Search for dark matter with the XENON1T detector

Les Rencontres de Physique de la Vallée d'Aoste

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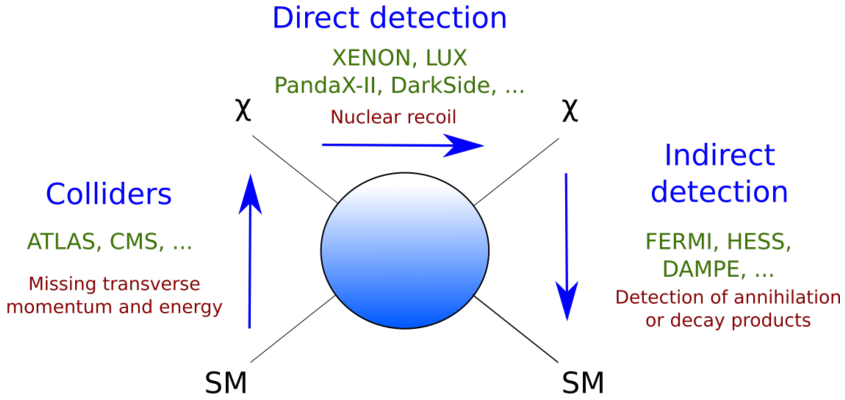
Paths to search for particle dark matter



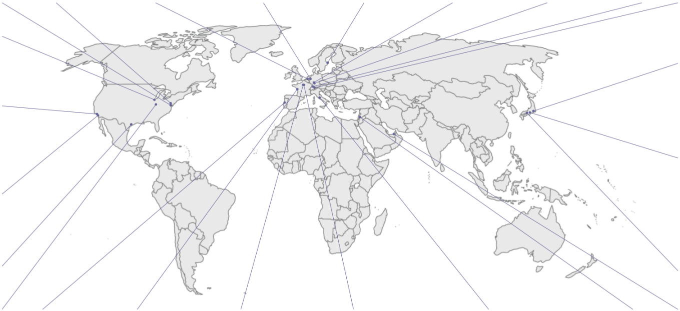
- Direct: recoil of [1-100] keV for scattering of WIMPs with masses in [1-1000] GeV/c^2
- Colliders: collision of SM particles producing DM particles
- Indirect: self-annihilation thanks to gravitational accumulation or dark matter decay

The XENON collaboration

XENON Dark Matter Project

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

Chicago · UCLA · UCSD · Rice

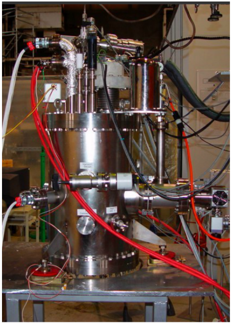


Tokyo · Nagoya · Kobe

Purdue · Coimbra · Subatech · LPNHE · LAL · Bologna · LNGS · Torino · Napoli · Weizmann · NYUAD

From XENON10 to XENONnT

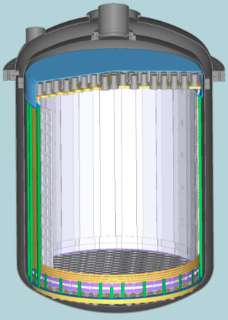
- Since 2005, XENON detectors operated at LNGS
- XENON10: Target (total) mass of 14 (25) kg
- XENON100: Target (total) mass of 62 (161) kg
- XENON1T: Target (total) mass of 2000 (3200) kg
- XENONnT: Planned target (total) mass of 6000 (8000) kg



2005 - 2007

2008 - 2016

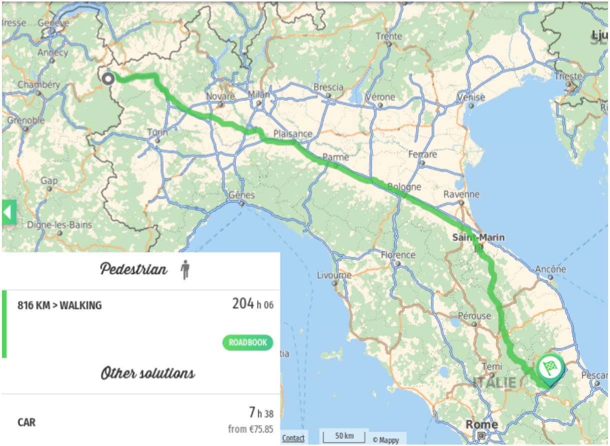
2013 - 2018

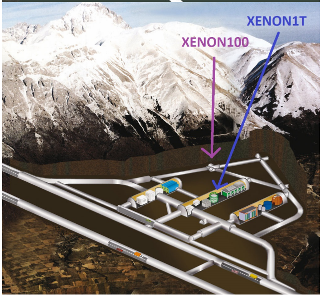


From 2019

XENON1T @ LNGS

- *Laboratori Nazionali del Gran Sasso* in central Italy
- Located inside the 10 km long *Traforo del Gran Sasso*
- XENON1T in Hall B with an overburden of 3600 m.w.e.





XENON1T @ LNGS

EPJ C (2017), 77, 881

Purification systems
Cryogenic systems

DAQ and Slow Control

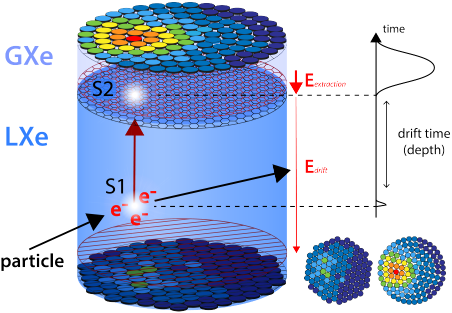
Krypton distillation column

ReStoX (Xenon storage and recuperation)
Bottle rack (Xenon filling)

Water tank: Time Projection Chamber (TPC) and Cherenkov muon veto

XENON1T: Dual phase Xenon TPC

- Energy deposits from interaction ⇒ excitation and ionization of LXe
- Light signal (S1) from scintillation after deexcitation



- Ionization e^-'s drift upwards in E field
- e^-'s extracted at LXe/GXe interface to excite and ionize GXe atoms
- Secondary scintillation $\propto N_{e^-}$ extracted (S2)
- S2 observed by both PMT arrays, S1 mostly by bottom array
- Drift time and S2 pattern provide 3D position of the initial interaction

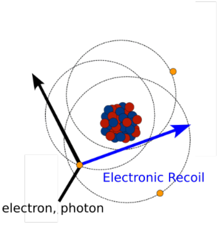
XENON1T @ LNGS

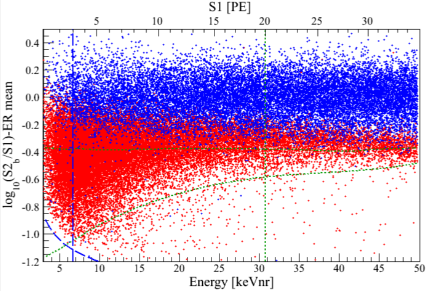
- Dual-phase xenon TPC with 2t of LXe in active volume
  EPJ C (2017), 77, 881
- 2 PMT arrays (127, top & 121, bottom) with average QE of 34.5% @ 178 nm EPJC 75 (2015) 11, 546
- $\sim$ 1 m drift length

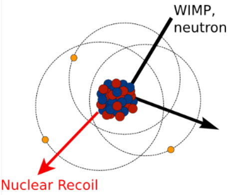
Expected signal and backgrounds

- Nuclear and electronic recoils through interactions with nucleus (WIMPs, neutrons) or atomic electrons (βs, γs)
  $\Rightarrow$ excitation and ionization of LXe

- Discrimination between ER and NR possible due to different contributions to ionization and excitation (S2/S1 ratio)

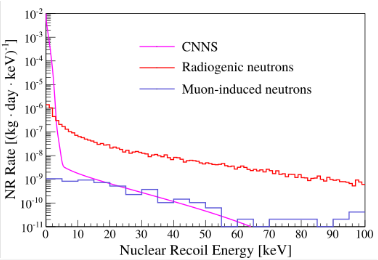


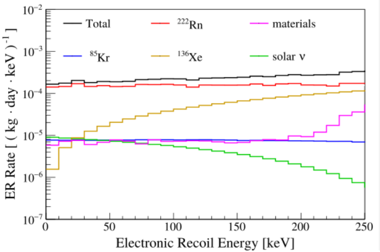




Background sources for XENON detectors

- Nuclear recoils:
  - Neutrons from muon spallation
    $\Rightarrow$ underground laboratory + Cherenkov muon veto
  - (α,n) reactions and spontaneous fission
    $\Rightarrow$ material selection
  - Coherent Neutrino-Nucleus Scattering (CNNS)
- Electronic recoils:
  - γs from natural radioactivity
    $\Rightarrow$ xenon self-shielding and material selection
  - Internal contamination:
    - ^{136}Xe Two-neutrino double-β decay
    - ^{85}Kr from nuclear power plant operation
      $\Rightarrow$ cryogenic distillation
    - Radon and daughters
      $\Rightarrow$ material selection and cryogenic distillation

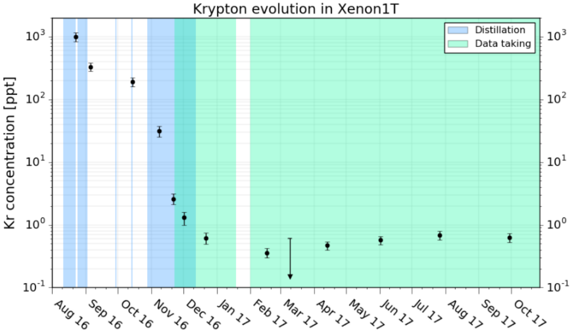




JCAP 1604 (2016), 04, 027

Background from krypton

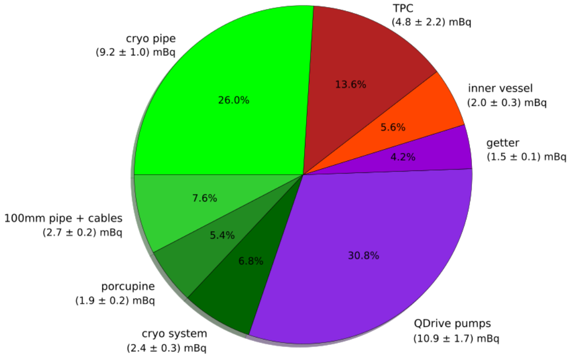
- Rare Gas Mass Spectrometer (RGMS) for Kr concentration measurements EPJ C (2014) 74, 2746
- Regular samples taken from liquid phase



- Successful krypton distillation allowing sub-ppt level EPJ C 77 (2017) 5, 275
- $(1.7 \pm 0.3)\ 10^{-4}$ events / (kg.day.keV) with 1300 kg FV and 5-40 keV (NR): Lowest ER background in a DM detector
- Background dominated by ^{222}Rn progenies

Background from radon

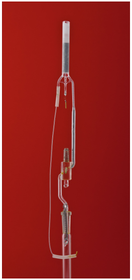
- ^{222}Rn: current most critical background source
- Radon budget in XENON1T: $\sim 10\mu$Bq/kg

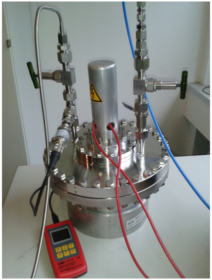


- Individual radon sources identified by emanation measurement
- Fighting strategies: material selection (HPGe, ICPMS, Rn emanation), surface cleaning, cryogenic distillation

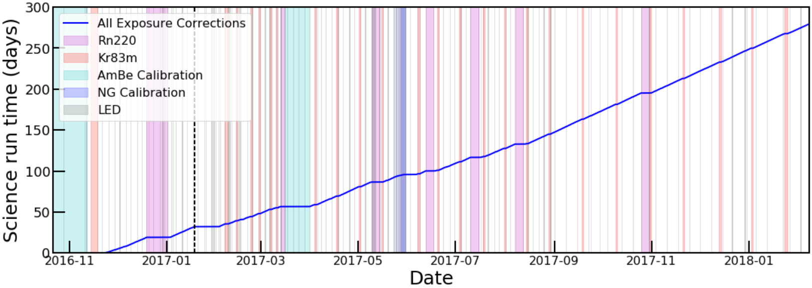
Radon emanation measurement strategies

- Proportional counters for sensitive radon emanation measurement
- Electrostatic radon monitors
- Parallel measurements available for high sample throughput
- Automatized emanation measurements with Auto-Ema setup for reproducibility



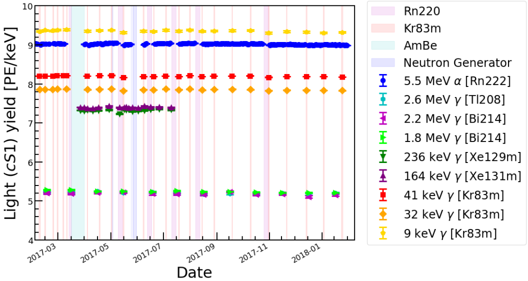


Exposure in XENON1T science runs

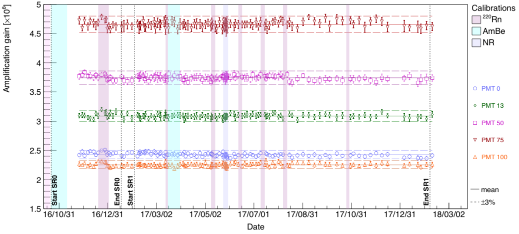


- Total exposure in XENON1T science runs (SR0+SR1): 32.1+246.7 live days and 92% of detector uptime
- Regular ER (^{220}Rn) and NR calibrations (AmBe and Neutron Generator)
- PMT response monitoring with LED
- ^{83m}Kr calibration for study of xenon purity with e^{-}-lifetime evolution

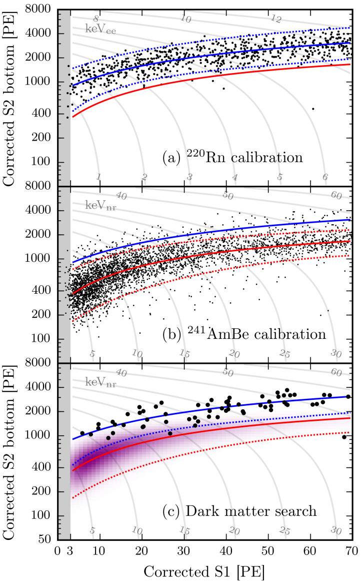
Detector stability



- Stable charge yield, light yield and PMT gains for science data



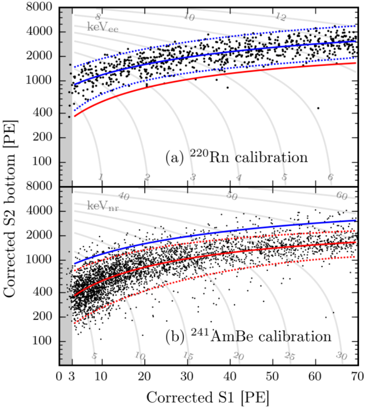
First result from XENON1T science runs



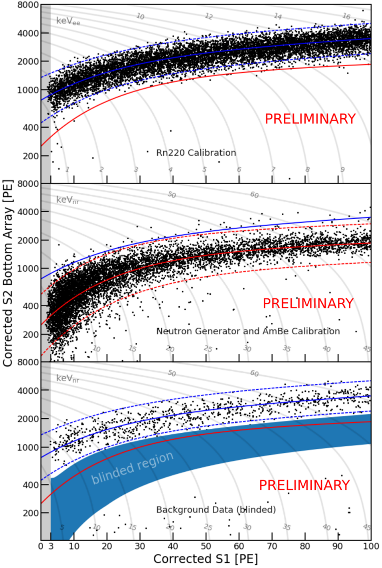
- ER band from ^{220}Rn calibration data
- NR band from AmBe calibration data
- No excess above expected background in ROI
  $\Rightarrow$ exclusion limit
- Spin-independent WIMP-nucleon scattering cross-section reached for the first time:
  7.7×10^{-47} cm^2
  @ $m_\chi = 35$ GeV/c^2 PRL 119 (2017)

Latest result from XENON1T science runs

SR0



SR1

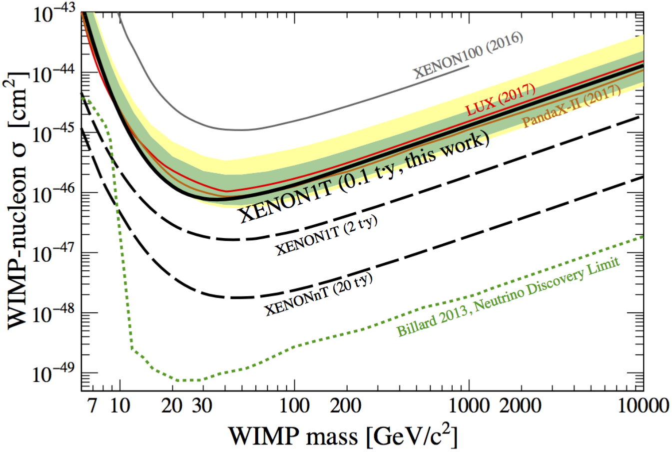


- Calibration statistics improved for SR1
- Extra NR calibration with NG

Latest result from XENON1T science runs

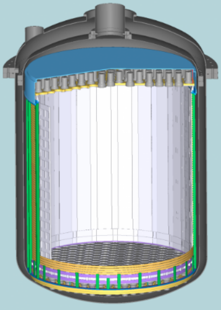
- Spin-independent WIMP-nucleon scattering cross-section reached for the first time: 7.7×10^{-47} cm^2 @ $m_\chi = 35$ GeV/c^2

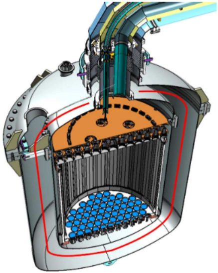
PRL 119 (2017)



- Sensitivity significantly improved for XENONnT

XENONnT: direct upgrade for XENON1T



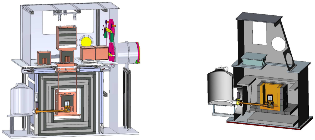


- Most subsystems of XENON1T designed for quick upgrade
- Minor modifications to cryogenic and purification system
- New TPC with an extra 246 PMTs
- Second emergency recovery system for 10t of xenon
- Should access the CNNS floor at low WIMP mass
- Preparation ongoing during XENON1T operations

Background reduction strategies for XENONnT

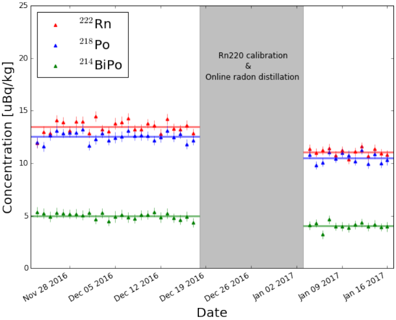
- Radon is the dominating background in XENON1T
- Material screening and selection with γ-spectrometry

EPJ C (2017), 77, 890



- Online reduction using cryogenic distillation,
- Proofs of principle EPJ. C (2017), 77, 143 and XENON100

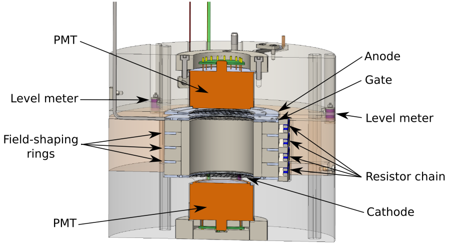
EPJ C (2017), 77, 358

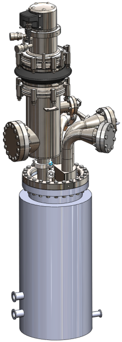


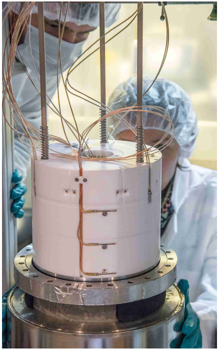
- Expected reduction factor for the column: 100

Background reduction strategies for XENONnT

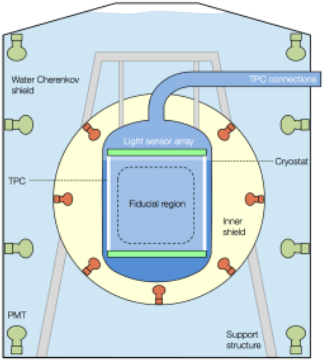
- Clean room to prevent deposition of dust containing ^{238}U
- Surface cleaning for ^{222}Rn daughters reduction
- Validation of surface cleaning techniques:
    - 5-20 cm drift length LXe TPC
    - e^--lifetime measurement for purity monitoring after surface cleaning
    - Inner core exchangeable
    - External ports allowing larger samples to be introduced in GXe flow







The DARWIN consortium



- 50t of xenon and 40t in the active volume
- Sensitivity to spin-independent WIMP-nucleon scattering cross-section of few 10^{-49} cm^2 @ $m_\chi = 50$ GeV/c^2

  JCAP (2016), 11, 017
- Science run could start in 2023 lasting at least 7 years
- Other potential physics goals:
  - Detection of events from CNNS
  - pp-ν detection from the Sun
  - Search for neutrinoless double-β decay
  - Observation of supernova neutrinos

Conclusion and outlook

- XENON1T: first tonne-scale LXe TPC for dark matter searches
- Outstanding first results on SI WIMP-nucleon scattering cross-section
- Lowest background level for DM searches with 0.2 events$\times$tonne$^{-1}\times$keV$^{-1}\times$d^{-1}
- 1 tonne$\times$year exposure will yield world-leading result
- Data from second science run still blinded
  Results to be announced in March 2018
- XENON1T continues data taking until installation of XENONnT, end of 2018

http://www.xenon1t.org/
Twitter: @Xenon1T

Thank you for your attention!