Exploring the dark side of the Universe

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Introduction

Astronomical observations show that about 95% of the energy density of the Universe cannot be accounted for in terms of mass and energy of which about 26.8% is considered to be dark matter. The detection of this dark matter is one of the major and interesting unsolved problems in Physics. There are many experiments running worldwide at different underground laboratories for the direct detection of dark matter, mainly WIMPs (Weakly Interacting Massive Particles), the most favoured candidate of dark matter. Direct detection experiments expect to detect the dark matter directly by measuring the small energy imparted to recoil nuclei in occasional dark matter interactions with detector, stationed at earth's laboratory. In the subsequent sections, the challenges of such experiments are discussed followed by the details on PICASSO/PICO dark matter search experiment at SNOlab, activities related to this experiment at SINP and the future direction of dark matter experiments.

Challenges

The expected event rate from WIMPs is very low, less than 1 events /kg/day of the target but the background rate is comparatively extremely high. This background is both intrinsic and external. The intrinsic background is coming from the contamination of the detector material. The sources of external background are the environmental radioactivity, cosmic rays, neutrons, gamma rays, muons etc. To reduce the external background, the dark matter direct search experiments are planned at the underground laboratories with proper neutron and gamma shielding. To observe the dark matter signal, we need to choose the material of the detector such that it has the minimum intrinsic background, maximum capacity of reducing the external background and can be fabricated in large mass. Therefore, to fabricate the large mass but with low radioactive activity to see the dark matter signal is really a technical challenge.

PICASSO & PICO experiment

PICASSO (Project In CAnada to Search for Supersymetric Objects) is one of the leading experiments looking for the spin dependent

Fig.1. PICASSO detector set up at SNOlab.

WIMP interactions on ^{19}F target of C_4F_{10} superheated droplet detector. Superheated droplet detector consists of droplets of about 200 micron sizes of superheated liquid suspended in clean purified polymer gel matrix. Until Dec, 2013, 3.0kg phase was running at 2 km deep underground at SNOlab, Canada with 32 detectors of 4.5L each. WIMP is expected to give a kink to the detector nuclei undergoing elastic scattering and the recoil nuclei deposit the energy in the liquid. If this energy deposition exceeds the energy required for bubble formation in a certain critical diameter, the critical bubble forms and it explodes to the visible bubble with the emission of acoustic waves. Piezo electric sensors are used to detect the acoustic pulse converting them into electrical signal and subsequently processed by the Labview based DAQ system. The latest result from PICASSO sets the upper limit on spin dependent cross-section to be 0.032pb for 20 GeV/c2 WIMP which was the world-leading result among all SD-sector dark matter experiments. In the next stage, from 2013, PICASSO has merged with another dark matter experiment, COUPP (Chicagoland Observatory for Underground Particle Physics) to form the new collaboration PICO at SNOlab. PICO is running with bubble chamber filled with 2L C_3F_8 superheated liquid from Nov, 2013 with three piezo electric sensors and two cameras collecting the bubble nucleation events.

Some other leading dark matter direct search experiments are CDMS, LUX, ZEPLINE, CRESST, COGENT, DAMA-LIBRA, KIMS, DRIFT etc located worldwide underground laboratories using cryogenic detector (Ge, Si), scientillator (NaI), liquid noble gas etc. Signals are detected mainly through the process of phonon generation, ionization, scintillation or combination of these three.

SINP activities

SINP is actively involved in the PICASSO/PICO experiments in detector simulation, data analysis detector fabrication for PICASSO at SNOlab

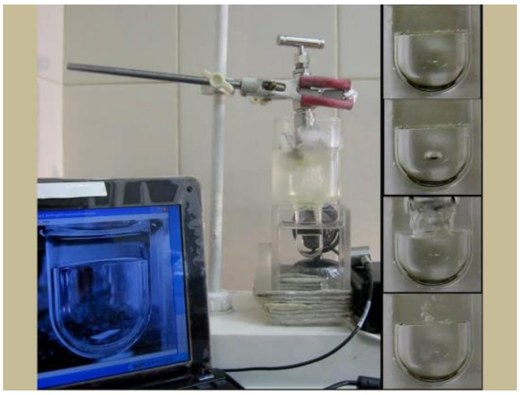

Fig.2. Prototype of Geyser at SINP

and R & D for large mass low background detector development using superheated liquid. The simulation results show the origin of the alpha - contamination whether it is in the sensitive liquid or in the supporting matrix. The data analysis tool improves the resolution of the alpha-neutron discrimination significantly to about 35% in some cases by including the time-gain correction to the acoustic data. The detector R & D for large mass low background leads us to fabricate a prototype of bulk superheated liquid in a single module system called the Geyser with surfactant as a buffer on the top surface. The dead time of this device is estimated to be about 5sec within which about 90% recovery of the pressure after each bubble nucleation occurs. A universal energy calibration curve valid for both dark matter and neutron has been established by using the reduced degree of superheat and effective recoil nuclei energy.

Future direction :

In next generation, high mass target low background experiments like, Super-CDMS, LZ,

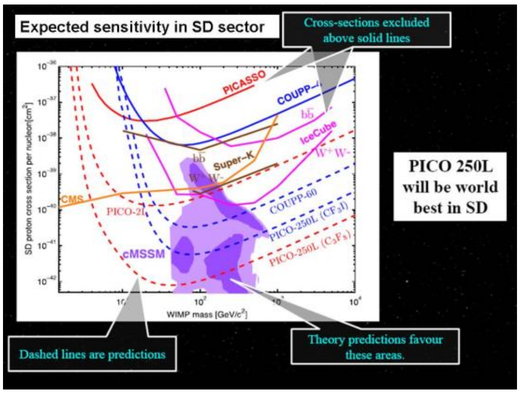

Fig.3. Expected limits from few experiments [2]

PICO-250L etc are coming to search for both the SD and SI sector for both low and high mass dark matter with very high technologies. All these experiments are also preparing to move to ton-scale target with zero background in near future which is the ultimate challenge of all dark matter experiments.

References

[1] Phys Lett B vol 711, pp.153 (2012).
[2] *PICASSO* collaboration presentation.