The worldwide experimental effort in the field of direct Dark Matter search

Marcello Messina Ricercatore INFN ai LNGS
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Contatto: marcello.messina@lngs.infn.it
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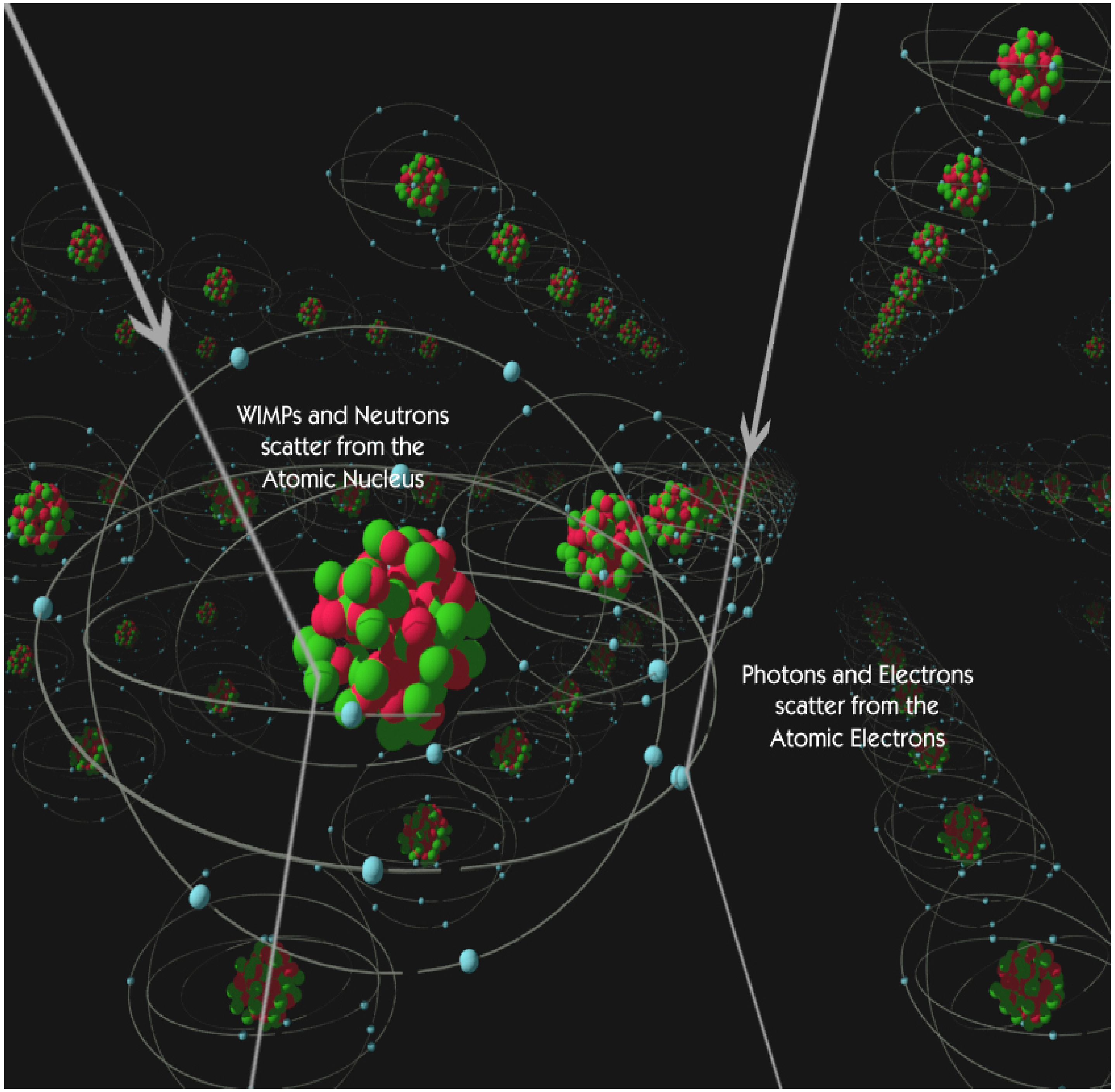
A World of Dark Matter Searches

Direct detection principle



Collisions of invisibles particles with atomic nuclei

REVIEW D VOLUME 31, NUMBER 12

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

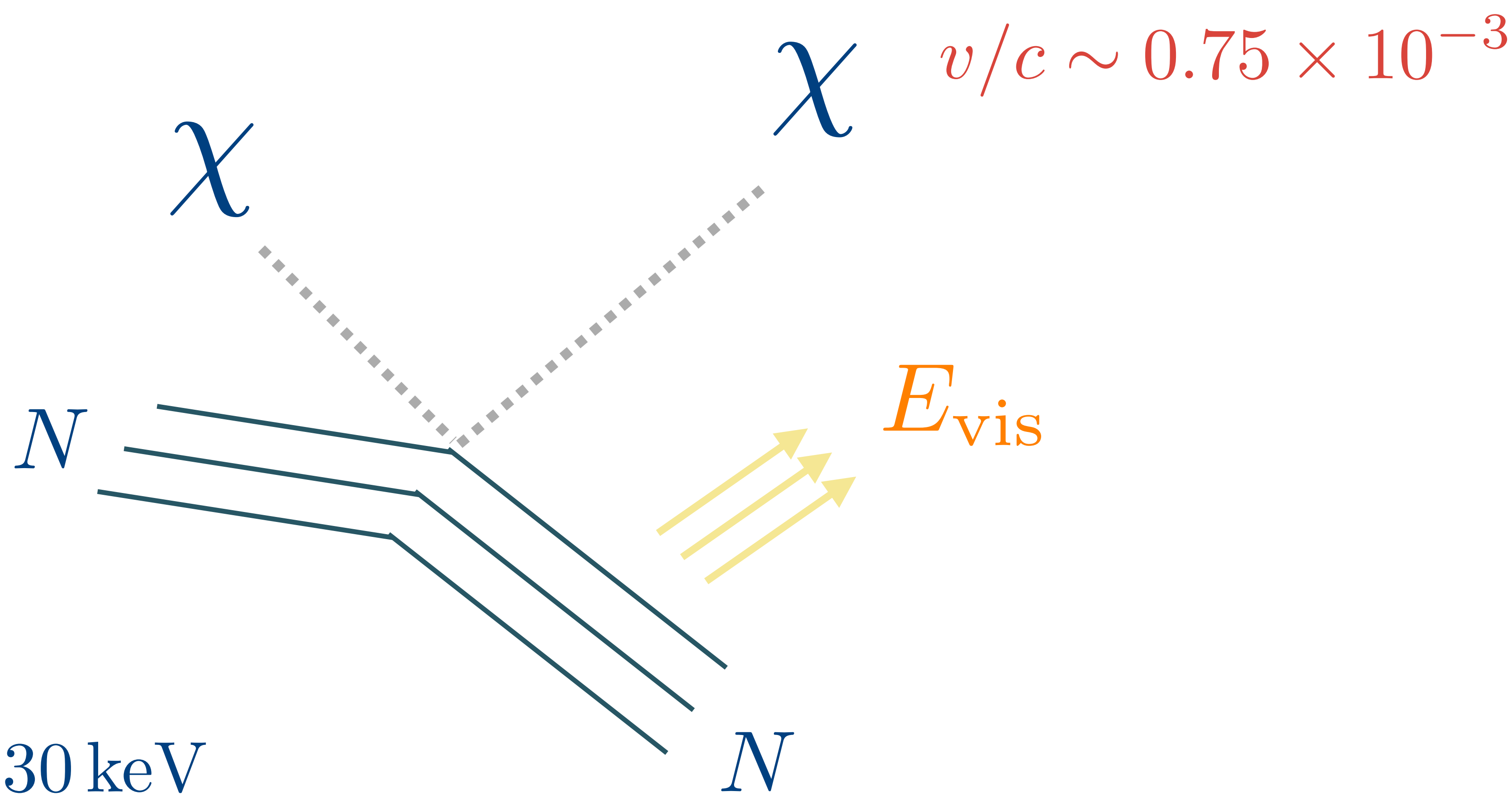
We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

Direct detection principle

Scattering of a WIMP with an atomic nucleus

Momentum transfer ~ few tens of MeV

Energy deposited in the detector ~ few keV - tens of keV



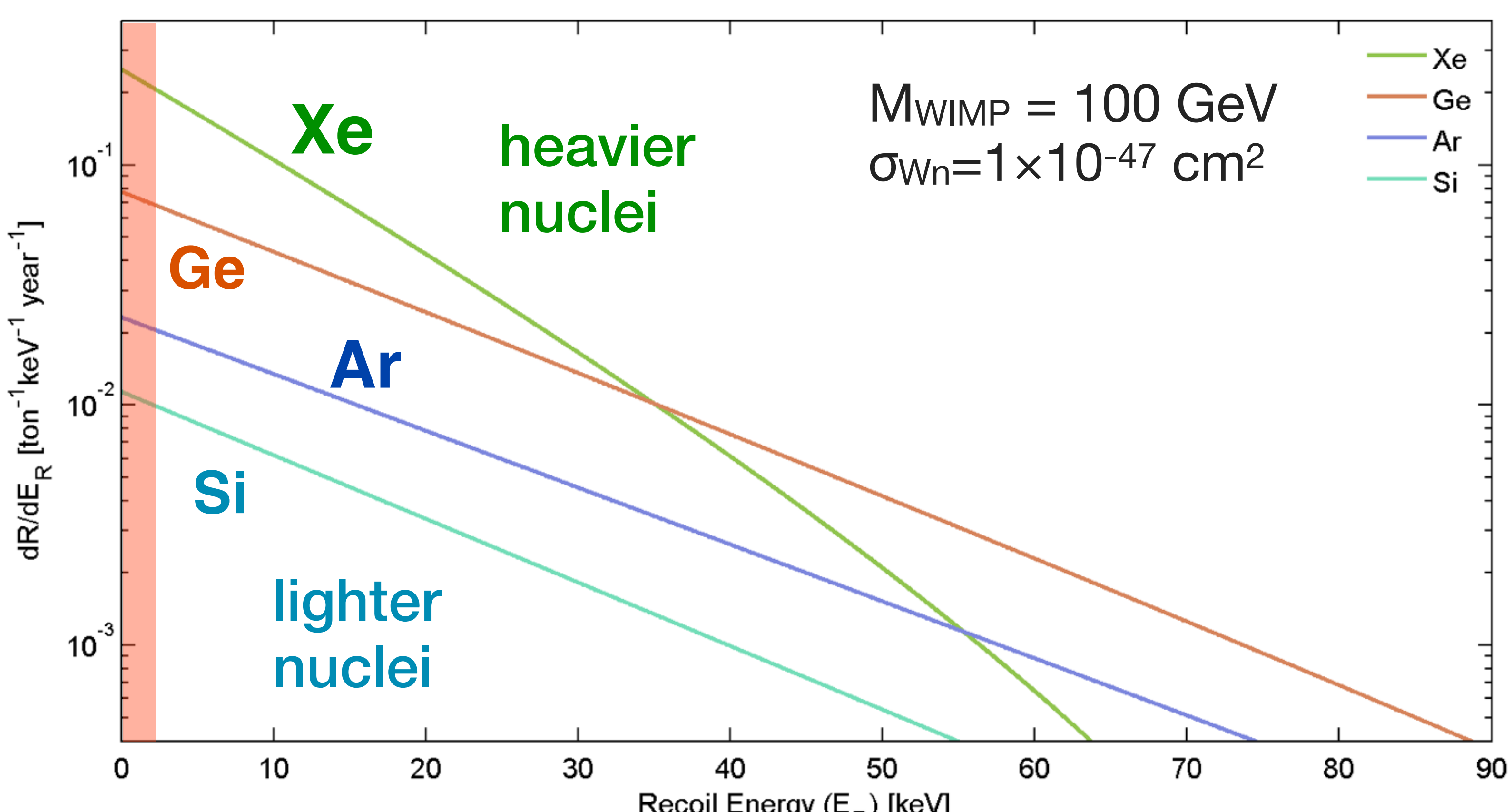
$$E_R = \frac{q^2}{2m_N} < 30\,\text{keV}$$

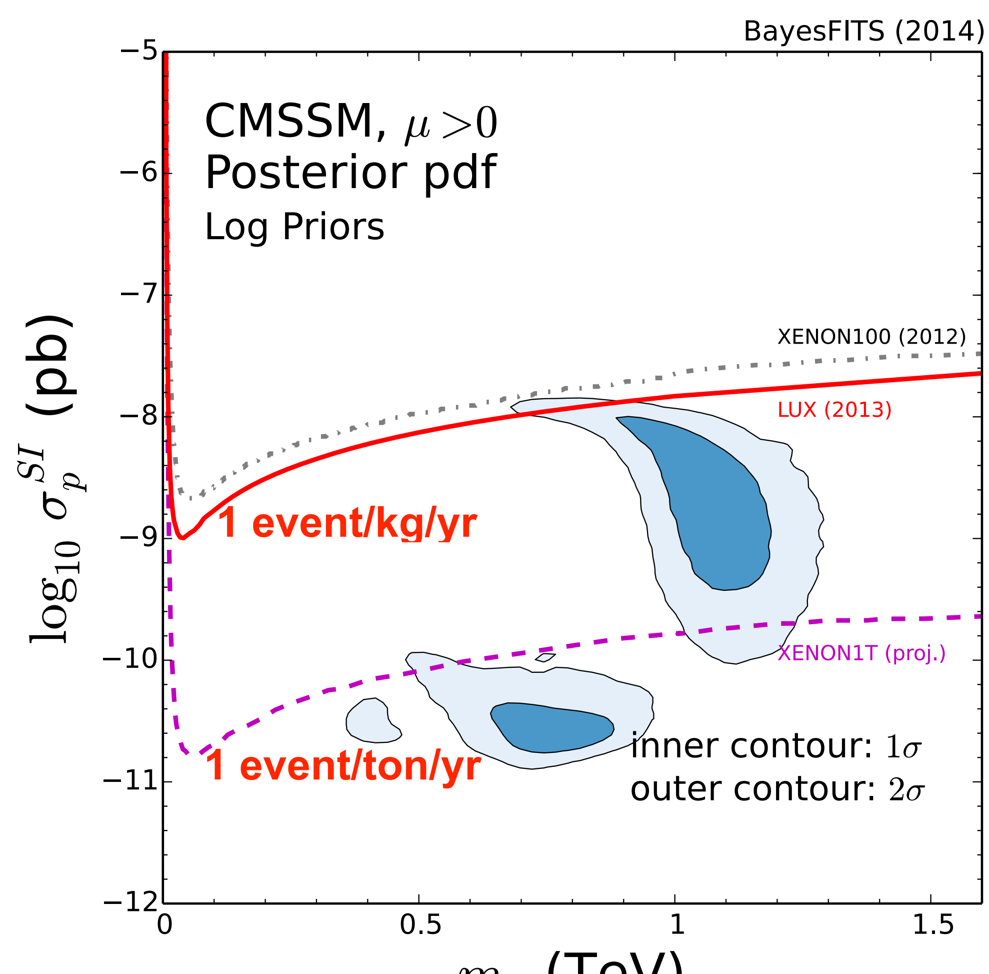
Observables: Rate

Event rate in a terrestrial detector

Detector physics	Particle/nuclear physics	Astrophysics
N_N, E_{th}	$m_W, d\sigma/dE_R$	$\rho_0, f(v)$

$$R \sim N_N \times \frac{\rho_0}{m_W} \times \langle v \rangle \times \sigma$$

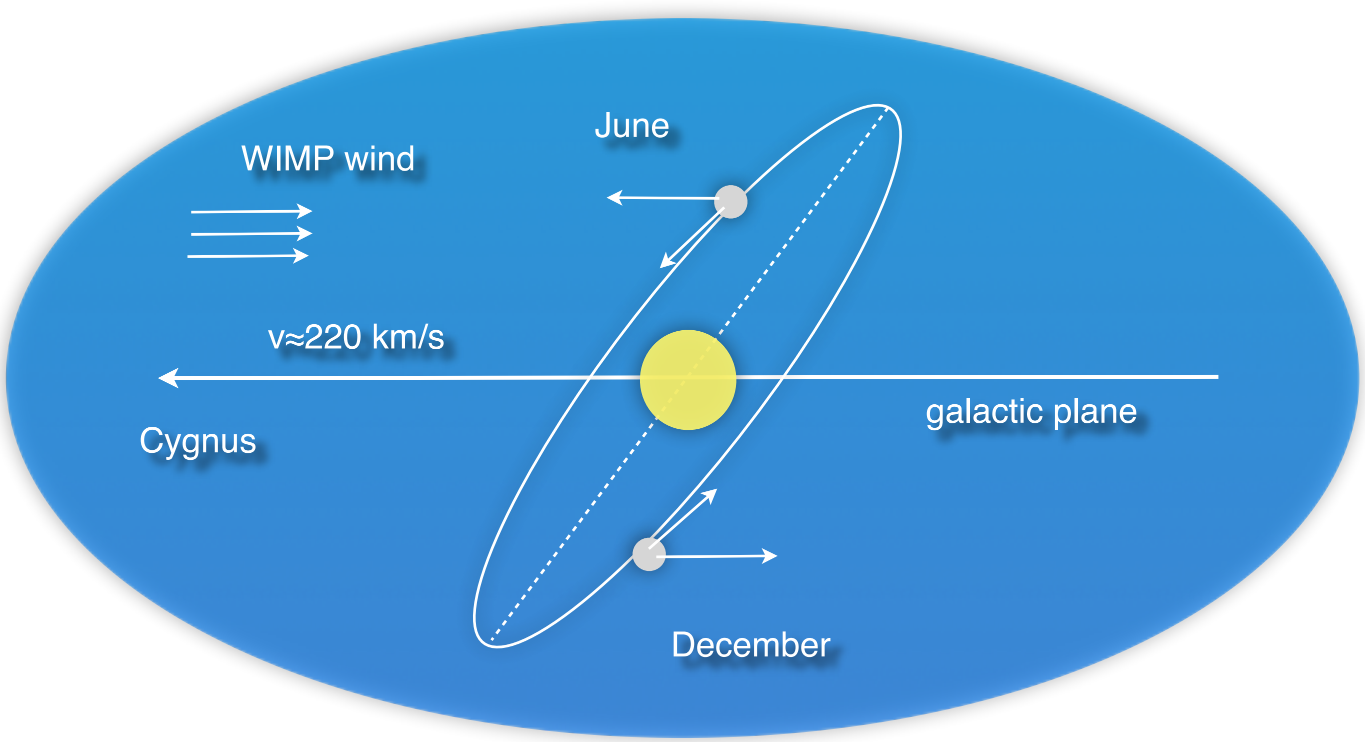




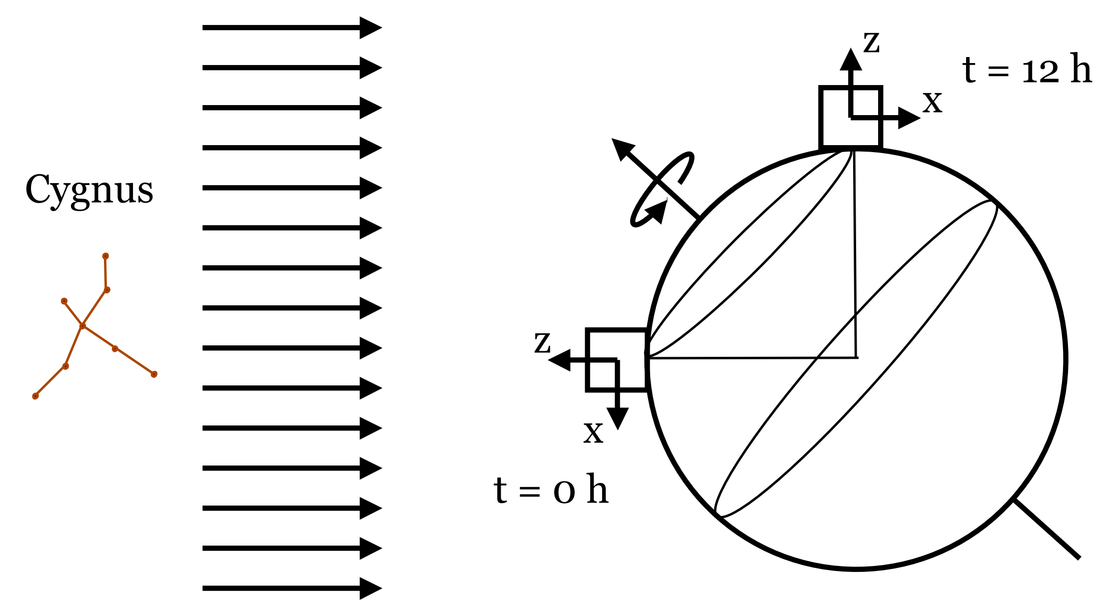
Observables: rate modulations

The soft WIMP wind

- **Rate and shape of nuclear recoil spectrum depend on target material**
- **Motion of the Earth causes:**
  - annual event rate modulation: June - December asymmetry ~ 2-10%
  - sidereal directional modulation: asymmetry ~20-100% in forward-backward event rate



Drukier, Freese, Spergel, PRD 33,1986



D. Spergel, PRD 36, 1988

Background Suppression: the holy grail

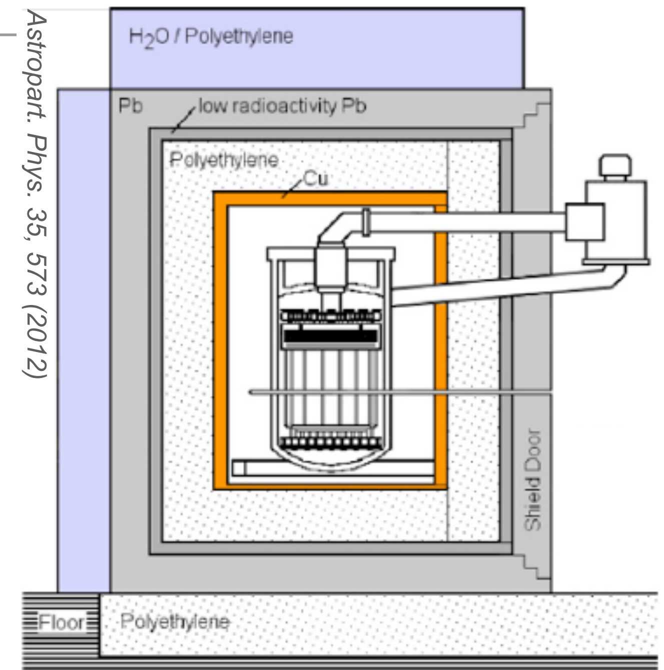
Avoid Backgrounds

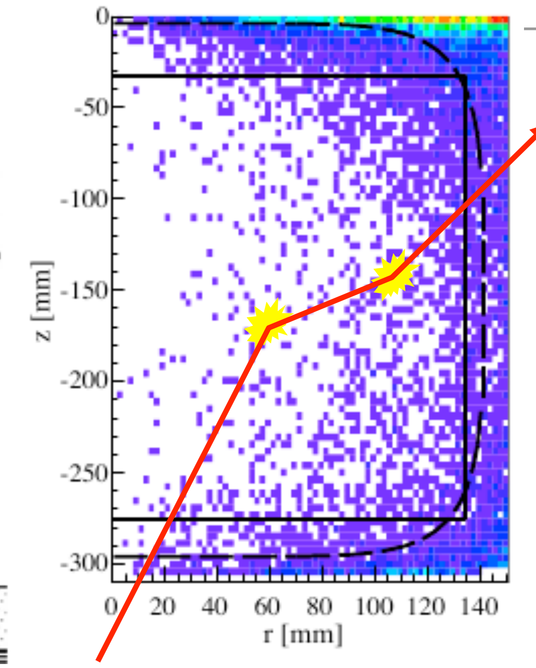
Shielding

deep underground location
large shield (Pb, water, poly)
active veto (μ, coincidence)

self shielding → fiducialization

Select radiopure materials





Use knowledge about expected WIMP signal

WIMPs interact only once

→ single scatter selection

requires some position resolution

WIMPs interact with target nuclei

→ nuclear recoils
exploit different dE/dx from signal and background →

Examples:

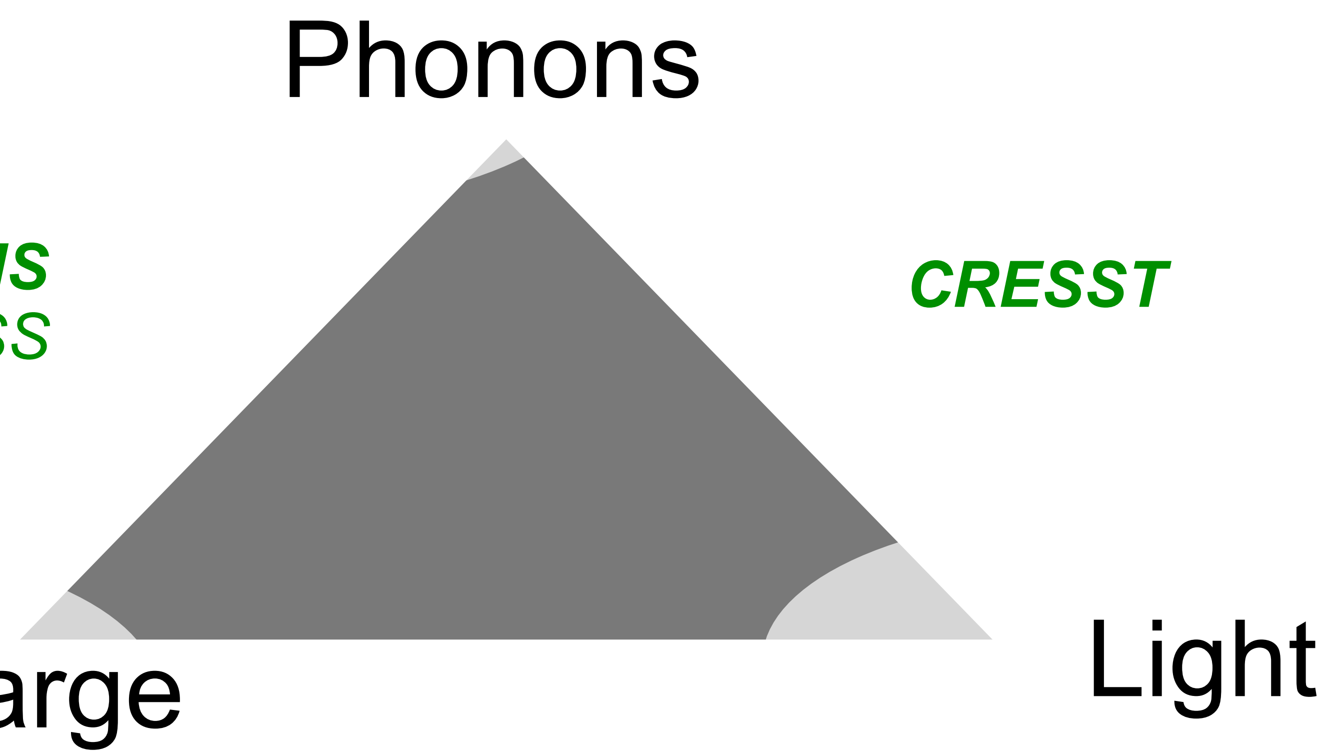
- scintillation pulse shape
- charge/light ratio
- ionization yield

WIMPs Direct Detection Experiments

Crystals (NaI, Ge, Si)
Cryogenic Detectors
Liquid Noble Gases

CRESST-I
CUORE

Tracking:
DRIFT, DMTPC
MIMAC,
NEWAGE



SuperCDMS
EDELWEISS

CRESST

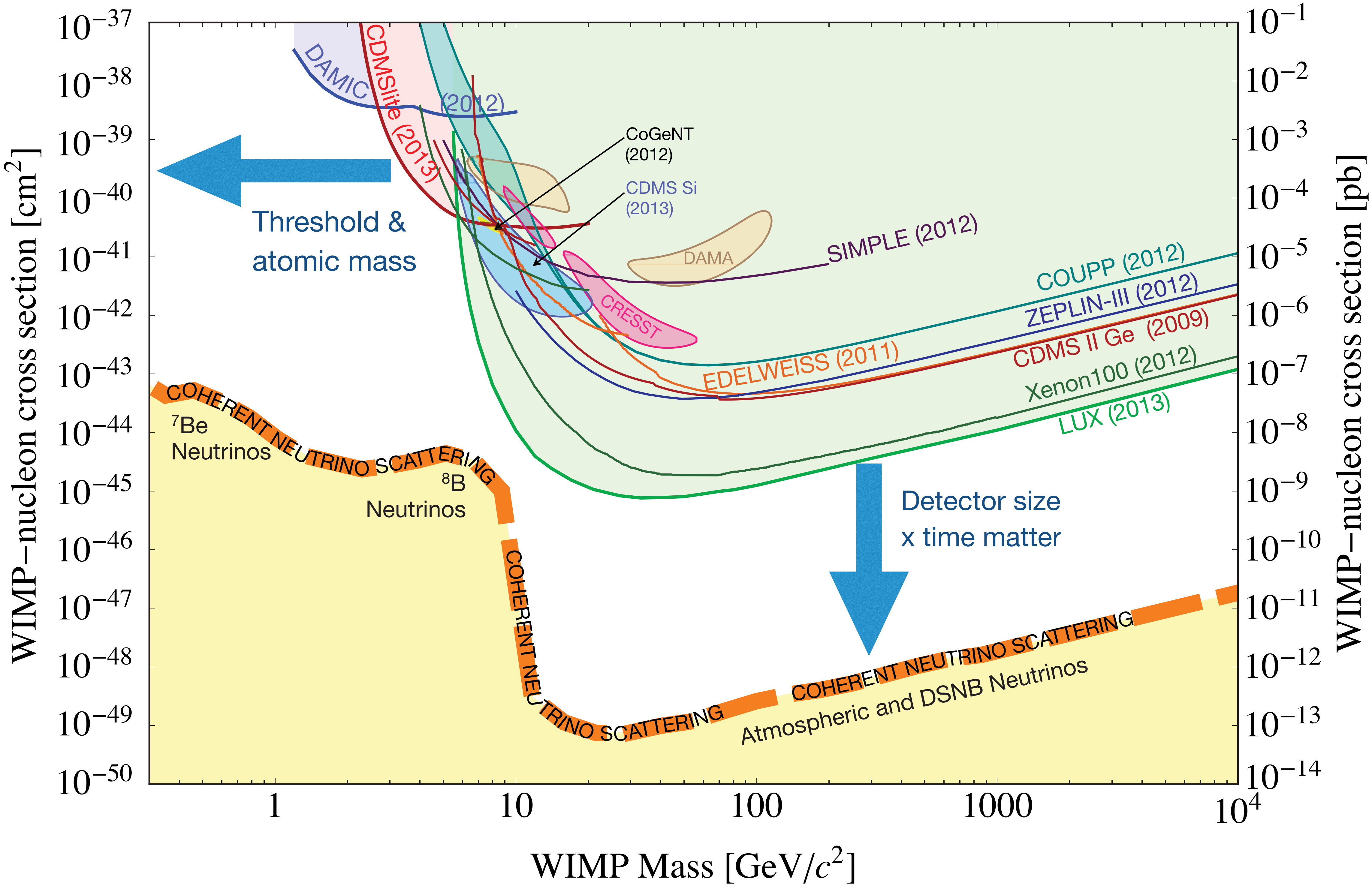
Superheated
Liquids:
COUPP
PICASSO
SIMPLE
PICO

CoGeNT
CDEX
Texono
Malbek
DAMIC

XENON**, **LUX/LZ
*ArDM, **Panda-X***
Darkside, DARWIN

***DEAP-3600**, CLEAN*
***DAMA**, KIMS*
***XMASS**, DM-Ice,*
*ANAIS, **SABRE***

The WIMP landscape



DAMA/Libra experiment

233 kg of pure NaI crystals readout by PMTs with a screen of concrete, polipropilene, Pb and Cu

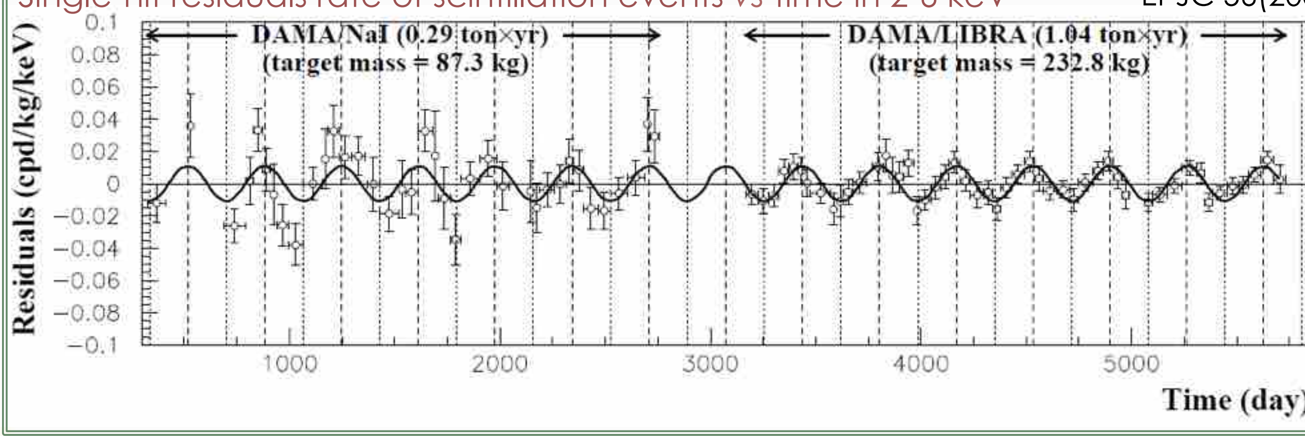
Belli - IDM 2016

Model Independent Annual Modulation Result

DAMA/NaI + **DAMA/LIBRA-phase1** Total exposure: 487526 kg×day = **1.33 ton×yr**

Single-hit residuals rate of scintillation events *vs* time in 2-6 keV

EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648



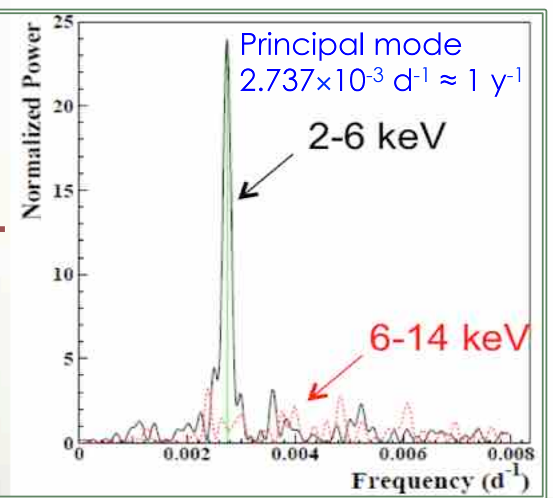
continuous line: t_0 = 152.5 d, T = 1.0 y

A=(0.0110±0.0012) cpd/kg/keV
χ^2/dof = 70.4/86 9.2 σ C.L.

Absence of modulation? No
χ^2/dof=154/87 P(A=0) = 1.3×10^{-5}

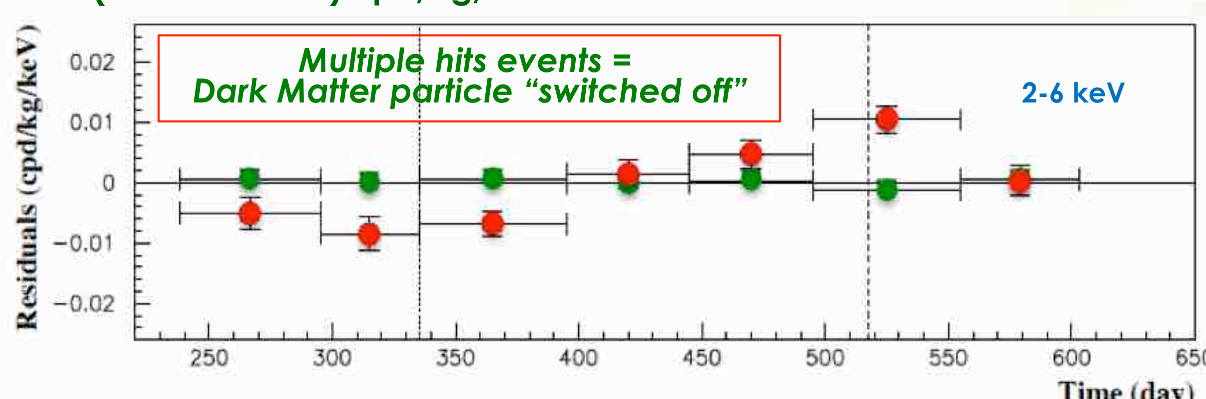
Fit with all the parameters free:
A = (0.0112 ± 0.0012) cpd/kg/keV
t_0 = (144±7) d - T = (0.998±0.002) y

Power spectrum



No systematics or side reaction able to account for the measured modulation amplitude and to satisfy all the peculiarities of the signature

Comparison between **single hit residual rate (red points)** and **multiple hit residual rate (green points)**; Clear modulation in the single hit events; No modulation in the residual rate of the multiple hit events
A=-(0.0005±0.0004) cpd/kg/keV

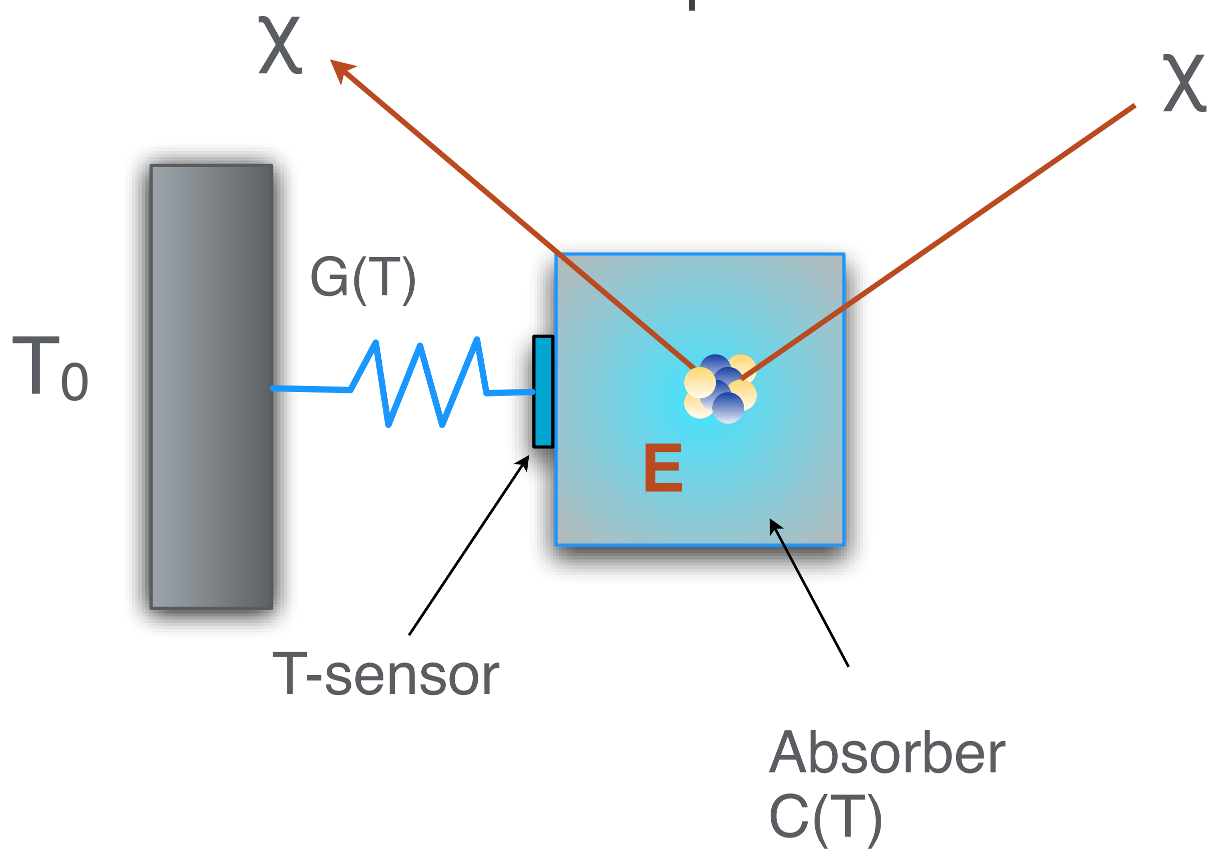


This result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background

The data favor the presence of a modulated behaviour with all the proper features for DM particles in the galactic halo at about 9.2σ C.L.

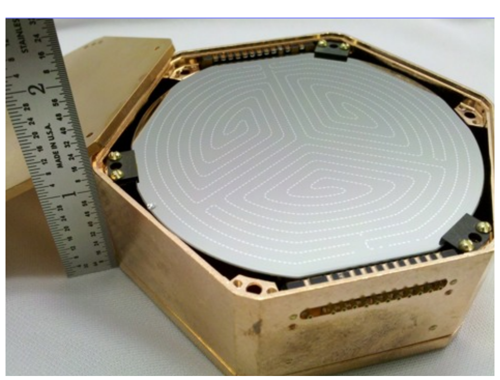
Cryogenic micro-calorimeter at T ~ mK

- Detect a temperature increase after a particle interacts in an absorber

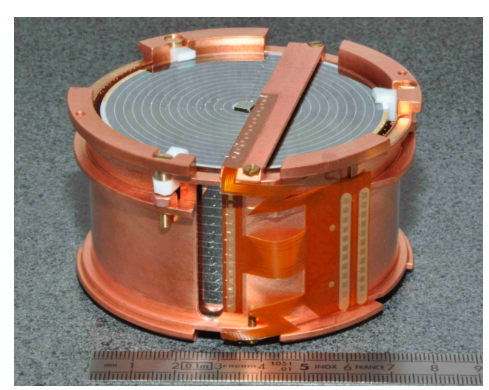


$$\Delta T = \frac{E}{C(T)} e^{-\frac{t}{\tau}}$$

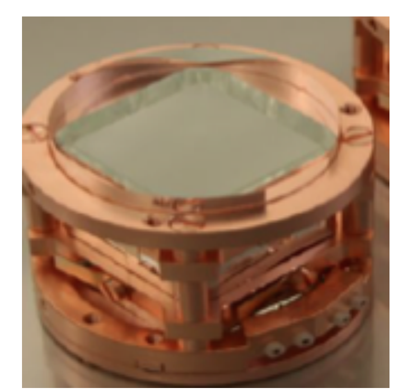
$$\tau = \frac{C(T)}{G(T)}$$



SuperCDMS: Ge, Si



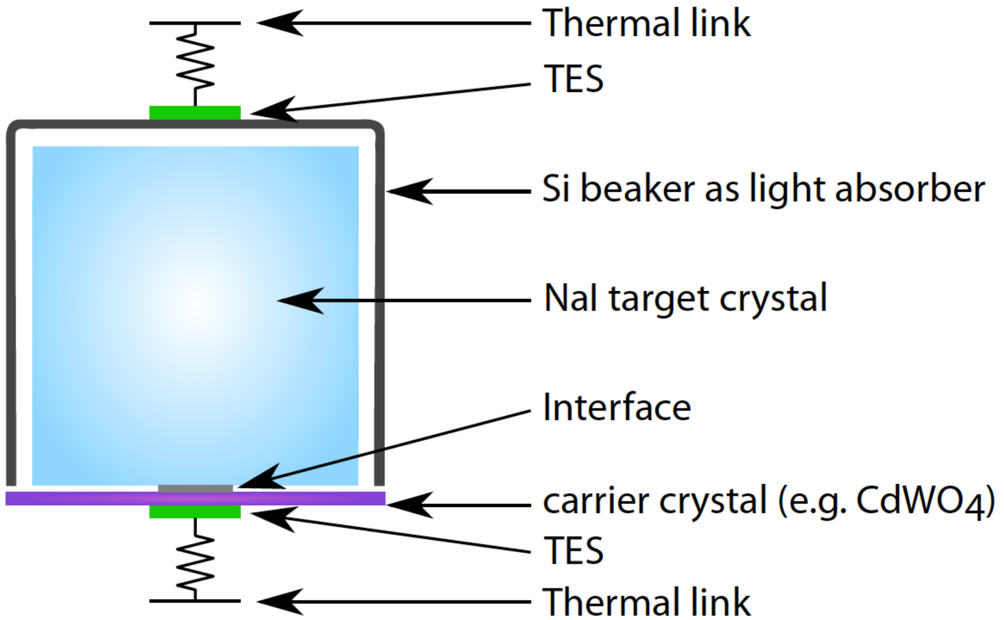
EDELWEISS-III (Ge)



CRESST ($CaWO_4$)

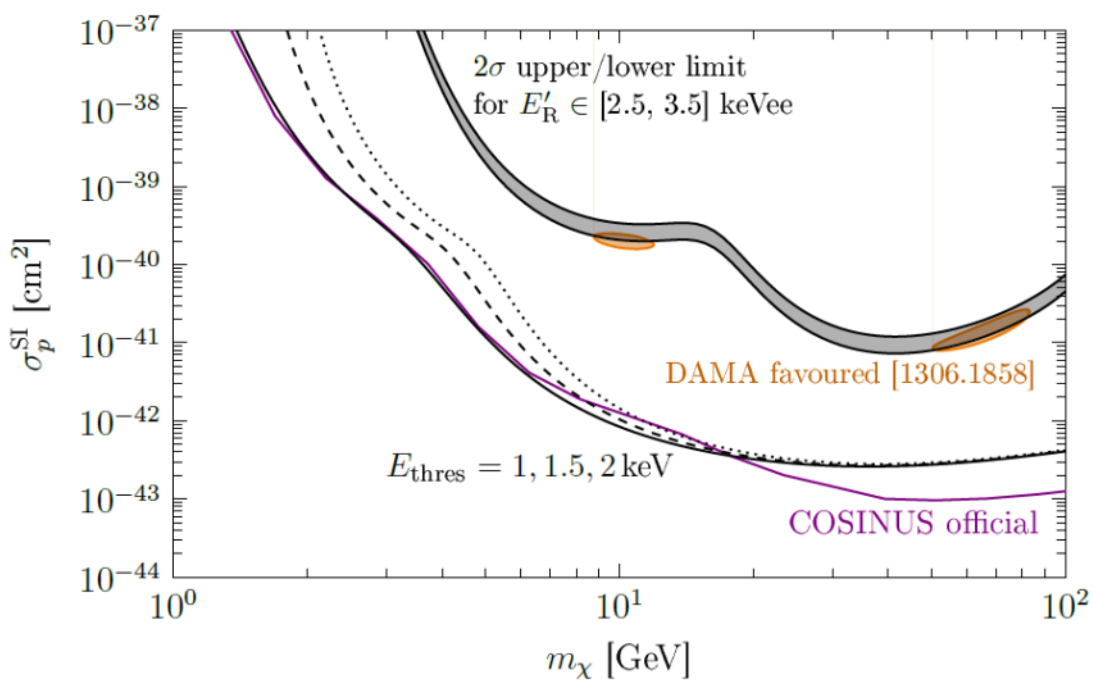
COSINUS a Promising R&D project: Cryogenic NaI detectors at T ~ mK

Recently granted by
Max-Planck Research Group (MPRG) grant:
duration 5 years, starting 2019



COSINUS (arXiv:1603.02214)

Strategy:
- first NaI detector with particle discrimination
- precise measurement of deposited energy
- design goal: 1 keV threshold on NR
- light channel (quenching) strongly particle type dependent-
- Status: started in 2016 at LNGS; first NaI prototype detector (66g) assembled and cooled down in the CRESST test facility
- reaching performance of existing scintillating bolometers (CRESST)

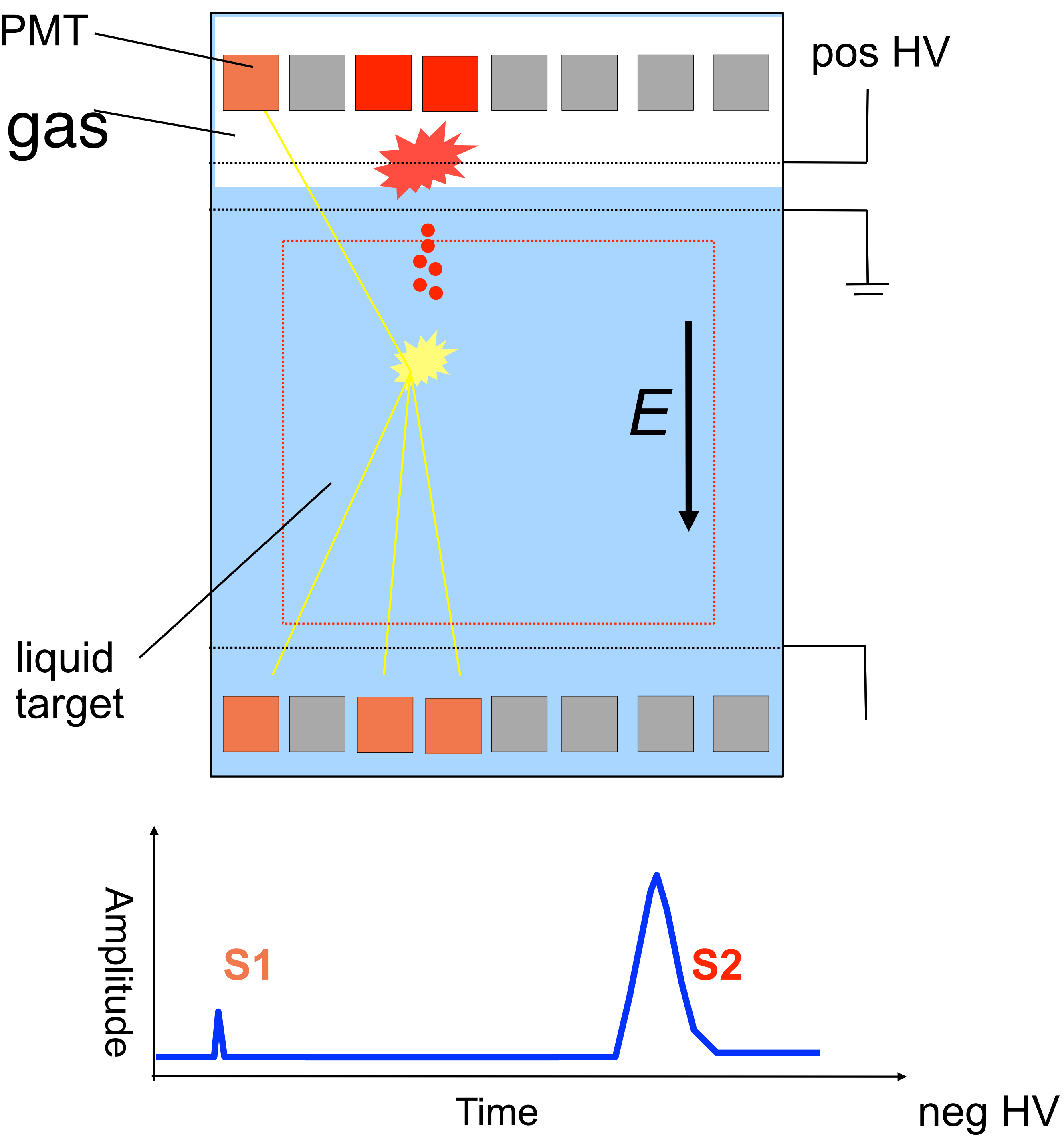


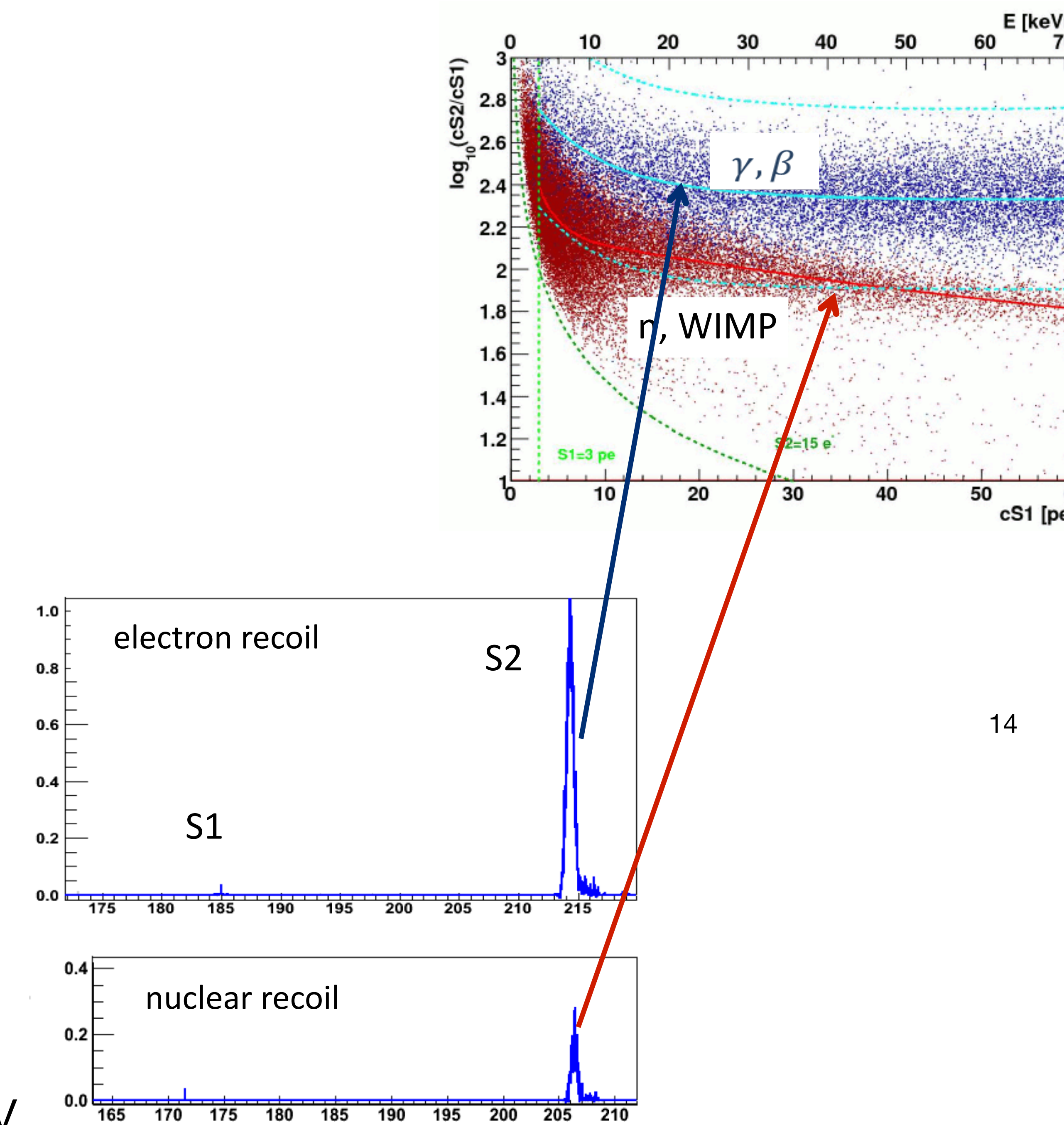
COSINUS should be able to exclude or confirm DAMA signla by about two orders of magnitude in cross section with an exposure of 100 kg days

Let’s have a look in the High Mass WIMP sensitivity region

Noble Liquid Detector Concepts

Time Projection Chamber (TPC)
a doppia fase

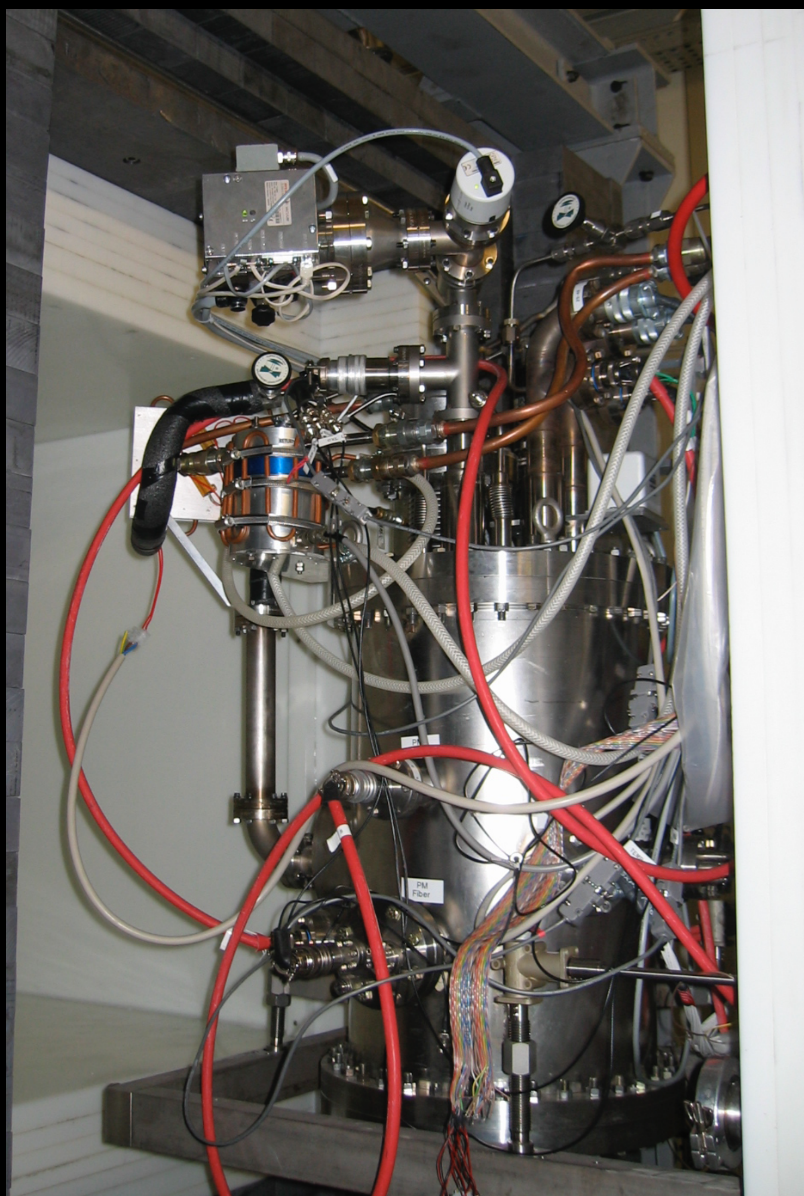
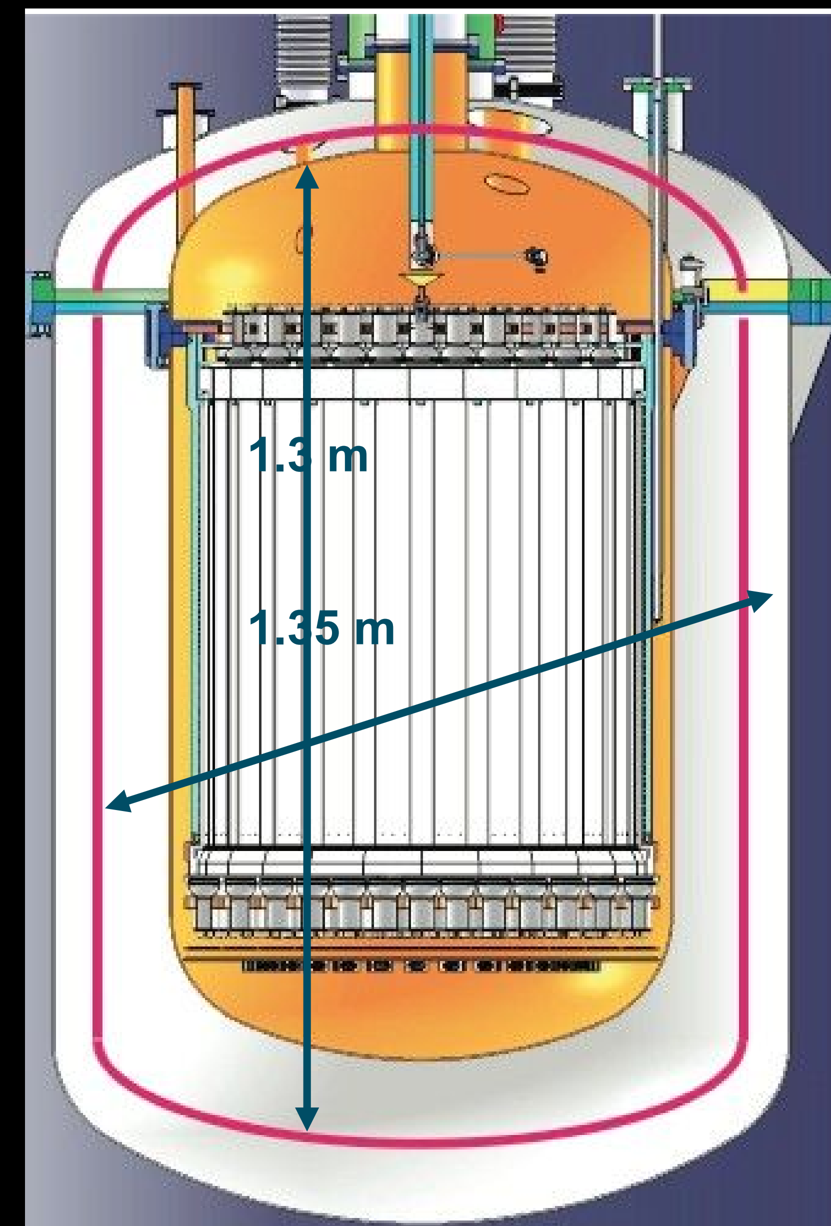




Dual Phase TPC Experiments: present and future

XENON @ LNGS - present and future

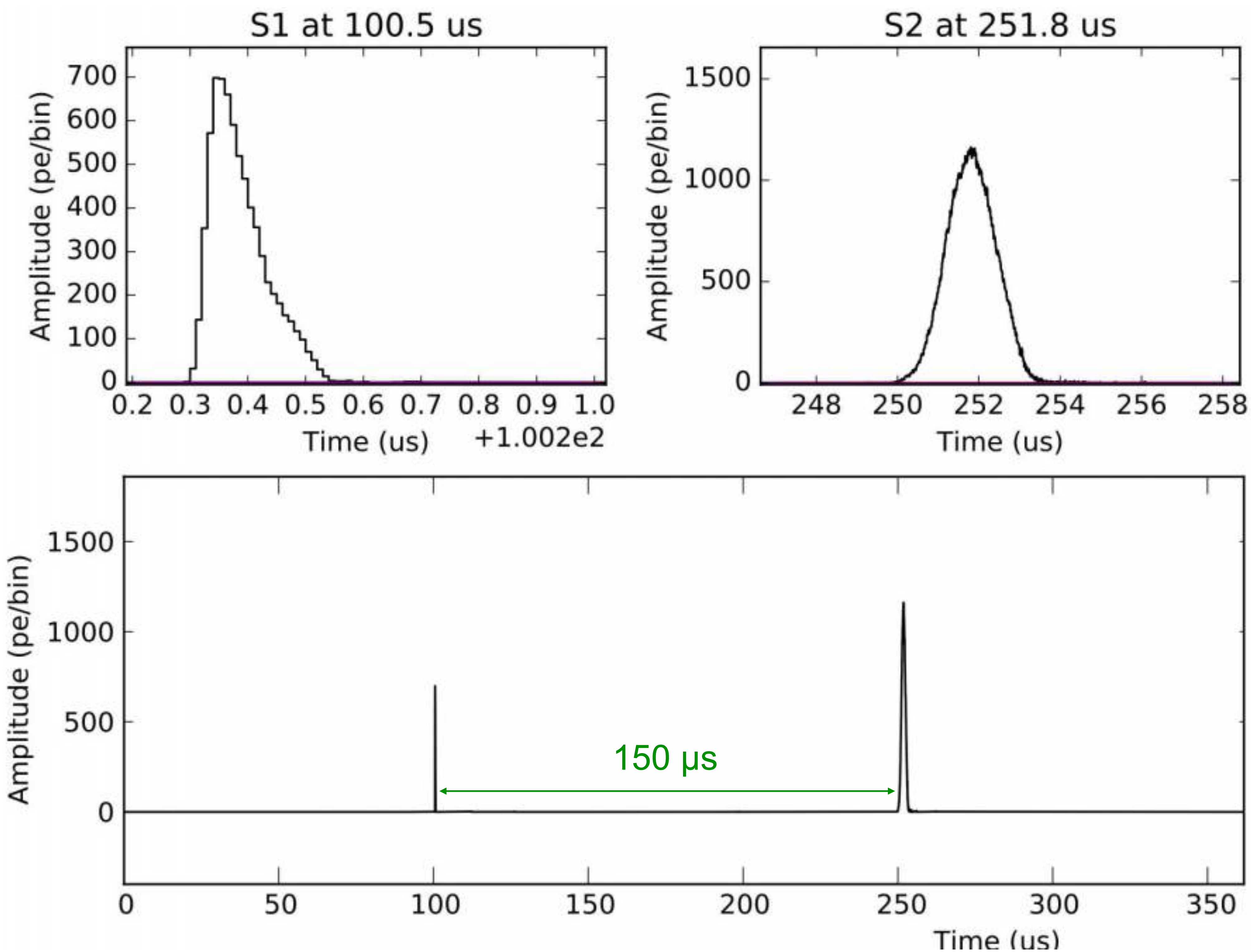
XENON
Dark Matter Project

2005-2007	2007-2015	2012-2022
		
XENON10	**XENON100**	**XENON1T/XENONnT**
15 cm drift TPC - 25 kg	*30 cm drift TPC - 161 kg*	*100 cm drift TPC - 3500 kg/7000 kg*
~10^{-43} cm^2	*~10^{-45} cm^2*	*~10^{-47} cm^2 / 10^{-48} cm^2*

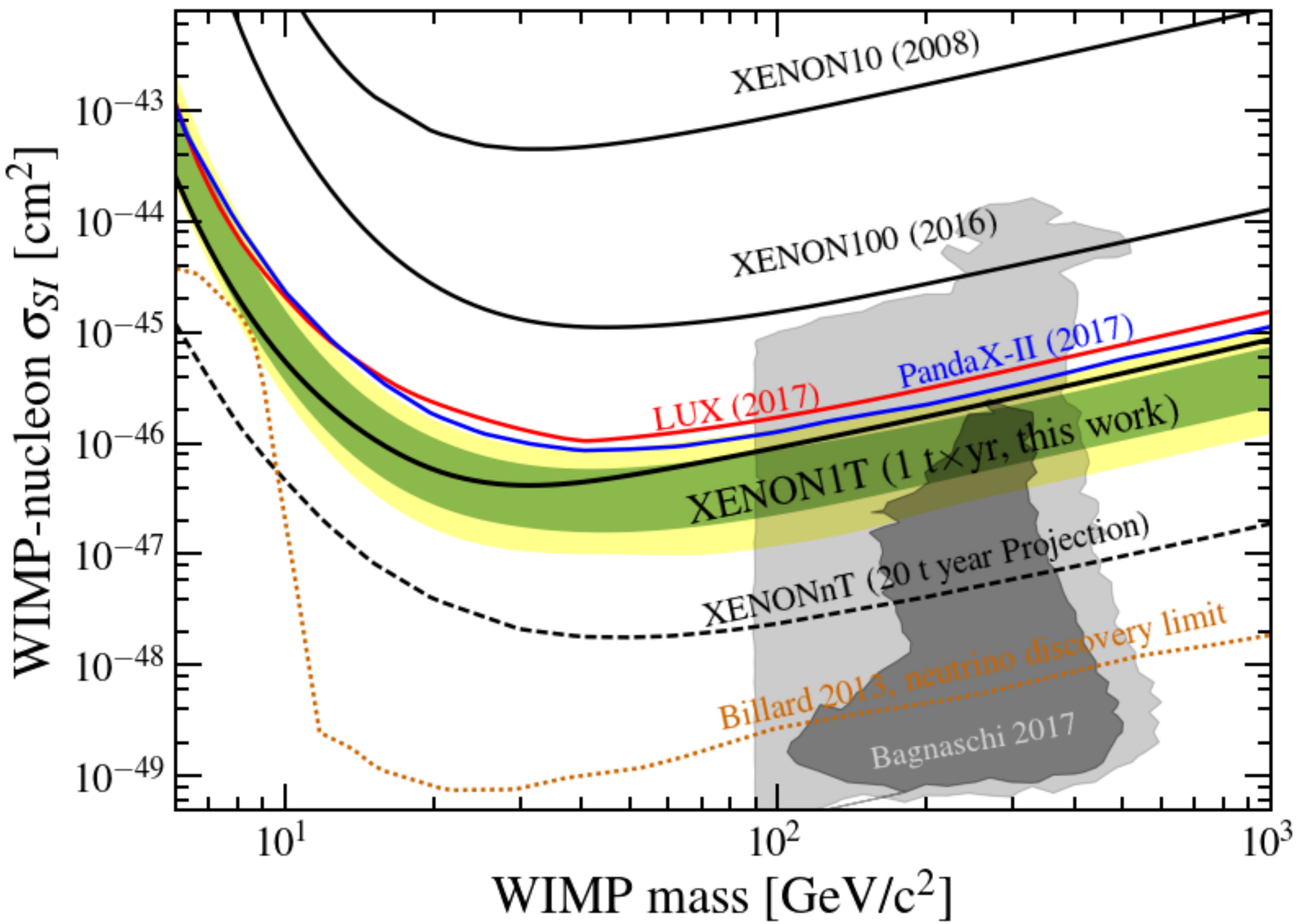
The XENON1T Experiment

- **Science goal**: 100 x more sensitive than XENON100
- **Target/Detector**: 3.5 ton of Xe/ dual-phase TPC with 250 high QE - low radioactivity PMTs.
- **Shielding:** water Cherenkov muon veto.
- **Cryogenic Plants:** Xe cooling/purification/ distillation/storage systems designed to handle up to 10 ton of Xe. Upgrade to a larger detector ***(XENONnT)*** planned for fall 2019
- **Status: data taking stopped in December 2018.**
- **Exclusion limit: 4.1 x 10^{-47} cm^2 @ 30 GeV in 1 ty**

e-lifetime and TPC performance rapidly improving -
- Kr-distillation started- getting ready for WIMPs time !!

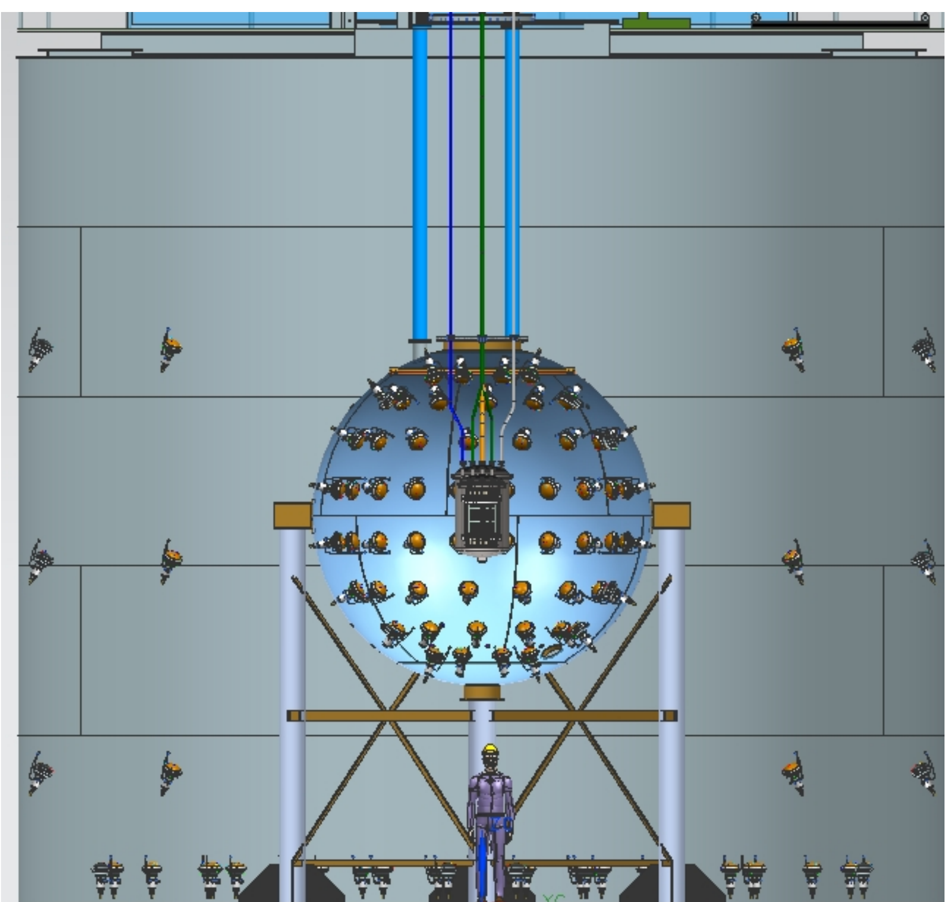


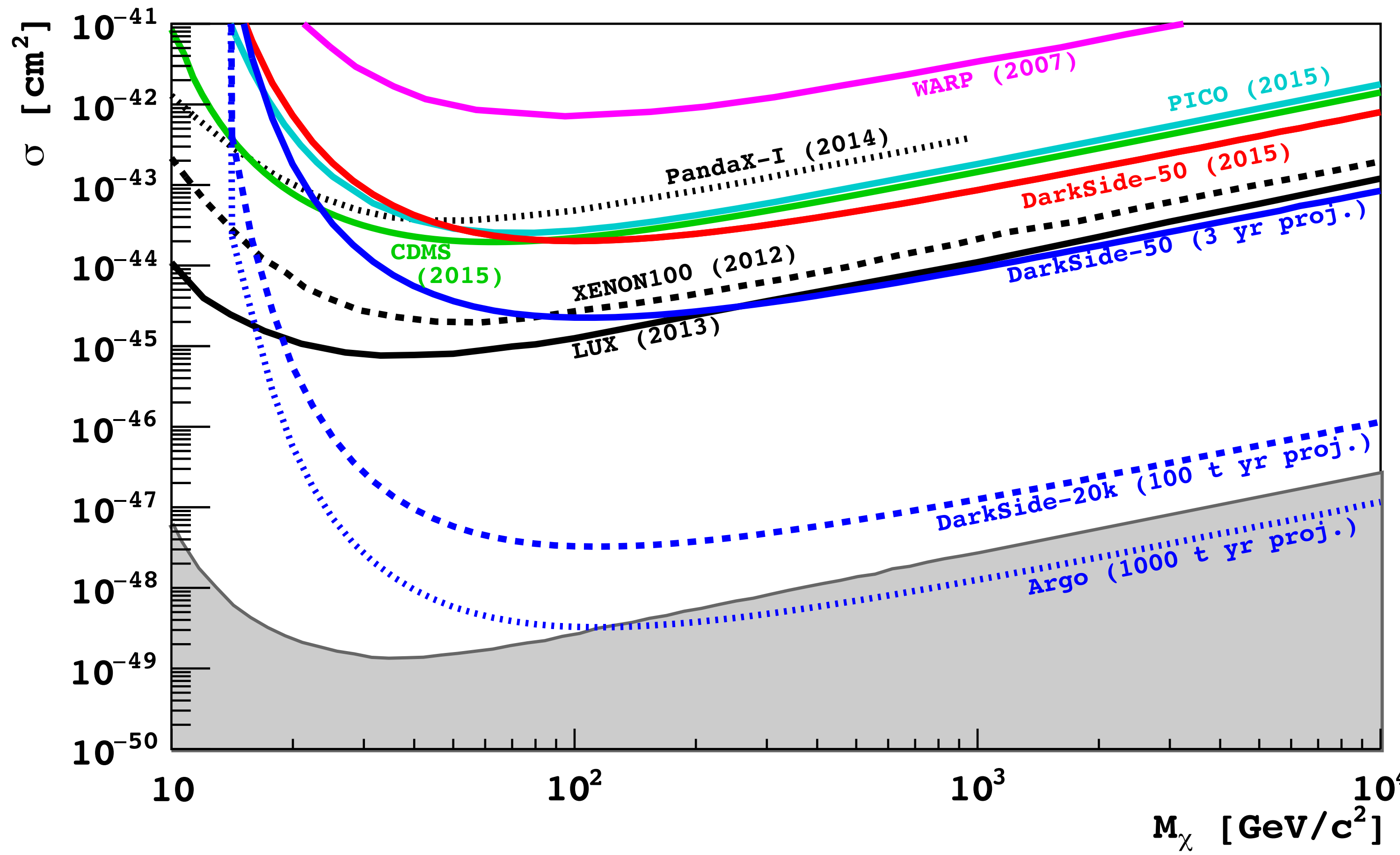
XENON1T latest results and XENONnT_expected sensitivity



DarkSide @ LNGS : present and future

- Dark Side 50: dual phase TPC with 46 kg ^{39}Ar-depleted LAr (1400 background reduction factor) inside 30 tons LS neutron veto inside a 1000 tons water Cherenkov muon veto
- 1st result from 2616 kg d with depleted Ar -> no event in search region . Still taking data
- Proposed DS20k. Large R&D effort on SiPMs and other technologies. Construction of the very large distillation facility (350 m column) placed inside a coal mine (Seruci, Sardinia) has started.





Conclusions

Cold dark matter is a explanation for many cosmological & astrophysical observations

- It could be made of WIMPs - thermal relics from an early phase of our Universe
- So far, no convincing evidence of a dark matter particle was found
- However, DAMA/LIBRA experiment is claiming an observation of an annual modulation since long time.

Excellent prospects for discovery and clarification

- New experiments, based on NaI technology, are getting ready to run in view of clarifying once and for all the nature of the DAMA/LIBRA longstanding annual modulation. Better late than never.
- Direct detection: increase in WIMP sensitivity by 2 orders of magnitude in the next few years
- reach neutrino background (measure neutrino-nucleus coherent scattering!) this/next decade
- high complementarity with indirect & LHC searches