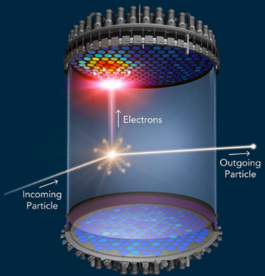
GraSPA2024

LAPP
Laboratoire d'Annecy de Physique des Particules

Evidence of Dark Matter
Dark Matter Detection
Direct Detection
XENONnT Experiment
Improvements
References
Extra

Dark Matter Search with XENONnT

Bachelor Research Project in Physics



Jordy Ram

Summer School
on Particle and Astroparticle Physics

July 15, 2024

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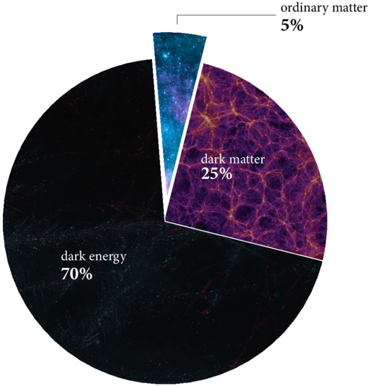

Figure 1: Energy Content of the Universe (Wolz 2022)

Cosmological:

- Temperature Fluctuations in the Cosmic Microwave Background
- Cosmic Structure Formation

Astrophysical:

- Gravitational effects on matter: motion of stars and galaxies
- Gravitational effects on light: gravitational lensing

Detection of Dark Matter

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- **Collider:**
  DM could be produced in high energy collisions at particle colliders
- **Direct Detection:**
  DM may scatter off SM particles in Earth based detectors
- **Indirect Detection:**
  Self-annihilating DM may be indirectly observed through the production of SM-particles

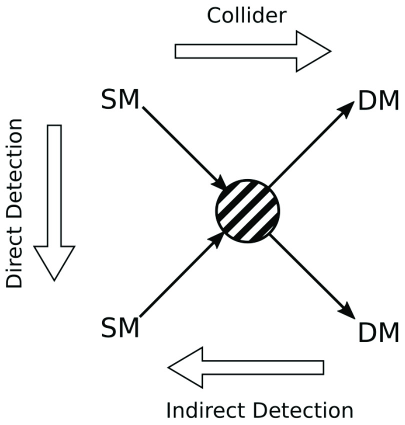

Figure 2: Dark Matter Interactions (Giagu 2019)

Direct Detection of Dark Matter

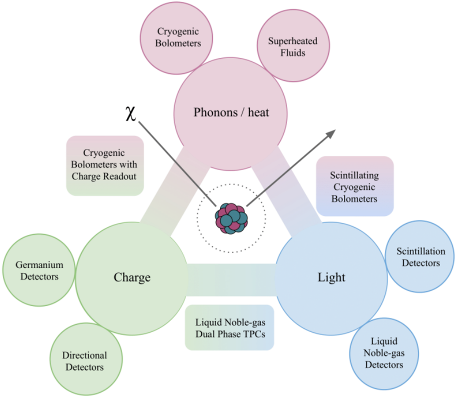

Figure 3: Interaction Signals (Angevaare 2023)

Direct detection is currently possible through a combination of the following:

- Heat
- Charge
- Light

XENONnT uses the latter two

XENONnT Experiment

Background particles interact with electronic shell

- Electronic Recoil (ER)
- More ionisation (S2)

WIMPs interact with nucleus

- Nuclear Recoil (NR)
- More excitation (S1)

$$\left(\frac{S2}{S1}\right)_{NR} < \left(\frac{S2}{S1}\right)_{ER}$$

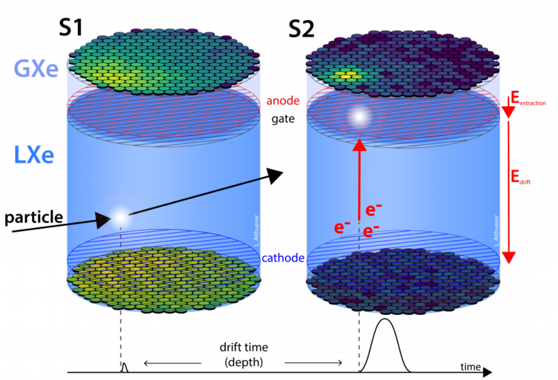

Figure 4: Particle Interaction inside a Time Projection Chamber (L. Althüser, 2020)

Improvements in Dark Matter Detections

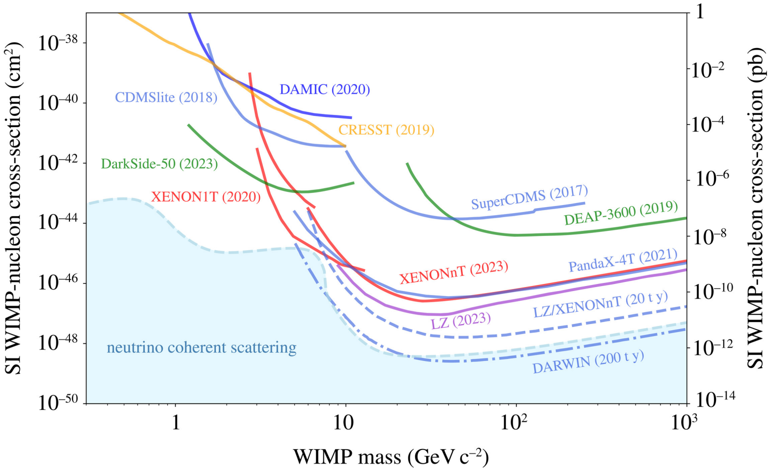

Figure 5: Exclusion limits on the SI WIMP-nucleon cross-section (Baudis 2023).

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Angevaare, Joran Remco (June 2023). "First WIMP results of XENONnT and its signal reconstruction". PhD thesis. University of Amsterdam. 179 pp. ISBN: 978-94-6419-809-6. URL: https://pure.uva.nl/ws/files/126087832/Thesis.pdf.

Baudis, L. (Nov. 2023). "Dual-phase xenon time projection chambers for rare-event searches". In: *arXiv (Cornell University)*. DOI: 10.48550/arxiv.2311.05320. URL: https://arxiv.org/abs/2311.05320.

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Giagu, Stefano (May 2019). "WIMP dark matter searches with the ATLAS detector at the LHC". In: *Frontiers in Physics* 7. DOI: 10.3389/fphy.2019.00075.

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Cosmic Microwave Background

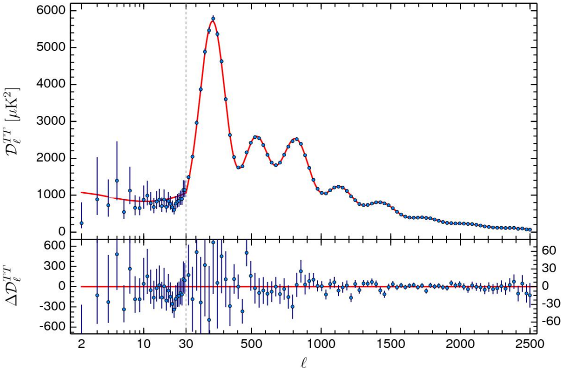

Figure 6: Power Spectrum of the Cosmic Microwave Background (Planck Collaboration et al. 2016).

ΛCDM Model fits the cosmological data perfectly

- Energy density of dark matter

$$\Omega_{c,0} = 0.259 \pm 0.002$$

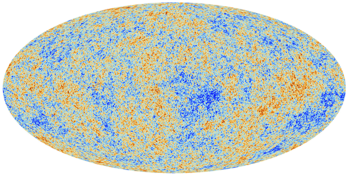

Figure 7: Cosmic Microwave Background (Planck Collaboration et al. 2016)

Galaxy Rotation Curves

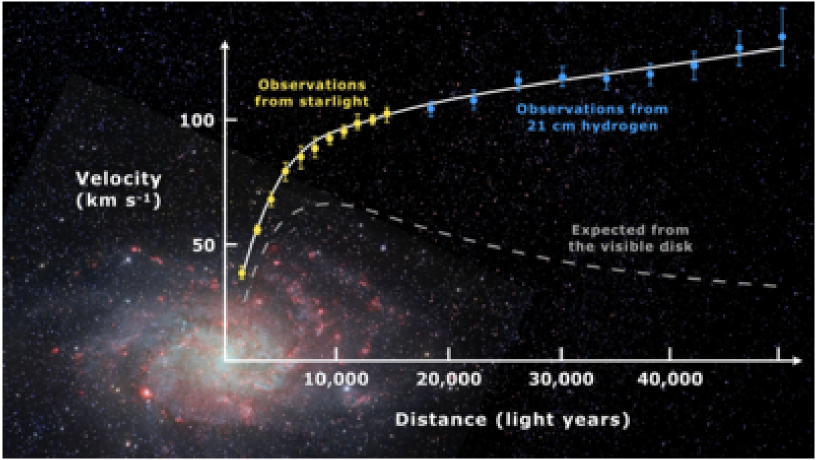

Figure 8: The galaxy rotation curve of Messier 33 (De Leo 2018).

Xenon as Target Material

- Nobles gasses are transparent for their own scintillation light
- High atomic mass ($A = 131$) and therefore large nuclear cross-section
- Relatively high scintillation yield
- In nature, approximately half even and half-odd isotopes
- High charge number ($Z = 45$) and therefore high stopping for low-energy gammas

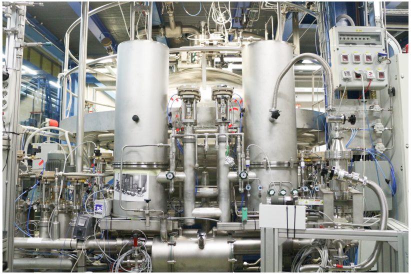

Figure 9: Liquid Xenon Purification

- Can be cleaned to high purity levels

Energy Deposition in Xenon

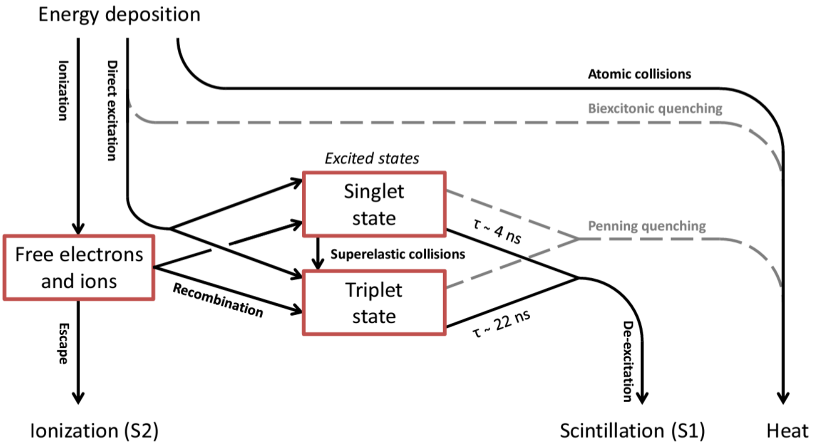

Figure 10: The energy disposition in xenon is resulting ionisation, scintillation and heat through multiple processes (Hogenbirk et al. 2018)

Photomultiplier Tubes in XENONnT

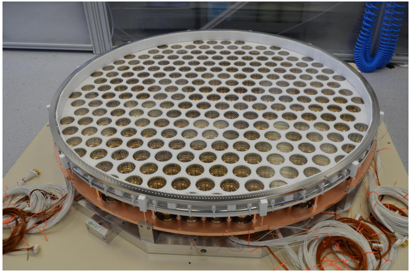

Figure 11: Bottom PMT array in the time projection chamber (Aprile 2024)

XENONnT consists of 494 PMTs

- 253 are located at the top of the TPC
- 241 are located at the bottom

Working of a PMT

- Photon from scintillation liberates a photoelectron
- Photoelectron gets amplified by multiple dynodes

S1 Integration Method

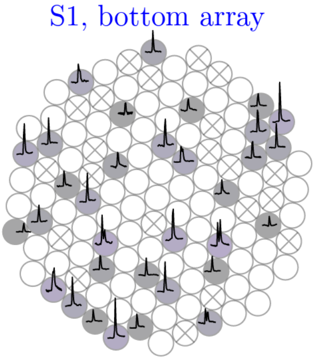

Figure 12: Example of nuclear recoil event in XENON1T (Aalbers 2018)

Set gain for XENONnT PMTs

- 1 photoelectron $\rightarrow 10^6$ electrons

Integration Method

- Integrating the received charge
- Dividing by the gain
- Summing over all the PMTs

WIMP-Nucleon Cross-Sections

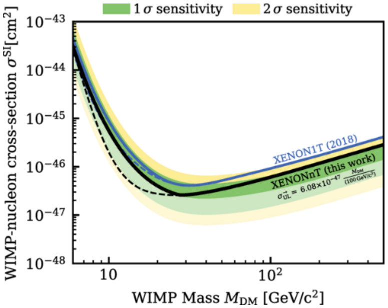

Figure 13: The WIMP-nucleon cross-sections probed by XENON1T in 2018 and XENONnT in 2023. Figure from (Aprile et al. 2023).

The spin-independent cross-section of the dark matter nucleus expressed in σ_n is given by

$$\sigma_{N,0,SI} = \sigma_{n,SI}\frac{\mu_N^2}{\mu_n^2}A^2$$

where μ_N is the dark matter-nucleus reduced mass, μ_n is the dark matter-nucleon reduced mass and A is the number of nucleons in the nucleus.

Thank you for your attention!

Extra References

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Planck Collaboration et al. (Sept. 2016). "Planck 2015 results". In: *Astronomy and Astrophysics* 594, A1. DOI: 10.1051/0004-6361/201527101. URL: https://doi.org/10.1051/0004-6361/201527101.

Merging Galaxy Clusters

Figure 14: The Bullet Cluster is one of the most well-studied clusters of merging galaxies from which the existence of non-baryonic matter could be inferred. The red shades indicate the gas distribution obtained with gravitational lensing, and the blue shades indicate the centres of mass. Furthermore, the contours of both galaxy clusters are shown. Figure from (Clowe et al. 2006).