Recent status and prospects of CDEX @CJPL

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OUTLINE

• Direct detection of Dark Matter
• Introduction to CDEX
• Recent status of CDEX-1 and CDEX-10
• Future prospect of CDEX@CJPL-II, R&D of key technologies
• Summary
Dark Matter in Cosmology

(1) Direct

(2) Indirect

(3) Accelerator

DM \rightarrow SM

New Physics

DM \leftarrow SM
Direct detection of DM

Elastic Scattering

- Lower Background
- Lower Energy threshold
- Larger Exposure (Mass*Time)

Annual/ Diurnal Modulation

- Lower Background
- Lower Energy threshold
- Long-time stability

Direction Detection

- Lower Background
- Lower Energy threshold
- Good Angular Resolution

Cygnus Constellation

(l = 90°, b = 0°)
Direct detection of DM

- Dark matter detection competition is becoming increasingly fierce;
- **Light dark matter detection**: low background level, low energy threshold, large mass detector target
China Dark matter Experiment

• Formed in 2009, 11 institutions and ~100 people now; http://cdex.ep.tsinghua.edu.cn/
• Key technology: P-type Point-Contact (PPC) Ge detectors;
• Physics targets: Direct detection of light DM + Ge-76 0νββ
CDEX Roadmap

• **CDEX-1 (2009-2016):** Development of PPC Ge detector, bkg understanding
• **CDEX-10 (2016-2022):** Performances of Ge array detector immersed in LN$_2$
• **CDEX-50 (2021-202X):** 50kg Ge detector arrays for DM searches
• **CDEX-300ν (2021-202X):** 300kg enriched Ge detector arrays for 0νββ Exp.

Details in parallel 6A, 30th Aug.
China Jinping Underground Laboratory

• World’s deepest underground lab, CJPL
  ✓ Near Xichang city, Sichuan Province, Southwest China
  ✓ Rock overburden: 2400m (~6720 m. w. e.)
  ✓ Main Hall: 6.5m(W) x 6.5m(H) x 42m(L), Total space: ~4000 m³
  ✓ Two DM exp. (CDEX, PandaX)+LBF(radio-assay) operated in CJPL-I
  ✓ Extension project, CJPL-II, final exam and expected to be completed in 2025
CDEX-1

- Two single-element 1kg pPCGe detectors;
- Traditional cold finger refrigeration;
- Passive shield: Low-bkg Pb, OFHC Cu, PE;
- NaI(Tl) anti-Compton detector;
- Located in PE room at CJPL-I;
CDEX-1B Results

- Detector upgraded w/ lower JEFT noise and material bkg;
- >4 years run (Run-1&Run-2), >1200 kg·day exposure;
- Achieving 160 eVee energy threshold;
- Sensitivity improved and extending to 2 GeV/c².

Detector | FWHM of pulser
---|---
CDEX-1A | 130 eVee
CDEX-1B | 80 eVee

Run-1 Time-integrated (TI) analysis: CPC 42, 023002, 2018
CDEX-10

- Array detectors: 3 strings with 3 detectors each, ~10kg total;
- Direct immersion in LN$_2$;
- Prototype system for future hundred-kg to ton scale experiment
  ✓ Light/radio-purer LN$_2$ replacing heavy shield i.e. Pb/Cu;
  ✓ Arraying technology to scalable capability;

*Science China-PMA* 62, 031012 (2019)
CDEX-10 Results

- First results from 102.8 kg·day exposure w/ Eth 160 eVee;
- Bkg level: ~2 cpkkd @ 2-4 keV;
- New SI limit on 4-5 GeV/c²;
Dark Matter Direct Detection

\[
\frac{dR}{dE_R} = N_T \frac{\rho \chi}{m_\chi} \int d^3\vec{v} f_\nu (\vec{v} + \vec{v}_E)
\]

**DM sources related:**
- ✓ WIMP (Standard Halo Model)
- ✓ Annual Modulation (velocity change)
- ✓ Boosted DM
- ✓ Dark Photon, axions et al.

**Interaction process:**
- ✓ DM-nucleus elastic scattering
- ✓ DM-nucleus inelastic scattering
- ✓ DM-electron scattering
- ✓ Others (All energy deposited)

*WIMP: weakly interaction massive particles*
More physics analysis

**Annual Modulation + DM-nucleus elastic scattering**

**WIMP (Standard Halo Model) + Migdal effect**

**WIMP (Standard Halo Model) + DM–Electron Scattering**

*References*

**PRL** 123:221301 (2019)

**PRL** 123:161301 (2019)

**PRL** 129:221301 (2022)
More physics analysis

CR Boosted DM + DM-nucleus elastic scattering

WIMP (Standard Halo Model) + Earth shielding, Migdal effect

Solar dark photon + All energy deposited

PRD 106:052008 (2022)

PRD 105:052005 (2022)

PRL 124:111301 (2020)
- **Ge detectors** array directly immerse into **Liquid Nitrogen** for cooling and shielding;
- Composed of **5 strings, 10 detectors/string**;
- Target mass (Ge) reaches ~50kg;
- **BEGe + PPCGe**;
CDEX-50 Projected sensitivity

- Bkg level: <0.01 cts/(keV·kg·day) @1 keV
- Energy threshold for data analysis: 160 eV
- Exposure reaches ~50 kg·year
- WIMP SI sensitivity reaches $10^{-44}$ cm$^2$
- Multi physics channel analysis:
  - axion
  - dark photon
  - ...

![Graph showing projected sensitivity of various dark matter detection experiments](image)
Bkg level: \(<0.01 \text{ cts/(keV·kg·day)} @1 \text{ keV}\)

- Mainly comes from the $^3\text{H}$ and cosmogenic radionuclides in crystal
- The contribution from CEvNS and M-shell X-rays should be well understood
Technical R&D towards next-stage

- **Large scale detector array**
  10 kg → 50 kg
- **Low background**
  2 cpkkd → 0.01cpkkd @ 2-4 keV
- **Prototype detectors → Strings**
- **Strings → Arrays**

- **Large shielding and cooling system**
- **Ge detector fabrication**
  - Low mass detector unit and VFE design
  - Low bkg cables or flexible PCB
  - CMOS ASIC Front-end Electronics
- **Underground E-forming copper**
- **Cosmogenic bkg control**
• Develop bare HPGe detectors immersed into LN$_2$;
• Long time stability;
• Further reduce the radioactive background;
• ASIC-based preamplifiers can work well in liquid nitrogen;

79 g Cu + 10 g PTFE

Leakage Current (pA) vs Time (h)

Bare HPGe detectors
PPC: $\phi$50mm x 50mm, Depleted voltage: ~800V
CMOS ASIC Front-end Electronics

- Light DM search $\rightarrow$ low noise/threshold (low capacity, etc)
- Very close to Ge detectors $\rightarrow$ low bkg (radiopure, low-mass, etc)
- ASIC preamplifier @ 77K
  - PCB material: PTFE(Rogers 4850);
  - ENC $\sim 26e (<200eV)$ w/ 4$\mu$s shaping time, mainly from 1/f noise ($\sim 21e$);

Details in JINST (2018) 13: 8019

Noise components analysis
Underground E-forming copper and Assay

- Prototype setup for underground EF-Cu production
  - Cathode mandrel: 316L stainless steel, φ95x380mm;
  - Plating bath: PE, φ400x500mm;
  - Goal: Majorana copper, U/Th content ~ O(0.1μBq/kg);
- Test run in Tsinghua U. and moved to CJPL-I;
- U/Th Analysis by ICP-MS
  - Wet chemistry testing... , blank sensitivity ~10^{-13} g/g

![E-forming setup](image1)
![optimized electrical parameters](image2)
![ICP-MS](image3)
Future Plan – New location

• CJPL-I to CJPL-II
  • Volume: 4000 m³ to 300,000 m³;
  • 1 main hall (6.5x6.5x42m) to 8 main halls (14x14x60m each);
  • Additional pit for next-generation CDEX;

Layout of CJPL-II
Future Plan - CDEX @CJPL-II

• Prepare for HPGe experiment in Hall C1 @ CJPL-II
• 1725m$^3$ liquid nitrogen, shielding and cooling system (inner: $\phi 13m \times H 13m$)
• Inner bkg level: <10$^{-4}$ cpkkd@1keV, <10$^{-6}$ cpkkd@2MeV
Future Plan - CDEX @CJPL-II

- Construction of LN$_2$ tank has completed at end of 2019
- A new steel working platform has been constructed in October 2022
- Liquid nitrogen filling is expected to start at the end of 2023
- CDEX-50 stage under technical design, report comes soon
Summary

- CDEX: unique advantages of Ge detectors for light DM search at CJPL;
- Recently CDEX has made great progress, published many leading results for low mass DM, with multi physics channels analysis and different DM candidates;
- CDEX-50 has started and will locate in Hall C1 of CJPL-II;
- Many key technologies R&D are ongoing and have made very good progress.
Summary

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Thanks for your attention!