Review of Dark Matter Direct Detection

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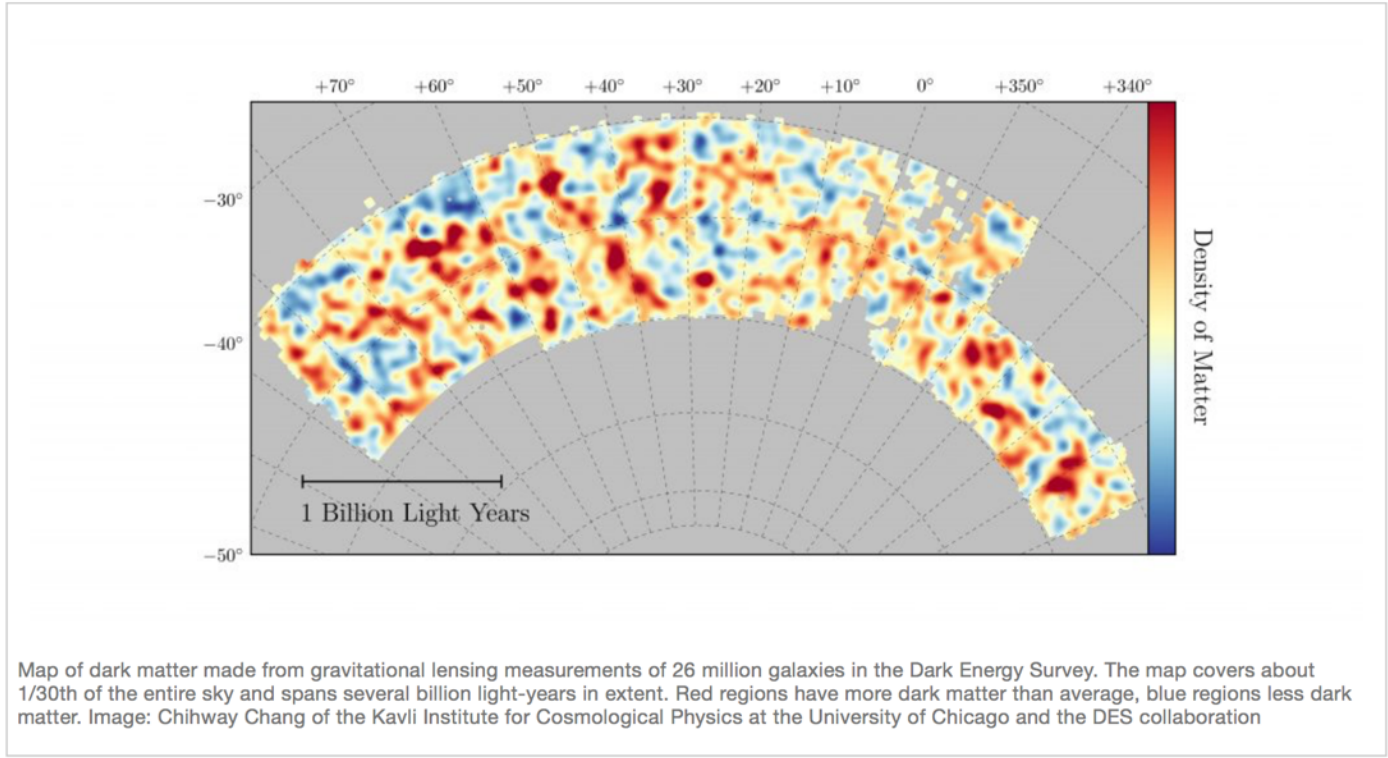
UKRI/STFC/Rutherford Appleton Laboratory

DMUK meeting, Durham, 13 July 2018

We are in the dark …

Dark Energy Survey reveals most accurate measurement of dark matter structure in the universe

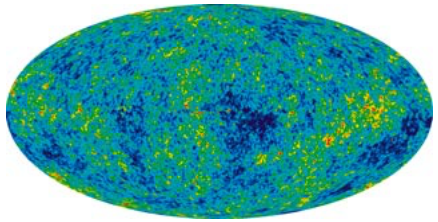


Map of dark matter made from gravitational lensing measurements of 26 million galaxies in the Dark Energy Survey. The map covers about 1/30th of the entire sky and spans several billion light-years in extent. Red regions have more dark matter than average, blue regions less dark matter. Image: Chihway Chang of the Kavli Institute for Cosmological Physics at the University of Chicago and the DES collaboration

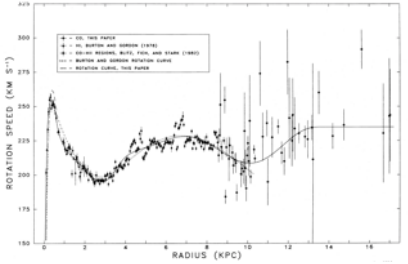
From: http://news.fnal.gov/2017/08/dark-energy-survey-reveals-accurate-measurement-dark-matter-structure-universe/

We know it exists:

1. CMB



2. Galactic rotation curves



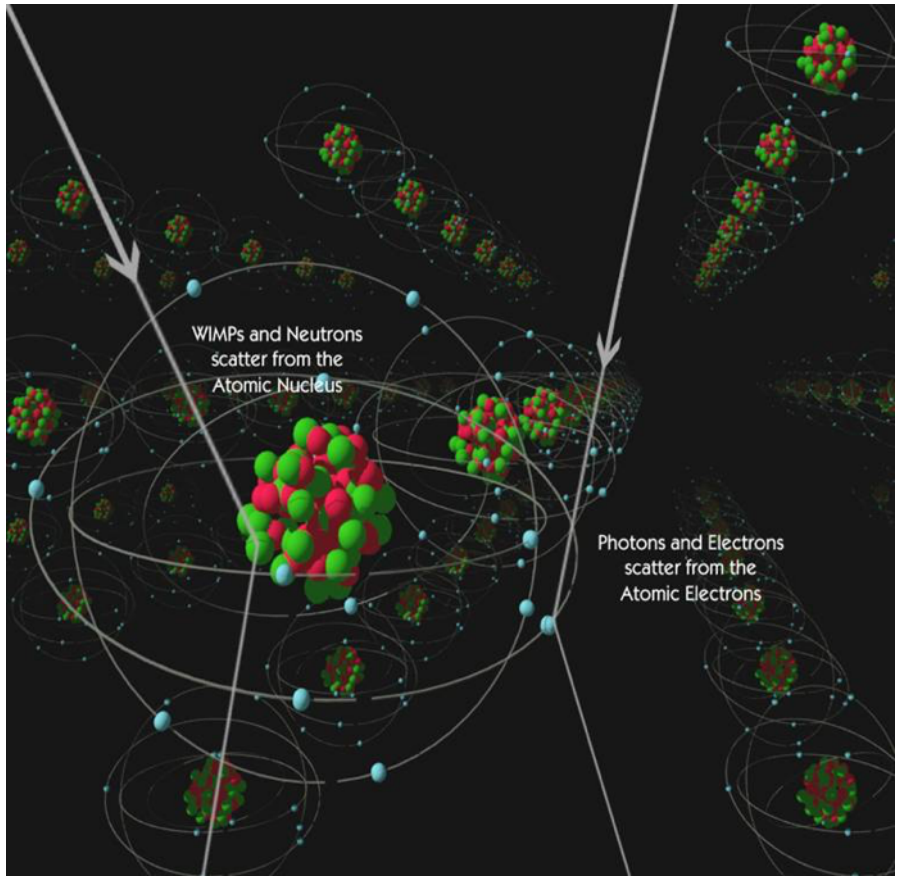
3. Clusters of galaxies

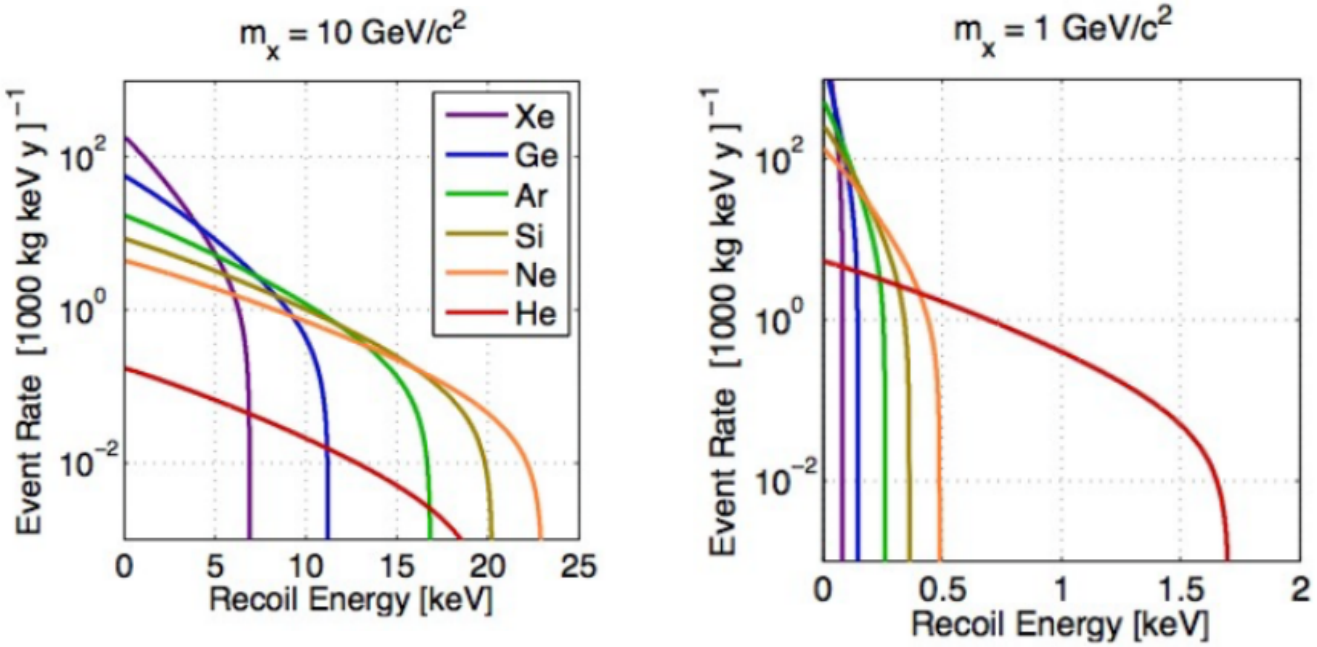
4. Bullet cluster

BUT yet we do not know what it is.

Direct detection of WIMPs

Looking for collision of dark matter particle with atomic nuclei

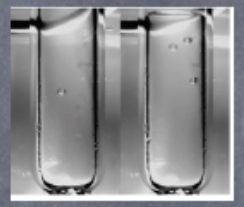




Rates for 10 and 1 GeV Wimp for different targets

Dark Matter direct detection techniques

Heat and ionisation bolometers : CDMS
EDELWEISS



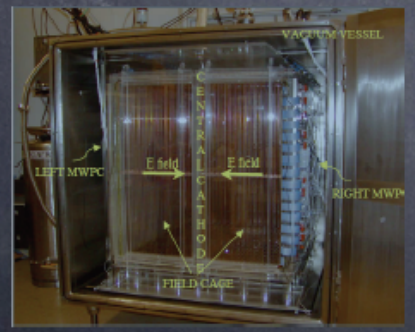
Bubbles and Droplets:
CUOPP
PICASSO

Light and heat Bolometers:
CRESST
ROSEBUD

Phonons/Heat

dE/dx

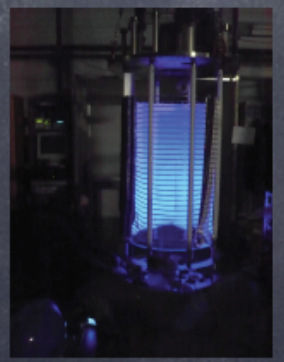
Charge



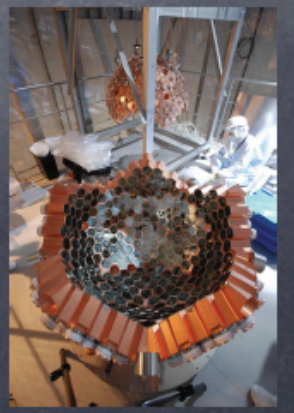
Ionisation detectors: DMTPC
DRIFT, GENIUS, NEWAGE,
HDMS, IGEX, CoGeNT

Light

Scintillation and ionisation charge detectors:

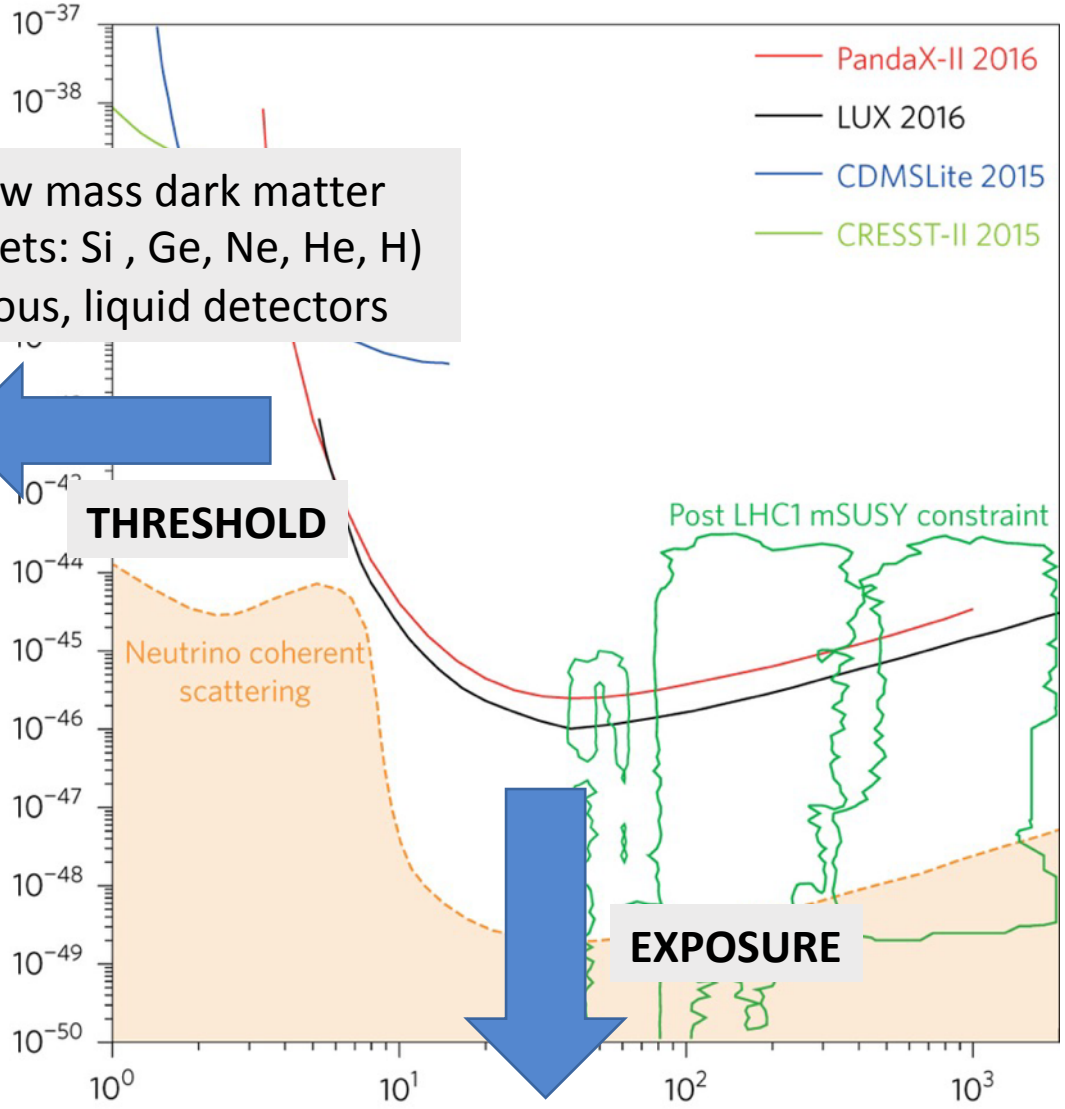


XENON
WARP
ArDM
ZEPLIN
LUX
LUX-ZEPLIN



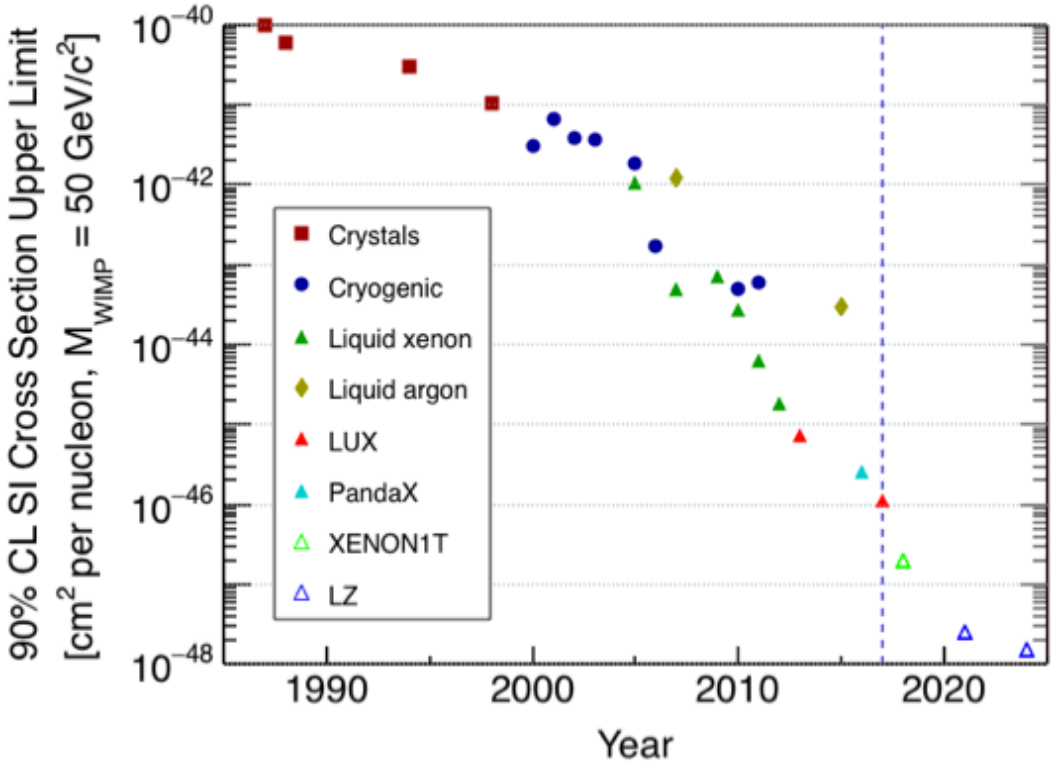
Scintillators :
DAMA
LIBRA
XMASS
CLEAN
ANAIS
KIMS
DEAP-1
DEAP-3600

Direct detection of WIMPs



Towards low mass dark matter
(low A targets: Si , Ge, Ne, He, H)
Solid, gaseous, liquid detectors

Towards high sensitivity, large liquid detectors



Great progress towards high sensitivity DM detectors with background free large mass noble liquids

Review of the current DM experiments

- 6th Symposium on Neutrinos and Dark Matter , NDM 2018

(Daejoen, June/July 2018)

https://indico.ibs.re.kr/event/212/timetable/?ttLyt=room#20180630.detailed

- ICHEP 2018

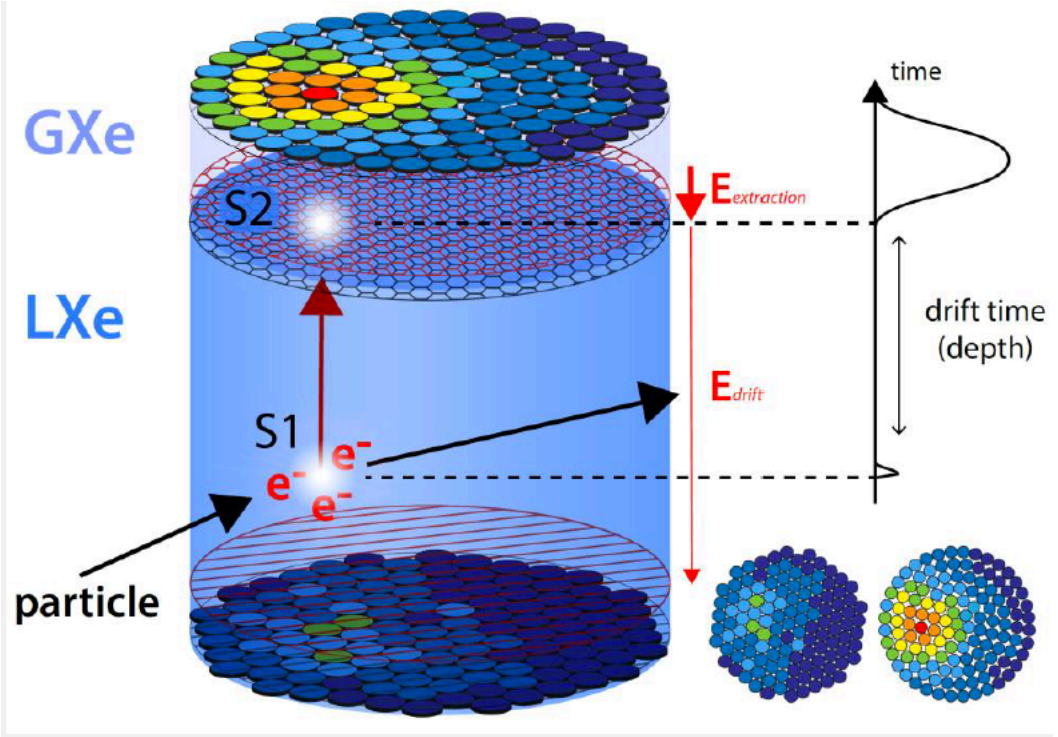
(Seoul, 4-11 July 2018)

https://indico.cern.ch/event/686555/sessions/276020/#20180707

Two next talks are on LUX-ZEPLIN and SYGNUS

XENON1T and XENONnT

165 scientists
27 Institutions
11 Countries

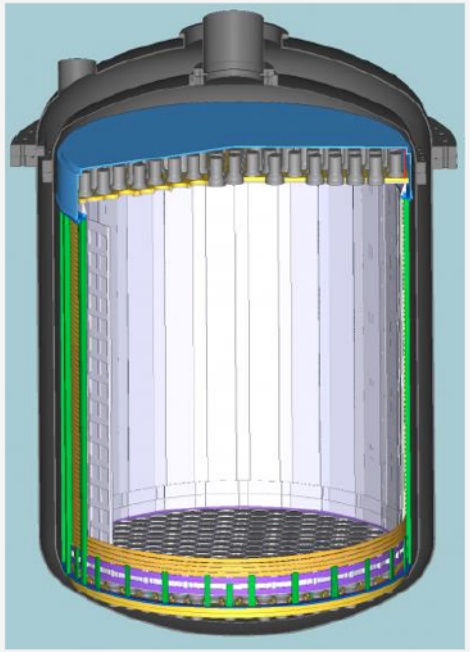


S1 - Light signal:
Prompt scintillation photons

S2 - Charge signal:
Secondary scintillation photons from GXe due to drifted ionization charge

3D position reconstruction:
XY from S2 hit pattern
Z: drift time T_{S2}-T_{S1}

XENON1T and XENONnT

XENON10	XENON100	XENON1T	XENONnT
			
2005 - 2007	2008 - 2016	2012 - 2018	2019 - 2023
25 kg – 15 cm drift	161 kg – 30 cm drift	3.2 tons – 1 m drift	8 tons – 1.5 m drift
$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$\sim 10^{-47}$ cm^2	$\sim 10^{-48}$ cm^2

XENON1T and XENONnT

Water tank
700 t ultra-pure water
+
Muon veto
84 PMTs

External Calibrations
AmBe, Cs-137, Th-228, D-D neutron generator

Cryostat

TPC
3.2 t LXe
248 PMTs

Cryogenic + Purification + Internal Calibrations
Kr-83m, Rn-220

DAQ + Slow control

Distillation column
Kr, Rn removal

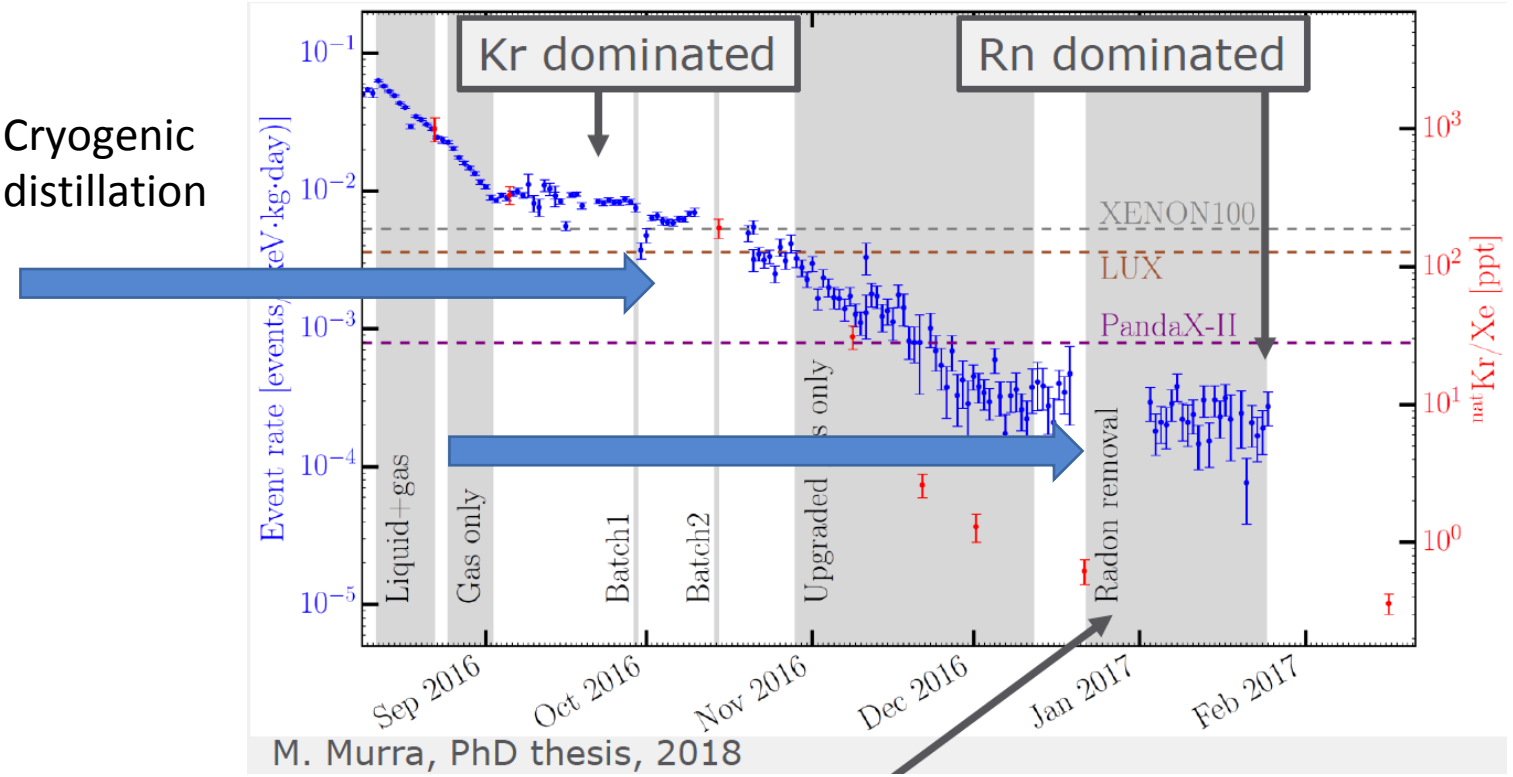
Xe Storage and Recovery
Up to 7 tons

Bottle rack

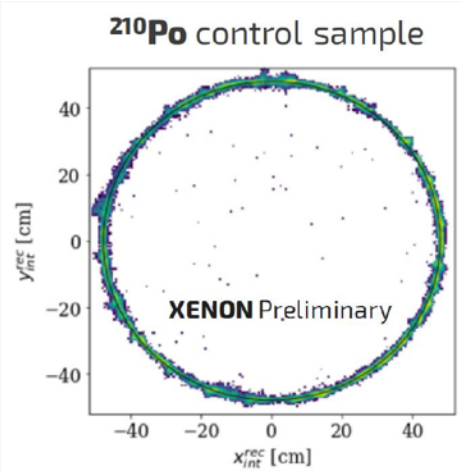
Eur. Phys. J. C. (2017) 77:881

XENON1T and XENONnT (backgrounds)

Cryogenic distillation



M. Murra, PhD thesis, 2018

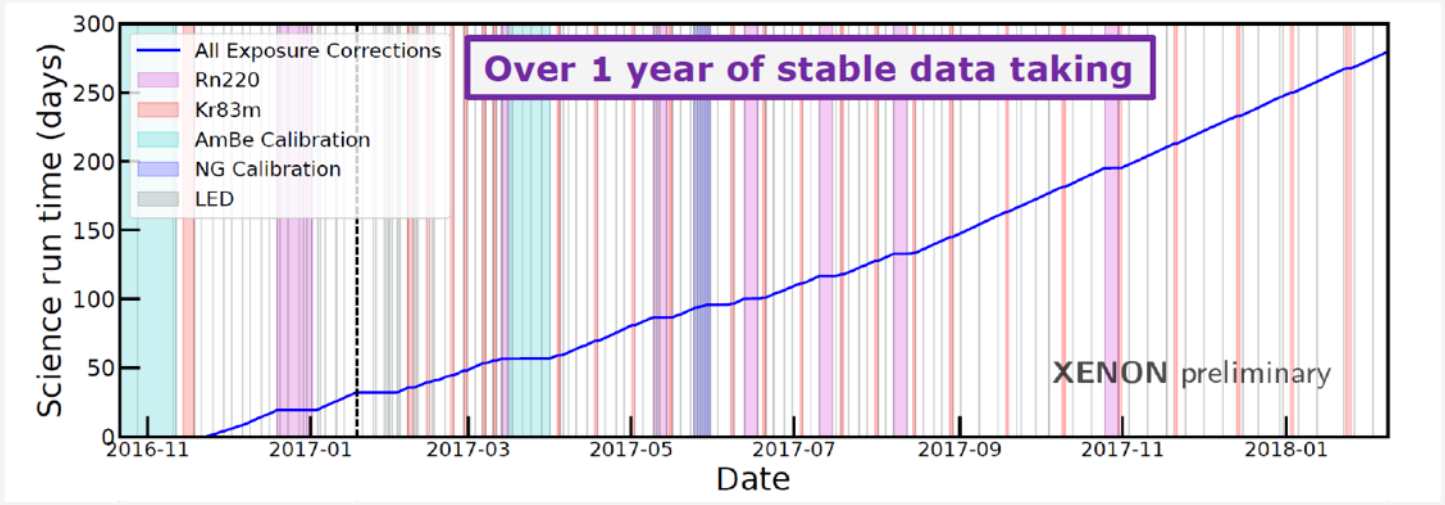


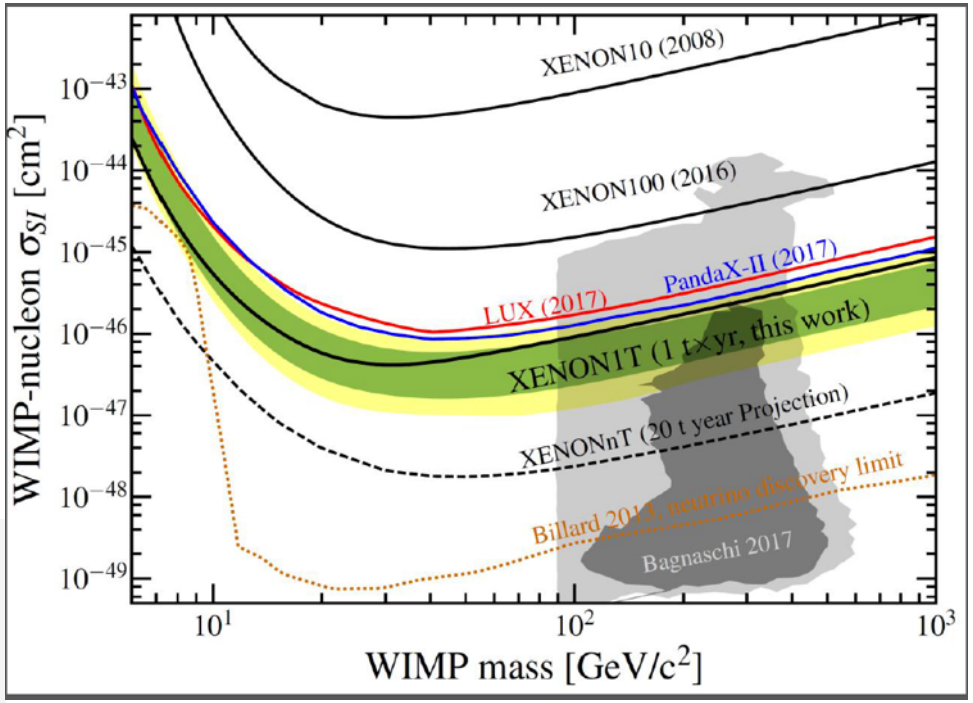
Surface events
+
Fake interactions
(Single S1 + single S2)

Type	Fraction [%]
^{222}Rn (^{214}Pb)	85.4
^{85}Kr	4.3
solar ν	4.9
Materials	4.1
^{136}Xe	1.4

Type	Fraction [%]
Cosmogenic neutrons	<2.0
Radiogenic neutrons	96.5
CEνNS	2.0

XENON1T and XENONnT





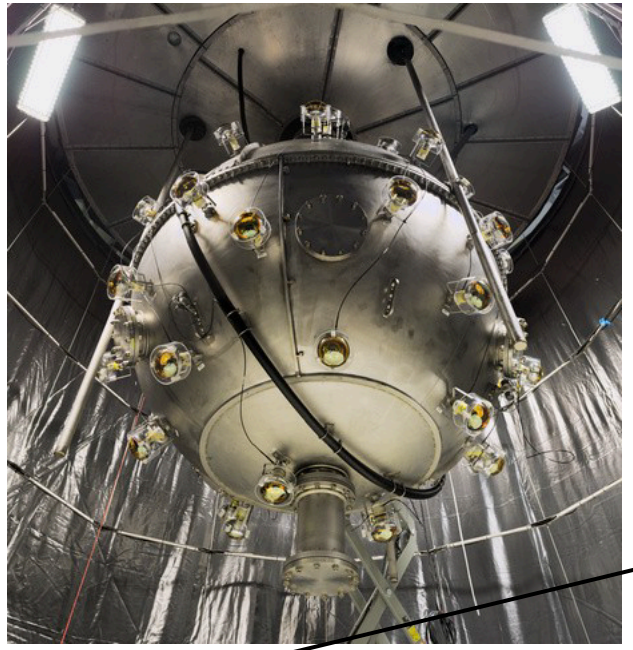
Minimal Upgrade
The XENON1T infrastructure and subsystems were originally designed to accommodate a larger LXe TPC

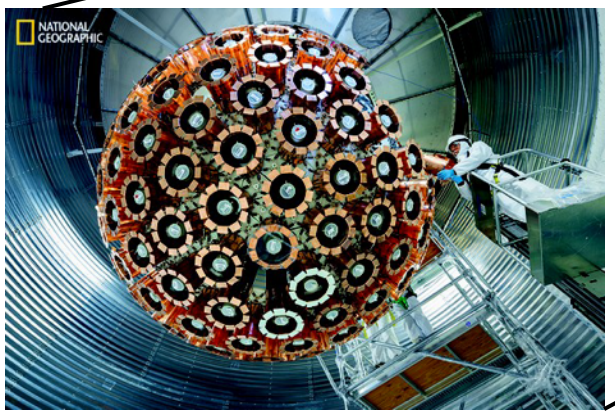
Fiducial Xe Target
XENONnT TPC features:
total Xe mass = 8 t
target mass = 5.9 t
fiducial mass = ~4 t

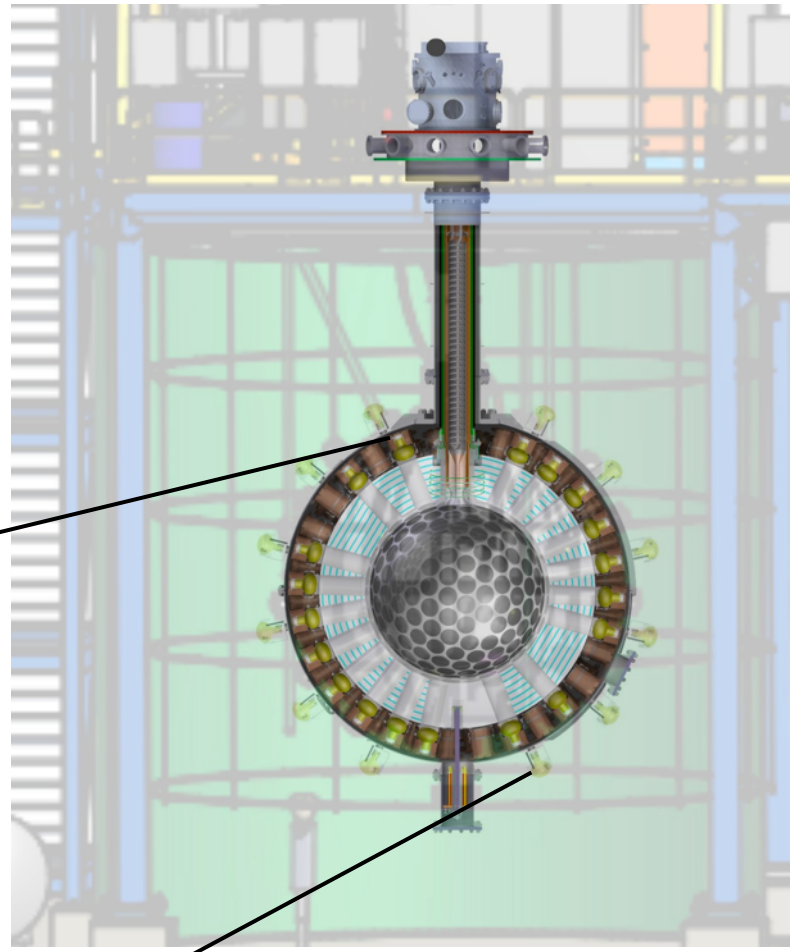
Background
Record low-back levels in XENON1T dominated by ^{222}Rn-daughters.
Identified strategies to effectively reduce ^{222}Rn by ~ a factor 10.

Fast Turnaround
Use XENON1T subsystems, already tested
Fast pace:
Installation starts in 2018
Commissioning in 2019

DEAP-3600
Single phase LAr experiment at SNOLAB

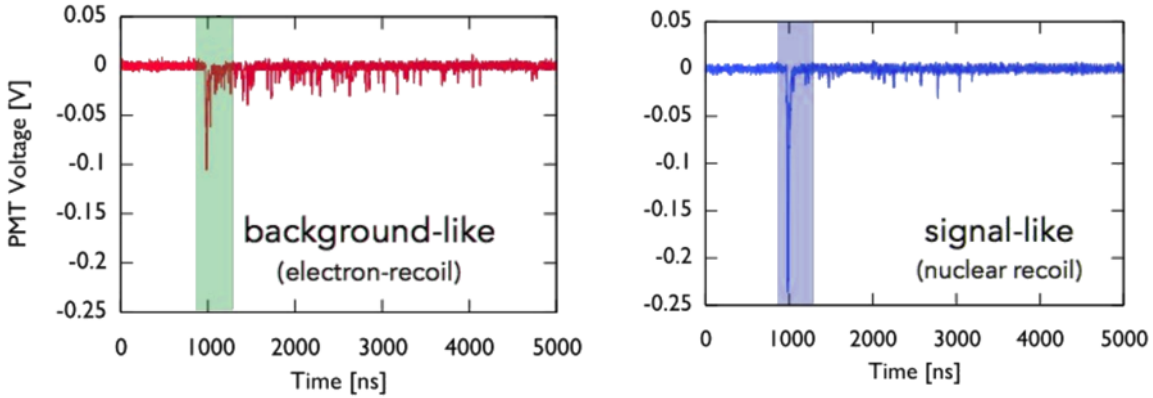




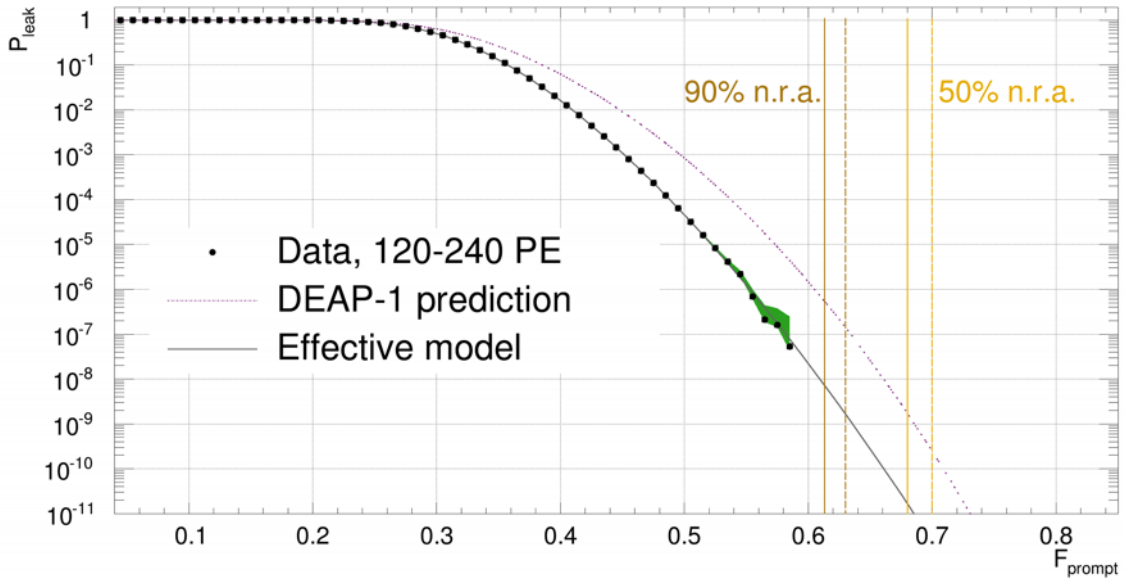


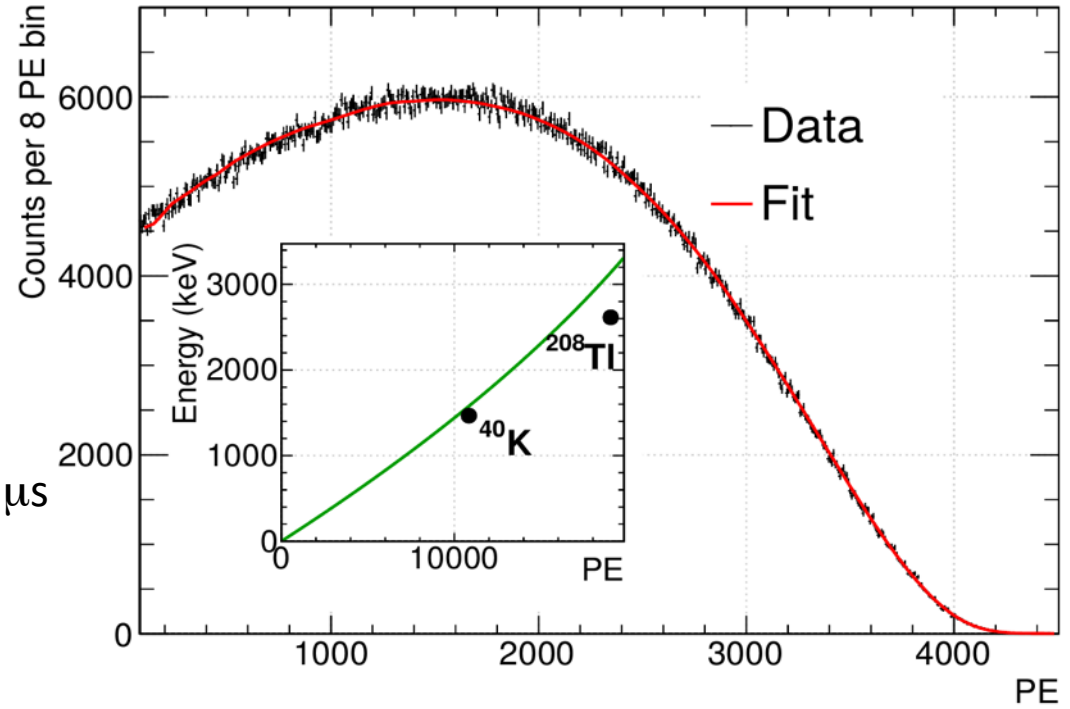
1. Located at SNOLAB
   Cube Hall 2000 m UG
2. Filled with 3300 kgs LAr in acrylic vessel
3. Single phase : detects scintillation light
4. Target background 1<evenet in 3 tonnes x years
5. Uses 255 low radioactivity PMTs from Hamamatsu
6. 3 μm TPB is used for converting UV from LAr to visible spectrum
7. Water Cherenkov muon veto with 48 PMTs

DEAP-3600 (excellent pulse shape discrimination)



Singlet : 6 ns Triplet: 1.3 μs; F_{prompt}= Prompt[1,150] ns/ Total [0,10] μs

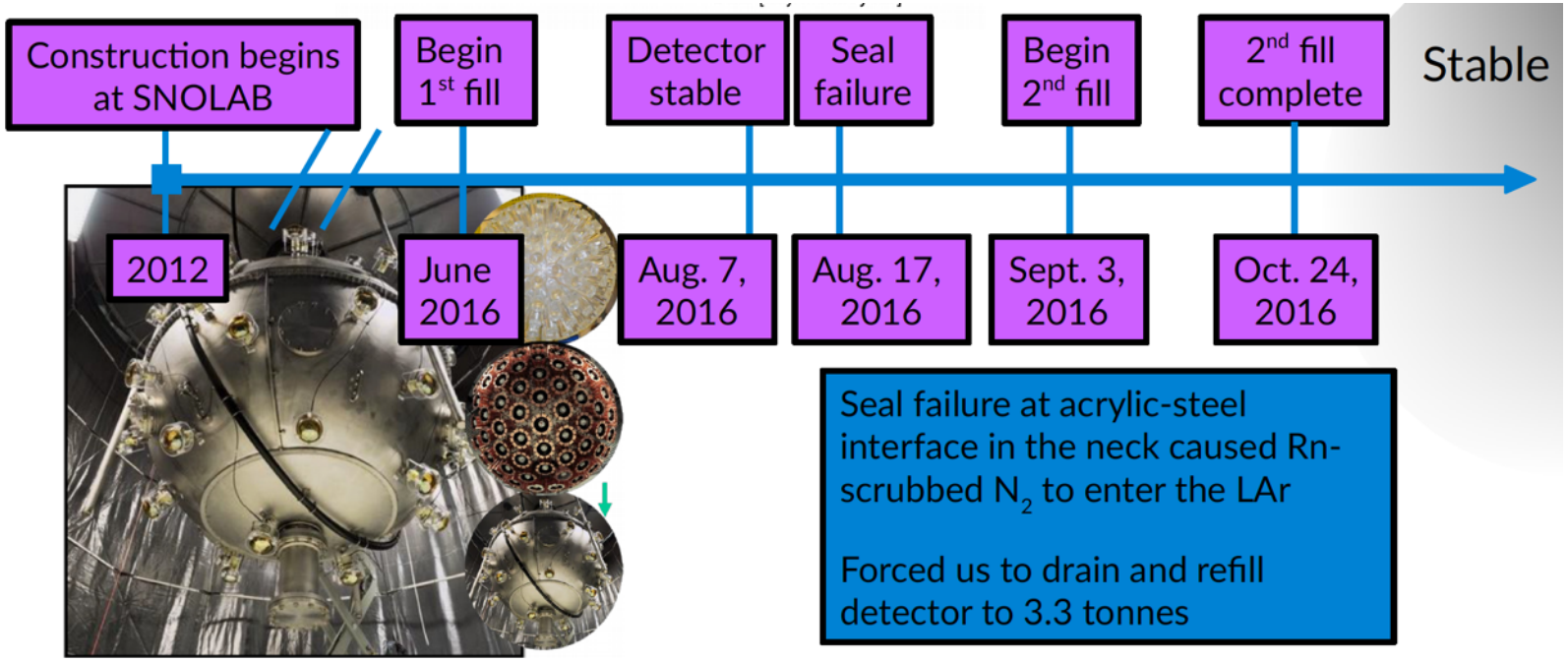


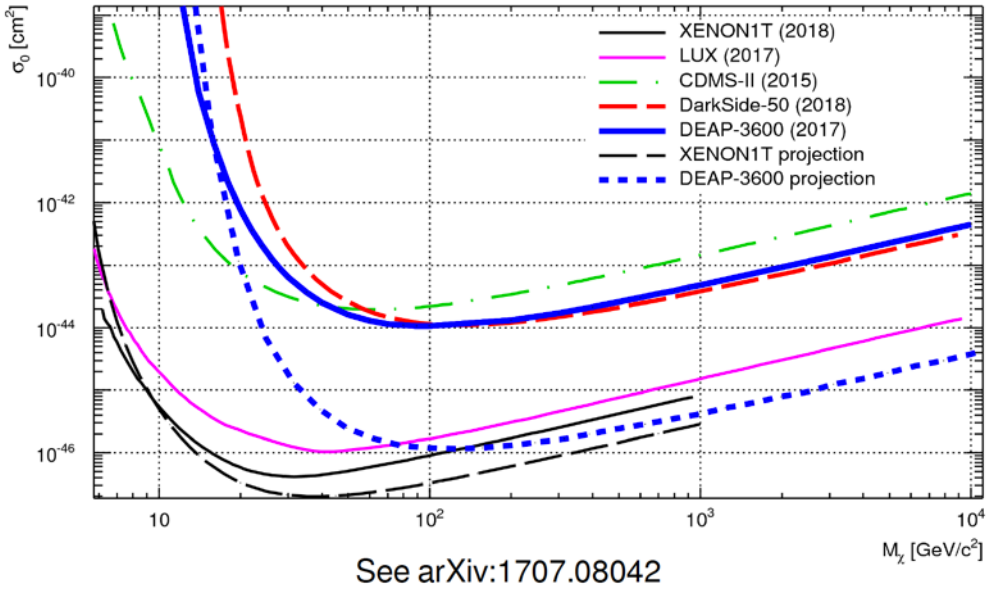


Energy response to LAr intrinsic background
~ 1 Bq/kg of ^{39}Ar

Leakage probability 10^{-8} with 90% NR acceptance
10^{-10} with 50% NR acceptance

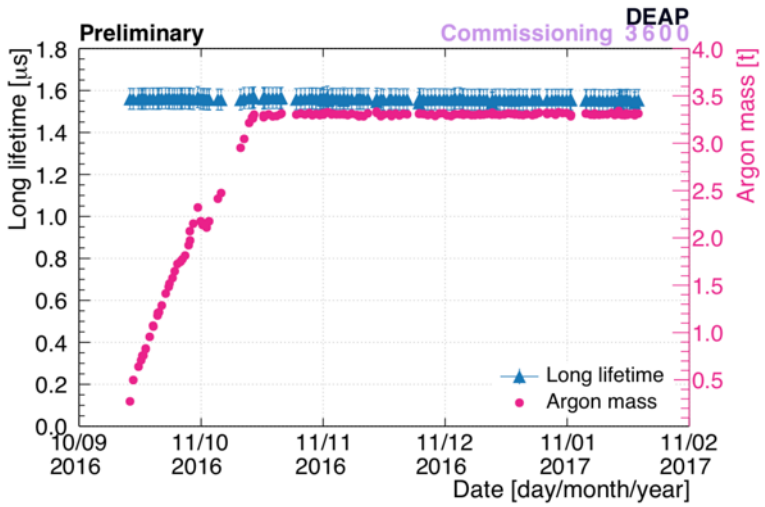
DEAP-3600 Timeline and latest results





See arXiv:1707.08042

- 4.4 live days during first fill, before seal failure
- 2.2 tonne fiducial mass
- 0 events in ROI

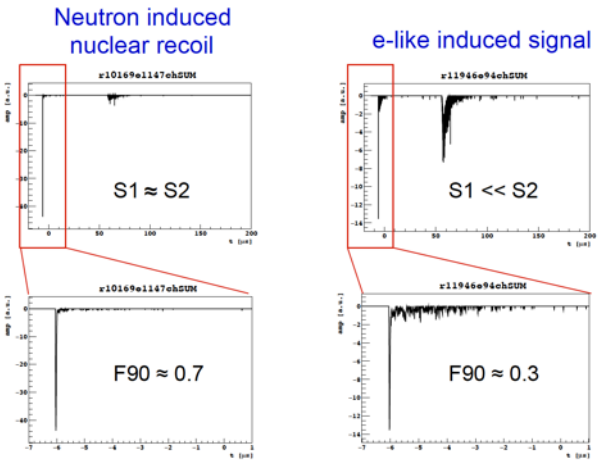


- … and still going …
- Preparing an unblind analysis of ~250 live days of data in the second fill
  (… coming soon!)
- Blinding scheme in place for data after Jan 2, 2018
- Plans for improving energy calibration with ^{83m}Kr source
- Target exposure: 3 tonne·years

DARK-SIDE 50kg and future prospects

Double phase LAr experiment at Gran Sasso

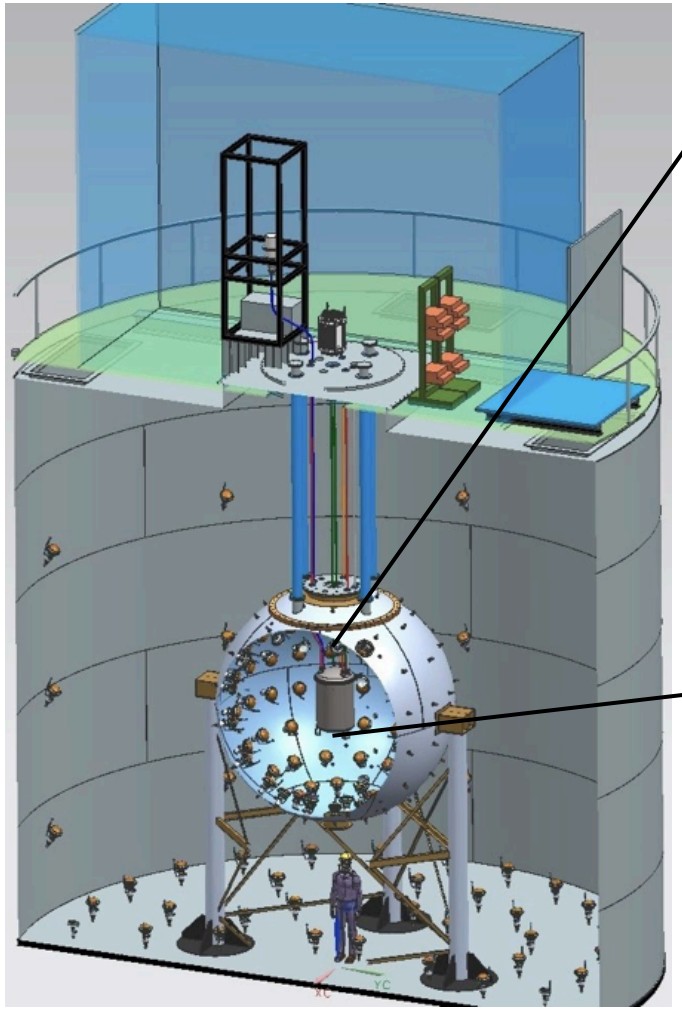
- LAr TPC
- 30 T liquid scintillator veto
- 1000 T of water Cerenkov veto
- PSD based in f90:

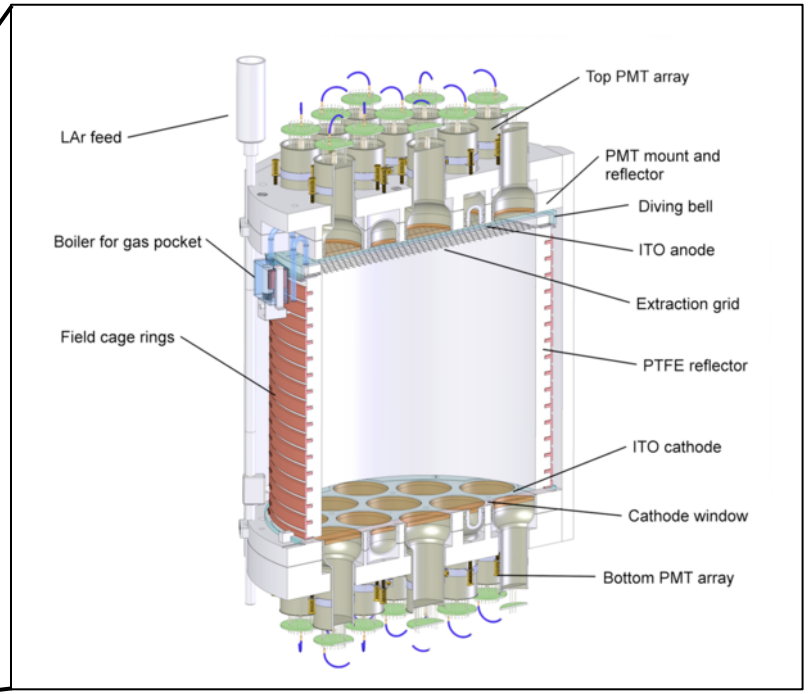


S1 light signal time profile allow primary particle identification by using the f90 parameter

$$f90 = \frac{S1\ [0;\ 90]\ ns}{S1\ [0;\ 7]\ \mu s}$$

Leading to rejection power better 10^7

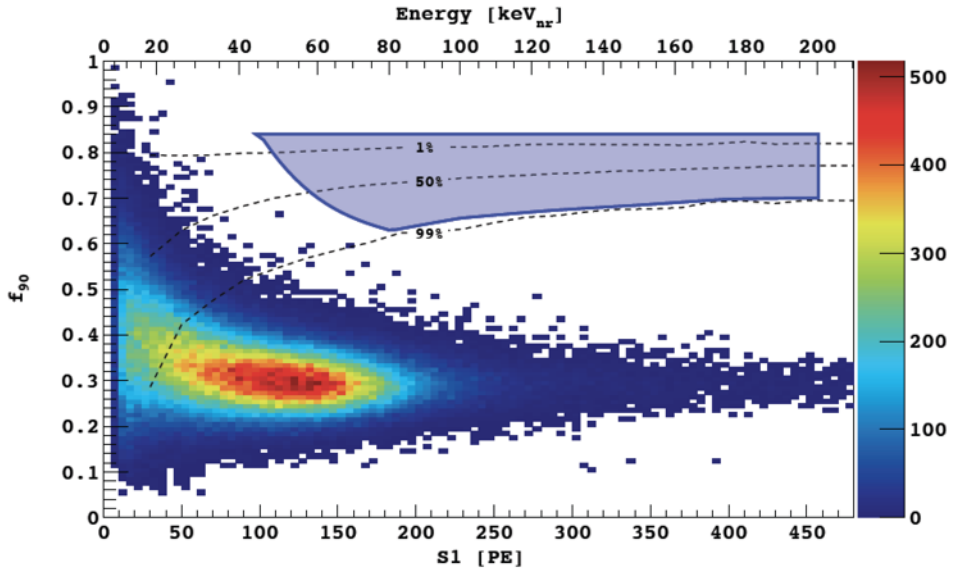


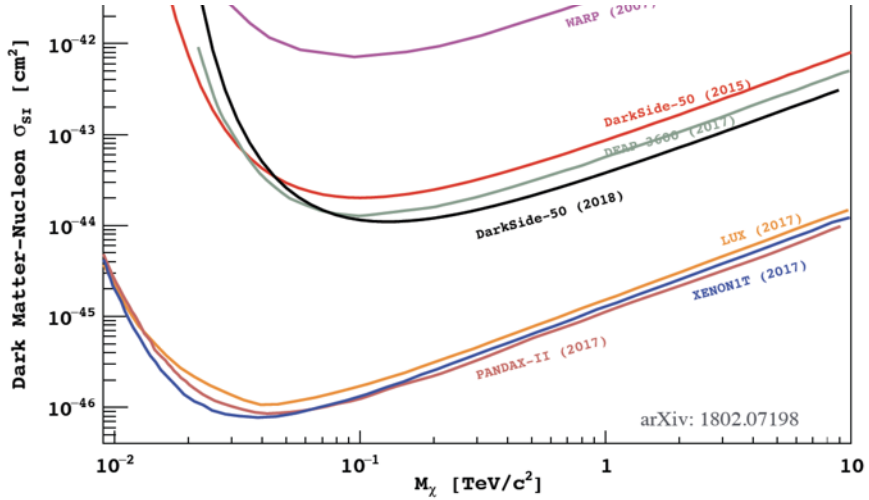


- 150 kg LAr: total mass
- 49 kg LAr: inner volume
- 19 +19 Hamamatsu PMTs

DARK-SIDE (50kg) results

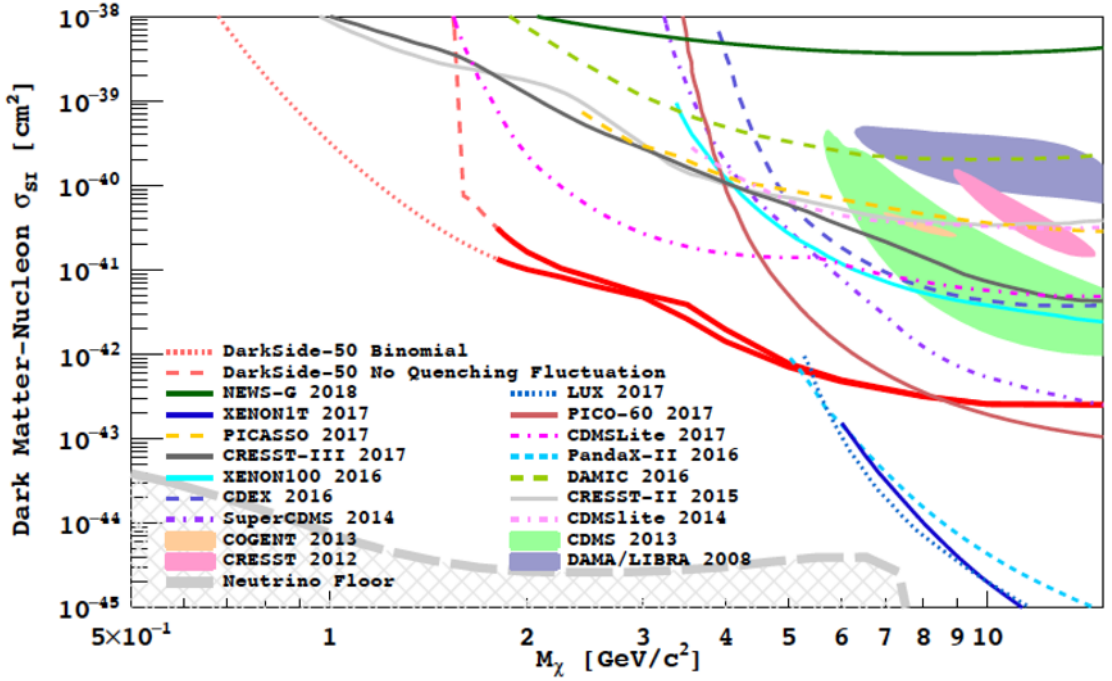
From blind analysis : no events found in the RoR





Low-mass Dark Matter Search with the DarkSide-50 Experiment

P. Agnes,[1] I. F. M. Albuquerque,[2] T. Alexander,[3] A. K. Alton,[4] G. R. Araujo,[2] D. M. Asner,[5] M. P. Ave,[2] H. O. Back,[3] B. Baldin,[6,a] G. Batignani,[7,8] K. Biery,[6] V. Bocci,[9] G. Bonfini,[10] W. Bonivento,[11] B. Bottino,[12,13] F. Budano,[14,15] S. Bussino,[14,15] M. Cadeddu,[16,11] M. Cadoni,[16,11] F. Calaprice,[17] A. Caminata,[13] N. Canci,[1,10] A. Candela,[10] M. Caravati,[16,11] M. Cariello,[13] M. Carlini,[10] M. Carpinelli,[18,19] S. Catalanotti,[20,21] V. Cataudella,[20,21] P. Cavalcante,[22,10] S. Cavuoti,[20,21] A. Chepurnov,[23] C. Cicalò,[11] L. Cifarelli,[24,25] A. G. Cocco,[21] G. Covone,[20,21] D. D'Angelo,[26,27]



With S2 signal only, exclusion limit from 1.8 GeV/c^2

DARK-SIDE 20k

Today

DarkSide-50

DEAP-3600

miniCLEAN

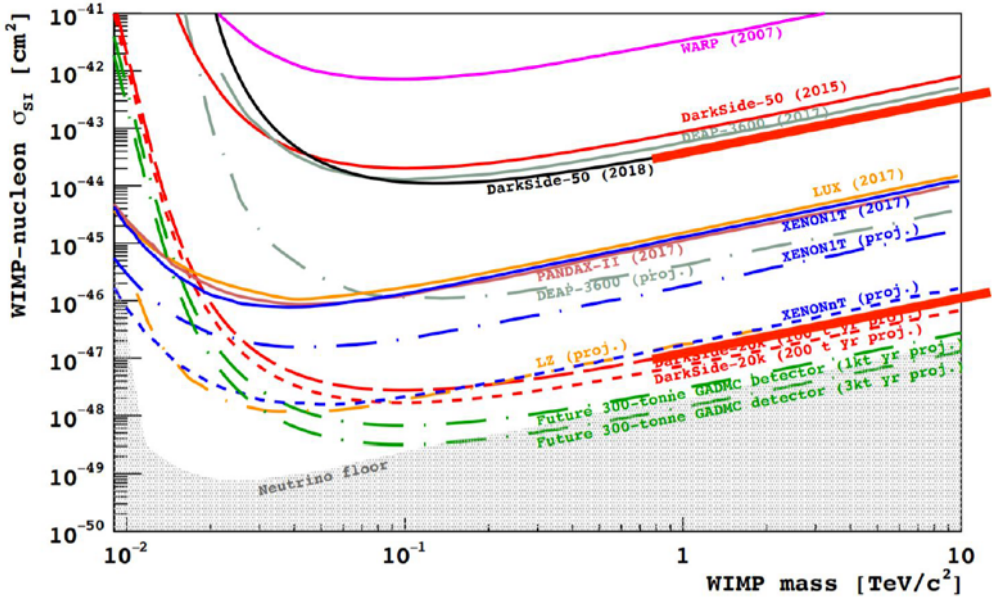
ArDM

Short-term Future

DarkSide-20k

Long-term Future

300T Detector

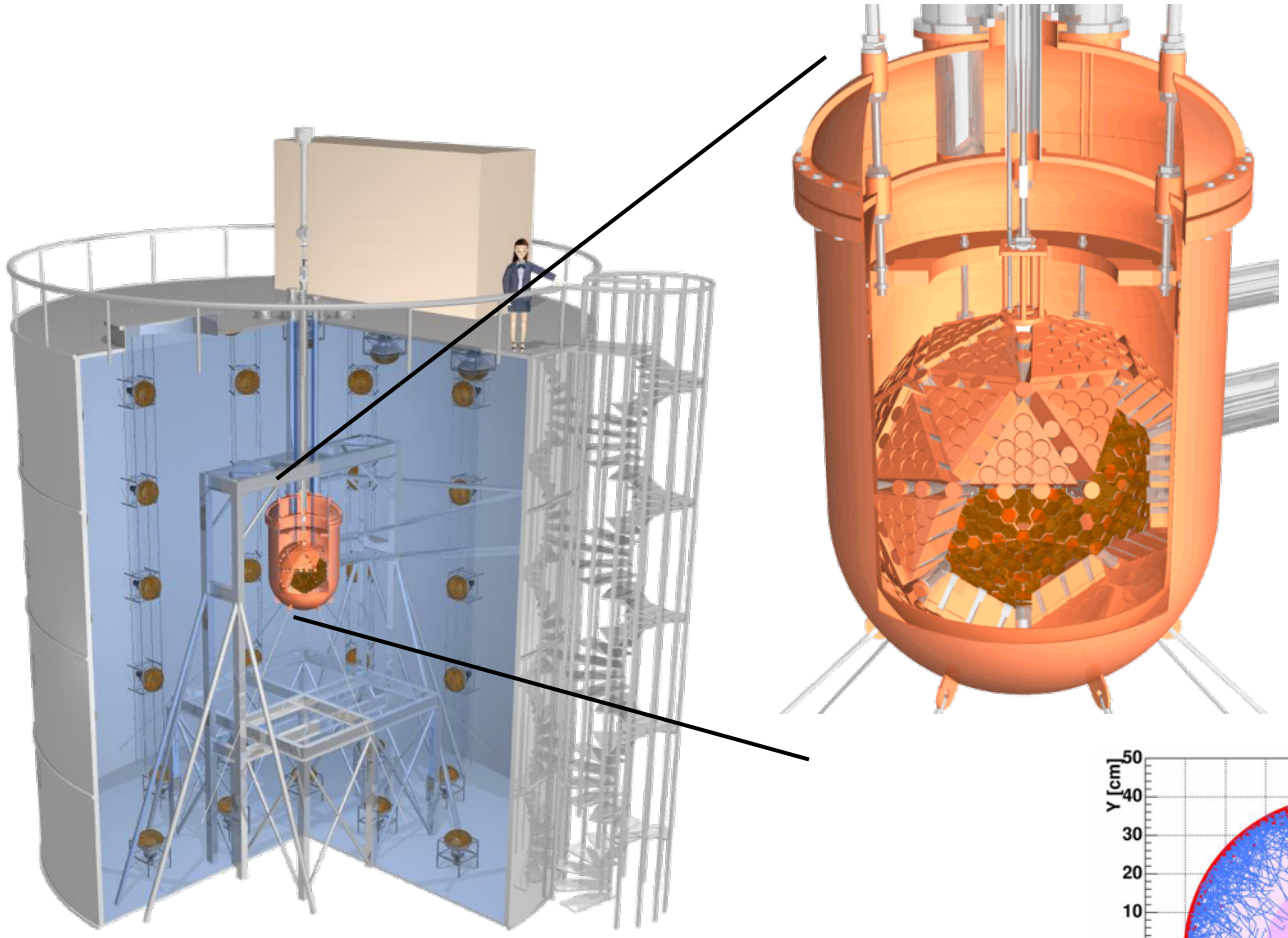


Global Argon Dark Matter Collaboration

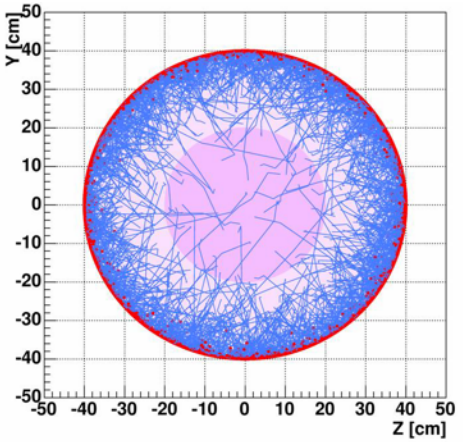
XMASS

Single phase LXe experiment in Kamioka mine

- 1000 m underground
- Collaboration : 40 physicists ,
- 11 institutes
- Large mass : 823 kg, 642 hexagonal PMTs, photocathode coverage 62 %
- High LY , low threshold 0.5 keV_{ee}
- Water Cherenkov veto with 72 PMTs

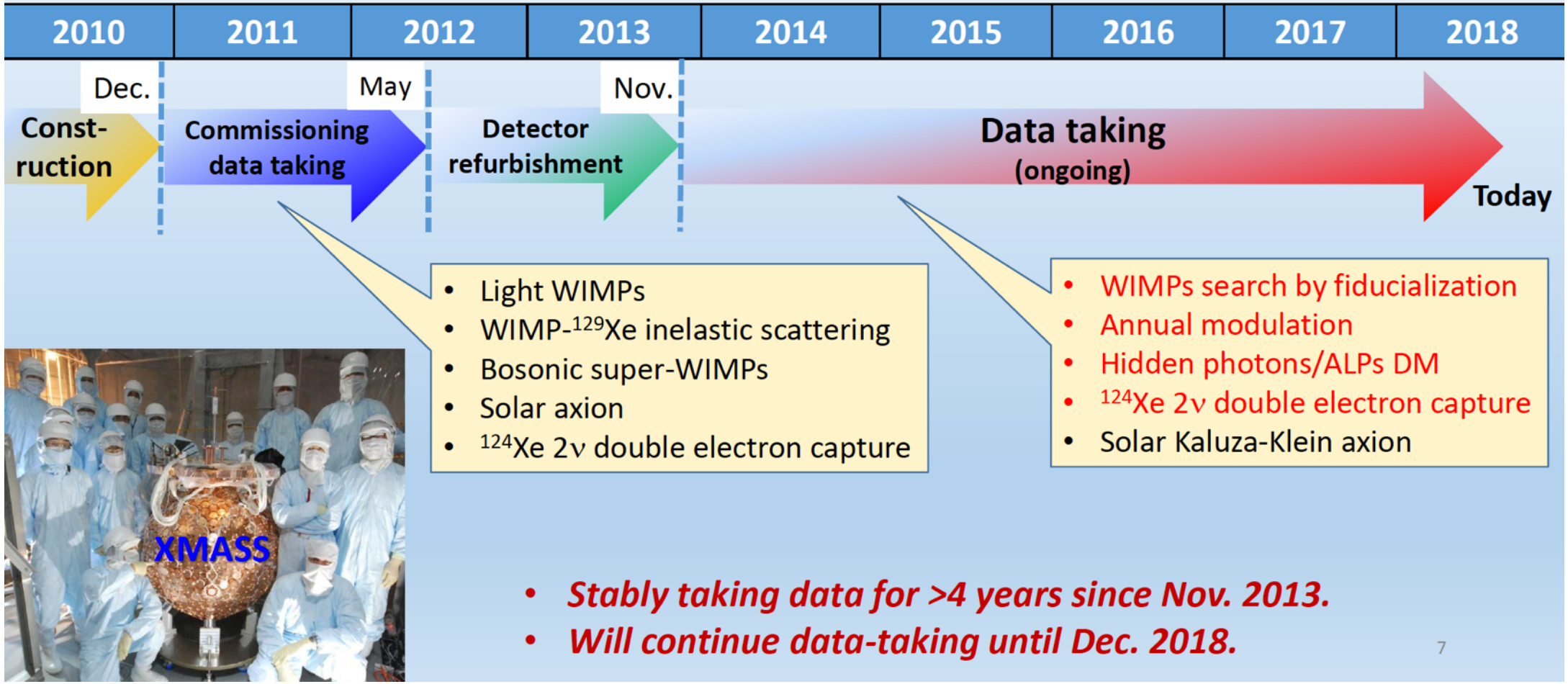


Traces of gammas from PMTs
R<20 cm fiducial volume



XMASS

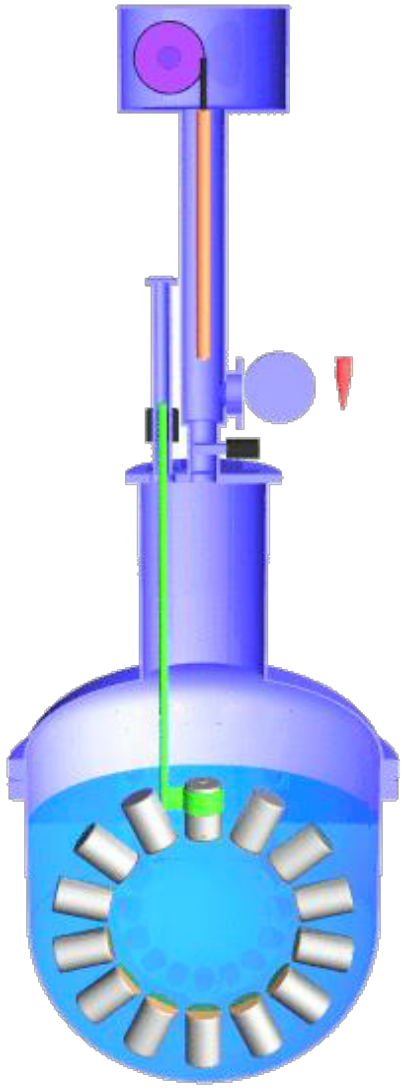
History of XMASS-I data-taking

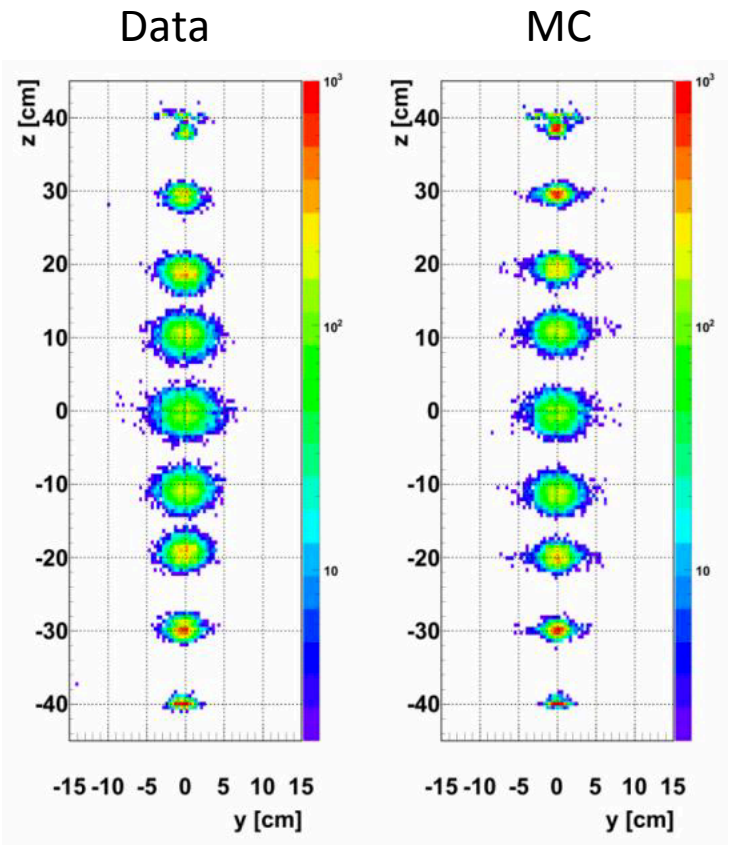


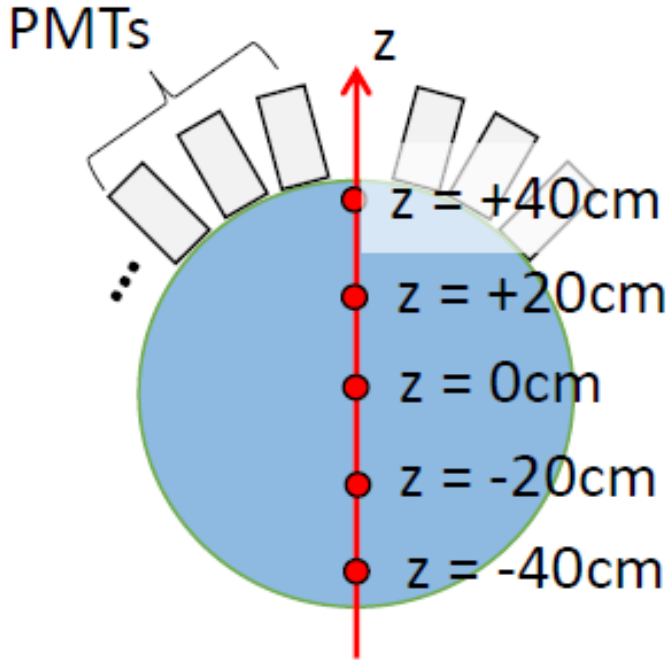
- ***Stably taking data for >4 years since Nov. 2013.***
- ***Will continue data-taking until Dec. 2018.***

XMASS (calibration, vertex reconstruction)

Calibration Mechanism

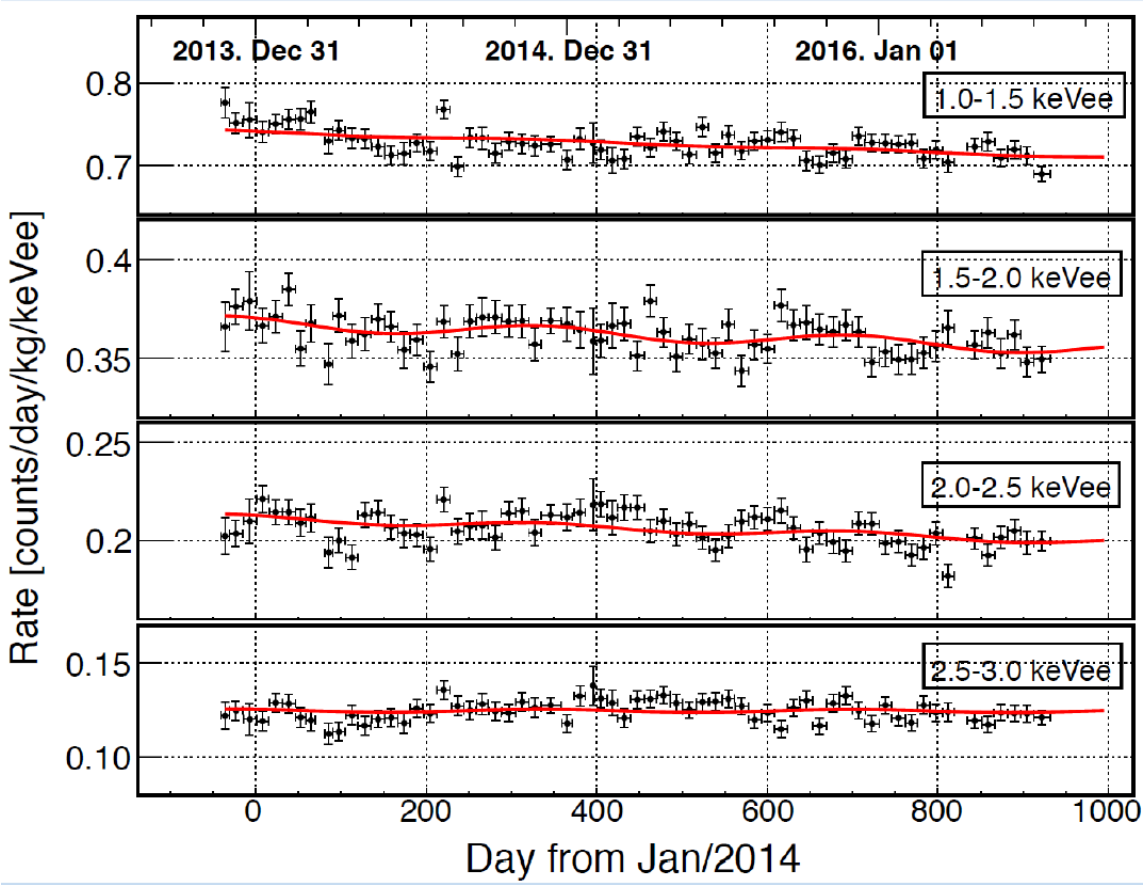




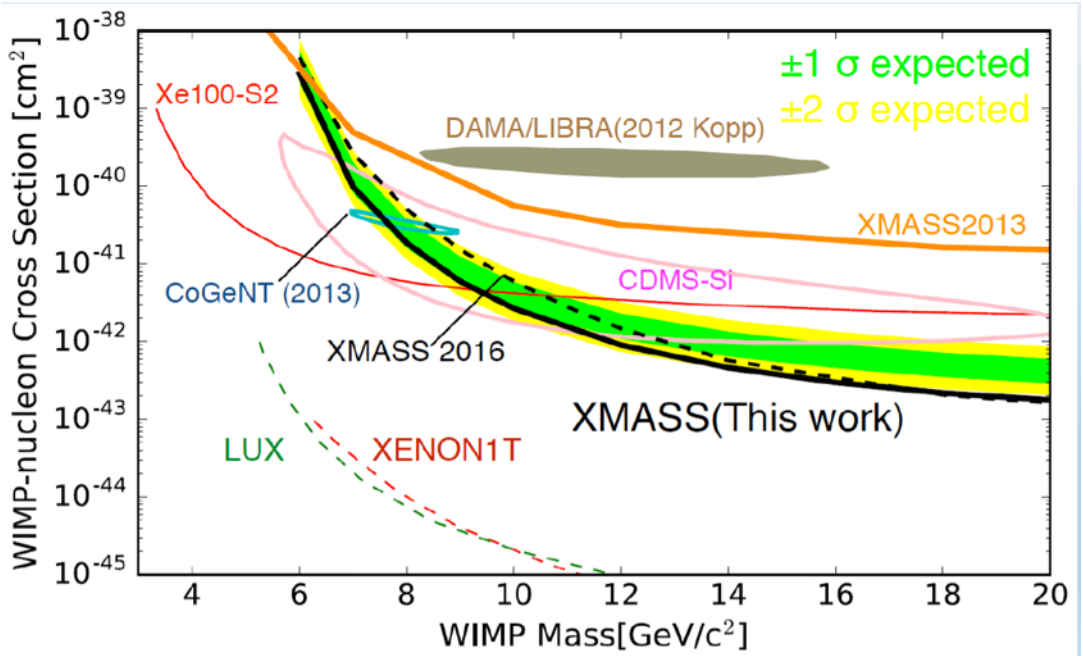


Source rod with Co^{57} at the tip of the needle

XMASS (annual modulation searches)



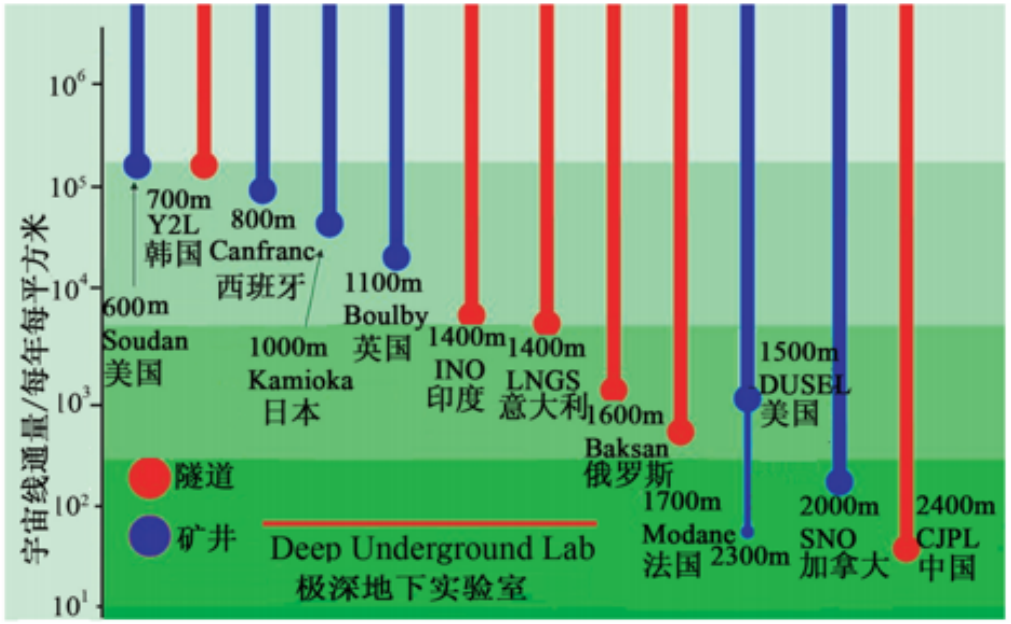
Event rate as a function of time for two years

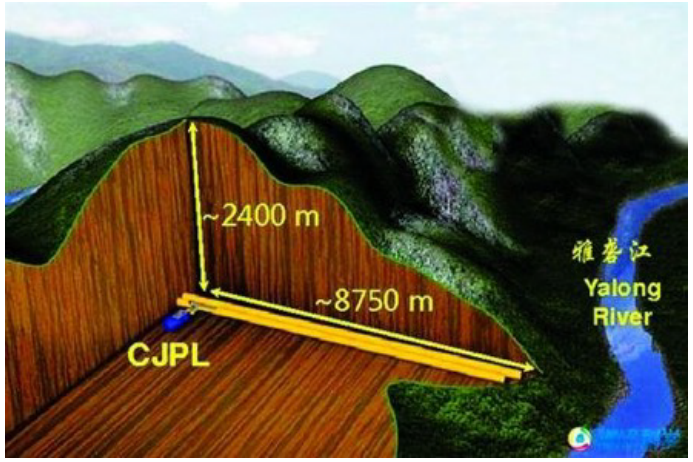


Experiment	Amplitude (/day/kg/keVee)	
DAMA/LIBRA	~20×10^{-3}	(2-3.5 keV_{ee})
XENON100	$(1.67+/-0.73)\times10^{-3}$	(2-5.8 keV_{ee})
XMASS	$<(1.3\text{-}3.2)\times10^{-3}$	(2-6 keV_{ee})

Dama/Libra allowed region has been excluded by annual modulation search to the level of 1.9×10^{41} cm^2 for 8 GeV/c^2

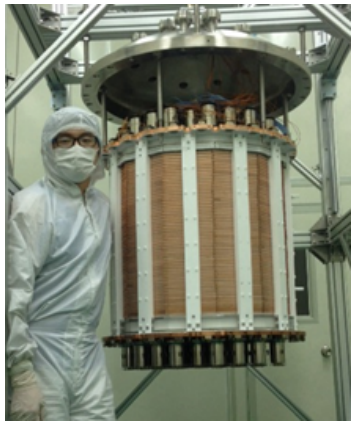
PANDAX (Chinese LXe DM programme)





Deepest laboratory in the world
Horizontal access

PandaX-I 120 kg



PandaX-I 580 kg

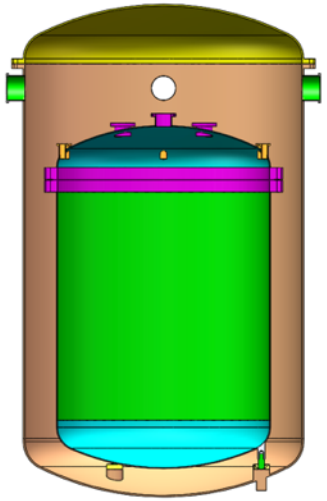
Near future:

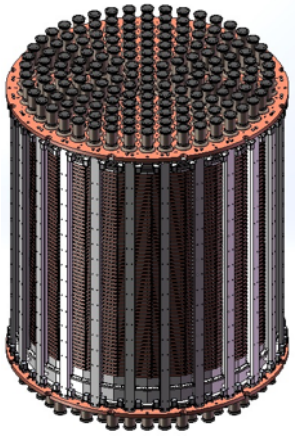
Panda-XT

4 tonnes

Commissioning

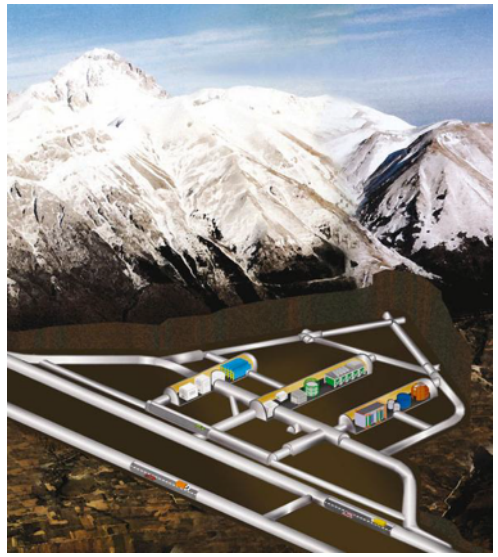
2019-2020





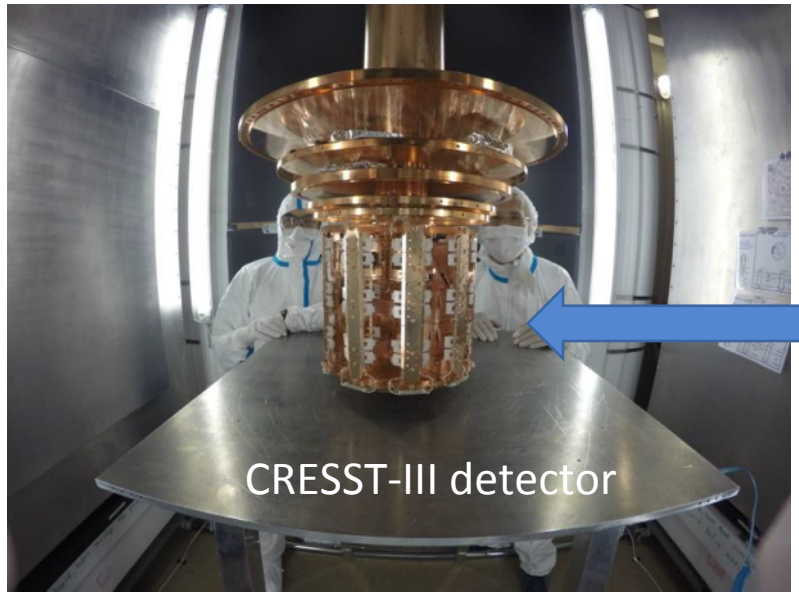
CRESST-III

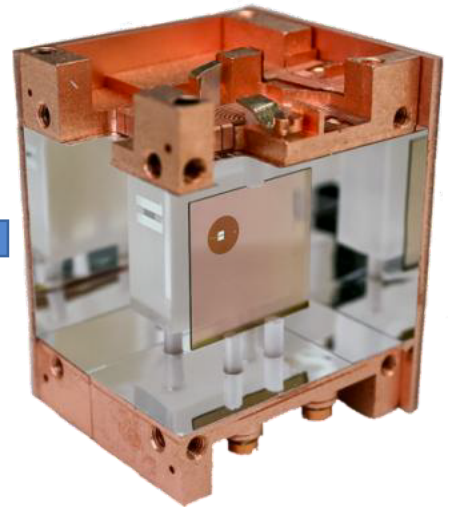
Cryogenic Rare Event Search with Superconducting Thermometers

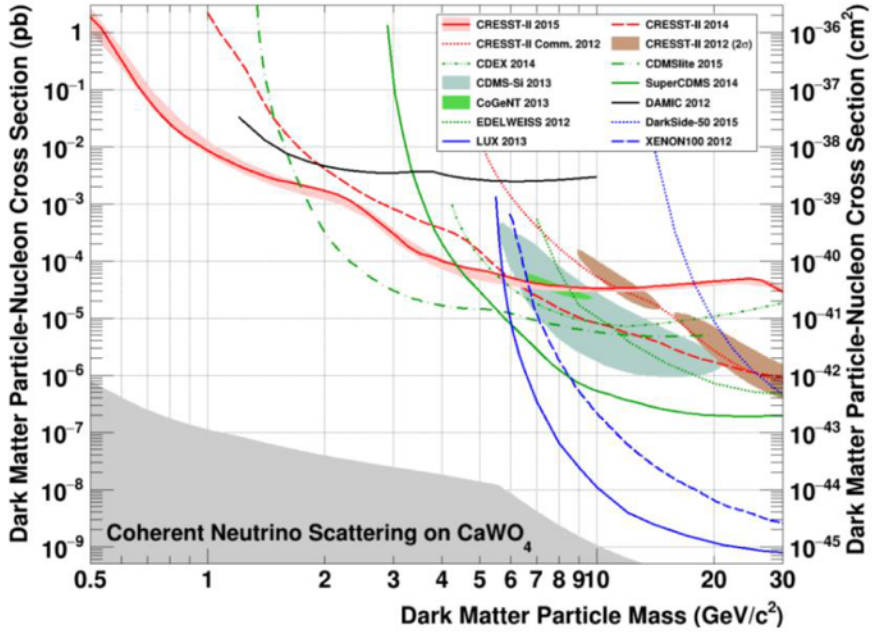


6 Institutions
46 Members
Location : Gran Sasso
Target: $CaWO_4$
Readout channels: phonons and scintillation light

CRESST-III phase 1 - 10 modules







Parameter space explored down to 0.5 Gev/c^2

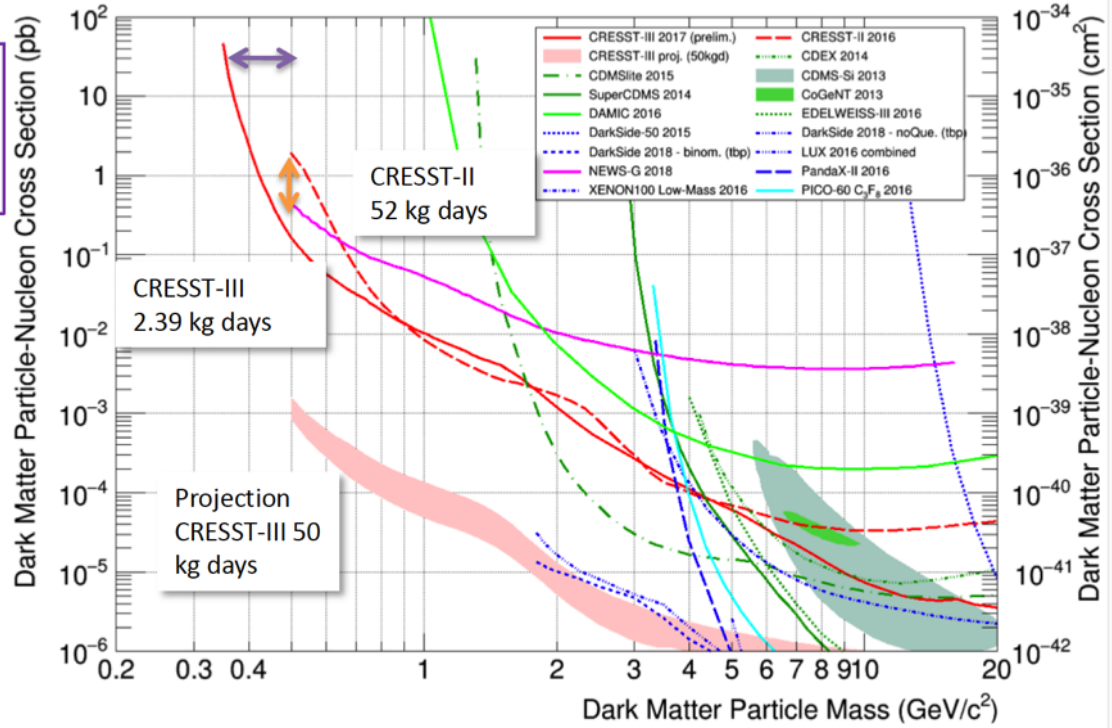
Target mass : 25 g
Temp. readout: Tungsten transition edge sensor
Phonon threshold : E_{th}< 100 eV
Light detector resolution: ~ 5 eV

CRESST-III

Limit with Det A 2.39 kg · day

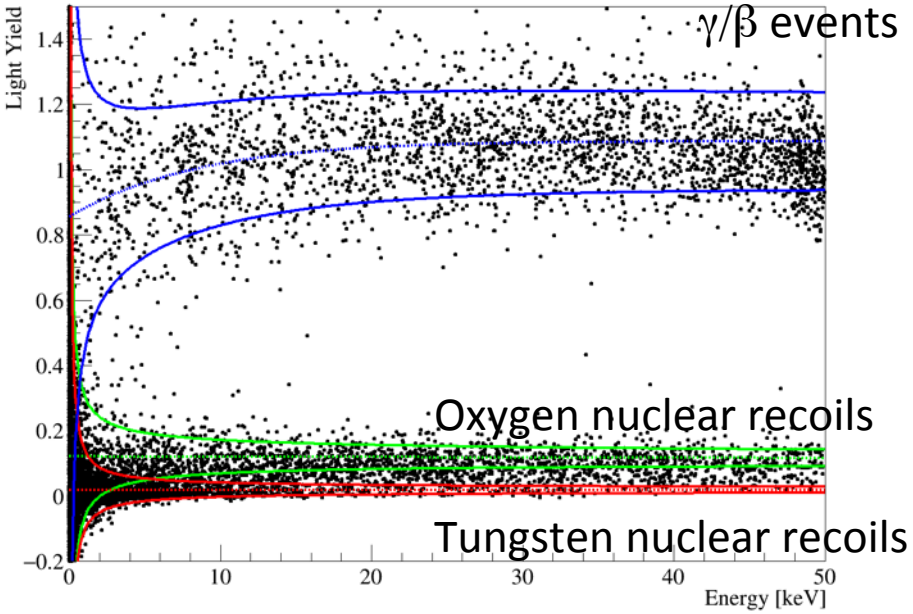
Extend reach from 0.5GeV/c2 to 0.35GeV/c2

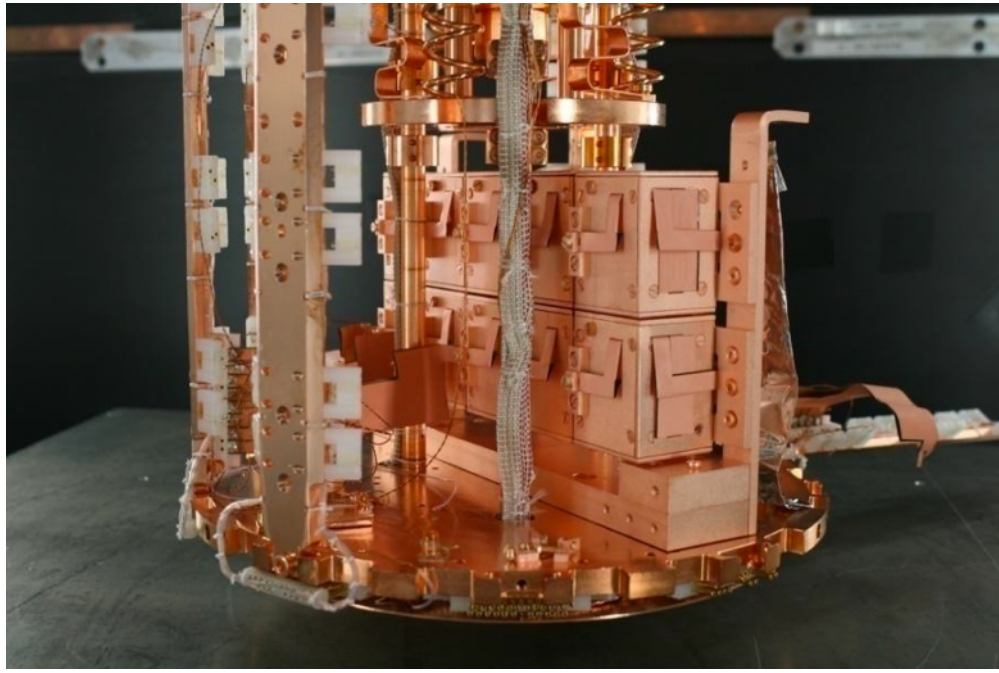
One order of magnitude improvement at 0.5 GeV/c2



February 2018 - end of run
Total exposure 30 kg * day
Unblinded 1 module above 100 eV: 2.39 kg * day
New data release and results will come soon

Neutron Calibrations





Summary

- Major large LXE projects constructions or upgrades very advanced.
  - 2019-2020 : LZ, XENONnT, PANDA-XT
- Constant progress in low mass WIMPs searches by cryogenic detectors
- Future: few large experiments BUT even small step takes very long time