PhD in Physics and Nanoscience - XXXVI cycle
Third year report

Matteo Rossi

Tutors:

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Gemma Testera

Research activity:

My activity is focused on the direct detection of Dark Matter particles and I am working on the design of the DarkSide-20k Dark Matter experiment. The whole detector consists of a 20 t fiducial volume liquid Argon Time Projection Chamber, surrounded by a neutron veto, with all the system immersed in liquid Argon and closed in a cryostat. The interaction between a candidate for a Dark Matter particle, namely a Weakly Interacting Massive Particle (WIMP), and an atomic nucleus of a scintillator, as liquid Argon, is expected to generate photons, that can be collected using photosensors as cryogenic Silicon PhotoMultipliers. Since the small WIMP-nucleon cross section, it is necessary to identify spurious events that can mimic a Dark Matter particle interaction with Argon atoms. Neutrons are responsible for these events and the role of the veto is to moderate and record the events generated by neutrons; indeed, when the material that constitute the veto itself, that is Gadolinium-loaded plastic, captures a neutron, that results in emitted photons that can be collected in the veto volume as these photons interact in veto liquid Argon.

My contribution is focused on simulating the DarkSide-20k detector exploiting the Geant4 software, aligning the drawings in Geant4 with the CAD ones, and analysing the results of several physics simulations in order to understand the best way to construct the detector and evaluate its performance. In addition, my work is to find out the best way to place photosensors in the veto, that consist of arrays of cryogenic Silicon PhotoMultipliers, reaching the highest and most uniform light collection. I also worked to have CAD drawings directly imported into Geant4, that can be useful to implement complex volumes in the simulations and test several approximations done in the current simulation of the detector.

I am also working on ARTIC (ARgon Test InfrastruCture), which is a cryostat in Genoa which will allow tests in liquid Argon and liquid Nitrogen, useful for DarkSide components. In particular, I am working on the LabVIEW program to control and monitor the cryostat (temperature, pressure, liquid level, ..).

Last year I started collaborating in the tests of the new-produced arrays of cryogenic Silicon PhotoMultipliers; on one side, this means to place few photosensors in a dewar and emulate liquid Argon scintillation with a laser, to test their performances and parameters. On the other hand, I am collaborating in the writing of a LabVIEW software useful for large scale tests. This activity takes place both in Genova and at Laboratori Nazionali del Gran Sasso.

In the past year I have significantly focused on Monte Carlo biasing techniques in the context of simulating the DarkSide-20k experiment. In order to assess the radioactive backgrounds present in the detector, I simulated the background emitted by various components to understand what fraction of events, particularly neutron-related, the entire detector is sensitive to and what percentage of events from the simulated background sample it could identify. However, simulating neutrons originating from the outermost volumes and far from the core of the detector is an extremely time-consuming and resource-intensive process. This

happens because, on one hand, only a few events survive until the TPC (Time Projection Chamber) as they pass through shieldings, and only a few of these meet the physical parameters compatible with a Dark Matter scattering event. On the other hand, tracking them up to the TPC requires time and computational power. To optimize these simulations, I implemented a biasing algorithm in the DarkSide-20k Monte Carlo code. A geometric biasing algorithm based on the *split&kill* method is a technique that increases the importance of particles moving towards regions of greater interest within the detector (such as the Time Projection Chamber) and decreases it for particles moving in the opposite direction, i.e., towards the outer regions of the detector. Fine-tuning the biasing parameters allowed to achieve an overall computational efficiency gain of a factor greater than 15 for simulations with active biasing, compared to standard Geant4 simulations. This improvement effectively reduces computational times and significantly increases the statistics of the simulations. This, in turn, enables us to obtain a more precise and accurate estimation of the neutron-induced background in the detector and its sensitivity.

Courses and exams:

Metodi di simulazione applicati alla fisica (F. Parodi)
Computer games (A. De Gloria)

Schools:

Gran Sasso Hands On school 2023, to be attended in September 2023

Publications:

The DarkSide-20k Collaboration, Directionality of nuclear recoils in a liquid argon time projection chamber, arXiv, 28 luglio 2023. arXiv.org, https://doi.org/10.48550/arXiv.2307.15454

The DarkSide-20k Collaboration, Measurement of isotopic separation of argon with the prototype of the cryogenic distillation plant Aria for dark matter searches, arXiv, DOI.org (Datacite), https://doi.org/10.48550/ARXIV.2301.09639

A. Elersich et al, Study on cosmogenic activation above ground for the DarkSide-20k experiment, Astroparticle Physics, vol. 152, ottobre 2023, p. 102878. DOI.org (Crossref), https://doi.org/10.1016/j.astropartphys.2023.102878

P. Agnes et al, Sensitivity projections for a dual-phase argon TPC optimized for light dark matter searches through the ionization channel, Physical Review D, vol. 107, fasc. 11, giugno 2023, p. 112006. DOI.org (Crossref), https://doi.org/10.1103/PhysRevD.107.112006

P. Agnes et al, Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos., Journal of Cosmology and Astroparticle Physics, vol. 2021, fasc. 03, marzo 2021, p. 043. DOI.org (Crossref), https://doi.org/10.1088/1475-7516/2021/03/043

P. Agnes et al, Separating ^{39}Ar from ^{40}Ar by Cryogenic Distillation with Aria for Dark-Matter Searches, The European Physical Journal C, vol. 81, fasc. 4, aprile 2021, p. 359. DOI.org (Crossref), https://doi.org/10.1140/epjc/s10052-021-09121-9

M. Rossi, The DarkSide-20k Neutron Veto, Il Nuovo Cimento C,

vol. 44, fasc. 1, maggio 2021, pp. 1–4. DOI.org (CSL JSON), https://doi.org/10.1393/ncc/i2021-21011-0

Conferences:

IFAE 2023: Incontri di Fisica delle Alte Energie. Presented a poster; DarkSide-20k: Dark Matter direct search, April 12-14, Catania, Italy

DarkSide collaboration meeting. Presentation: Biasing techniques for G4DS, June 12-16, LNGS, Italy

Extra:

For one week I received students from high schools for a stage on particle physics, which included both theoretical lessons and hands-on sessions. Their final goal was to build a muon detector and obtain a value for the muon flux at sea level, at different zenith angles.