Summer Student Programme 2023

"R&D on LAr-TPC for neutrinos and rare events"

Supervisors : Pascal PRALAVORIO (CPPM) & Francesco PIETROPAOLO (CERN)

Abstract

Lucas BOISTAY

Summer 2023

Contents

Introduction 3

I Monitoring and data analysis in DarkSide-20k 3

1 Dark Matter 3
1.1 Existence of Dark matter . . . 3
1.2 Dark matter candidates and WIMPs . . . 4

2 DarkSide-20k and TPC calibration 5
2.1 Liquid Argon Dual Phase TPC . . . 5
2.2 Goals for dark matter search . . . 6
2.3 Calibration . . . 7
2.4 Different Mock-ups . . . 7
2.5 Parameters to supervise . . . 8

3 journal 8

II Proto-DUNE 10

1 10
1.1 . . . 10

III Catalogue 11

1 Maths 11
1.1 Matrices . . . 11
1.2 Représentations . . . 11
1.3 Analyse . . . 11
1.4 Symboles courants . . . 12

2 Ajouts visuels 12
2.1 Boite . . . 12

IV Annexe 13

1 13
1.1 . . . 13

Introduction

For my post-graduation internship, I was accepted in the CERN Summer Student Programme. During 11 weeks, I was working on precise important research project in very interesting fields of physics.

Firstly, I worked on the DarkSide-20k, which is aimed at detection of dark matter. For the most part of it, I was monitoring the prototype of the final guide tube system, which will calibrate the TPC. Furthermore, I was analysing the data to understand how the motor system react through stress, or different periods left without any move (ice formation).

Part I

Monitoring and data analysis in DarkSide-20k

1 Dark Matter

1.1 Existence of Dark matter

A β-decay is a radioactive decay where an electron is emitted from a particle.

In the 30s, scientists expected to see a Dirac distribution for the energy. Indeed, when an electron is released, the energy distribution should take the energy of the electron decayed, this means 0 if no decay, and e if so.

But measures of kinetic energy distribution found that the distribution is continuous. In this way, the radioactive β-decay should not only release an electron, but also another particle, which was found to be the neutrino.

This discovery launched the Fermi race, in which the goal was to find others particles from the Standard Model (SM) and to reach the $\Lambda_F = 550$ GeV constant that is the order of energy of these particles. They successfully discovered W_{1983}, Z_{1983}, top_{1995} and H_{2012} !

We now have a strong Standard Model with precise measurements in all sectors, and up to TeV it even seems there are no new particles.

Unfortunately, it is becoming increasingly difficult to gain larger and larger energy. The LHC seems to be almost on the edge of the constituent collision energy possible with a collider technology.

In this context, astrophysicists started to worry about gravitational speed. Indeed, in galaxies, star systems far from the galactic centre should not be that fast. It seems like something is increasing their speed, meaning there is more mass than we can see.

This mass was called dark matter, and that is what we are trying to search in the DarkSide experiment.

Our solar system is floating into a fog of dark matter, which to our perspective looks like a stream from our galaxy halo of order of magnitude 0.1 GeV/cm^3 moving at $v = 250$ km/s toward earth.

There are no particles from the SM that has the required properties of the dark matter. This is a call for new physics !

1.2 Dark matter candidates and WIMPs

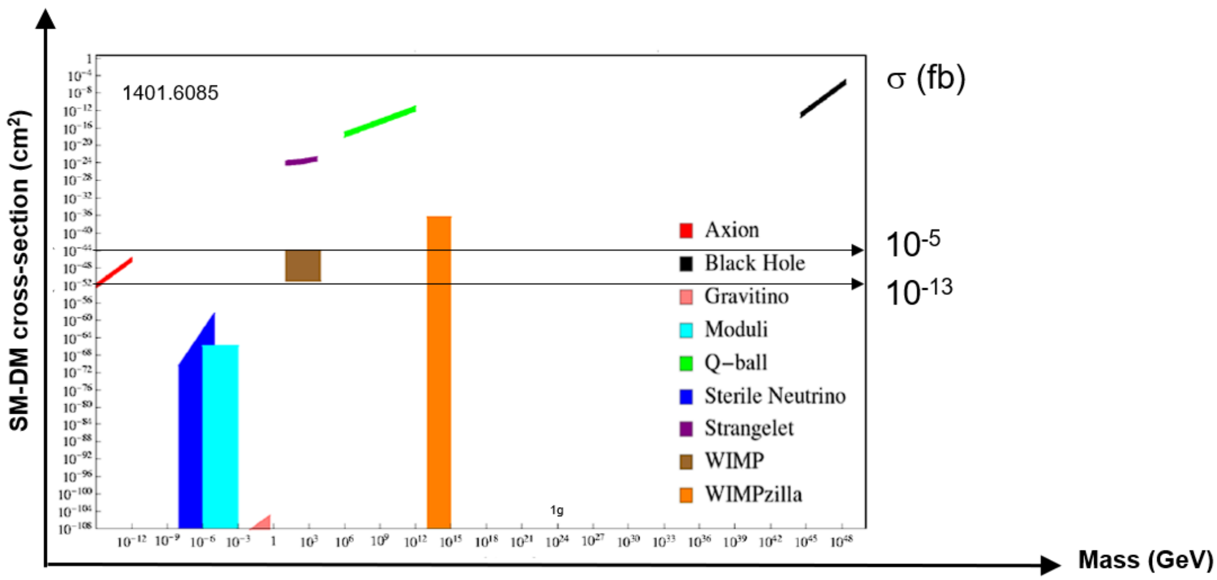

Figure 1: Candidates for dark matter.

In all candidates for the dark matter, there is almost 60 order of magnitudes for the mass and 108 for the cross-section. (see Figure 1). From Black Holes to new particles we still need to find.

Here, we're going to take interest into the WIMPs particles. Those particles are motivated by particle physics and is in the same range as the constant Λ_F.
Indeed, a 10 to 10^5 GeV weakly interactive particle can explain dark matter. We can find from the theory that this WIMPs should follow a Feynman diagram we can see in **??**.
The direct detection is the collision of a WIMP particle (χ) and a SM particle (q), and that's the theory behind DarkSide-20K.

But still, having 8 order of magnitude for the cross-section of the theoretical WIMPs and 4 for the mass is huge and need different experiment to explore the whole domain.

2 DarkSide-20k and TPC calibration

DarkSide is an experiment developed by CERN, CPPM, APC and LPNHE. The goal is to detect dark matter rare events in a purified liquid argon tank.

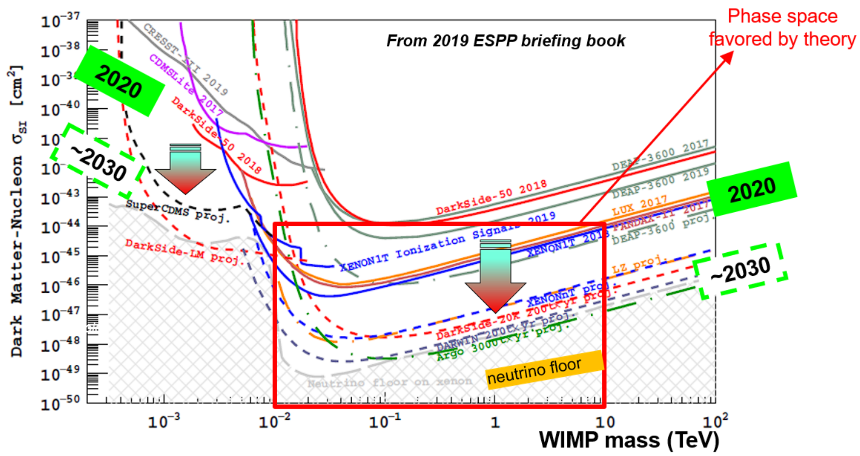

Figure 2: View on current research for WIMPs. DarkSide20k is the red dotted line.

From the Figure 2, we see that DarkSide-20k will be able to detect WIMP up to almost 10^{-48} cm^2 and from 10^{-2} TeV, which is the phase space favoured by theory.

It's in this spot we have the highest chance to detect a WIMP, still we need to find a way to detect it. Moreover, there is a neutrino floor that keeps up from getting lower cross-sections; when we pass it, neutrinos will be able to interact with the detector and gives us false positive.

That's a rough competition between laboratory to get a magnitude improvement. There are mainly two types of detectors : Liquid Argon like ours and Liquid Xenon. Both are based on the TPC, which will be explained later. However, these two technologies face different problems. For example, Liquid Argon TPC face the issue from ^{39}Ar, which is an internal source of radioactive decay from the Argon inside the tank.

Let's see the technology behind DarkSide-20k.

2.1 Liquid Argon Dual Phase TPC

DarkSide-20k rely on the Purified Liquid Argon Dual-Phase Time Projection Chamber technology (LAr-TPC).

A dual phase TPC is a tank of Purified Argon, a noble gas, existing mainly in liquid form (LAr) and with a small gas pocket at the top of the tank (dual phase). When a particle collide with an Ar atom, the atom will acquire energy and emits a photon (128 nm). Then, this photon drift and get reflected to have a wavelength of 420 nm, then, it will be detected by SiMP modules (photon detectors placed at the base and the top of the TPC). There are actually two components to the light, the Nuclear Recoil (NR) and the Electronic Recoil (ER). The first one mainly produces a scintillation signal (S1) directly detected ($\sim$ ns), as the second one produces principally ionisation signal (S2) which will be detected a long time

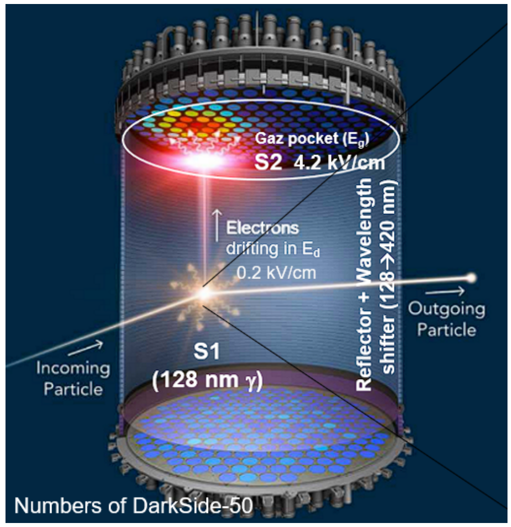

Figure 3: TPC

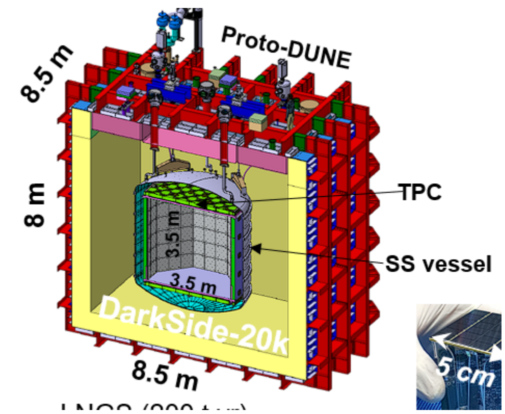

Figure 4: DarkSide-20K

after the first one, following a chain of electron which will interact and form wider and bigger signals.

Getting both signals let scientists know very precisely the energy left by the incoming particle and the coordinates of the collision.

2.2 Goals for dark matter search

If indeed WIMPs particles exist, some collisions should appear between the LAr in the TPC and a WIMP particle orbiting the Milky Way.

A WIMP can be experimentally accessed in 3 ways (see Figure **??**) :

- **Efficient annihilation :** When two WIMPs collide with enough energy, they will produce two SM particles. This is call an indirect detection.
- **Efficient scattering :** When a WIMP collide with a SM particle, it produces a WIMP and a SM particle. This is call a direct detection.

- **Efficient production :** When two SM particles collide into each other, they produce two WIMPs. This happens in particle colliders, but there is no detection then to get any signal if any WIMP is produce.

As explained before, we can see DarkSide-20k will be a direct detection of WIMPs.

2.3 Calibration

To be able to detect and analyse a signal given by the TPC, we firstly need to calibrate our project.

Indeed, a TPC is able to detect any particle within the cross-section range allowed. That means other particles (as neutron, photon for instance) can react in the TPC and appear as a signal. In this case, we need a way to differentiate WIMPs signals from neutron or photon signals.

To do so, we're going to use a calibration of the TPC.

The calibration process is done by letting some radioactive sources go through a tube surrounding the TPC. When the source emits a radiation (photons, neutron ...), this may appear in the TPC and be detected by the Silicon PhotoMultipliers (SiPM) modules placed on the top and bottom of the TPC. Then, the signal will be analysed.

Because we know the mass (= energy) of the radiation particle, we can calibrate.

The calibration process can take some time, because firstly, if the detectors are way too sensitive, there might be noise, or even detect a photon already detected by a neighbour module (which will create a cascade of detection). However, if the detectors are too opaque to any given signal, they might not even detect the dark matter signal.

My predecessor worked on the calibration process and succeed to find the correct parameters, preventing too many noises, but allowing the detection in most of the cases.

As said before, another problem is that the TPC will not only detect Dark Matter, it can detect other radiation, that might come from any material surrounding the TPC. Moreover, inside the TPC the argon is not perfectly purified. Indeed, ^{39}Ar is an instable and radioactive isotope that is naturally found in ^{40}Ar. Even tho the Argon is purified, it's send from the USA and during the trip, cosmic rays can capture a neutron from a ^{40}Ar to transform it into a ^{39}Ar. The disintegration of a ^{39}Ar produce an electron that might interact with the TPC.

In the models we have for our detector, we take care to include all those possibilities. Then, we add what should a WIMP add to these detections. If what we get at the final experiment looks similar than those models, we might have just detected a dark matter particle.

In that way, we're sure that a WIMP detection have been done.

2.4 Different Mock-ups

The goal of our lab here in CERN is to be sure it's possible to calibrate the TPC by moving a radioactive source inside the tubes. Indeed, at liquid Argon temperatures, water ice can form inside the tube if the humidity is not 0. Moreover, we want to see how are behaving the motors and the rope at different temperatures and with differences in shapes of tubes.

We can see that in the final experiment, all elbows will have 40 cm radius, letting us test this configuration on our Mock-ups.

The first Mock-up called MU_CS was to test motors in a cold environment. The tank was cooled until Liquid Nitrogen (LN2) at $-196\ °C$. This only took data during 8 hours and was successful.

Then, there was a second Mock-up, MU_W who was happening in ambient temperature, but with the right proportions of the final tube at scale 1:1. This was supposed to test the bends of the tube and the tension resulting by them.

Now, we will have a Mock-up based on the robustness in cold environment. This will take place in a LN2 tank during 4 weeks. This long time might enable ice formation inside the tube, or this could have an effect on the speed of the source or the tension of motors.

2.5 Parameters to supervise

The mock-up system is composed of a LN2 tank, 2 motors and a tube going into the tank. A rope is putting through the tubes and allow us to control a source's position from a Linux terminal.

From this terminal, we have access to the source position (DS2 rope length and DS3 rope length), the tension from the motors, and errors coming from the theoretical rope length and the actual measure. Moreover, from the total rope length, we can check if there is any elongation or contraction.

In addition to this Linux terminal, we have a Windows computer getting all kinds of information from different captors around the tank. For example : temperature, humidity or current inside motors. One of these data is the temperature inside the tank at different spots, called PT100. There are 4 of them, placed from the top to the bottom and following the tube shape. These places are related to the places where the source stop during our tests.

3 journal

- **Plot solving for monitoring :** J'ai travaillé sur un petit programme rapide pour plot les différentes données selon l'heure etc...
- **Motor problem :** demander à peter/pascal de m'expliquer le soucis.
- **Monitoring issues with the software :** le programme qui récupère les données en python ouvre un fichier texte et écrit dessus. En même temps, celui-ci affiche ne temps réel des graphiques de toutes les données et nous donne les logs. Lorsque un des capteur n'est plus disponible (si manip un peu rapide car cables sensibles), il arrête de prendre de nouvelles valeurs et se stoppe.

  De plus, lorsque on copie le fichier de donnée actuellement en cours vers une clé USB, l'écriture du fichier ne vérifie pas si il est lock, ce qui empêche l'écriture du fichier pendant une copie un peu longue (sur une clé usb donc hors du DD par exemple). Le programme s'arrête donc et crash. Résolu en faisant un programme python qui copie le fichier localement pour l'envoyer vers la clé usb (lecture uniquement ne lock pas un fichier en python).

- **Coefficients de corrélation et début d'analyse des paramètres :**
- **Fill in cryostat :** Nous n'avons pas pu remplir le cryostat en temps voulu à cause des problèmes de moteurs. Le cryostat a été rempli vendredi 09 juin matin en ?? heures. Quelques soucis sur l'affichage du niveau de remplissage de la cuve.
- **Monitoring routine :**
- **Afternoon program :**
-

Part II
Proto-DUNE

1

1.1

Part III
Catalogue

Cette partie ne doit pas rester ici, elle doit être retirée

1 Maths

1.1 Matrices

$$\begin{matrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{matrix}$$

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

1.2 Représentations

$$\vec{v} = \langle v_1, v_2, v_3 \rangle$$

$$\left\{ \frac{1}{2} \right\}$$

$$\left[\frac{1}{2} \right]$$

$$\left(\frac{1}{2} \right)$$

$$\left| \frac{1}{2} \right|$$

$$\langle \Psi || \Psi \rangle = |\Psi|^2$$

1.3 Analyse

$$\lim_{x \to \infty} f(x)$$

$$\sum_{i=1}^{n} a_i$$

$$\int_a^b f(x)dx$$

$$\frac{d}{dx}f(x)$$

$$\frac{\partial}{\partial x}f(x,y)$$

1.4 Symboles courants

$$A \cup B, A \cap B, A \subseteq B, A \in B, A^c$$

$$\infty, \forall, \exists, \emptyset$$

$$\mathbb{N}, \mathbb{Z}, \mathbb{Q}, \mathbb{R}, \mathbb{C}$$

$$=, \neq, <, >, \leq, \geq, \approx$$

$$\wedge, \vee, \neg, \implies, \iff$$

$$\Gamma(x), \zeta(x), \mathrm{erf}(x)$$

$$\begin{cases} x + y = 2 \\ 2x - y = 1 \end{cases}$$

2 Ajouts visuels

2.1 Boite

coucou

coucou

coucou

coucou

Part IV
Annexe

Cette partie ne doit pas rester ici, elle doit être retirée ou mise à la fin pour servir d'annexe

1

1.1

LaTeX [1] is a set of macros built atop TeX [2]. [3]

References

[1] Prénom Auteur. Titre de l'article. *Titre du journal*, 2023. Lien.

[2] Donald E. Knuth. *The TeX Book*. Addison-Wesley Professional, 1986.

[3] Nom de l'auteur. Titre de la page web, 2023. https://www.example.com - Consulté le 14 avril 2023.