

## **107° Congresso Nazionale SIF**

16 Settembre 2021



# XENON

## THE XENON PROJECT: RECENT RESULTS, STATUS AND PROSPECTS



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XENON PROJECT



XENON1T RESULTS



OUTLOOK

XENONnT STATUS



- Direct DM search
  LXe TPC
- Detector evolution

- **XENON1T** experiment
- WIMP searches
- DEC discovery
- ER excess

- Larger TPC
- Neutron Veto
- Liquid Xe purification
- Rn distillation
- Science run

- WIMP sensitivity
- ER excess discrimination
- Other channels







# THE XENON COLLABORATION



XENON PROJECT



XENON1T RESULTS













# **DIRECT DARK MATTER SEARCH**

MILKY WAY GALAXY

DARK MATTER HALO



XENON PROJECT



XENONIT RESULTS











EARTH-BASED **EXPERIMEN** 

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**DIRECT DARK MATTER SEARCH** 



XE XENON

**XENON** PROJECT





LNGS

0 0

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3600 m.w.e.

UNDERGROUN

EARTH-BASED EXPERIMENT

# **DIRECT DARK MATTER SEARCH**



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XENONIT RESULTS











LNGS

UNDERGROUND

EARTH-BASED EXPERIMENT

# **DIRECT DARK MATTER SEARCH**







700 t WATER TANK

MUON VETO

XENONIT RESULTS















# DIRECT DARK MATTER SEARCH







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# LXe TPCs LEGACY

**BEST TECHNOLOGY SEARCHING FOR WIMP DARK MATTER** 

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XENONNT STATUS



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# THE XENONIT EXPERIMENT

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





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### **MUON VETO**

- <u>] JINST 9 P11006</u>
- 700 t ultra-pure water
- 84 PMTs

### TPC

- 2.0 t LXe target mass
- 8 248 PMTs <u>EPJ C75 11</u>

### **SERVICE BUILDING**

- Cryogenic system
- GXe purification
- DAQ <u>JINST 14 (2019) 07</u>
- Slow control
- Kr distillation column
- LXe storage and recovery

Careful material selection for excellent radiopurity

è <u>EPJ C77, 890</u>



XENON1T @ LNGS (Hall B)



XENON1T RESULTS





XENONnT PROJECTIONS







WIMP DARK MATTER





**XENONIT** RESULTS









EPJ C (2020) 80:785 (analysis R&D)

**TECHNICAL ANALYSIS PAPERS** PRD 99, 112009 PRD 100, 052014

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# WIMPS DIDN'T SHOW UP

### WORLD LEADING CONSTRAINTS ON WIMP-NUCLEON INTERACTION

For WIMP masses in the range [0.1, 2) - (3, 1000] GeV/c<sup>2</sup>





**XENONIT** RESULTS

BACKGROUND

**EXCLUSION LIMIT** 









# THE RAREST PROCESS EVER

### **DISCOVERY OF DOUBLE ELECTRON CAPTURE IN 124Xe**

Nature 568, 532-535 (2019)



Neutrino emission

Measured half-life:  $(1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22} \text{ yr}$ ~10<sup>12</sup> times larger than the age of the Universe

The rarest process ever directly observed!

WR





Expected signature: (64.3 ± 0.6) keV mono-energetic peak

Observed peak of 126 ± 29 events at (64.2 ± 0.5) keV

**4.4**  $\sigma$  Discovery

significance



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**Electron** capture



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# **EXCITING MYSTERY FROM ERS**

### **NEW PHYSICS OR UNEXPECTED BACKGROUND?**

140

120

80

60

40

20

events/(t·y·keV)

 $- H_0: B_0 + {}^3H$ 

 $H_1: B_0 + {}^3H + axion$ 

10

15

Energy [keV]

Phys. Rev. D 102, 072004

### Solar axions + (unconstrained) <sup>3</sup>H fit

.....

.....

<sup>3</sup>H

20

25

ABC axion

<sup>57</sup>Fe axion

----- Primakoff axion





**XENON1T** RESULTS











Estimated <sup>3</sup>H/Xe concentration in XENON1T



### **3.2** $\sigma$ TRITIUM BACKGROUND

<sup>3</sup> Fitted concentration: (6.2±2.0) × 10<sup>-25</sup> mol/mol <sup>3</sup>H/Xe

- <sup>3</sup> We don't expect that much <sup>3</sup>H from liquid purity
- Very difficult to confirm or exclude such a tiny abundance



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### **3.4** $\sigma$ SOLAR AXIONS

- Solution  $\Rightarrow$  Non-null coupling to electrons  $\rightarrow$  ABC and/or Primakoff Strong tension with astrophysical constraints
- $^{\otimes}$  Axions+<sup>3</sup>H favoured over <sup>3</sup>H-only at 2.1  $\sigma$



### **3.2** $\sigma$ NEUTRINO MAGNETIC MOMENT $\mu_{\nu}$

 $^{12}$   $\mu_{\nu}$  = [1.4, 2.9] × 10<sup>-11</sup>  $\mu_{\rm B}$ 

- $\approx \mu_{\nu}$  > 10<sup>-15</sup> would imply neutrinos to be Majorana fermions
- Tension with astrophysical constraints



### **3.0** $\sigma$ **BOSONIC DARK MATTER**

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

















XENON1T @ LNGS (Hall B)















# FAST UPGRADE TO XENONNT

**INSTALLATION COMPLETED DURING THE 2020 LOCKDOWN** 















# UPGRADES | NEW LARGER TPC







XENON1T RESULTS





and a summer of the Ala

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## 





### **TPC DATA - <sup>83m</sup>Kr CALIBRATION**

UPGRADES | NEW LARGER TPC

### **DETECTOR PERFORMANCE**

- Photon detection efficiency: ~0.17 PE/photon (0.14 in XENON1T)
- Energy resolution (@ 41.5 keV): ~7.6% (8% in XENON1T)
- S2 resolution: ~15.1% (13.7% in XENON1T)

### **PMTs PERFORMANCE**

<sup>xa</sup> 485 of 494 used in the analysis

0.5 1.0

Rate [A.U.]

Quantum efficiency: 34% avg.



S B

XENONIT RESULTS

XENONNT STATUS















### ▼ NR bkg

Neutron background suppression

- 0.2% Gd-doped water Cherenkov detector
- 120 PMTs
- Highly reflective volume
- 87% neutron tagging efficiency (expected)





XENONnT @ LNGS (Hall B)















# UPGRADES | NEUTRON VETO



### INFN **U-TUBES** New calibration system Sources displaced in different radial and azimuthal positions nVETO Top View N 0 O [cm -30 m] -60 Time [ns] 300 **CALIBRATION DATA** + -90 100 Gamma source (<sup>232</sup>Th) -120 0 200 -150 Neutron source (<sup>241</sup>AmBe) 60 02 80 0 +1cm 00000 000000 60 100 30 -30 -60 -30 00000 00000 YIcmj y [cm] Number of Hitlets per channel - Run 013213 60 0 0 00000 000000 400.00 .0000 00000 35000 -100 40 30000 00000 00+00 25000 -200 20 104 20000 15000 2.2 MeV -300 10000 n-capture bin [Hz] 5000 101 -100 100 200 4.4 MeV -300 -200 0 300 x [cm] 2020 2100 Channe gamma Number of hitlets Run 013213 Hitlet Matrix Rate 100 2120 С 2100 2080 Area [pei 1.6 1.4 + Residuals 5 2060 1.2 P 1 0.8 0.6 LW 2040 2020 09 9 10 11 12 13 14 15 2000 100 200 120 150 20 80 100 50 Time [ns] Event area [PE]

### **NEUTRON VETO CALIBRATION DATA**











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# UPGRADES | LIQUID Xe PURIFICATION

### ▲ Purity



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- Improve signal detection and target purity
- High purification flux (~1000 slpm) to remove electronegative impurites
- Ultra-low Rn emanation filters
- >20 ms electron lifetime reached





### Compared to XENON1T:

- x1.5 larger drift length (1.5 m vs 1 m)
- x30 better electron lifetime (20 ms vs 0.6 ms)
- **x3** better cathode events survival (>90% vs 30%)



### XENON PROJECT



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XENONNT STATUS









# UPGRADES | RADON DISTILLATION



### ER background reduction

- Dedicated Rn cryogenic distillation column
- <sup>©</sup> 1 μBq/kg <sup>222</sup>Rn level (XENONnT goal)
- In XENON1T was
  13 μBq/kg (science run)
  4.5 μBq/kg (latest R&D run)



- Equilibrium concentration by gas extraction only: 1.72 μBq/kg
- Planned future liquid extraction: factor ~2 more efficient







XENON1T RESULTS

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# XENONNT SCINCE RUN ON

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### XENON PROJECT



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### ER BAND CALIBRATION (220Rn)





### **NR BAND CALIBRATION (241AmBe)**



- Preliminary energy calibration
- Internal ER calibration: <sup>220</sup>Rn diffused in LXe
- External NR calibration: <sup>241</sup>AmBe in different
  U-tubes positions
- Science data taking is ongoing

# **XENONNT PROJECTIONS | NR CHANNEL**

WIMP SEARCHES JCAP 11 (2020) 031

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 $1.4 \times 10^{-48}$  cm<sup>2</sup> at 50 GeV/c<sup>2</sup> with 20 ty exposure



**XENONnT** PROJECTIONS





### **Compared to XENON1T:**

- Background further reduced by factor ~6
- >1 order of magnitude improvement of sensitivity





XENONnT can discriminate Axions from Tritium with few months of data

**XENONnT** PROJECTIONS











### **DARK MATTER MODELS**

- WIMP models
- Light dark matter
- **Mirror dark matter**
- Luminous dark matter etc...

### **SOLAR NEUTRINOS**

**8B CEvNS** 

**XENONNT PROJECTIONS | MORE** 

MANY OTHER PHYSICS CHANNELS TO EXPLORE

- pp elastic scattering
- Magnetic moment etc...





### **BEYOND SM**

- **Neutrinoless DEC**
- Neutrinoless doublebeta decay etc...

### **ASTROPHYSICS**

- Supernova neutrinos
- **GW** multi-messenger







## FIRST XENONNT RESULTS COMING SOON



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