

# Future Opportunities with Germanium Detectors at the China Jinping Underground Laboratories

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The China Jinping underground Laboratory (CJPL) is the deepest underground laboratory in operation in the world. The extremely low muon flux makes CJPL a good candidate to host low background experiments looking for rare events like neutrino-less double-beta decays ( $0\nu\beta\beta$  decay) or dark matter (DM) interactions. Feasibility and R&D studies are performed to combine these two searches in a common “One-Ton-Germanium facility” to be built in a low-background environment such as CJPL.

## 1 Rare event searches

The Standard Model (SM) is one of the most successful theories ever produced in physics. Nevertheless, there are experimental evidence, such as the presence of “Dark Matter” (DM) in the universe, neutrino oscillations and baryon asymmetry, which demands at least extensions of the SM framework. Neutrinos and DM are two sectors of particle physics which might give us hints about the expected new physics beyond the SM.

The isotope  $^{76}\text{Ge}$  can decay via normal double beta ( $\beta\beta$ ) decay. Thus, it is a candidate for neutrino less double beta ( $0\nu\beta\beta$ ) decay and germanium detectors are used to search for it. The observation of ( $0\nu\beta\beta$ ) decay would demonstrate Lepton Number Violation (LNV) and establish the neutrino as a Majorana particle. Germanium detectors are also used for direct DM searches. Weakly interacting massive particles (WIMPs) should interact in the germanium crystal depending on their mass and the cross section. So far neither DM nor ( $0\nu\beta\beta$ ) decay has been observed and limits have been established on both these processes.

The requirements on the germanium detectors are quite different for the two searches. Nevertheless, detector development studies are being performed aiming to build a detector which fulfills the different technical requirements for both searches, and which can be used in a 1-ton germanium multipurpose facility. The huge exposure achievable with 1 ton of germanium will, however, not improve the sensitivity of the experiment unless the background is low enough. Therefore, such an experiment should be built as deep as possible underground.

## 2 The China Jinping Underground Laboratory

Several underground facilities are in operation all around the world. The deepest underground laboratory is the China JinPing Underground Laboratory (CJPL) [1] with a rock overburden of 2400 m and a measured muon flux [2] of around 60 muons per square meter per year. The

CJPL is located in the south western province of Sichuan in China. It was built in the central part of one of the support tunnels of the Jinping hydro-power project managed by the Yalong river company. It has a horizontal access suitable for heavy transports. Its total volume of 2000 m<sup>3</sup> is divided in three sections hosting three different experiments as shown in Fig. 1a.

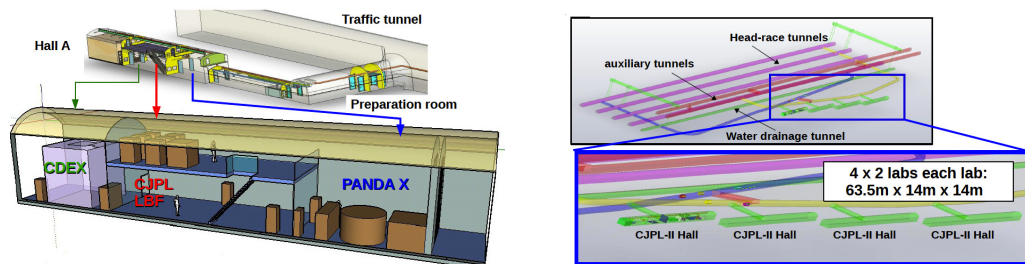


Figure 1: China Jinping Underground Laboratory: (a) shows the Experimental Hall A in CJPL-I; (b) shows the plan for CJPL-II with 4 new experimental double-halls.

The CJPL Low Background Facility [3] (CJPL-LBF) uses high purity germanium detectors as low background spectrometers to investigate environmental samples and select materials for low background experiments, especially for PANDA-X [4] and the China Dark Matter Experiment (CDEX) [5]. PANDA-X and CDEX are direct DM search experiments. The former uses liquid Xenon as target material, while the latter uses Germanium. PANDA-X has, in its first stage, a fiducial mass of 30 kg, easily scalable to 1 ton. Data taking is on going since March 2014, with first results already published in August 2014 [6]. CDEX, in its first stage CDEX-1, uses two high-purity germanium detectors. A 20 g low energy-threshold germanium detector is used to investigate how to lower the energy threshold and be sensitive to extremely low recoil energies corresponding to low-mass WIMP interactions. A 1 kg p-type point-contact germanium detector allows the CDEX collaboration to test software techniques to reject background events using pulse shape analysis. A first limit on WIMP interaction cross-sections was already published [7]. The CDEX collaboration plan to install further germanium detectors.

A plan to significantly enlarge CJPL to become CJPL-II [8] has already been accepted and tunneling will start in fall 2014. In Fig. 1b, the structure of CJPL-II is shown. Four new double halls, with a total volume of about 96000 m<sup>3</sup>, will be built to host not only the physics experiments themselves, but also support technology.

CJPL is to become an international laboratory hosting experiments operated by international collaborations. In preparation of this, the Tsinghua university, operating the laboratory, has entered a Sino-German cooperation with the Max-Planck-Institute for physics (MPI) in Munich, the university of Tübingen and the Shanghai Jaotong university. Within this cooperation, germanium detector development and the realization of CJPL-II are discussed.

### 3 Detector development at the MPI in Munich

The feasibility of a 1-ton germanium multipurpose facility in a laboratory like CJPL is studied. Since the muon induced background would be extremely low in CJPL, other kinds of background will become more important. One of the most dangerous and often limiting sources of background, both for  $0\nu\beta\beta$  decay and DM searches, is surface contamination, e.g. from lead,

resulting in  $\alpha$ -background. Therefore, it is really crucial to characterize the detector response to  $\alpha$  particles in order to be able to identify such events. This is one of the physics goals of the detector development studies performed at the MPI with the GALATEA test stand [9].

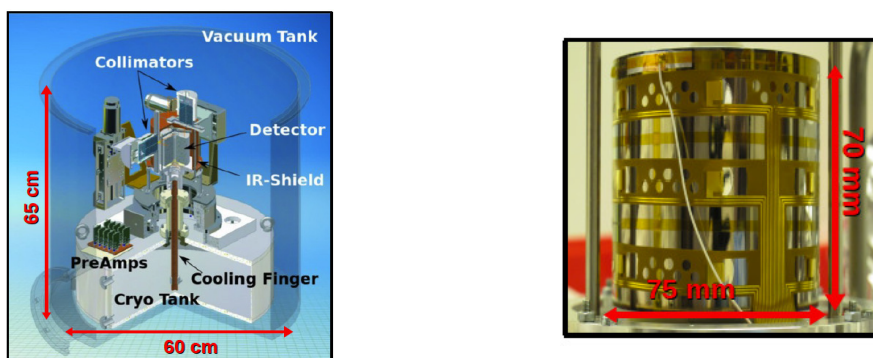


Figure 2: Detector development at the MPI: (a) a sketch of the GALATEA test stand [9]; (b) the detector prototype used to characterize alpha-induced events, SuperSiegfried [10].

In Fig. 2a, a sketch of the GALATEA test stand is presented. The detector prototype SuperSiegfried (SuSie) [10] shown in Fig. 2b is an 18+1 fold segmented true-coaxial high-purity germanium detector. The 19th segment is a 5 mm thick disk at the top of the detector. Inside GALATEA, there is no material between source and detector and thus the detector can be probed also with minimally penetrating sources like alphas and betas. A system of three motors moves two collimators in order to facilitate 3d scans. A  $^{241}\text{Am}$  source was placed inside the top collimator to irradiate the passivated top-surface of SuSie with alpha particles.

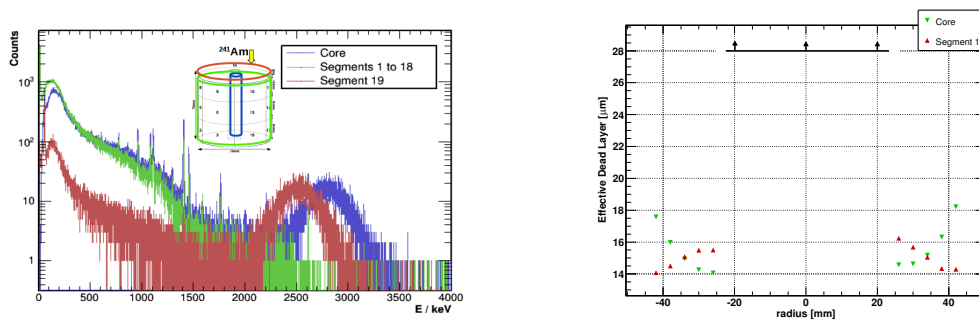


Figure 3: Top-surface scan with a  $^{241}\text{Am}$  alpha source: (a) energy spectra as measured with (blue) the core, all 19 segments but the top segment (green) and the top segment (red); (b) the thickness of the effective dead layer at different radii for both electrons (green) and holes (red).

Figure 3a shows typical energy spectra obtained with SuSie when the top is irradiated with alphas at a given point. The blue histogram is the energy spectrum obtained from the core, the red histogram from the top segment and the green one from all the segments but the top segment. The bump around 2 MeV is due to the alpha radiation. It only occurs in the core and the top-segment spectra, because alphas of about 5 MeV only penetrate around  $20\ \mu\text{m}$ .

The detector has an effective dead layer on top which consists of the passivation layer and an area of low field underneath. Only energy deposited underneath that layer is recorded. The position of the bump in the spectrum, i.e. the average energy deposited in the detector, should indicate the loss in the effective dead layer. However, the position of the bump is different for core and top segment. This indicates that the picture of well defined layers is oversimplified. The energy recorded in the core (segment) is dominated by the drift of electrons (holes). The two different charge carriers are subject to different trapping effects. This is a typical feature of surface events [11]. If the source is placed at large radii, the electrons are trapped with a higher probability as the holes due to their long path and the effective dead layer is thicker for electrons than for holes. As the source is moved towards the core, i.e. the center of the detector, the situation reverses and holes are more likely trapped than electrons; the effective dead layer for electrons (holes) decreases (increases). Figure 3a shows the recorded spectra at a point where more holes than electrons are trapped and thus, the energy recorded in the core is higher than in the top segment. Figure 3b shows the thickness of the effective dead layers at different radii for electrons (green) and holes (red). At radii below 25 mm, the effective dead layers increase such that they cannot be probed with alphas; this is due to detector geometry.

## 4 Outlook and Acknowledgments

Germanium detectors are good candidates for future dark matter and  $0\nu\beta\beta$  searches. The optimization of the detectors faces many challenges. The characterization of alpha events on the surface and their identification through spectra and pulse shape analysis is one of them. The groups involved plan to conduct further studies on the feasibility of a 1-ton detector at CJPL.

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## References

- [1] H. S. Chen, *Eur. Phys. J. Plus* **127** (2012) 105.
- [2] Y. C. Wu, X. Q. Hao, Q. Yue, Y. J. LI, J. P. Cheng, K. J. Kang, Y. H. Chen and J. Li *et al.*, *Chin. Phys. C* **37** (2013) 8, 086001 [arXiv:1305.0899 [physics.ins-det]].
- [3] Y. Mi, H. Ma, Z. Zeng, J. Cheng, J. Su and Q. Yue, arXiv:1403.1724 [physics.ins-det].
- [4] X. Cao, X. Chen, Y. Chen, X. Cui, D. Fang, C. Fu, K. L. Giboni and H. Gong *et al.*, *Sci. China Phys. Mech. Astron.* **57** (2014) 1476 [arXiv:1405.2882 [physics.ins-det]].
- [5] K. J. Kang *et al.* [CDEX Collaboration], *Front. Phys. China* **8** (2013) 412 [arXiv:1303.0601 [physics.ins-det]].
- [6] M. Xiao *et al.* [PandaX Collaboration], arXiv:1408.5114 [hep-ex].
- [7] Q. Yue *et al.* [CDEX Collaboration], arXiv:1404.4946 [hep-ex].
- [8] J. Li, X. Ji, W. Haxton and J. S. Y. Wang, arXiv:1404.2651 [physics.ins-det].
- [9] I. Abt, A. Caldwell, B. Doenmez, L. Garbini, S. Irlbeck, B. Majorovits, M. Palermo and O. Schulz, arXiv:1409.0493 [physics.ins-det].
- [10] D. Lenz PhD-thesis: Pulse Shapes and Surface Effects in Segmented Germanium Detectors
- [11] S. Irlbeck PhD-thesis: The GALATEA Test Facility and a First Study of alpha-induced Surface Events in a Germanium Detector.