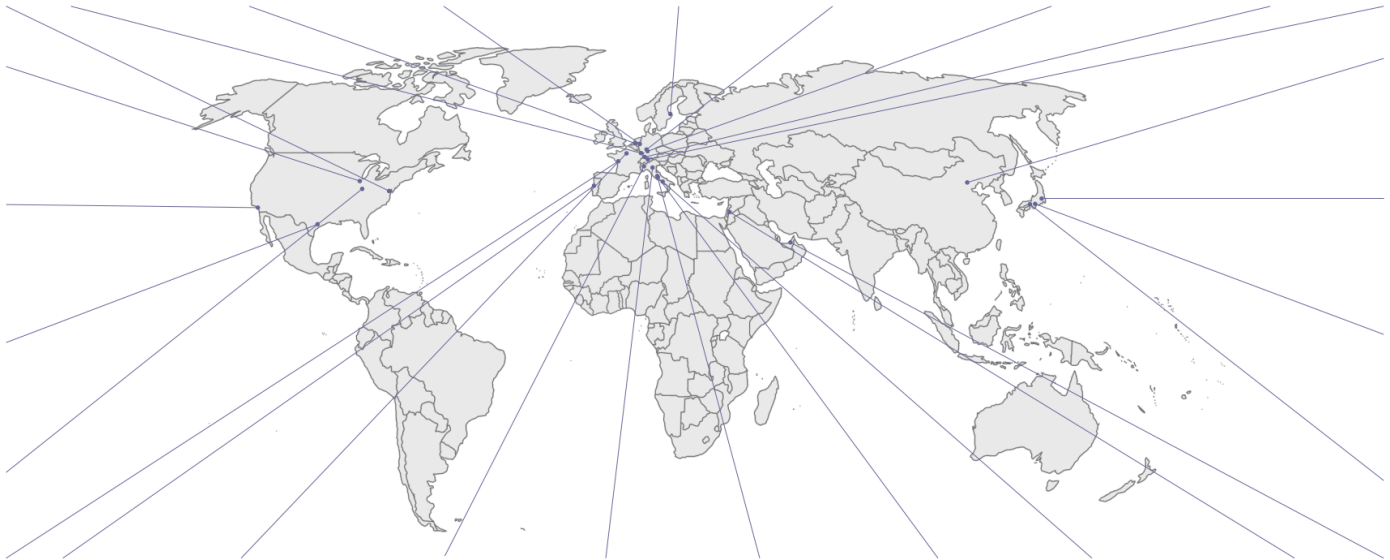
Rivelazione diretta di materia oscura con rivelatori allo xenon in doppia fase

XENON

Andrea Molinario

The XENON Collaboration

180 scientists 27 institutions 11 countries



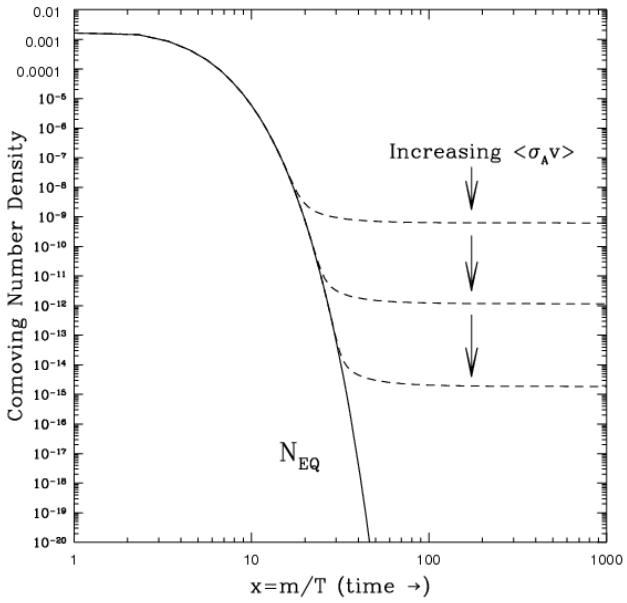
Columbia · KIT · Nikhef · Muenster · Stockholm · Mainz · MPIK, Heidelberg · Freiburg · Zurich

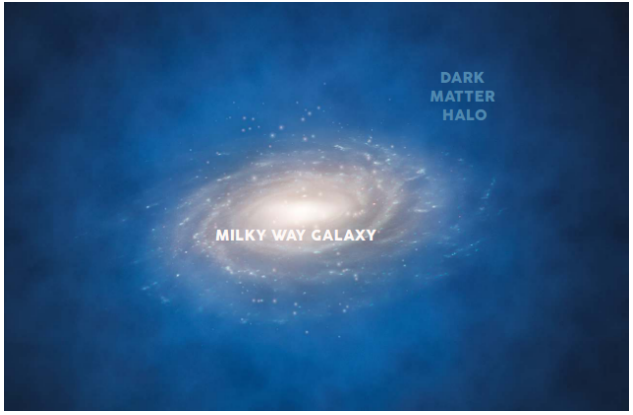
Chicago · Tsinghua · UCSD · Tokyo · Rice · Nagoya · Purdue · Kobe

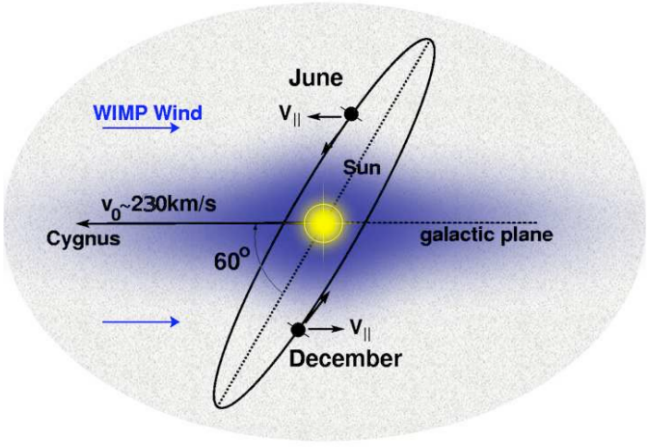
Subatech · Coimbra · LPNHE · Torino · Bologna · L'Aquila · LNGS · Napoli · Weizmann · NYUAD

Direct dark matter detection

WIMPs are candidates to dark matter particles





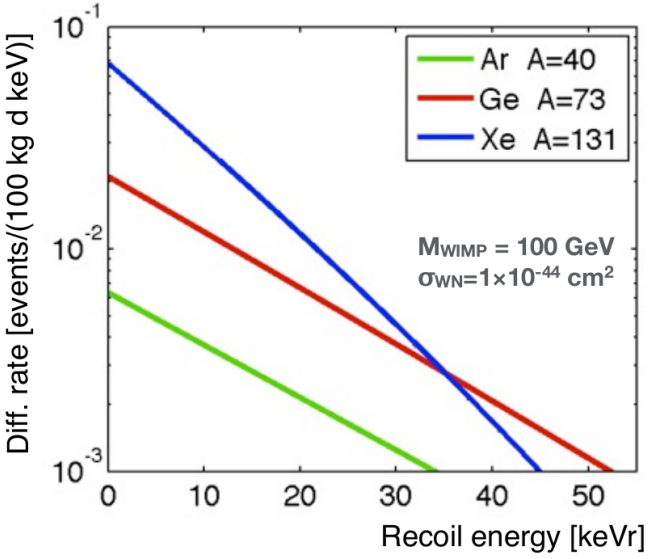


Detection of the dark matter particles in the Galactic halo

Annual modulation of the signal expected

Direct dark matter detection

WIMPs expected to induce *nuclear recoils* in a particle detector

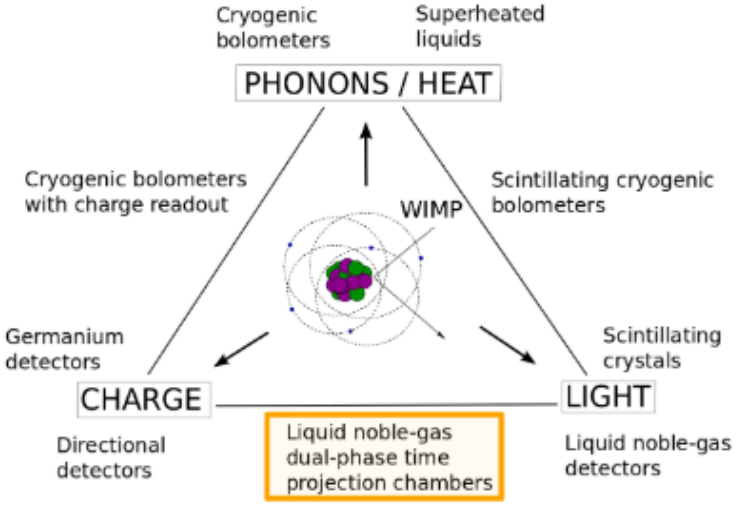


Nuclear recoil energies *O*(10 keV)

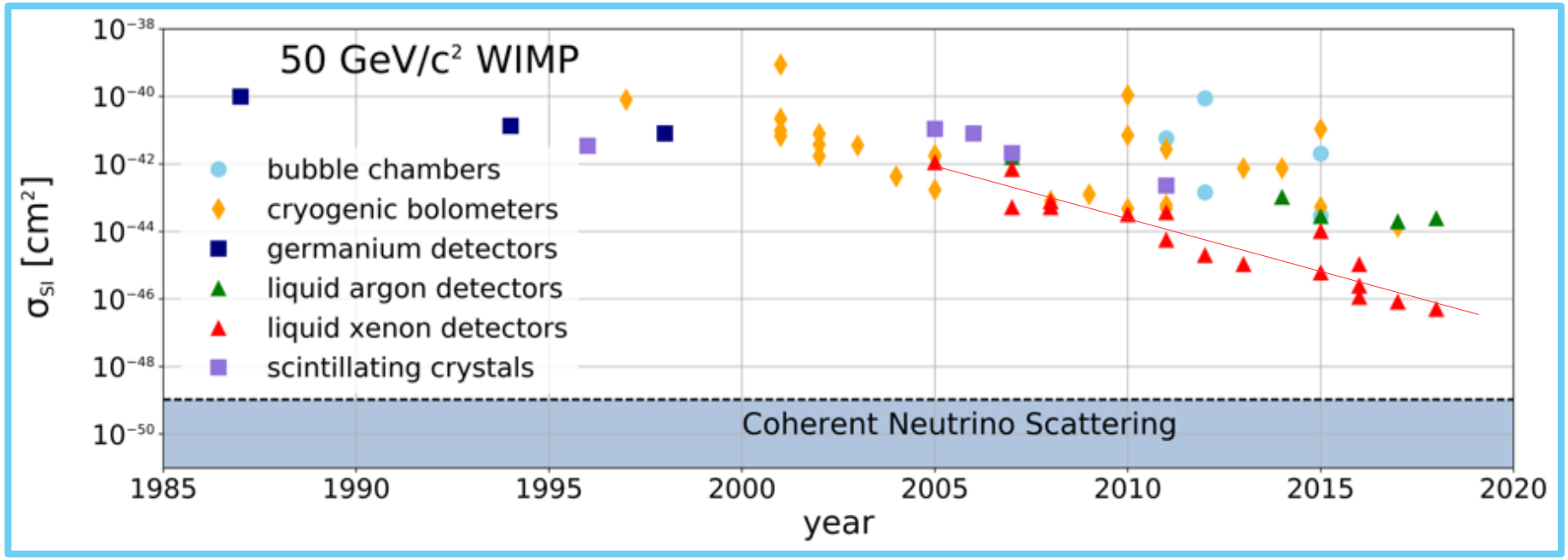
Total event rate as low as 10 / (ton*y)

Need for a low background environment

Detectors located underground

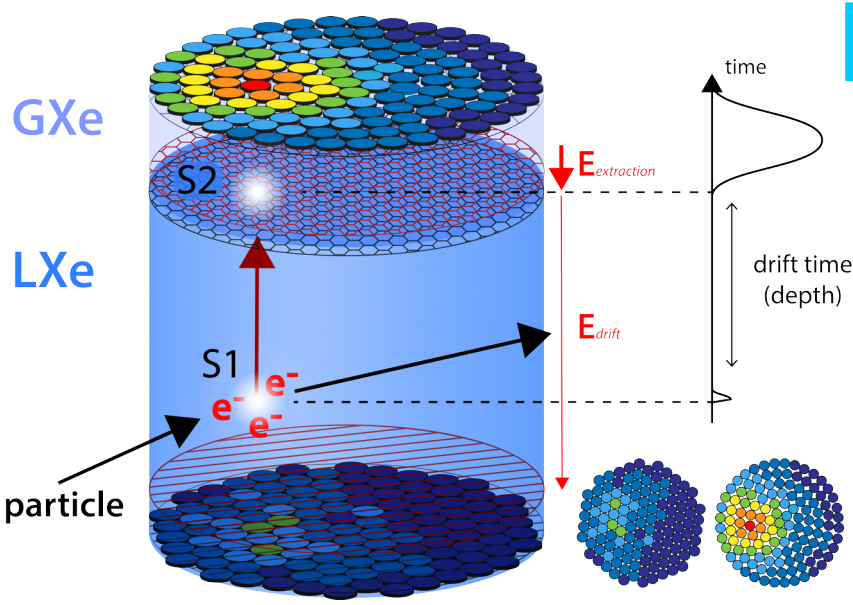


The LXe TPC legacy



Best technology to search for WIMP dark matter

Dual-phase Xenon TPC



Liquid Xenon

High density, self-shielding

Good scintillator

No long-living radioactive isotope

Time Projection Chamber

3D position

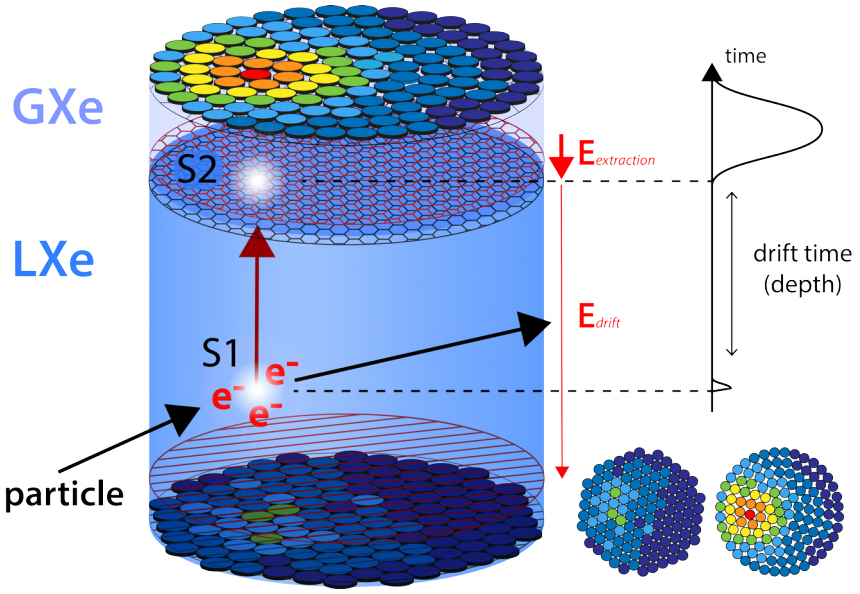
ER/NR discrimination

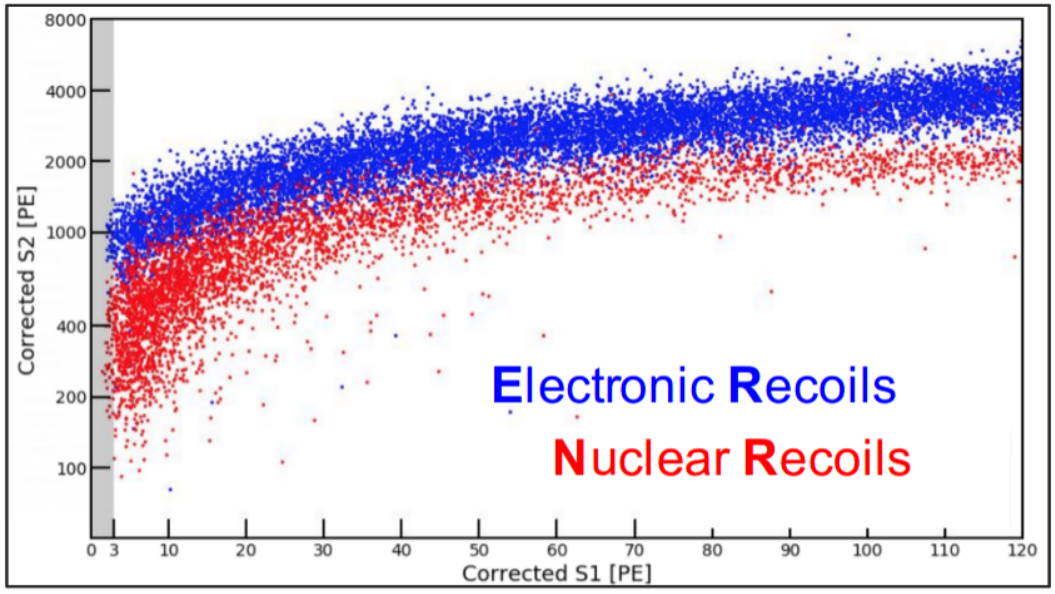
Multiple scatter rejection

Low energy threshold

Scalable to multi-ton

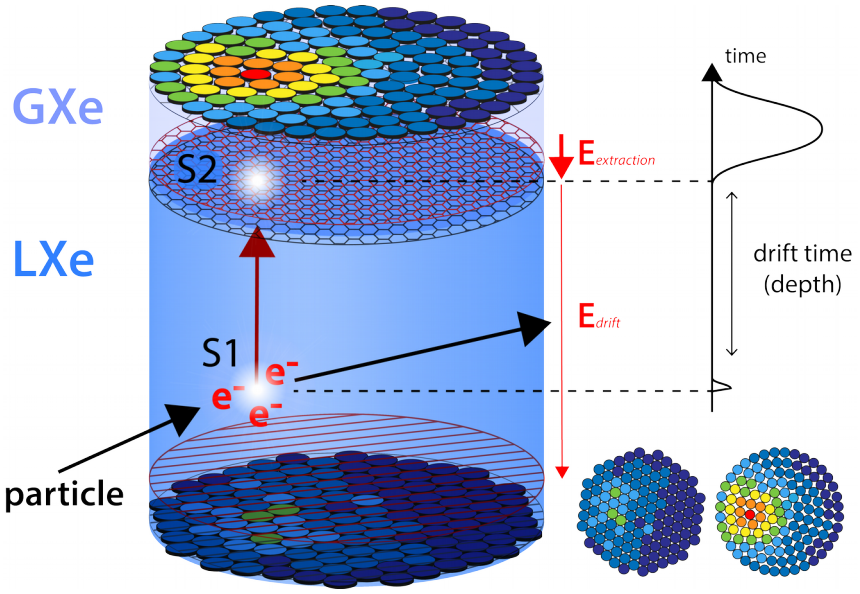
Dual-phase Xenon TPC

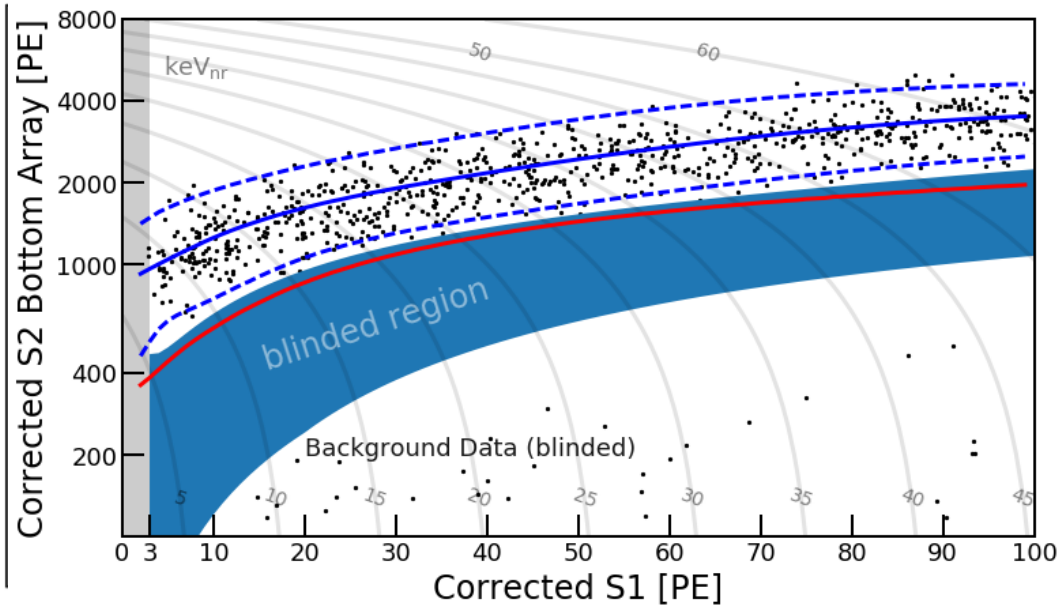




Ideal for WIMP and rare processes search

Dual-phase Xenon TPC

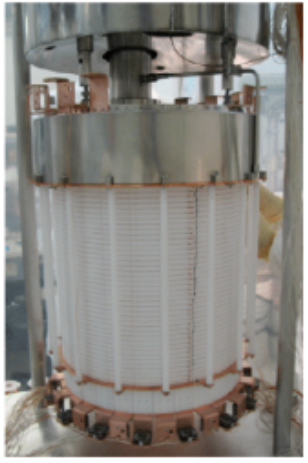
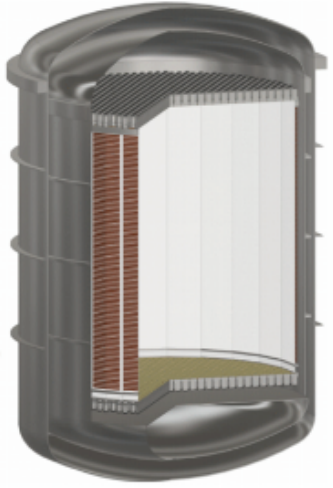




Ideal for WIMP and rare processes search

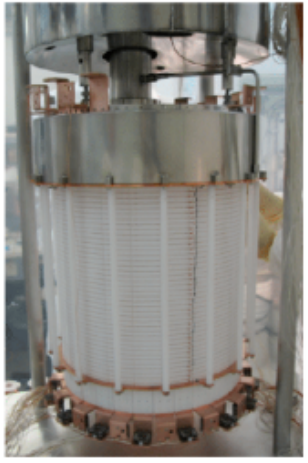
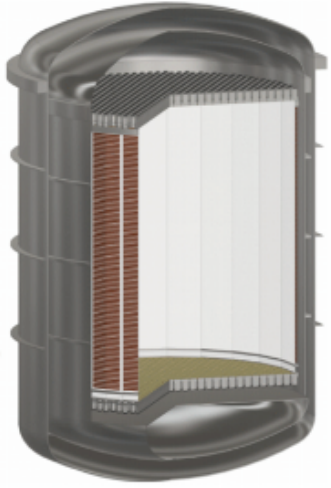
The XENON Project @ LNGS

XENON

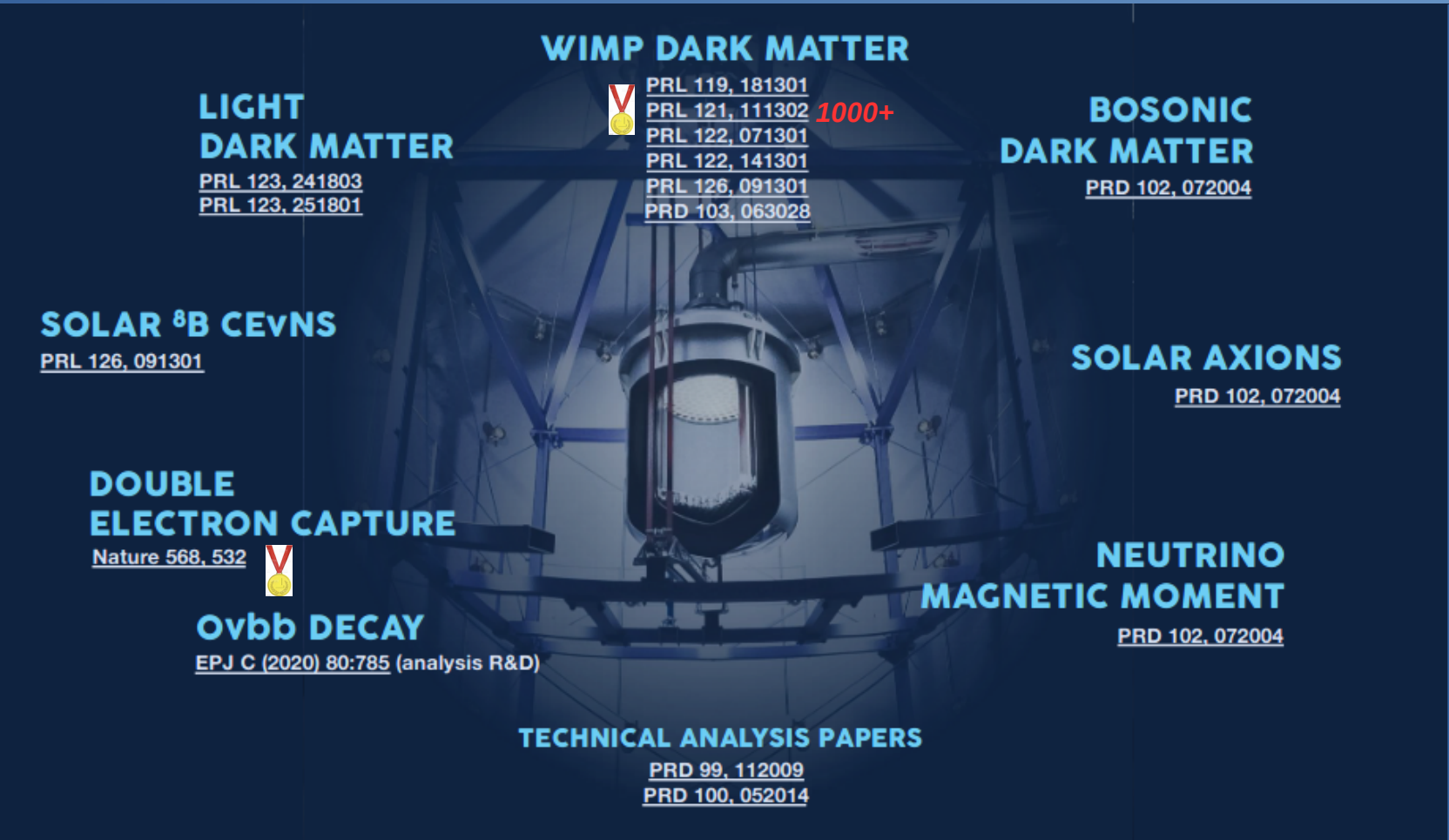
XENON10	XENON100	XENON1T	XENONnT	DARWIN
				
2005-2007	2008-2016	2012-2018	2020-2025	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm

The XENON Project @ LNGS

XENON

XENON10	XENON100	XENON1T	XENONnT	DARWIN
				
2005-2007	2008-2016	2012-2018	2020-2025	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm

Summary of XENON1T results



MEDIA INAF

https://www.media.inaf.it/2015/11/11/xenon1t-il-cacciatore-di-materia-oscura/

https://www.media.inaf.it/2019/04/24/xenon-doppia-cattura-elettronica/

https://www.media.inaf.it/2020/06/17/eccesso-di-eventi-al-gran-sasso/

https://www.media.inaf.it/2017/05/19/materia-oscura-xenon1t-in-pole-position/

https://www.media.inaf.it/2011/04/14/materia-oscura-xenon100/

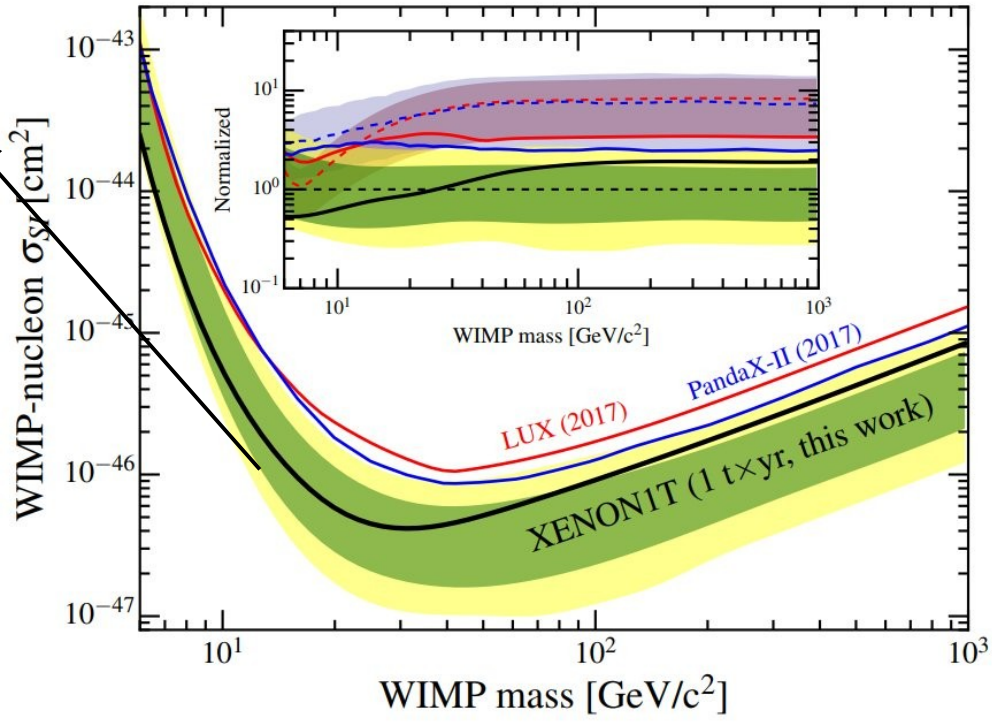
WIMP search

Dark Matter Search Results from a One Ton-Year Exposure of XENON1T, PRL 121, 111302

Light dark matter search with ionization signals in XENON1T | PRL 123, 251801

Search for Light Dark Matter Interactions Enhanced by the Migdal Effect or Bremsstrahlung in XENON1T | PRL 123, 241803

Search for Coherent Elastic Scattering of Solar ^{8}B Neutrinos in the XENON1T Dark Matter Experiment | PRL 126, 091301



1 tonne-year

Total exposure for the main WIMP search
1.3 t fiducial LXe mass
278.8 live days (Nov 2016 – Feb 2018)

World leading constraints on WIMP-nucleon interaction

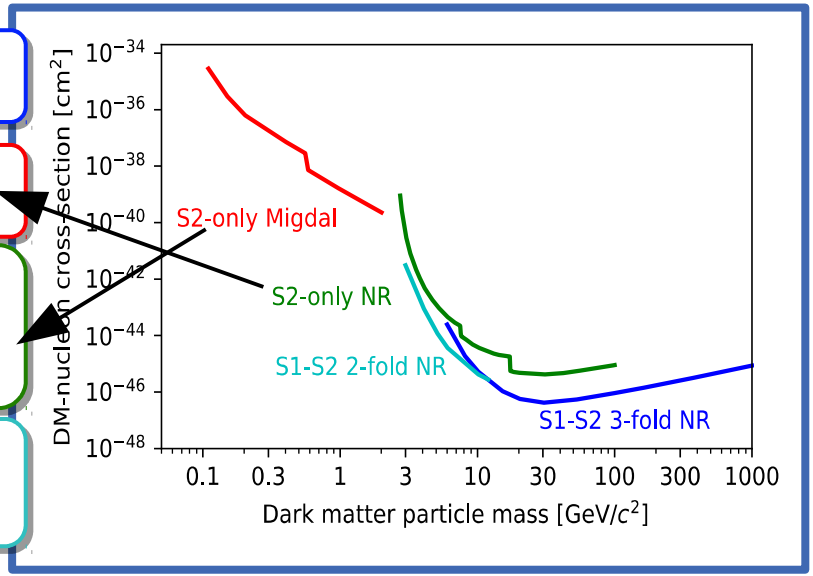
WIMP search

Dark Matter Search Results from a One Ton-Year Exposure of XENON1T, PRL 121, 111302

Light dark matter search with ionization signals in XENON1T | PRL 123, 251801

Search for Light Dark Matter Interactions Enhanced by the Migdal Effect or Bremsstrahlung in XENON1T | PRL 123, 241803

Search for Coherent Elastic Scattering of Solar ^{8}B Neutrinos in the XENON1T Dark Matter Experiment | PRL 126, 091301

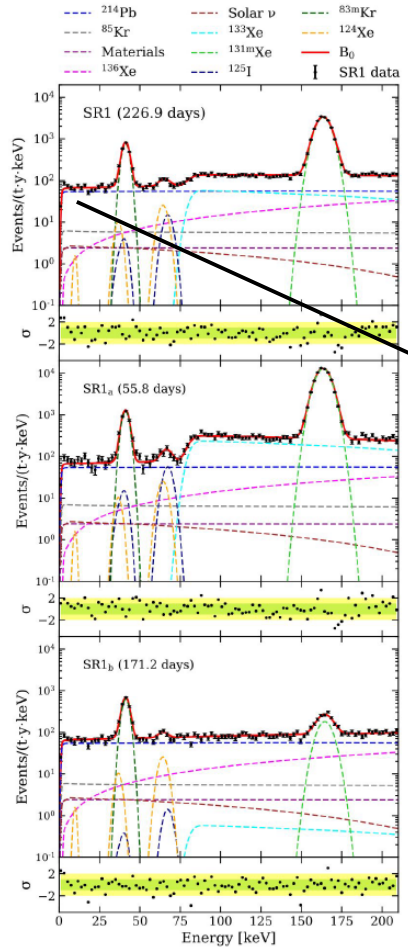


1 tonne-year

Total exposure for the main WIMP search
1.3 t fiducial LXe mass
278.8 live days (Nov 2016 – Feb 2018)

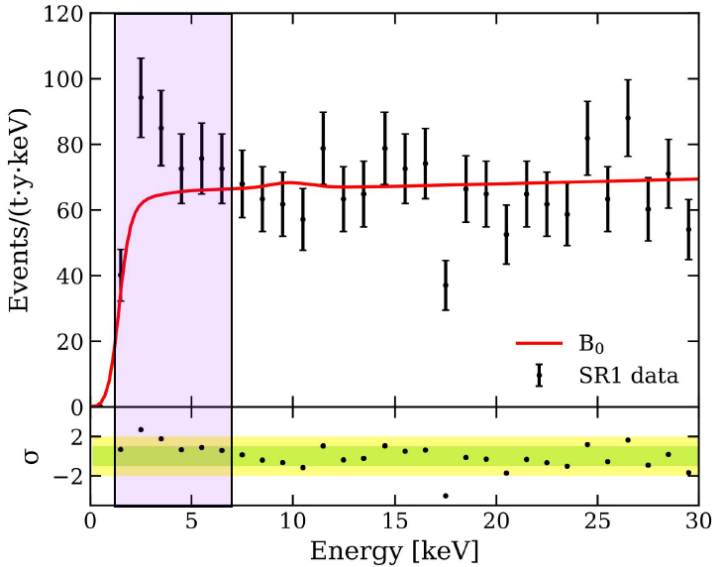
World leading constraints on WIMP-nucleon interaction

Low-Energy ER search



(76 ± 2) events / (tonne*year*keV$_{ee}$) in [1,30] keV$_{ee}$

Lowest ever achieved in this energy range!



Excess observed in the [1-7] keV$_{ee}$ energy range

285 events observed vs 232±15 expected from best fit (3.3σ fluctuation – *naive estimate*)

Low-Energy ER search

XENON

2σ TRITIUM BACKGROUND

Fitted concentration: $(6.2\pm2.0) \times 10^{-25}$ mol/mol ^{3}H/Xe
We don't expect that much ^{3}H from liquid purity
Very difficult to confirm or exclude such a tiny abundance

3.4σ SOLAR AXIONS

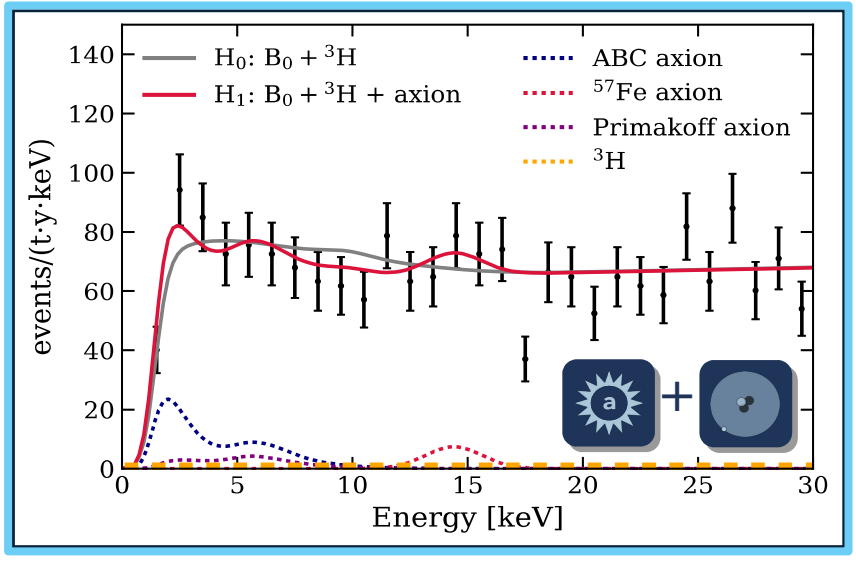
Non-null coupling to electrons → ABC and/or Primakoff
Strong tension with astrophysical constraints
Axions+^{3}H favoured over ^{3}H-only at 2.1 σ

3.2σ NEUTRINO MAGNETIC MOMENT μ_ν

$\mu_\nu = [1.4, 2.9] \times 10^{-11}$ μ_B
$\mu_\nu > 10^{-15}$ would imply neutrinos to be Majorana fermions
Tension with astrophysical constraints

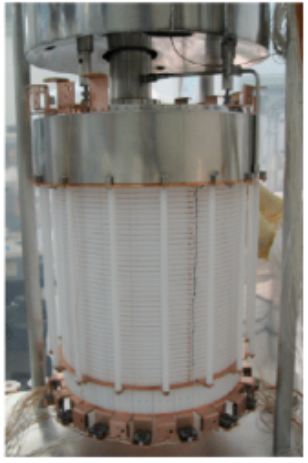
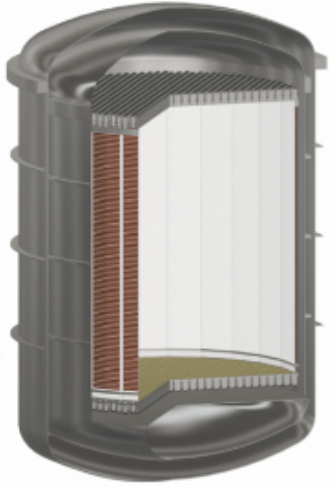
3.0σ BOSONIC DARK MATTER

Including pseudo-scalar (ALPS) and vector (dark photons) bosons
Most restrictive constraints to date set



The XENON Project @ LNGS

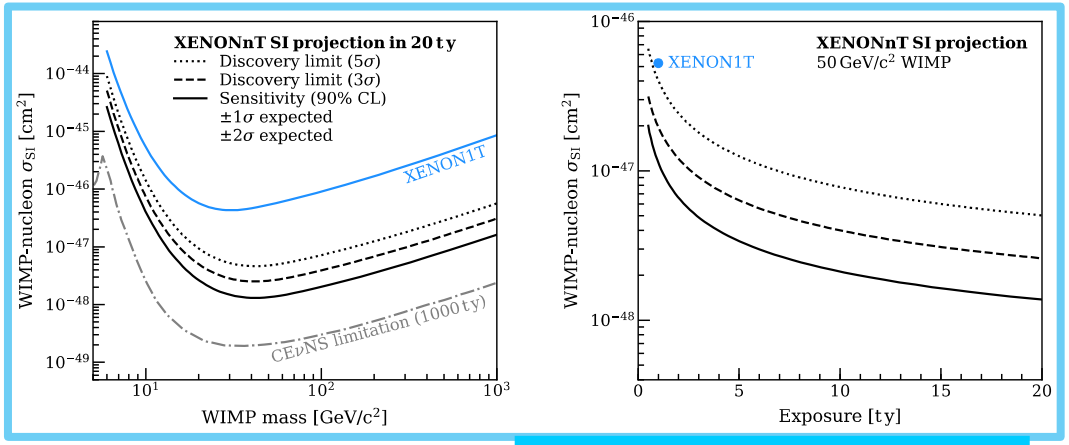
XENON

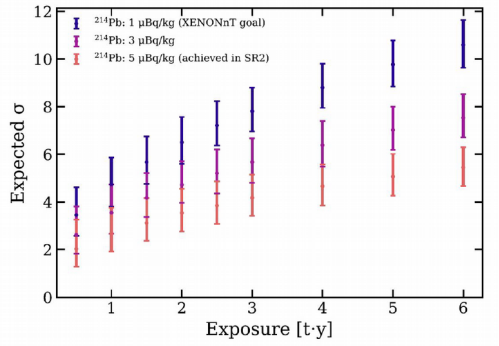
XENON10	XENON100	XENON1T	XENONnT	DARWIN
				
2005-2007	2008-2016	2012-2018	2020-2025	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm

Upgrade to XENONnT

×3
active volume

1/6
background





σ_{SI} = 2*10^{-48} cm^2 for a 50 GeV WIMP with 20 t*y

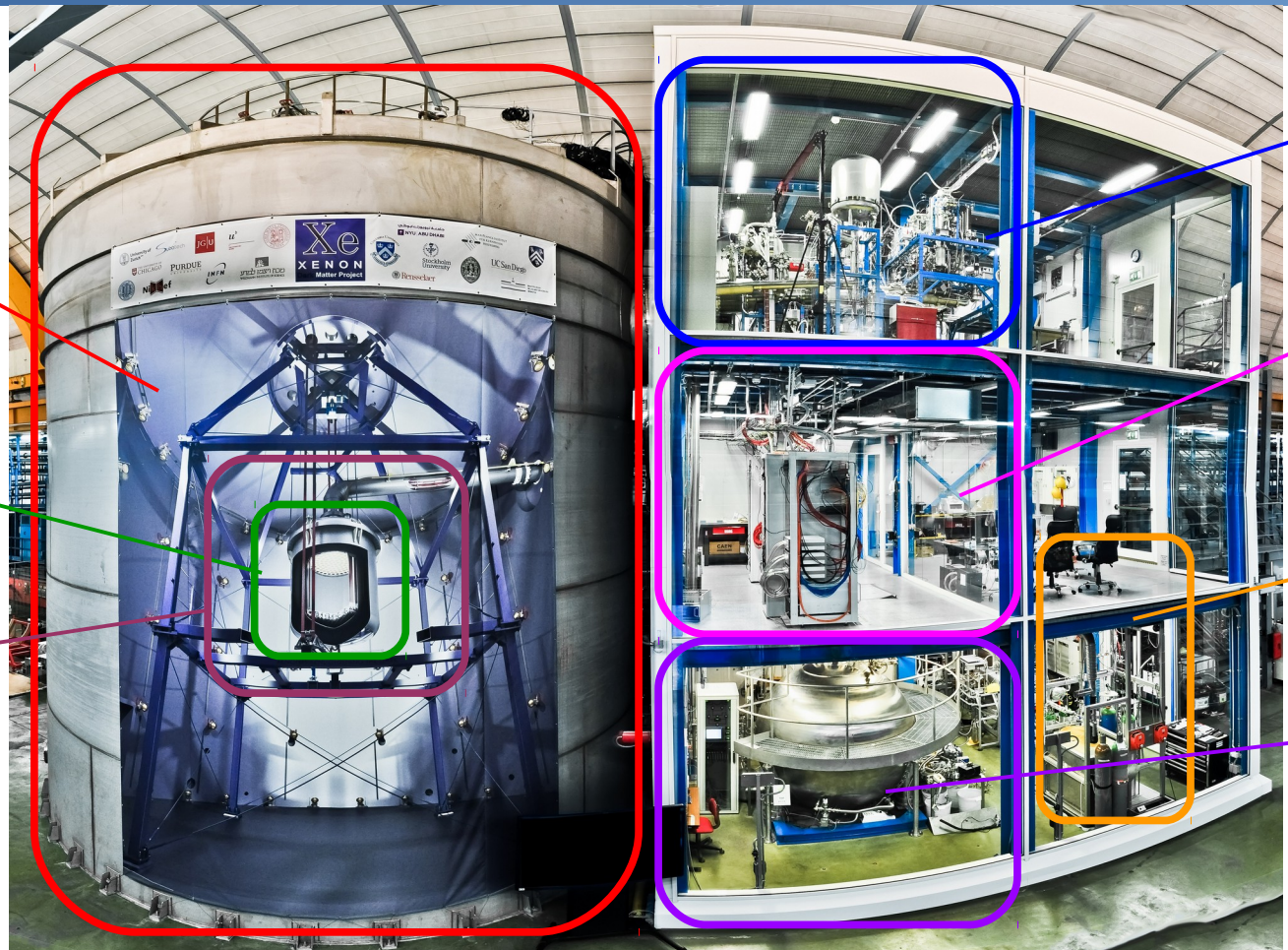
Discriminate axion hypothesis from ^{3}H with few months of data

XENONnT @ LNGS

Water tank
700 t ultra-pure water
Cherenkov Muon Veto
84 PMTs

Cryostat TPC

Neutron Veto



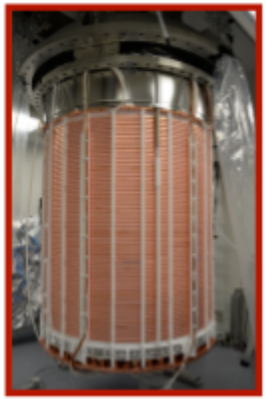
Cryogenics Purification

Electronics DAQ

Kr distillation column

Recovery and Storage

Upgrade to XENONnT



Larger TPC

- Total 8.4 t LXe
- 5.9 t in TPC
- ~ 4 t fiducial
- 248 → 494 PMTs

Neutron veto

- Inner region of existing muon veto
- optically separate
- 120 additional PMTs
- Gd in the water tank
- 0.5 % $Gd_2(SO_4)_3$

^{222}Rn distillation

- Reduce Rn (^{214}Pb) from pipes, cables, cryogenic system
- New system, PoP in XENON1T

LXe purification

- Faster xenon cleaning
- 5 L/min LXe (2500 slpm)
- XENON1T ~ 100 slpm

XENONnT Schedule

Marzo-Maggio 2020:
- commissioning PMTs ed elettrodi in vuoto
- commissioning sistema criogenia

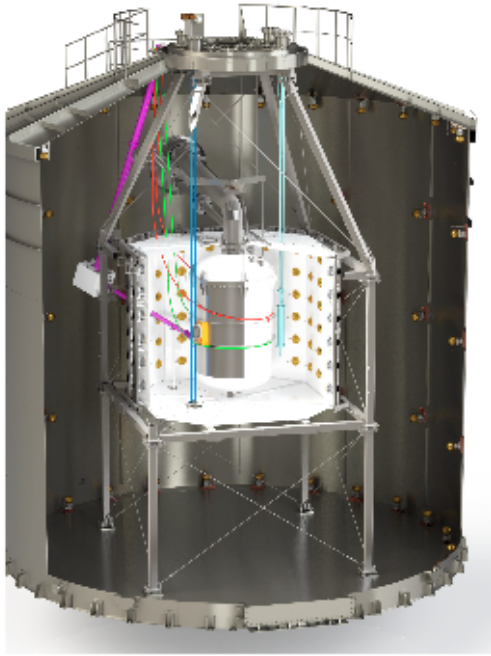
Giugno-Luglio 2020:
- preparazione installazione nVeto
- installazione sistema calibrazione
- installazione elettronica nVeto in DAQ room

Agosto-Settembre 2020:
- installazione nVeto

Ottobre-Novembre 2020:
- riempimento criostato con 8.6 t di LXe
- ripristino del Muon Veto

11 Dicembre 2020
- riempimento serbatoio con acqua demineralizzata

Gennaio 2021 -> now
- inizio commissioning nVeto e TPC
- … commissioning, commissioning, commissioning
- preparazione per impianto purificazione Gd



May 2021: start of Science Run

Fundings of upgrade to XENONnT

Voci di spesa		Costo (kEuro)
gas Xenon		360
elettronica TPC		90
pompa LXe		100
pompa GXe		45
nVeto	PMTs	200
	meccanica	130
	elettronica, HV, DAQ	230
	GdPlant	270
Totale		**1425**

INFN founded the upgrade to XENONnT with a total of 1425 k€ in the past 3 years

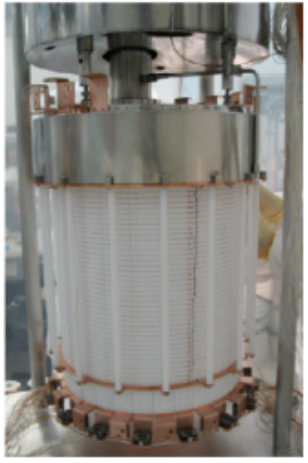
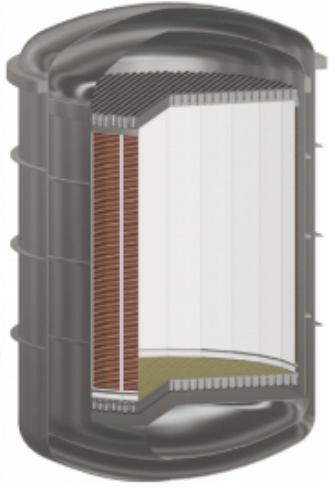
2021-2023 we expect 50 k€/year

Xenon gas is worth ~1500 k€/t

Total cost of the upgrade, including XENON1T, is 20 M€

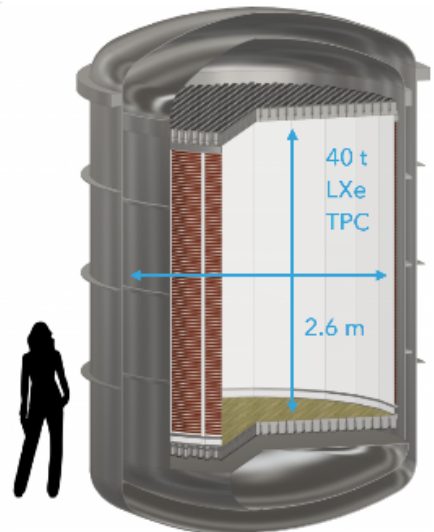
The XENON Project @ LNGS

XENON

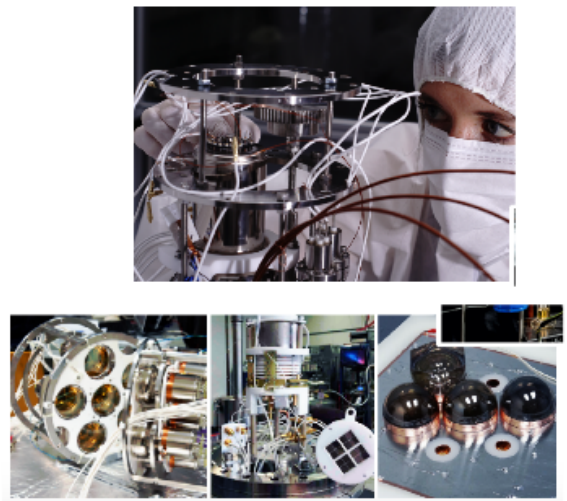
XENON10	XENON100	XENON1T	XENONnT	DARWIN
				
2005-2007	2008-2016	2012-2018	2020-2025	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm

Towards DARWIN

DARWIN LXe TPC

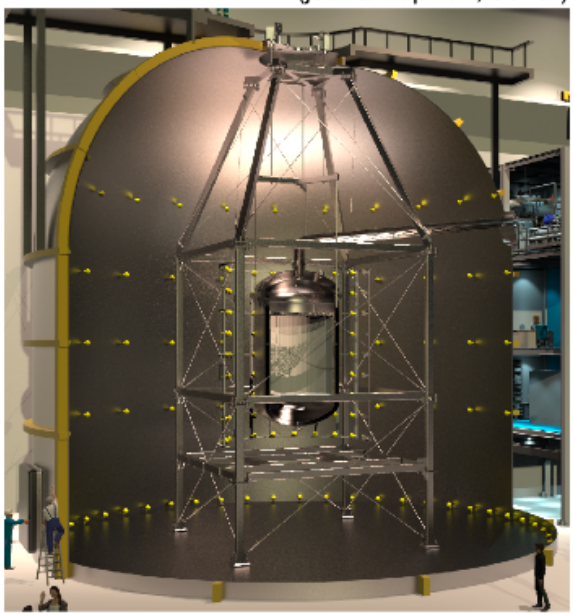


R&D on Photosensors and Electrodes



GdWater neutron veto

Visualisation of DARWIN in Borexino WT
(just an option, so far)



Possible interest in SiPMs as photosensors for DARWIN (>2027)

Synergies with others INAF groups

INAF in XENON

OATo
3 full time permanent researchers
Gian Carlo Trinchero (PI Torino) – Member of XENON CB *(0.8 FTE)*
Walter Fulgione (PI LNGS) – Member of XENON CB *(0.8 FTE)*
Andrea Molinario – Responsible of muon veto WG *(0.8 FTE)*

Università di Torino
1 PhD student
Emanuele Angelino *(1.0 FTE)*

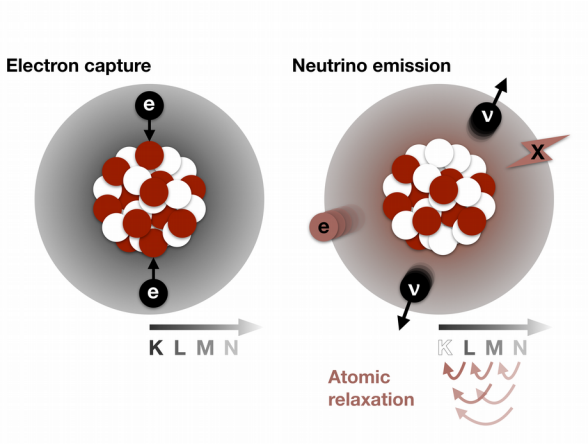
Working on neutron veto and muon veto electronics and DAQ
Data analysis
Low energy calibration with ^{37}Ar

Criticità

In prospettiva, sarebbe auspicabile un allargamento del gruppo (con TI, TD e AdR) per acquisire maggiori responsabilità in XENONnT e nell'ottica dello sviluppo dell'hardware per DARWIN

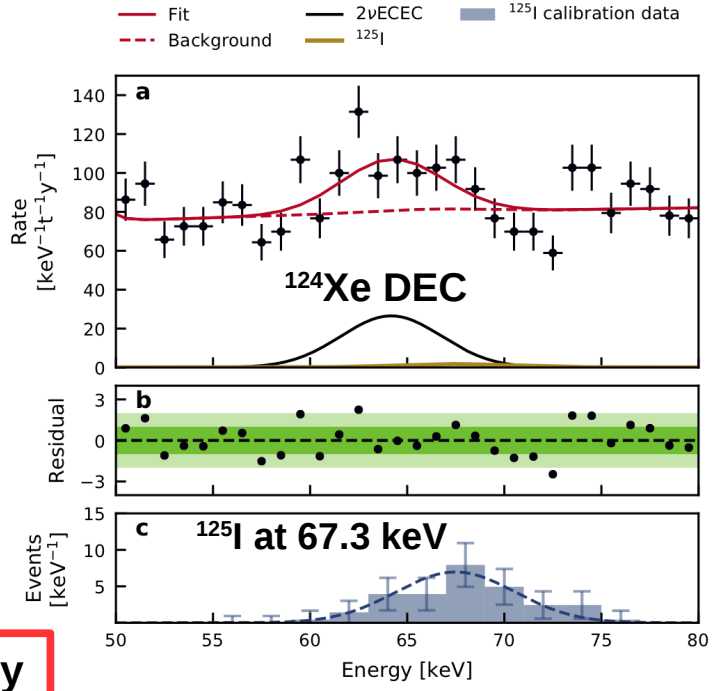
Backup

^{124}Xe Double Electron Capture



$^{124}Xe + 2e^- \rightarrow {}^{124}Te + 2\nu_e$

Detection of X-rays and
Auger electrons
Total energy (64.3±0.6) keV



Detected peak at (64.2±0.5) keV with 4.4σ significance

Measured half-life of the process $T_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ y

E. Aprile et al., Nature 568 (2019), no.7753, 532-535

Search for CEvNS of ^{8}B solar ν

XENON

How far are we from the neutrino floor ?

Search for Coherent Elastic Scattering of Solar ^{8}B Neutrinos in the XENON1T Dark Matter Experiment | PRL 126, 091301

There are ~600 CEvNS recoils from B8 solar neutrinos alone

$$R = \phi(\nu) \times \sigma_\nu \times N_{Xe} \times \text{exposure}$$
$$\simeq 600\,\text{events}/(\text{tonne} \times \text{year})$$

Can we increase the detection efficiency to ~1%? o(5) CEvNS

S2 threshold: S2 > 200 120PE

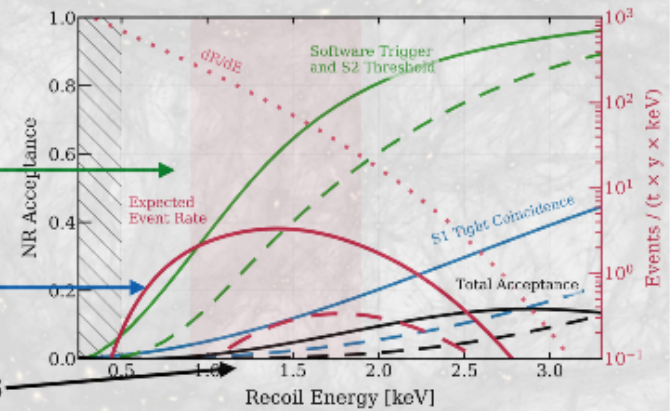
S1 threshold: ~~Three~~ Two PMTs seeing light within 50ns

Additional cuts ~~not~~ optimized for CEvNS

Expected Backgrounds in the standard WIMP analysis

Source	1.3 t	1.3 t, NR Ref.
ER	627 ± 18	1.6 ± 0.3
Radiogenic	1.4 ± 0.7	0.8 ± 0.4
CEvNS	0.05 ± 0.01	0.03 ± 0.01
Accidental	$0.5^{+0.3}_{-0.0}$	$0.10^{+0.06}_{-0.00}$
Surface	106 ± 8	4.8 ± 0.4
Total	735 ± 20	7.4 ± 0.6

arXiv:2012.02846



Expected Backgrounds in the dedicated low energy analysis

Source	Expectation
CEvNS	2.25
Accidental	5.14
ER	0.21
Radiogenic	0.03
Surface	Negligible
Total	7.65

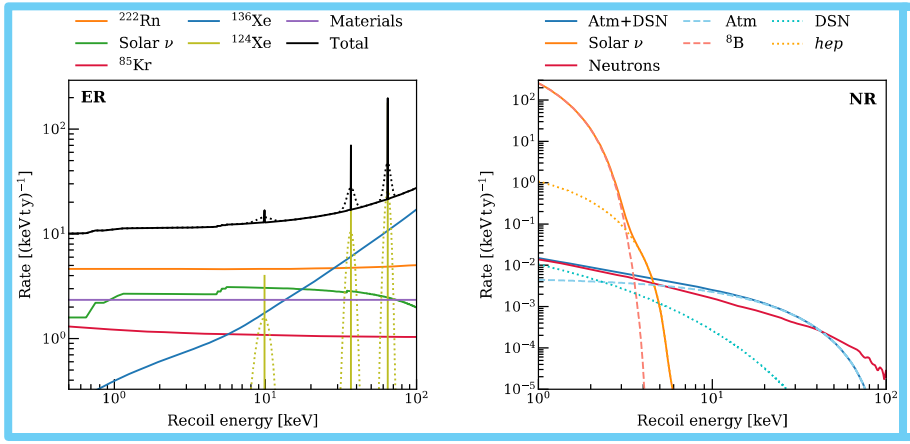
Results: no significant excess

HC	LHA	BG	Signal	Observed
0	≥ 2	0.10	0.13	0
0	< 2	3.58	0.46	4
1	≥ 2	0.06	0.25	0
1	< 2	1.58	0.84	2
2	≥ 2	0.02	0.18	0
2	< 2	0.05	0.39	0
	Total:	5.38	2.25	6

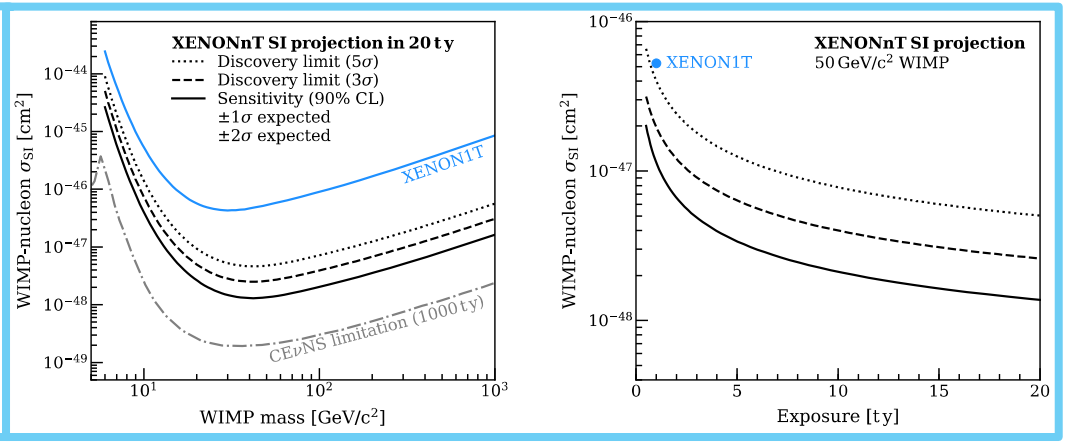
XENONnT Physics Reach

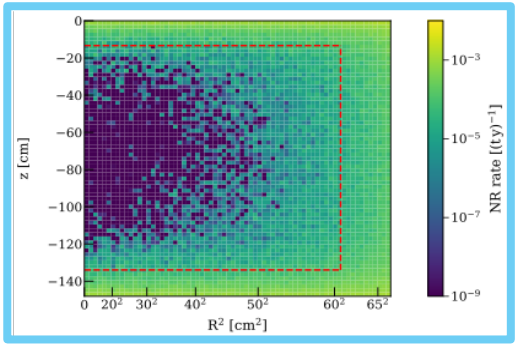
Goal: 1 μBq/kg ^{222}Rn level

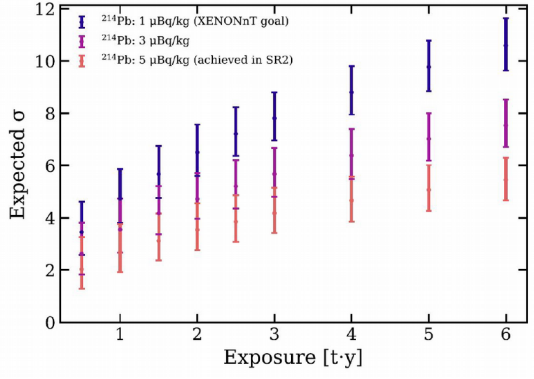
Expected background



NR CHANNEL: WIMP SEARCHES







ER CHANNEL:
TEST AXION HYPOTHESIS

XENONnT Physics Reach

AND MANY OTHER PHYSICS CHANNELS TO EXPLORE…

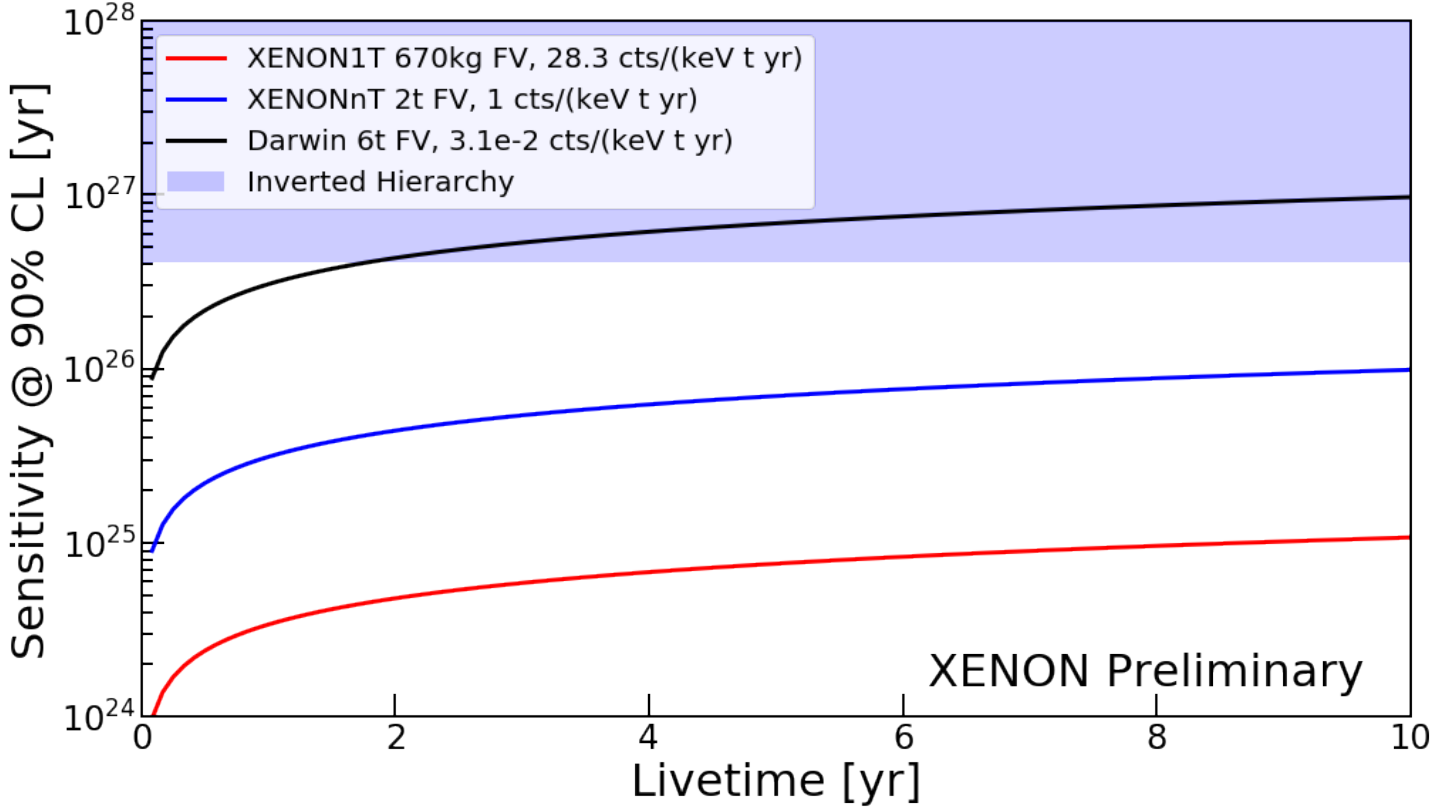
DARK MATTER MODELS
- WIMP models
- Light dark matter
- Mirror dark matter
- Luminous dark matter

SOLAR NEUTRINOS
- ^{8}B CEvNS
- pp elastic scattering
- ν Magnetic moment

BEYOND SM
- Neutrinoless DEC
- Neutrinoless double-beta decay

ASTROPHYSICS
- Supernova neutrinos
- GW multi-messenger

0νββ decay


XENON1T 670kg FV, 28.3 cts/(keV t yr)
XENONnT 2t FV, 1 cts/(keV t yr)
Darwin 6t FV, 3.1e-2 cts/(keV t yr)
Inverted Hierarchy
XENON Preliminary
Sensitivity @ 90% CL [yr]
Livetime [yr]
10^{28}
10^{27}
10^{26}
10^{25}
10^{24}
0
2
4
6
8
10