Dark matter search with noble gas two-phase emission detectors

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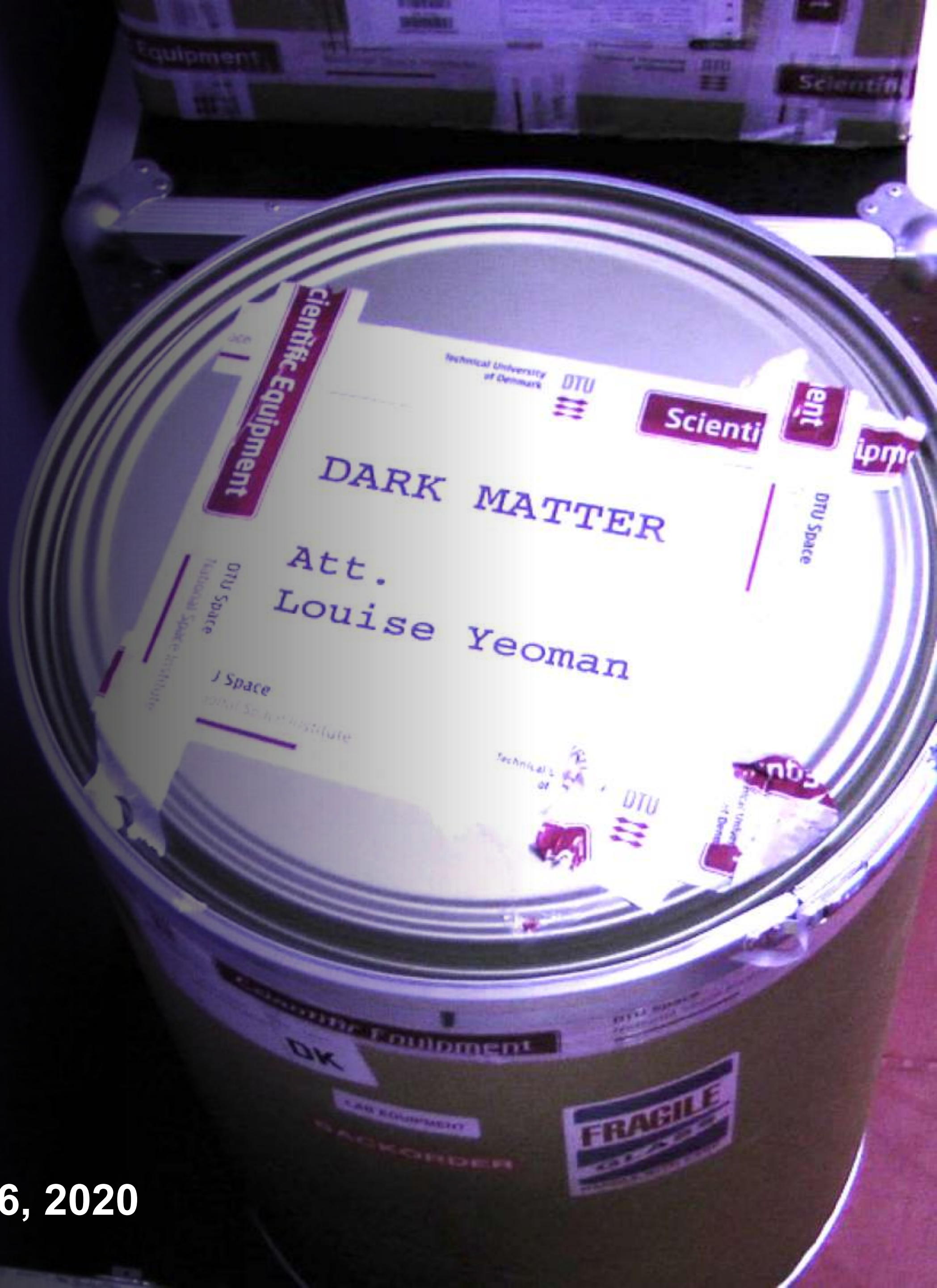
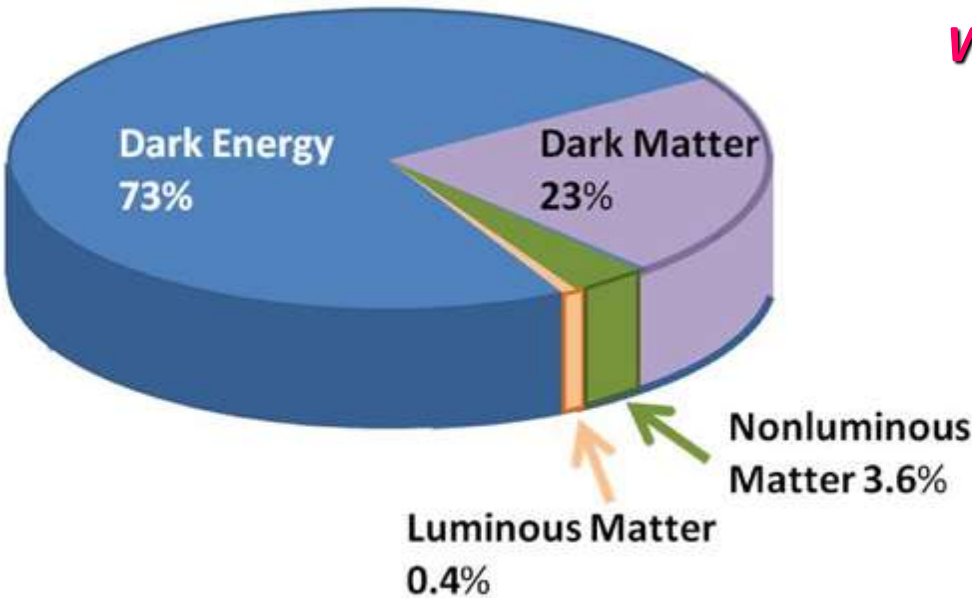


ICPPA 2020, Moscow, October 6, 2020

Dark matter

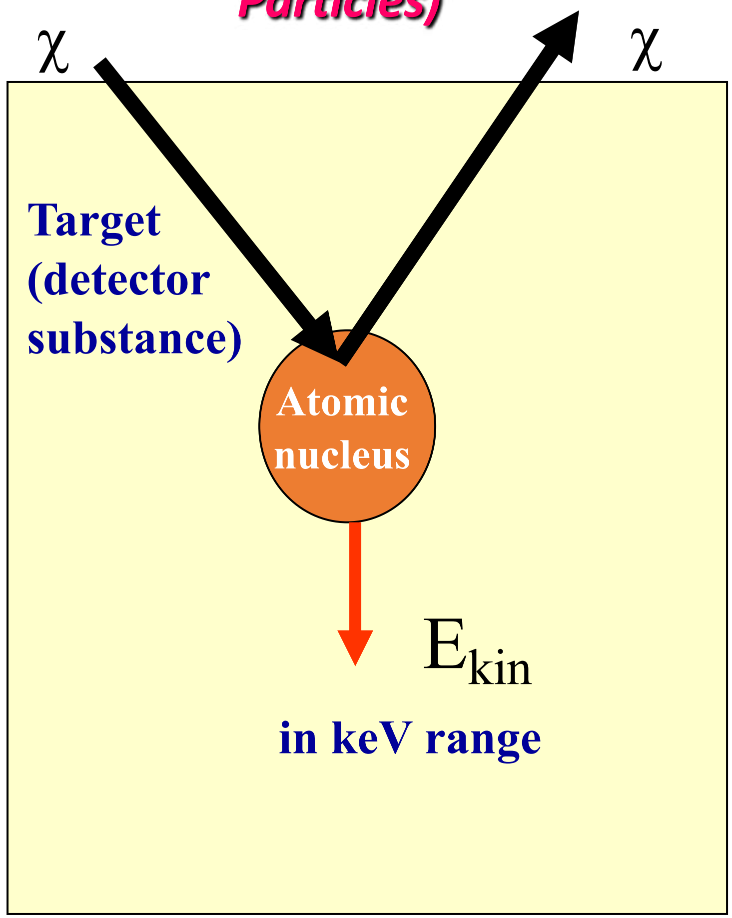
From astrophysical observations and modern cosmology we know:



$\sigma \sim A^2$	- spin-independent (SI)	interaction
$\sigma \sim J(J+1)$	- spin-dependent (SD)	interaction

The widely accepted hypothesis is Particle Dark Matter - elementary particles (relic from Big Bang) with a weak interaction only:

WIMPs - (Weakly Interacting Massive Particles)



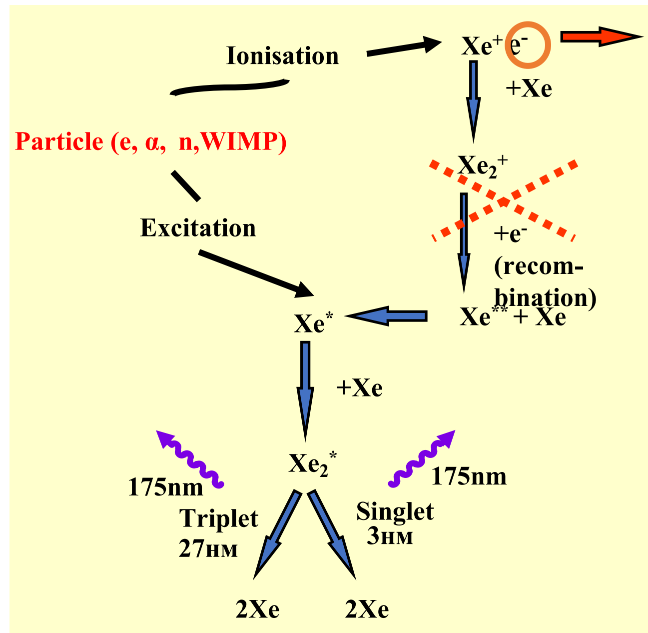
Two-phase emission detection technique

is very suitable for Dark Matter search

It combines the advantages of gas detectors: the possibility of proportional or EL amplification, 3D (XYZ) positioning, and the possibility to have the large mass!

This method was proposed by Russian scientists in MEPhI 50 y ago!

B.A. Dolgoshein, V.N. Lebedenko, B.U. Rodionov, JETF Letters (in Russian), 1970, v. 11, p. 513



Electrons are partly pulled out from the track: recombination is suppressed

Suppression depends on dE/dX

Ratio of SC/EL is different for different kind of particles

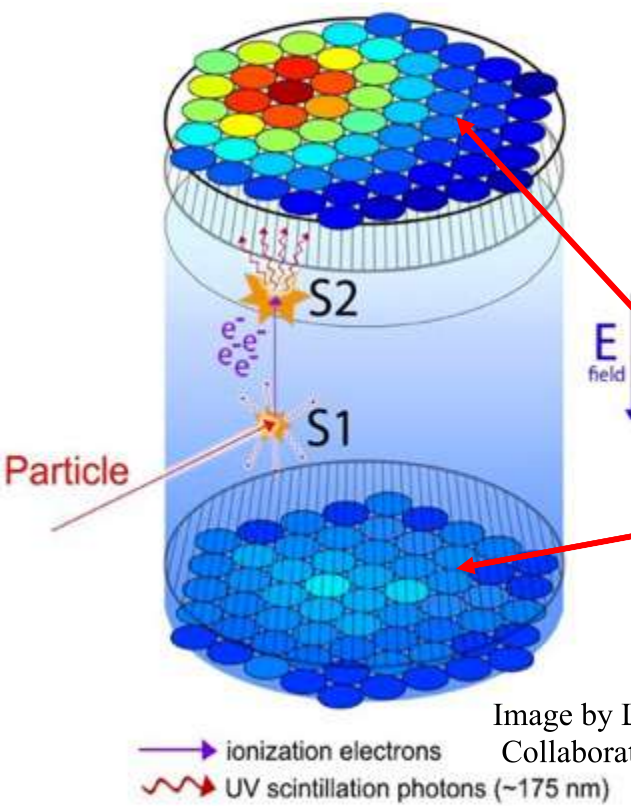
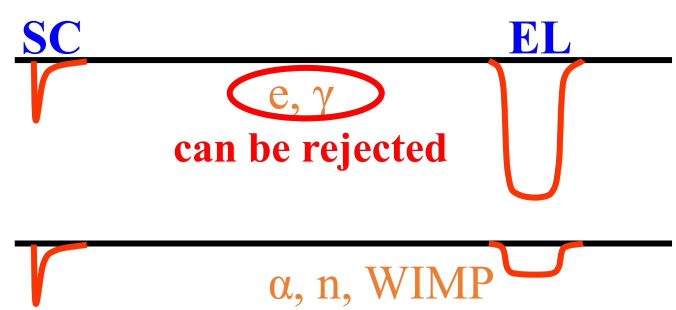


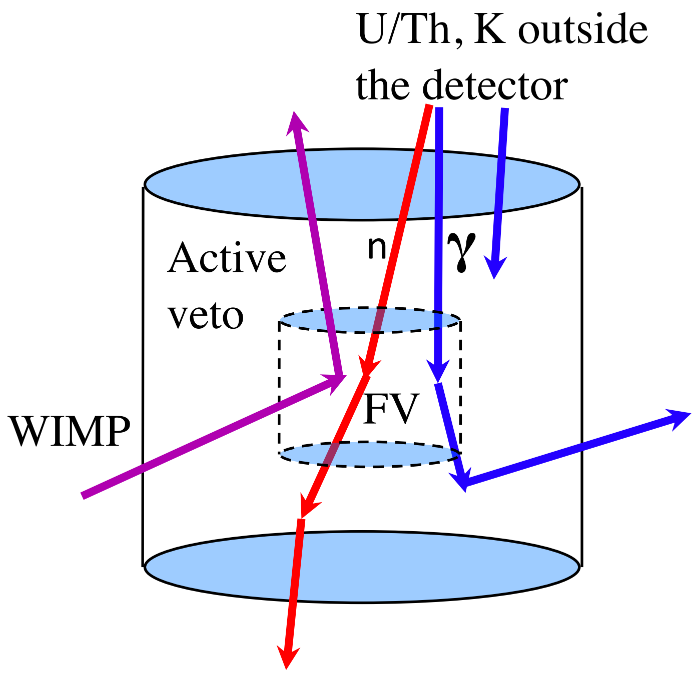
Image by LUX Collaboration

Photodetectors (photomultipliers)



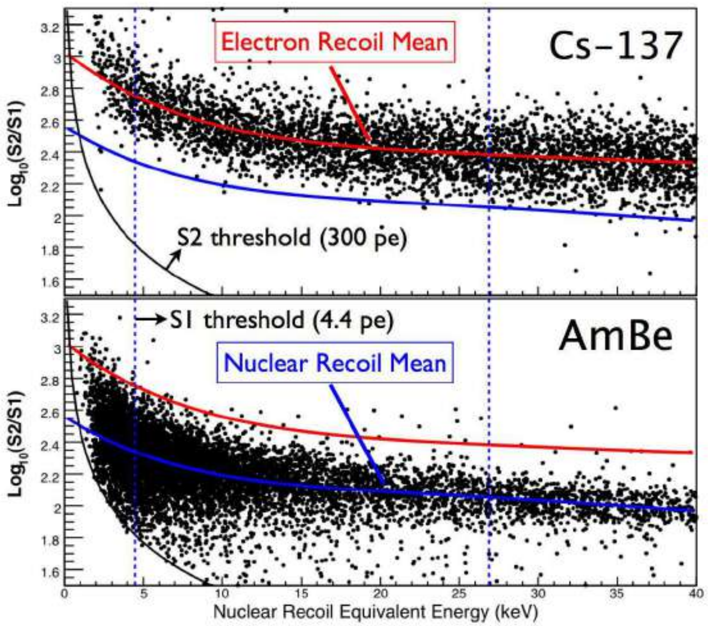
Advantages of two-phase noble gas emission detectors for WIMP search

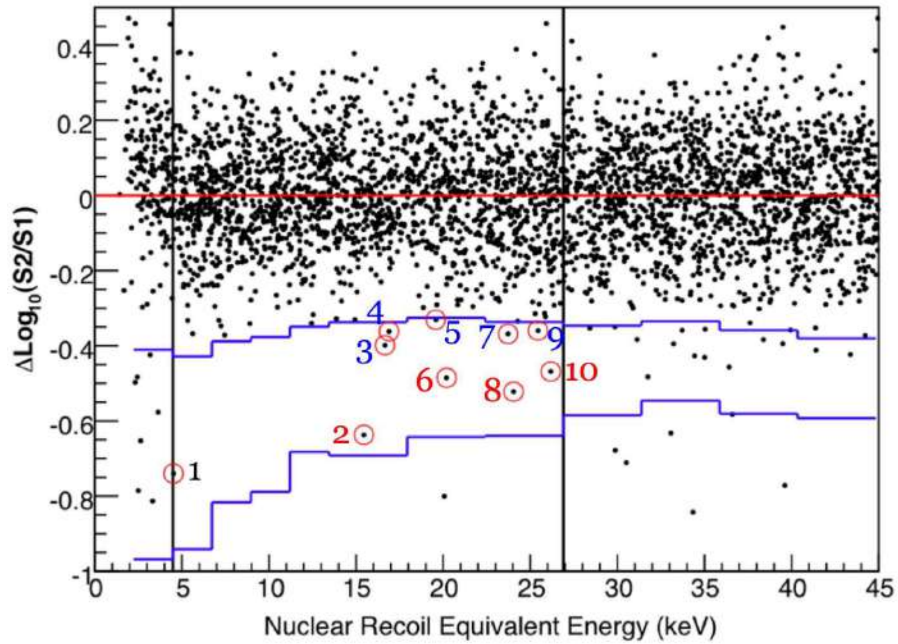
- No long-life own radioactive isotopes (Xe). Ar has cosmogenic ^{39}Ar, but production of depleted Ar is well developed
- very low contamination by U/Th, K (can be easily purified by filtering)
- possibility of discrimination by simultaneous measurements of scintillation and ionization signals in a two-phase mode
- possibility to build large and even very large (ton-scale) detectors
- 3D position sensitivity => "WALL-LESS" detector!!!



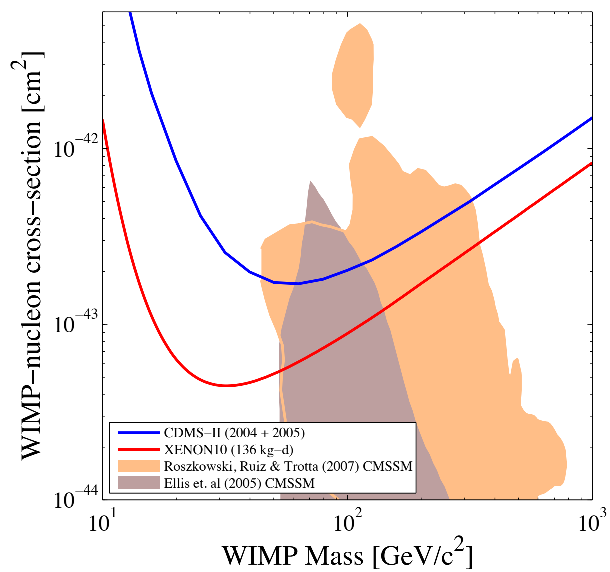
Particle identification is based on comparison of SC and EL signals

(on example of XENON10 experiment)



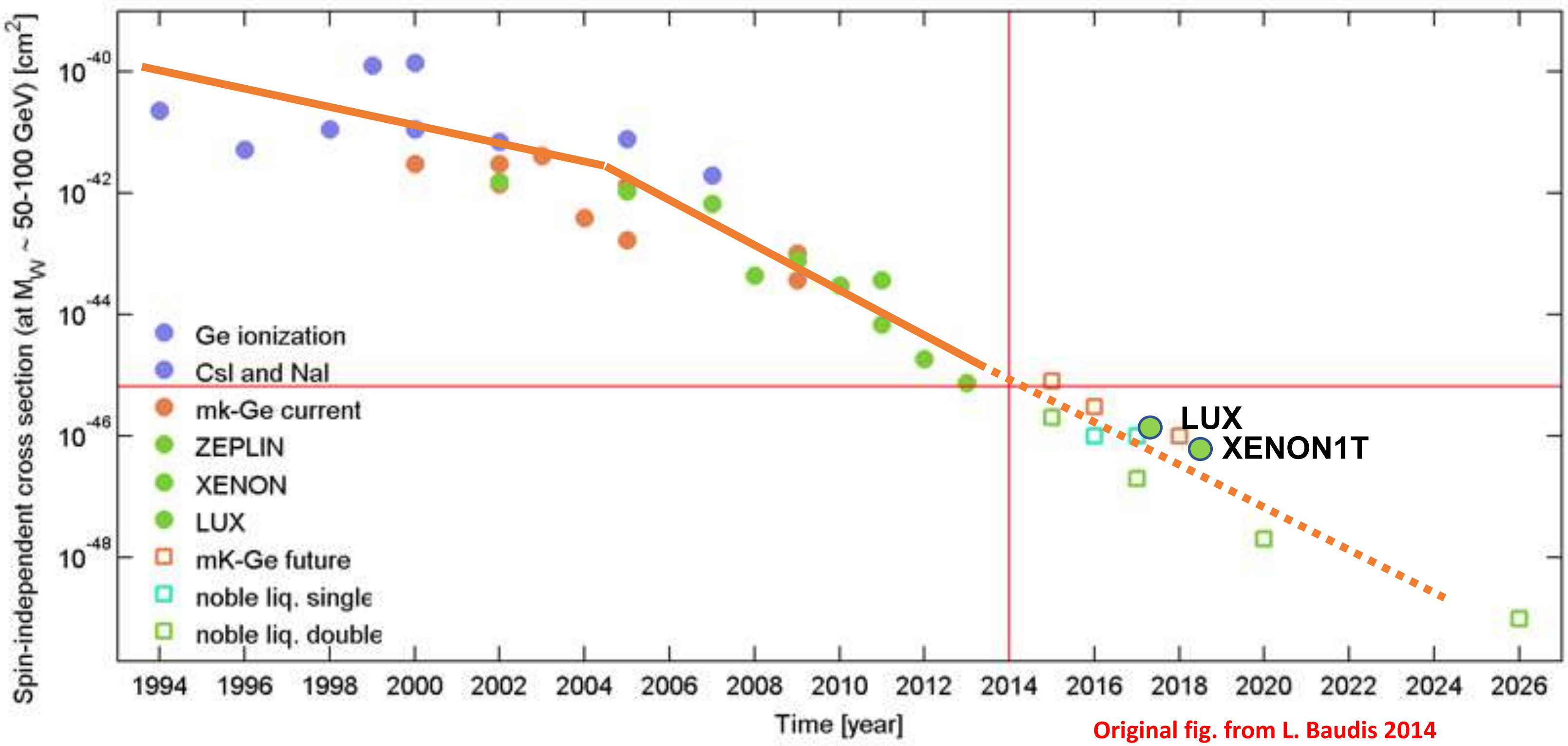


Exclusion plots are produced on the basis of collected statistics



Progress of setting limits on SI WIMP-proton interaction cross-section

In Dark Matter search experiments, the progress of setting limits has increased significantly when liquid noble gas two-phase detectors started operation



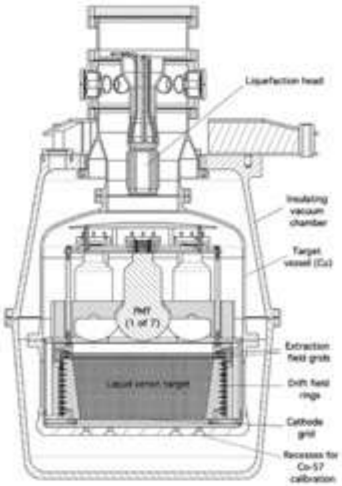
Original fig. from L. Baudis 2014

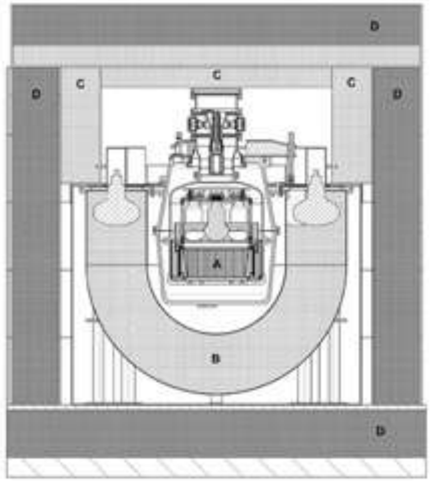
ZEPLIN program

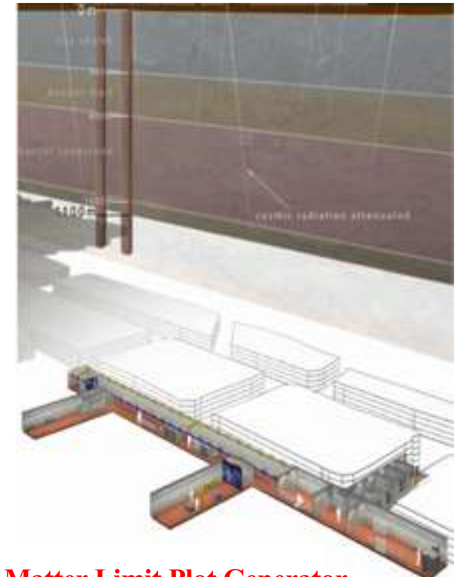
ZEPLIN II – the 1st two-phase emission DM detector

31 kg; 7.2 kg FV

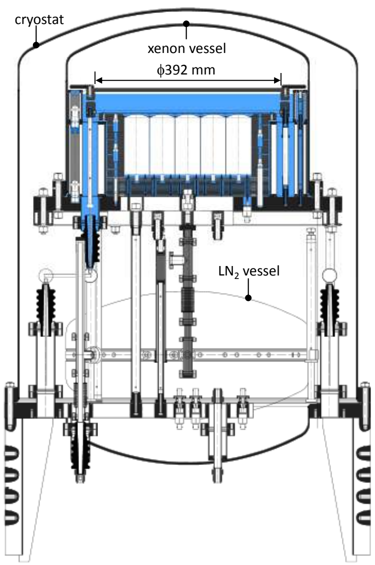
Boulby mine, U.K. 'Palmer lab'
1100m, 2.8km water equiv.
10^6 reduction in muon flux

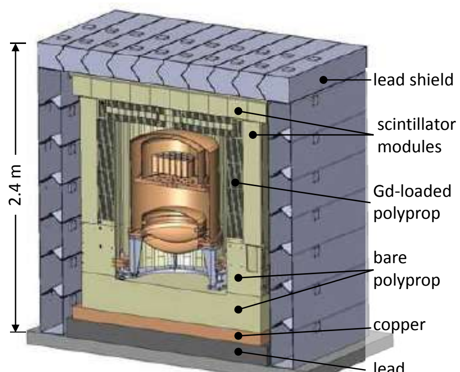


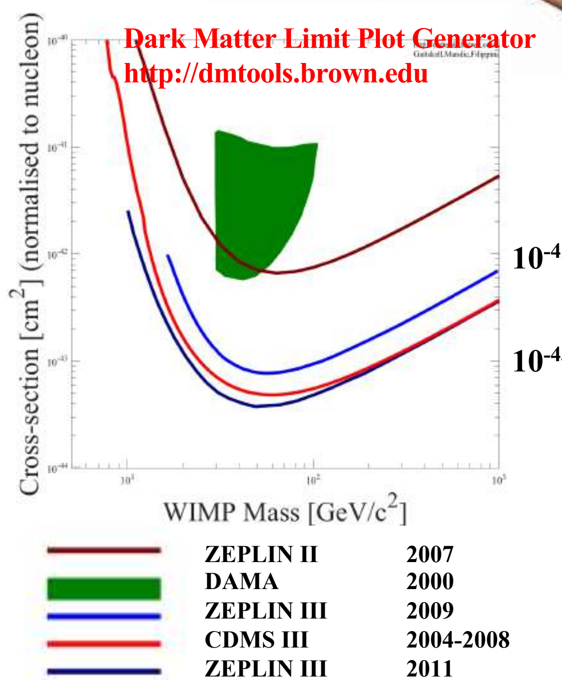




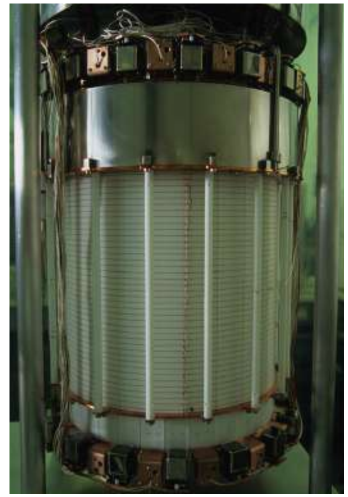
ZEPLIN III – "pancake" geometry; 50 kg total, 12 kg active, 6 kg FV







XENON program
at the Gran Sasso National lab., Italy

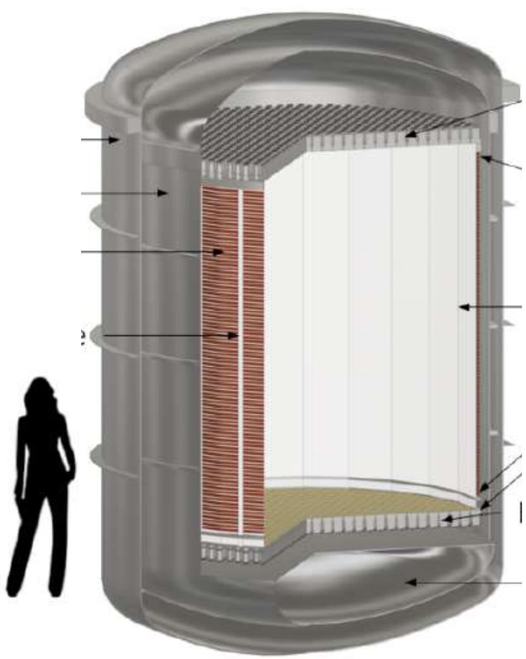



	XENON10	XENON100	XENON1T	XENONnT
Livetime [yyyy]	2005-2007	2008-2016	2015-2018	2020-202x
Xe mass [kg]	25	161	2300	8400
Target m [kg]	15	62	2000	5900
Drift [cm]	15	30	96	150
VETO	NO	NO	Muons	Muons+Neutrons
σ_{SI} [cm^2]	8.8×10^{-44} @ 100 GeV/c^2	1.1×10^{-45} @ 55 GeV/c^2	4.1×10^{-47} @ 30 GeV/c^2	**1.4×10^{-48} @ 50 GeV/c^2**

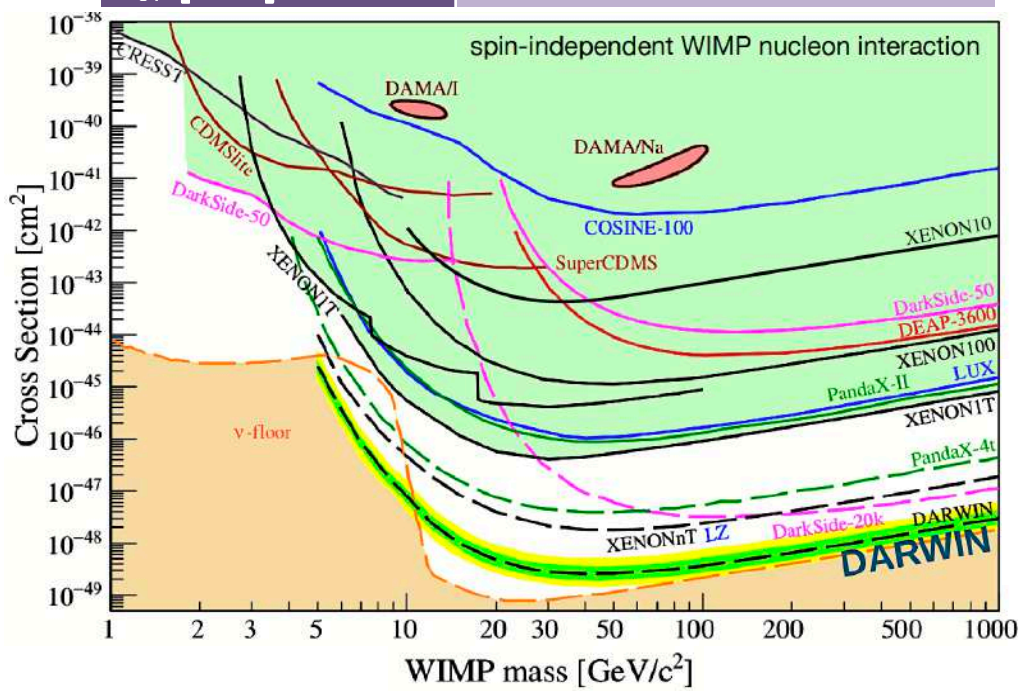
From A. Giovanni talk @ICHEP 2020

XENON program

DARWIN



VETO	Muons+Neutrons
Livetime [yyyy]	2026-203x
Xe mass [kg]	50000
Target m [kg]	40000
Fiducial m [kg]	Up to 30000
Drift [cm]	260
σ_{SI} [cm^2]	Few X 10^{-49} @ 50 GeV/c^2



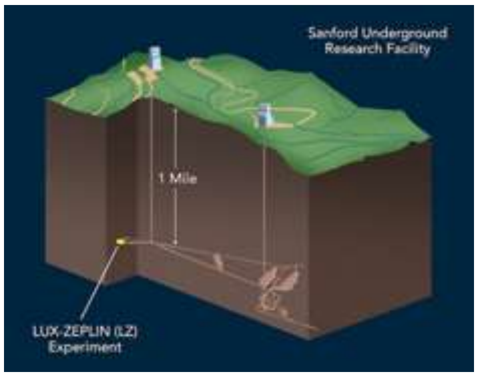
From A. Giovanni talk @ICHEP 2020

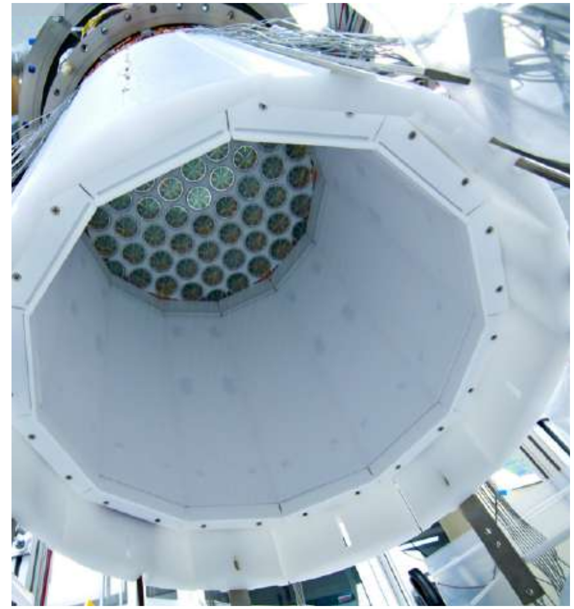
LUX

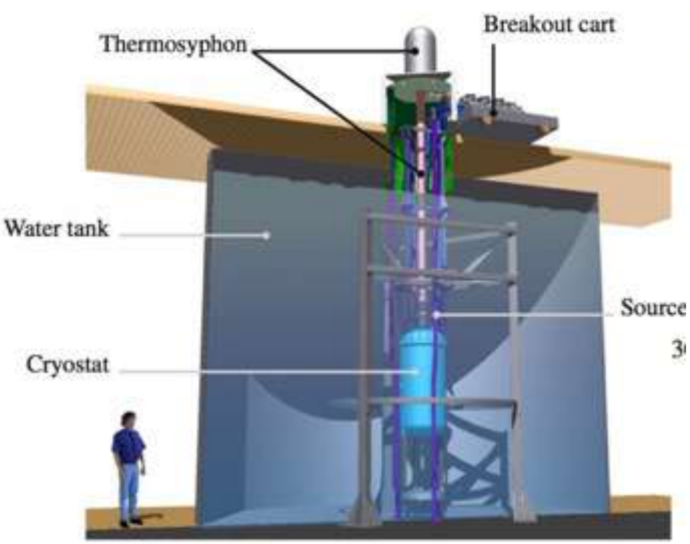
Large Underground Xenon detector

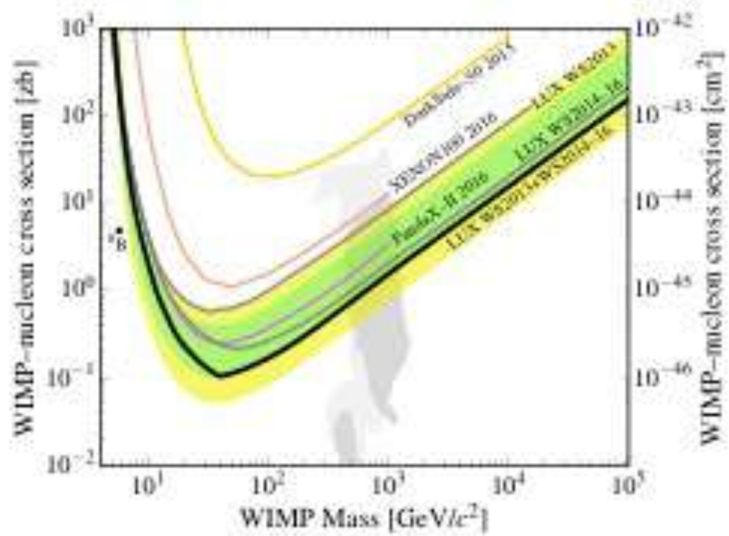
250 kg in active volume (TPC); 100 kg in FV

Homestake mine; South Dakota Davis cavern

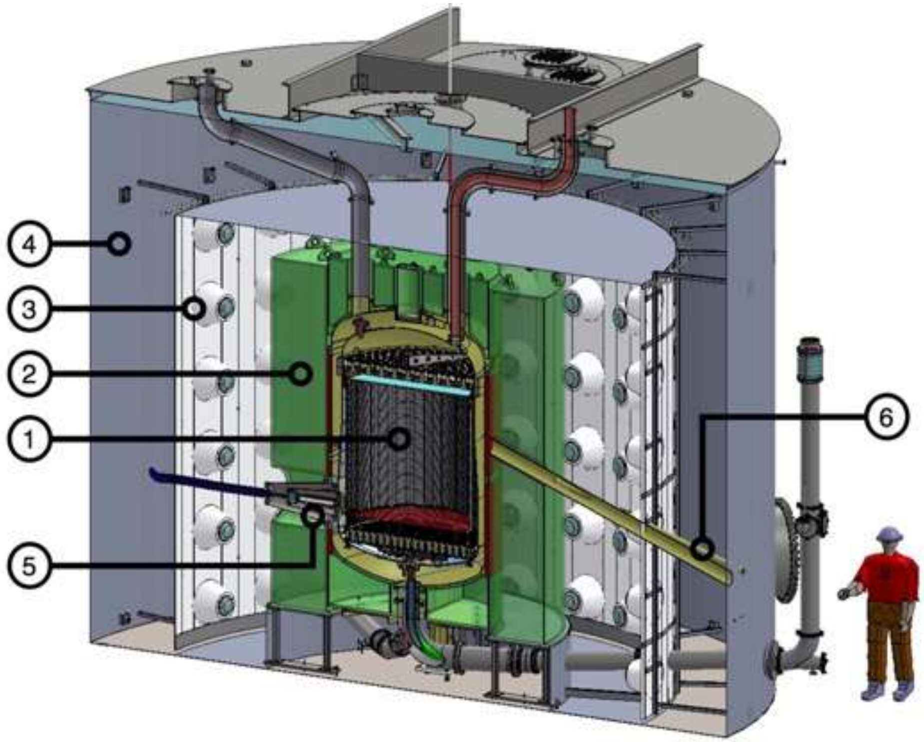




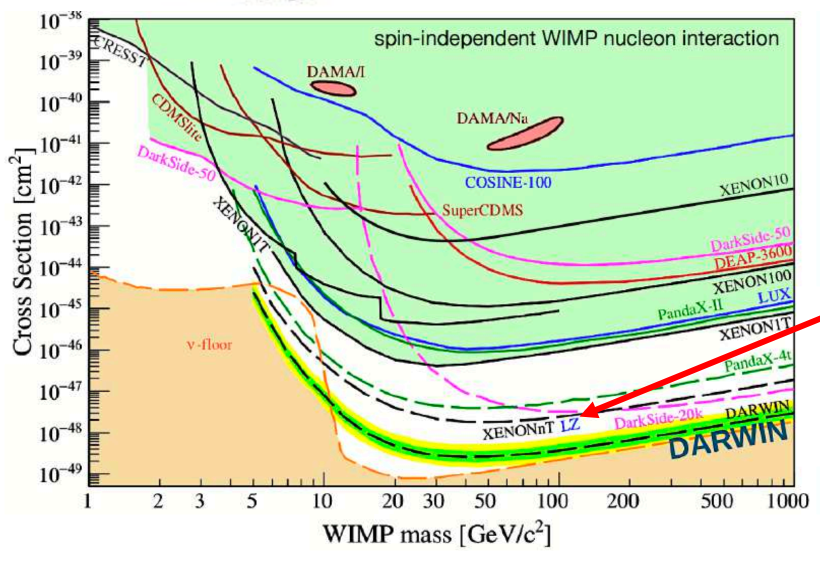




LUX-ZEPLIN - LZ



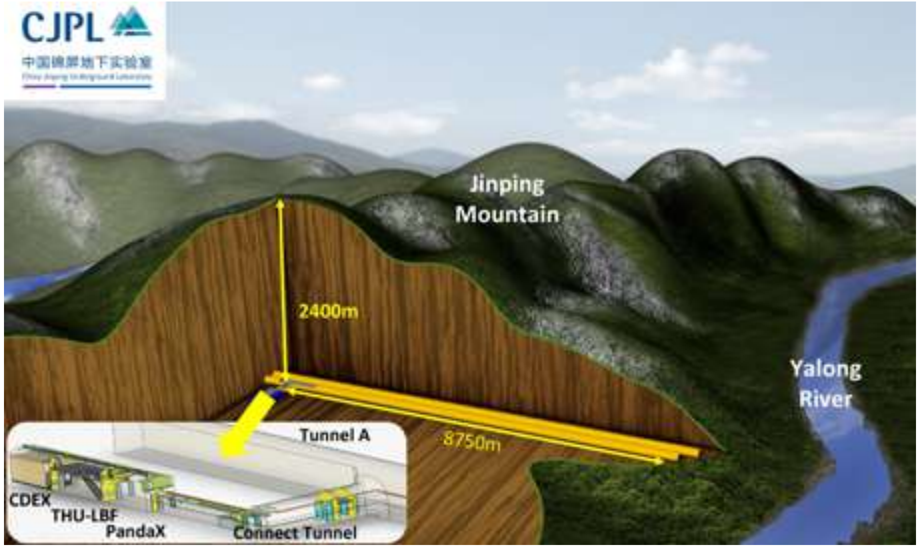
10 t, 7 t active



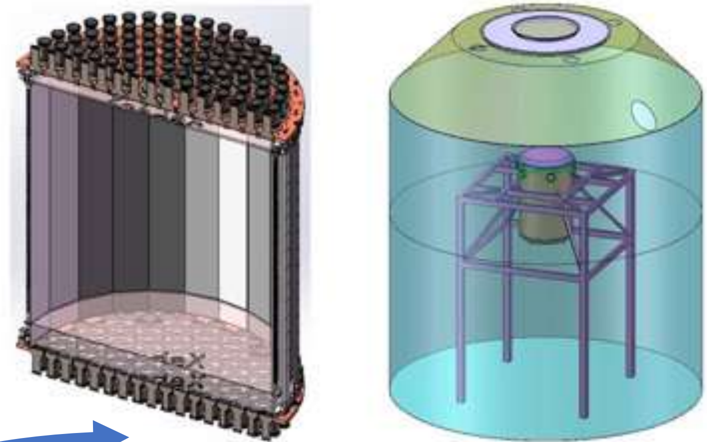
LZ

PandaX program

China Jinping underground laboratory (CJPL)



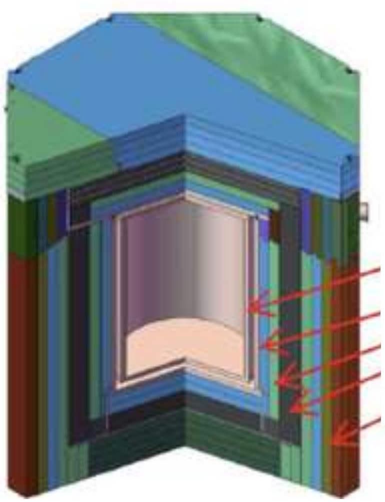
PandaX-4T
6 t, 4 t active



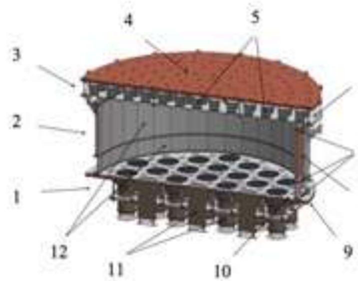
PandaX-I
250kg, 120 kg active;

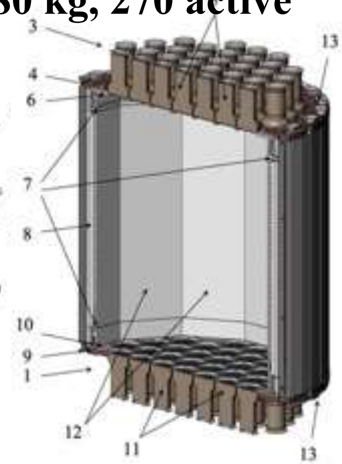
PandaX-II
580 kg, 270 active

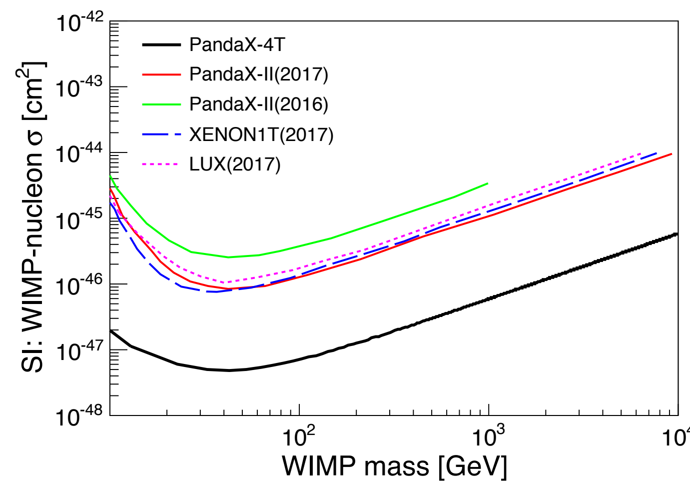
Passive shield



5-cm inner&outer copper vessels
20-cm inner PE
40-cm Pb
20-cm outer PE



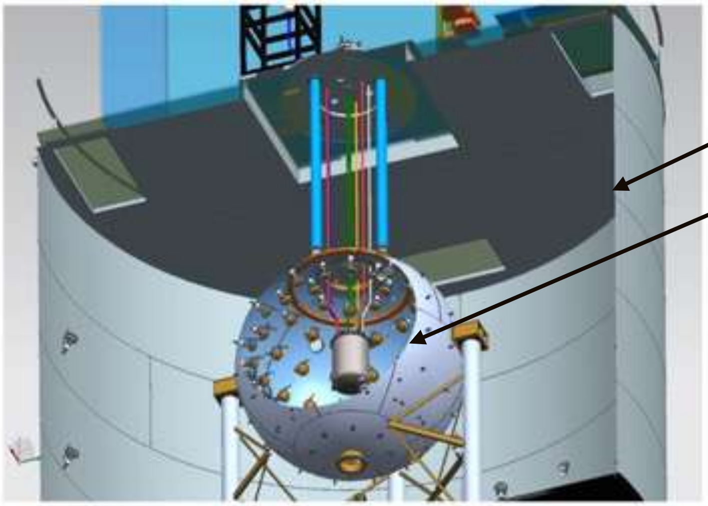




DarkSide program, LAr two-phase detectors

DarkSide50 @ Borexino TF in Gran Sasso

~ 46 kg active

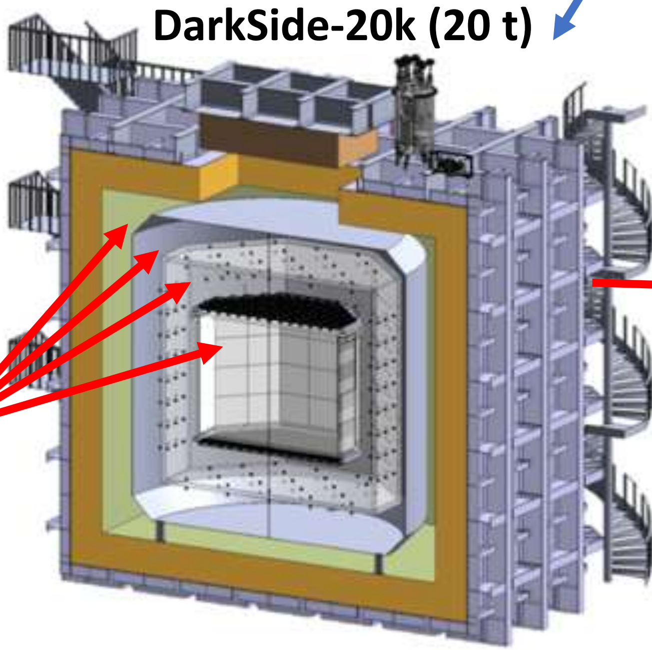


Water tank

Veto sphere with LSc inside

URANIA and ARIA projects to obtain large amounts of ^{39}Ar-free argon

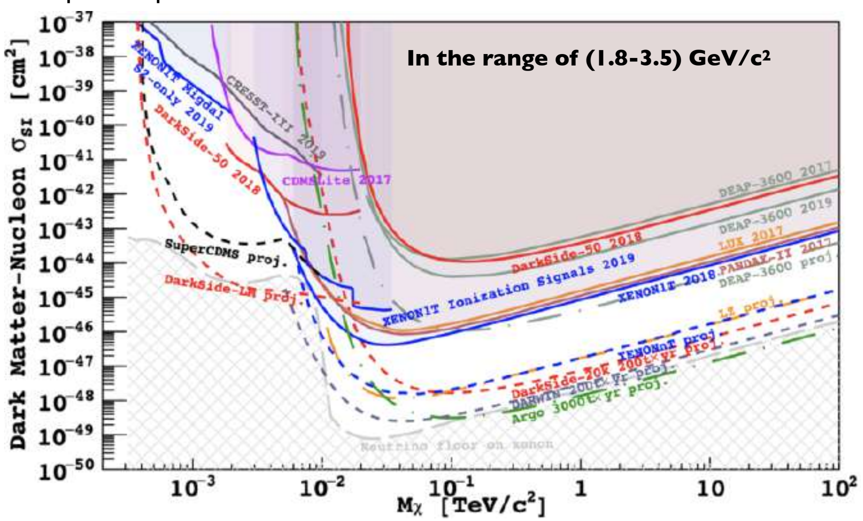
DarkSide-20k (20 t)



Argo 300 t

LAr

Spin-independent DM-nucleon cross section 90% C.L. exclusion limits



Summary

- We can see now a very rapid development over ~ two decades of a two-phase emission detection technology stimulated by Dark Matter search race.
- The Dark Matter search experiments with noble gas two-phase emission detectors have produced the best limits on WIMP-nucleon interaction (from ~10^{-42}cm^2 by ZEPLIN-II in 2007 to $4.1 \cdot 10^{-47}$ cm^2 by XENON1t in 2018)
- The development of two-phase emission detection technology have stimulated the progress in other areas:
  - development of new low-background, low-temperature photodetectors (including new large area SiPMs),
  - development of noble gas purification methods,
  - development of new calibration methods (by ^{83m}Kr, by T),
  - development of new position reconstruction methods,
  - detailed study of the energy transfer processes in liquid noble gases at low energies,
  - etc.