5 GeV range
- Analysis being optimized to reduce uncertainties in Qy and to reduce backgrounds



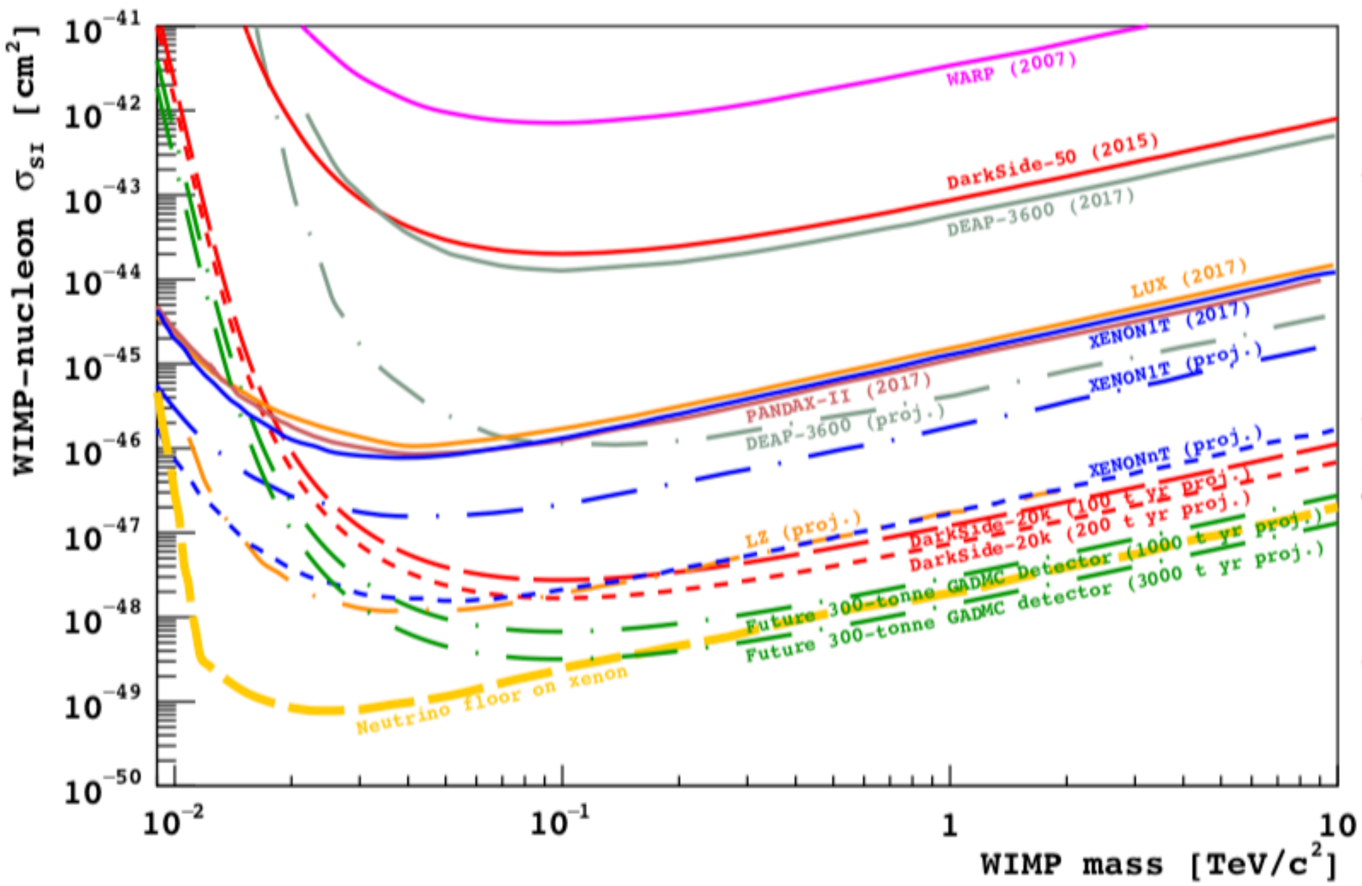


Liquid Argon Detectors: future

The Global Argon Dark Matter Collaboration

ArDM
DarkSide
DEAP
MiniCLEAN

} A Single Global Program for Direct Dark Matter Searches
Currently taking data: ArDM, DarkSide-50, **DEAP-3600**
Next step: DarkSide-20k at LNGS (2021-)
Last Step: **300 tonnes detector**, location t.b.d **(2027-)**



DarkSide-20k approved by INFN and LNGS in April 2017 and by NSF in Oct 2017
Officially supported by LNGS, LSC, and SNOLab
30 tonnes (20 tonnes fiducial) of low-radioactivity underground argon
14 m^2 of SiPM coverage

Summary

- Noble liquid detectors continue to lead the search for WIMPs with masses above 10 GeV. Most stringent limits and best sensitivity achieved with LXe two-phase detectors.
- Liquid Xenon Detectors:
  - Expect a wealth of new results from 1 ton-year of data with XENON1T
  - XENON1T will stop in a few months to start XENONnT. Commissioning by mid 2019.
  - LZ at similar timescale. At an intermediate size, PandaX-4T with similar timescale.
- Liquid Argon Detectors:
  - DarkSide-50 improved low mass WIMPs search via S2-only analysis
  - DEAP3600 has accumulated ~1 year of data beyond first result (~4 days)
  - DarkSide-20k construction started; aims at 2021 timescale