Liquid Xe purification in a large-scale dark matter search experiment XENONnT

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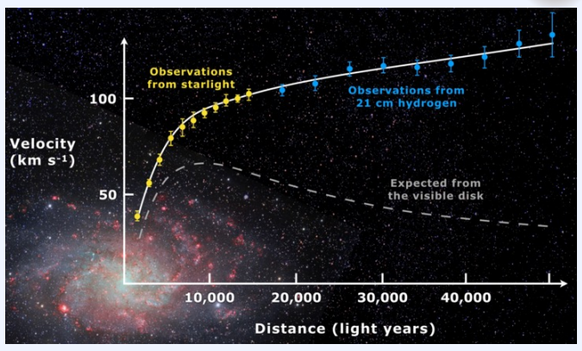
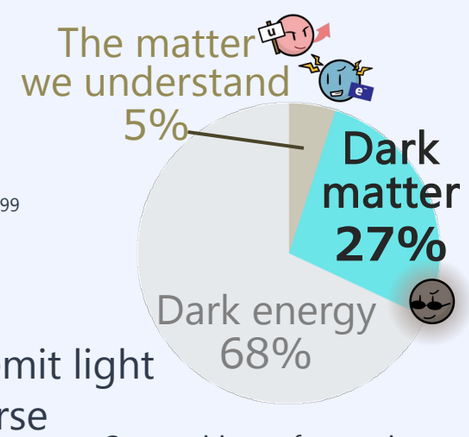
I. What is Dark Matter (DM)?

What we know about DM



Observed and predicted rotation curves of the M33 galaxy
Created by M. Leo, using E. Corbelli and P. Salucci, astro-ph/9909252, 1999

⇒ An unknown mass component is required! It could be a key to reveal the nature of the universe.



Compositions of our universe

DM properties

- Gravitationally interacting
- It does not absorb, reflect, or emit light
- Stable for the age of the universe

II. XENONnT experiment

The large direct DM search experiment

- Underground laboratory in Gran Sasso, Italy
- Using 8.5t of xenon (Xe)

	XENON10	XENON100	XENON1T	XENONnT
	2005-2007	2008-2016	2012-2018	2019-
Xe	25kg	161kg	3200kg	8500kg

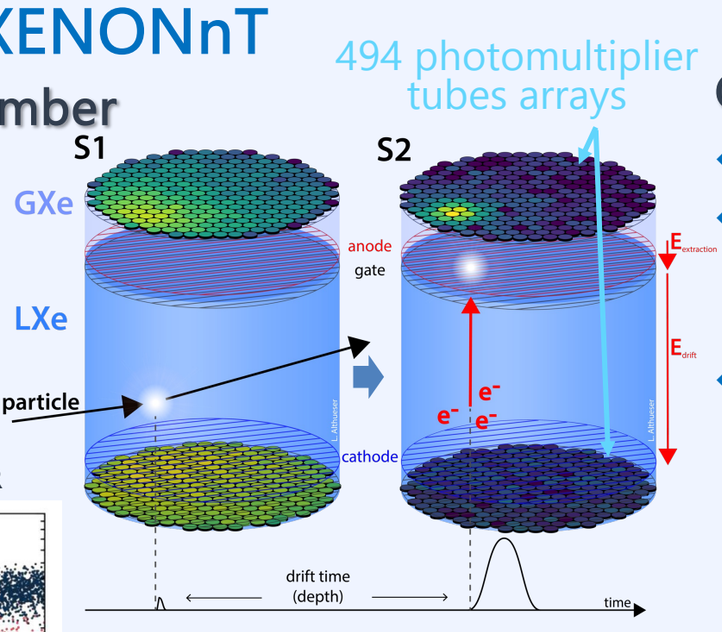
XENON collaboration

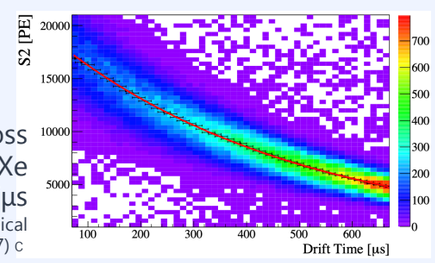
- Main target: **WIMPs**
  - Weakly Interacting Massive Particles
  - A good candidate of DM, mass ~x100 of proton
  - Very rare event (expected: ≦1 event/year)

III. Detector and Signals of XENONnT

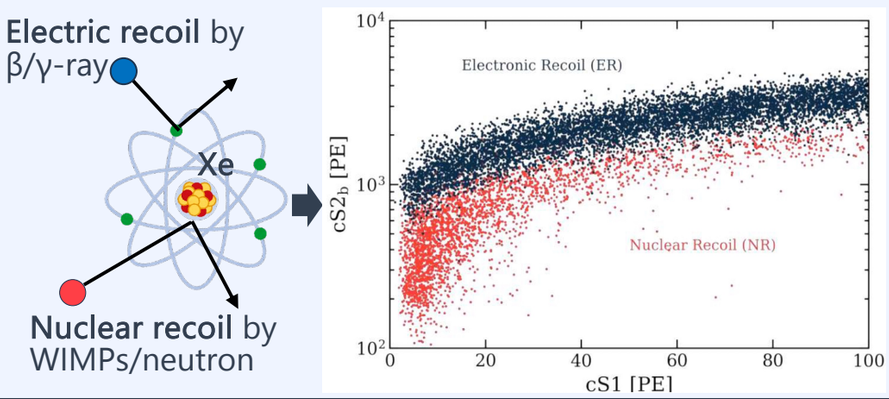
Dual-phase Xe Time Projection Chamber

- Liquid Xe; an excellent scintillator
- Online purification available
- S1 : Scintillation & S2 : Ionization signals
- 3D positions of interaction points : (**x, y** : S2 position, **z** : $time_{S2} - time_{S1}$)
- Particle identification : $(S2/S1)_{NR} < (S2/S1)_{ER}$





Electrons loss in the LXe at τ_e=467μs
The European Physical Journal C. **77**, 881 (2017) c



Challenges of operating a dual-phase TPC

- **Large mass & low background** are required
- Reduce radioactive background
  - Rn, Kr radioisotopes make background events
    ⇒ Removed by distillations
- Purification of large detector
  - H_2O absorbs light (attenuates S1 and S2)
    ⇒ Removed by gas phase purification
  - O_2 catches electrons (attenuates S2)
    ⇒ Removed by gas & **liquid phase** purification

$S2(t) = S2(0)e^{-t/\tau_e}$ (τ_e [s]: electron lifetime in Xe)

$$\tau_e = \frac{1}{k_{O_2} c_{O_2}} = \frac{M_{Xe}}{k_{O_2} x_{O_2} \rho_{LXe}} = \frac{257\ \mu s \cdot ppb}{x_{O_2}}$$

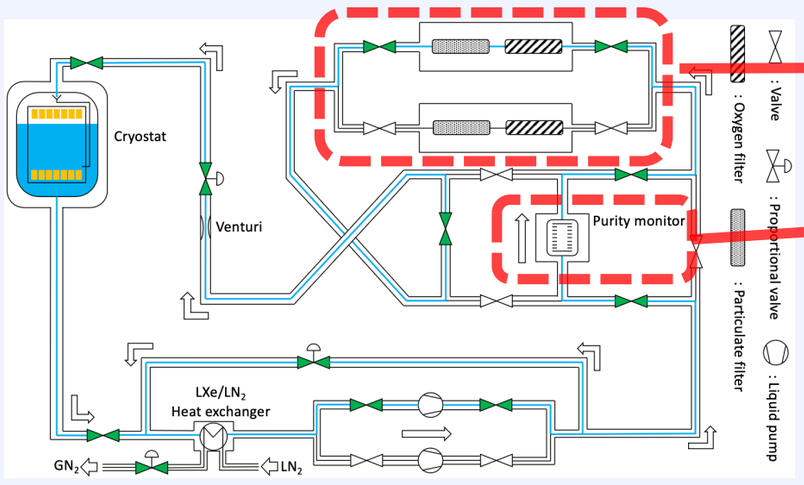
An indicator of S2 sensitivity

($k_{O_2} \sim 10^{11}$ [L/mol/s]: attachment rate, c_{O_2} [mol/L]: concentration)

IV. New LXe Purification System in XENONnT

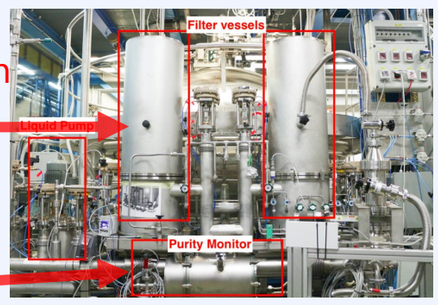
New LXe purification system and its performance

- Remove impurities from LXe by either Q5 or St707 (see below)
- High mass throughput thanks to liquid phase purification (500x GXe)
  ⇒ 1000 slpm (~12x GXe purification)



LXe purification filters

Purity monitor

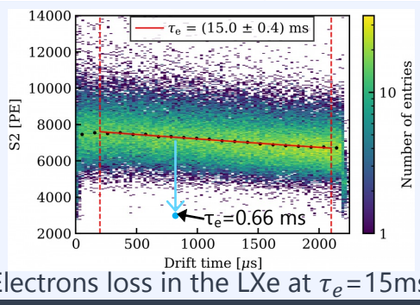


Q5（BASF "Cu-0226 S"）
Cu-based, for initial purification
High efficiency ~100% & High RI

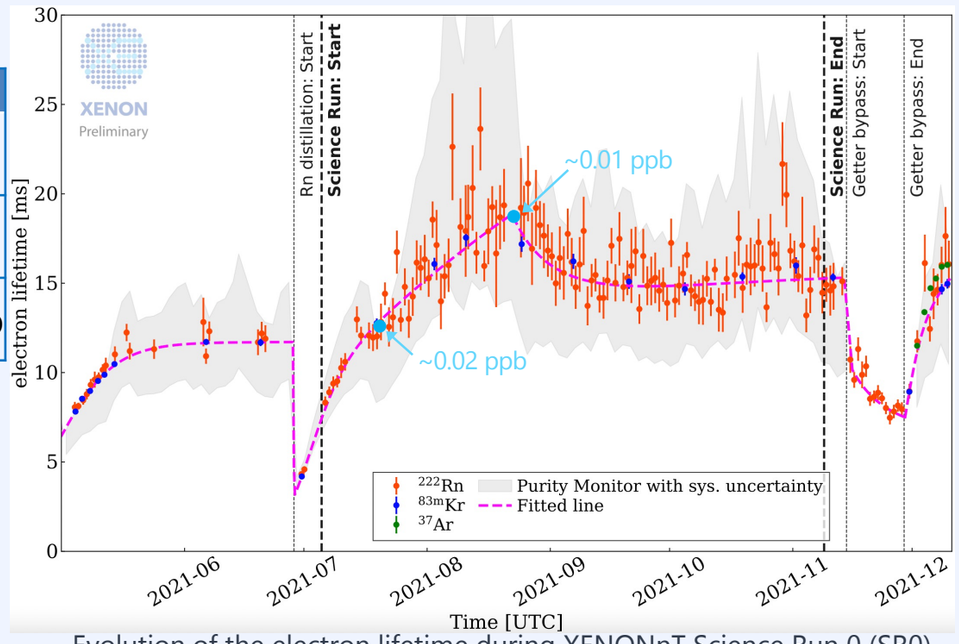
SAES St707
Getter-based, for science run
Middle efficiency ~56% & Low RI

- Achieved：

	XENON1T	XENONnT
Full TPC drift time	0.67 ms	2.2 ms
Electron lifetime	0.66 ms	**>10ms**
O_2 eq. purity	~1 ppb	~0.02 ppb



Electrons loss in the LXe at τ_e=15ms



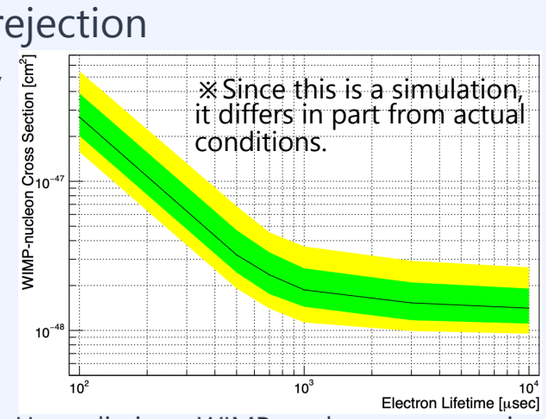
Evolution of the electron lifetime during XENONnT Science Run 0 (SR0)

Impacts of the Xe purity on physics

- Electron lifetime reaches >~5x the maximal drift time
  - High S2 sensitivity
  - Improved electron recoil rejection

⇒ Greater WIMPs sensitivity

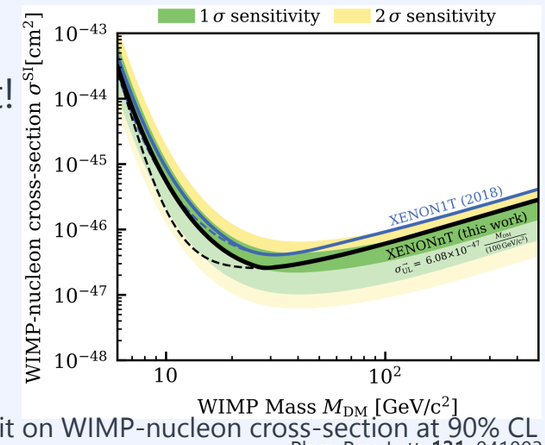
- Electron survival rate: **>80%** in XENONnT (was 30% in XENON1T)
- Also: Rn distillation in XENONnT reduced ^{222}Rn to < 1/7 of XENON1T



Upper limit on WIMP-nucleon cross-section vs. electron lifetime
(20 t*yr, WIMP: 50 GeV/c²) Kato, 2019

V. Summary

- XENONnT is searching for dark matter by using Xe.
- Purifying Xe is important for such a rare-event search.
- XENONnT contains the purest xenon on the Earth!
- XENONnT has the lowest background environment!
- XENONnT reached the upper limit given by in XENON1T in ~1/3 of exposure time (in SR0.)
- Data taking is ongoing!



Upper limit on WIMP-nucleon cross-section at 90% CL
Phys. Rev. Lett. **131**, 041003