中国锦屏地下实验室
China Jinping Underground Laboratory
CJPL
清华大学 · 雅砻江流域水电开发有限公司

中国暗物质实验
China Dark matter EXperiment

清華大學
Tsinghua University

Constraints on light fermionic dark matter with CDEX-10 experiment

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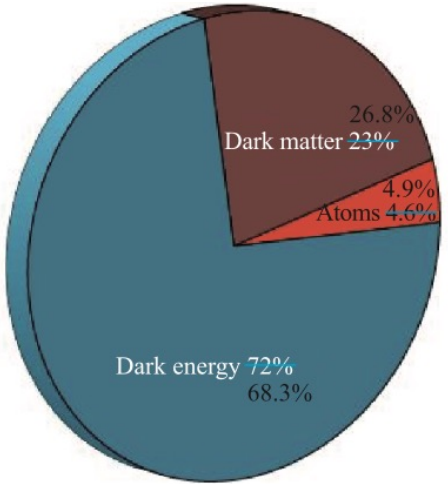
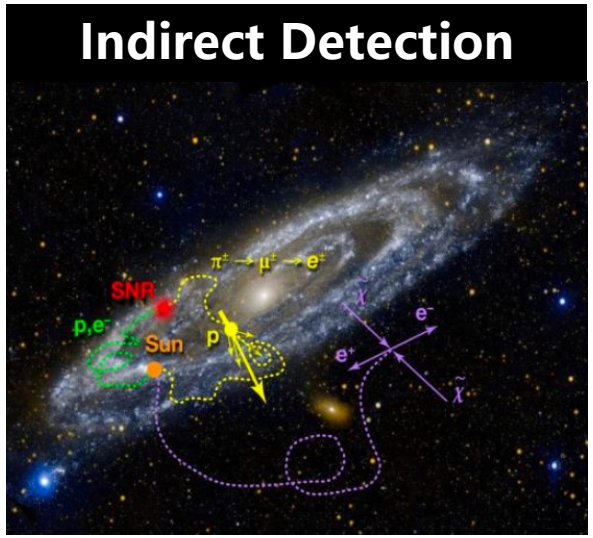
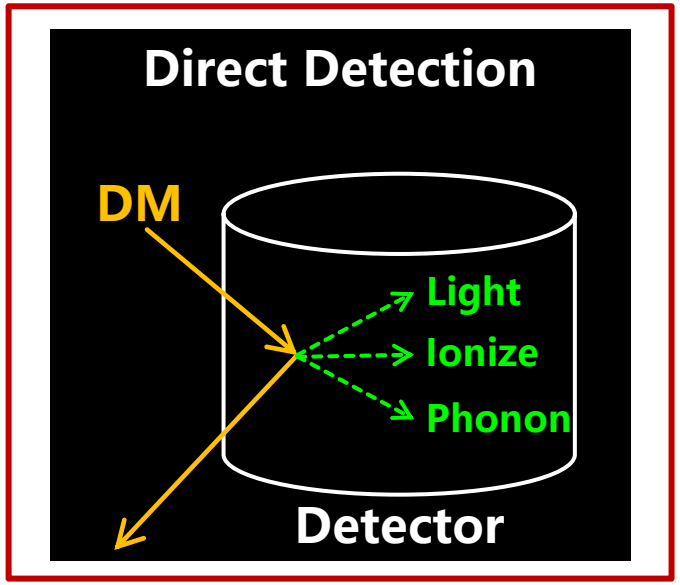
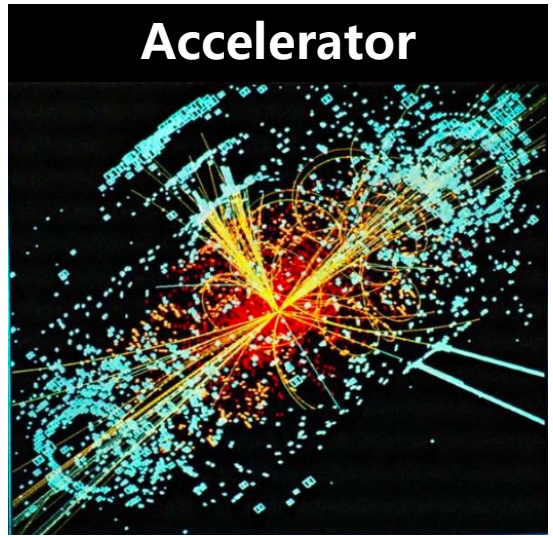
The Mystery of Dark Matter (DM)

- Majority of the Universe not explained by the Standard Model
- Evidences from Cosmology strongly hinted the existence of dark matter(DM)
- DM is not yet confirmed in experiment

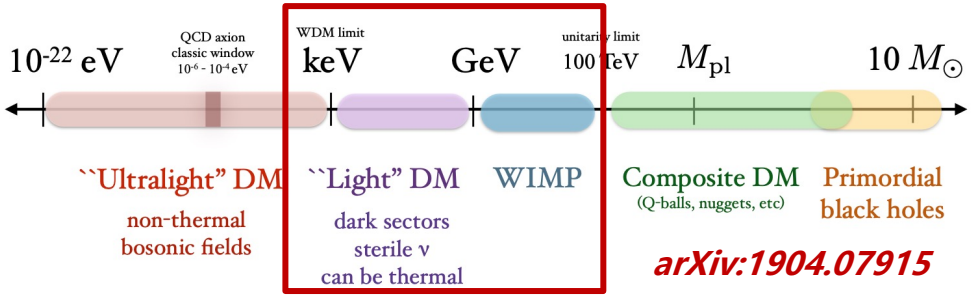




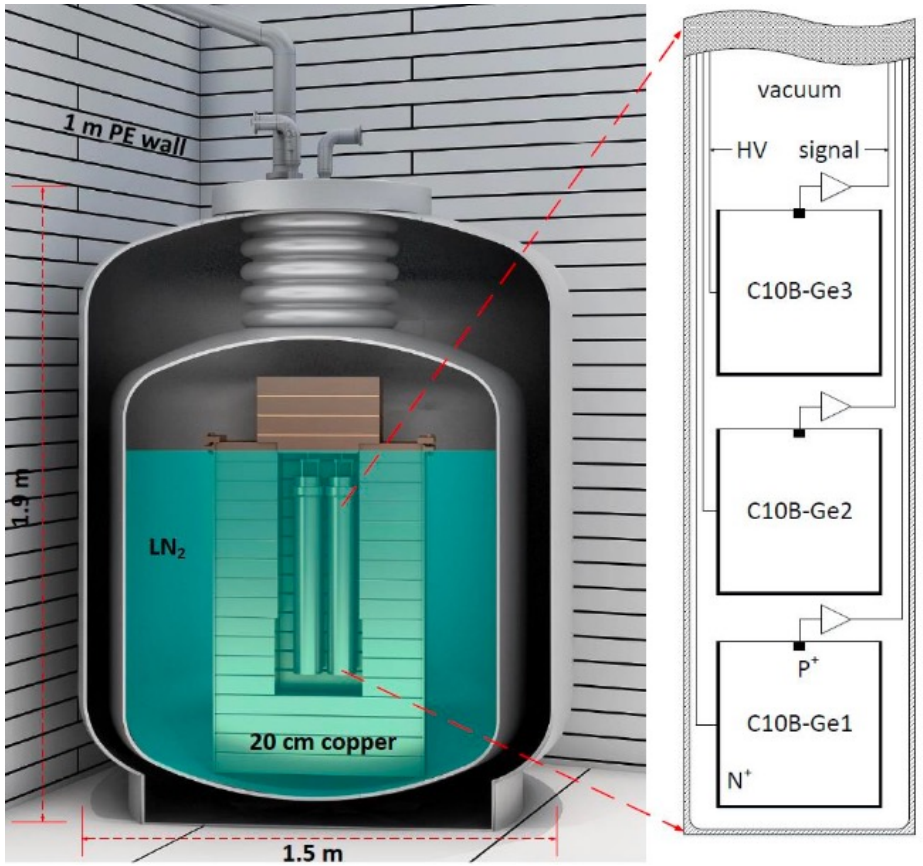


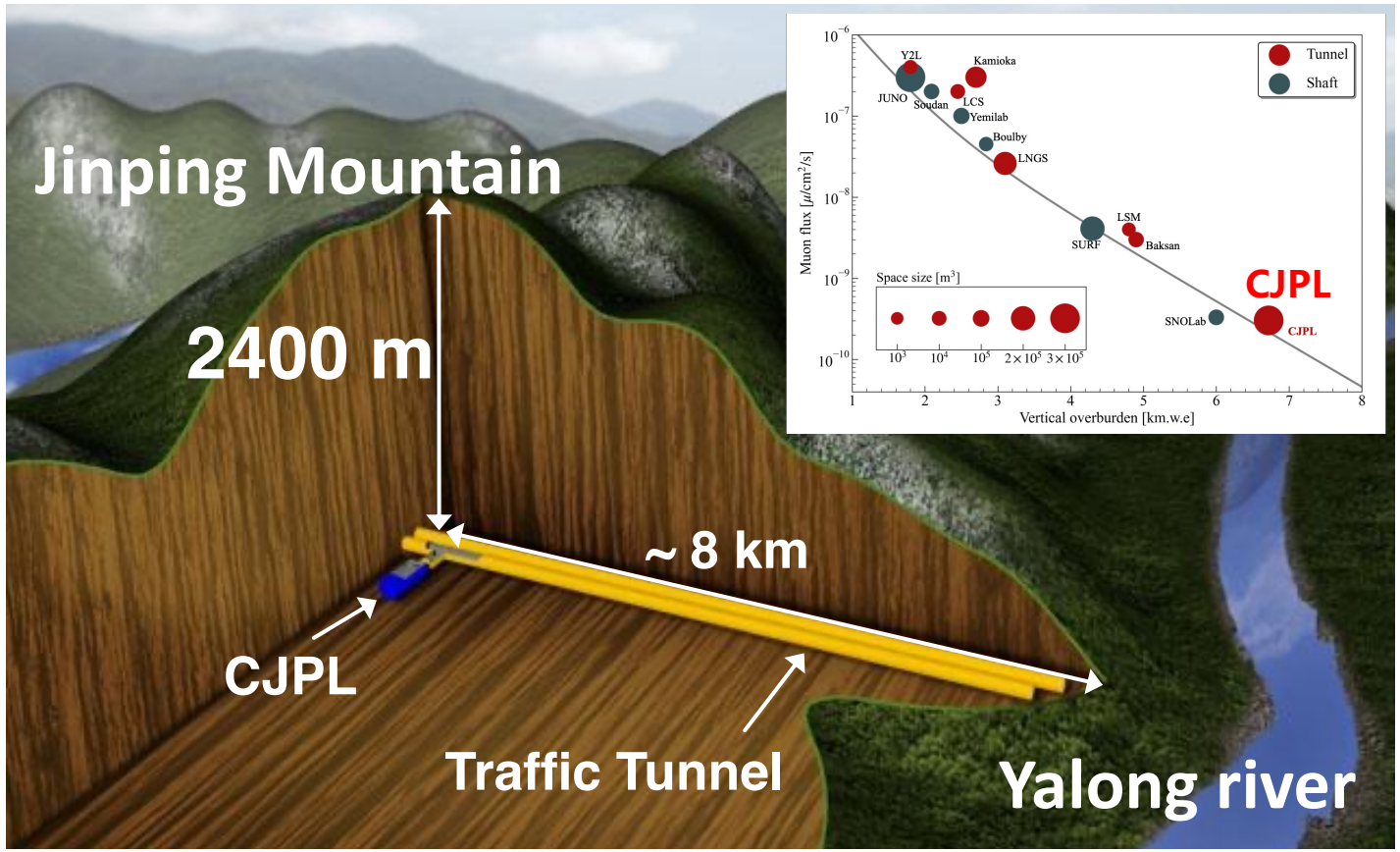


CDEX experiment: Probe DM with HPGe Detector at CJPL



- HPGe has
  - ✓ Low energy threshold for low-mass DM
  - ✓ Good energy resolution for peak-like-signal DM
  - ✓ Low intrinsic background level



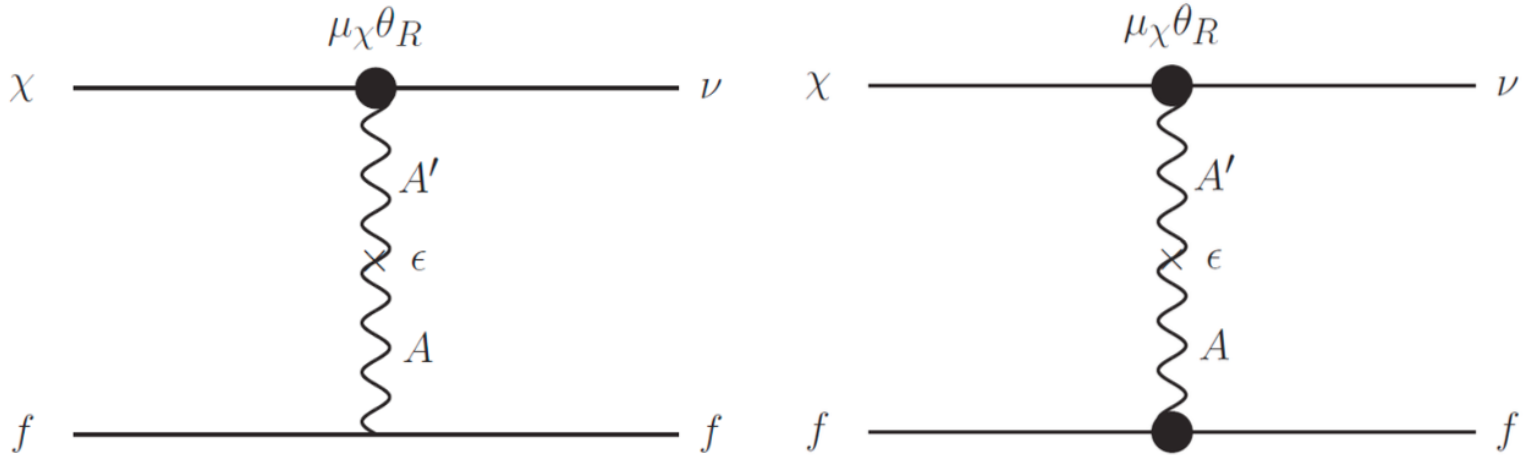


The DM model

Magnetic dipole-based absorption of fermionic dark matter

- Dipole-Charge interaction (DC)
- Dipole-Dipole interaction (DD)

$$\chi + N \rightarrow \nu + N$$
$$E_R \simeq \frac{m_\chi^2}{2m_N}$$



$$\frac{d\sigma_{NC}}{dE_R} = \frac{d\sigma_{DC}}{dE_R} + \frac{d\sigma_{DD}}{dE_R}$$
$$= \frac{\alpha\mu_\chi^2\theta_R^2\epsilon^2 m_\chi}{v m_N (m_{A'}^2 + 2m_N E_R)^2} Z^2 F_Z^2(E_R)\delta(E_R - E_R^0)$$
$$\left(6m_N^2 m_\chi E_R - 8m_N^2 E_R^2 - m_N m_\chi^3 + 4m_N m_\chi^2 E_R - 2m_N m_\chi E_R^2 + m_\chi^3 E_R\right)$$
$$+ \frac{\mu_\chi^2\mu_N^2\theta_R^2\epsilon^2 m_\chi E_R}{2\pi v (m_{A'}^2 + 2m_N E_R)^2} \frac{I+1}{3I} F_D^2(E_R)\delta(E_R - E_R^0)$$
$$\left(-4m_N^2 E_R^2 + 8m_N m_\chi^2 E_R - 8m_N m_\chi E_R^2 + 2m_N E_R^3 + m_\chi^4 + 4m_\chi^3 E_R - 3m_\chi^2 E_R^2\right)$$

Tong Li, et al. JHEP, 05, 071, 2022

The DM model

The DM spectra in Ge

- The DC, DD interaction rates:

$$R_{DC} = N_T \left(\frac{\rho_\chi}{m_\chi}\right) \frac{e^2 U^2}{4\pi (m_{A'}^2 + m_\chi^2)^2} \left(2m_\chi^4\right) Z^2 F_Z^2(q) \Theta(E_R^0 - E_{th})$$

$$R_{DD} = N_T \left(\frac{\rho_\chi}{m_\chi}\right) \frac{\mu_N^2 U^2}{2\pi (m_{A'}^2 + m_\chi^2)^2} \frac{I+1}{3I} \left(\frac{m_\chi^3}{2m_N}\right) F_D^2(q) \frac{m_\chi^4}{2m_N^2} (8m_N^2 - m_\chi^2) \Theta(E_R^0 - E_{th})$$

- In germanium, DC >> DD

$$\frac{R_{DC}}{R_{DD}} = 1.18\times10^5 \cdot \left(\frac{m_p}{m_\chi}\right)^3 \cdot \frac{F_Z^2(q)}{F_D^2(q)} \gg 1$$

- The DM energy spectrum in Ge (ignore DD):

$$R = \frac{\rho_\chi}{m_\chi} \sigma_{NC} Z^2 \sum_j N_{T,j} F_j(q)^2 \Theta(E_{R,j}^0 - E_{th})$$

$$\sigma_{NC} = \frac{2m_\chi^4}{4\pi \left(m_{A'}^2 + m_\chi^2\right)^2} \cdot e^2 U^2$$

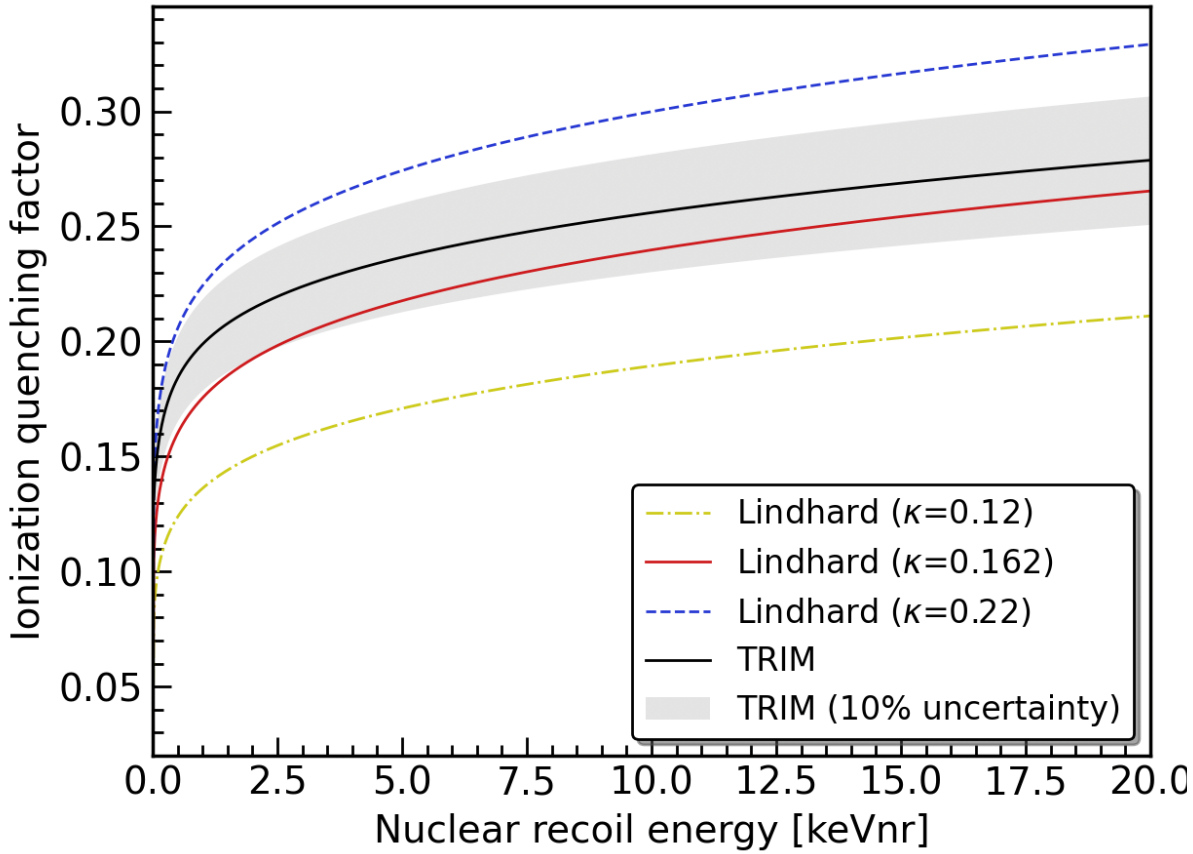
The DM model

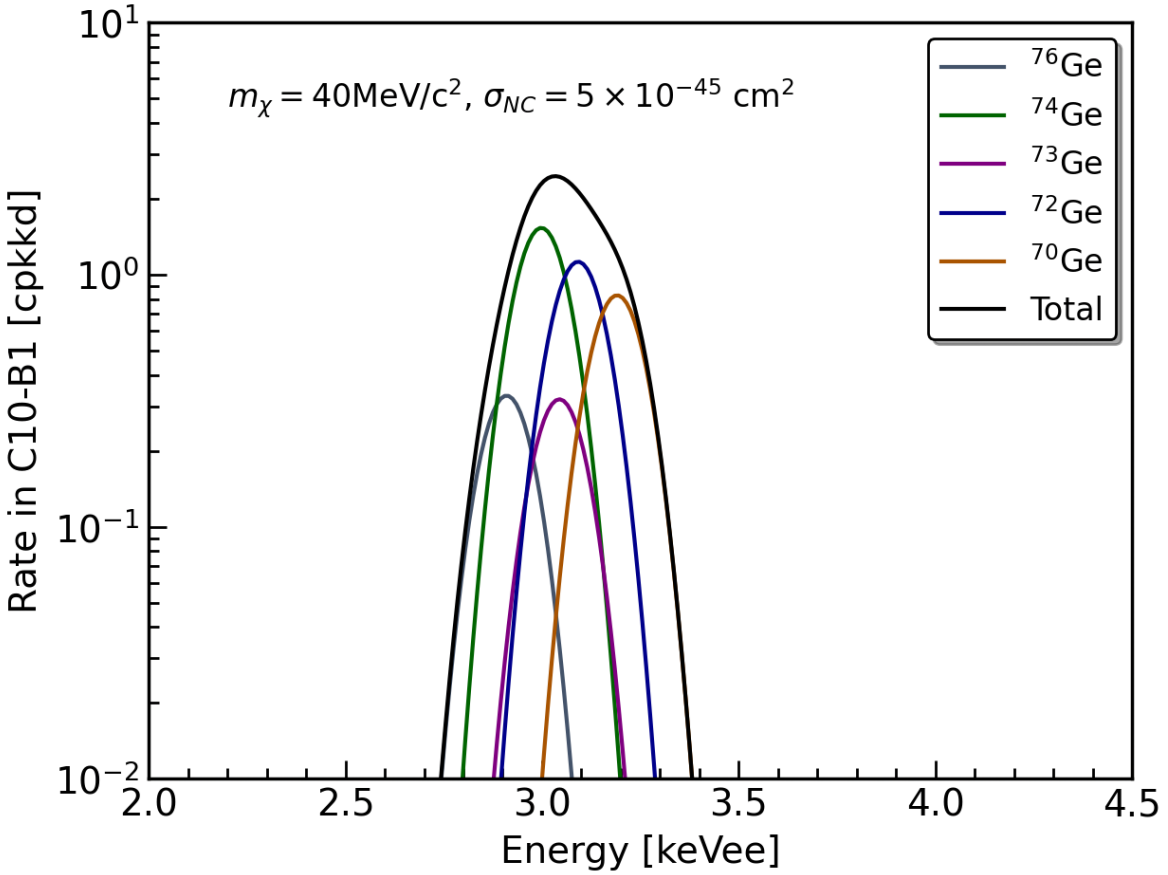
The DM spectrum in Ge

- Step1: the ionization energy deposition
- Step2: the Ge quenching factor: Lindhard ($\kappa = 0.162$)
- Step3: the detector energy resolution

$$F_q(E_{nr}) = \frac{\kappa \cdot g(\varepsilon)}{1 + \kappa \cdot g(\varepsilon)}, \qquad \kappa = 0.162 \pm 0.004$$
$$g(\varepsilon) = 3\varepsilon^{0.15} + 0.7\varepsilon^{0.6} + \varepsilon, \qquad \varepsilon = 11.5 \cdot Z^{-7/3} \cdot E_{nr}$$

A. Bonhomme, et al. Eur. Phys. J. C (2022) 82:815

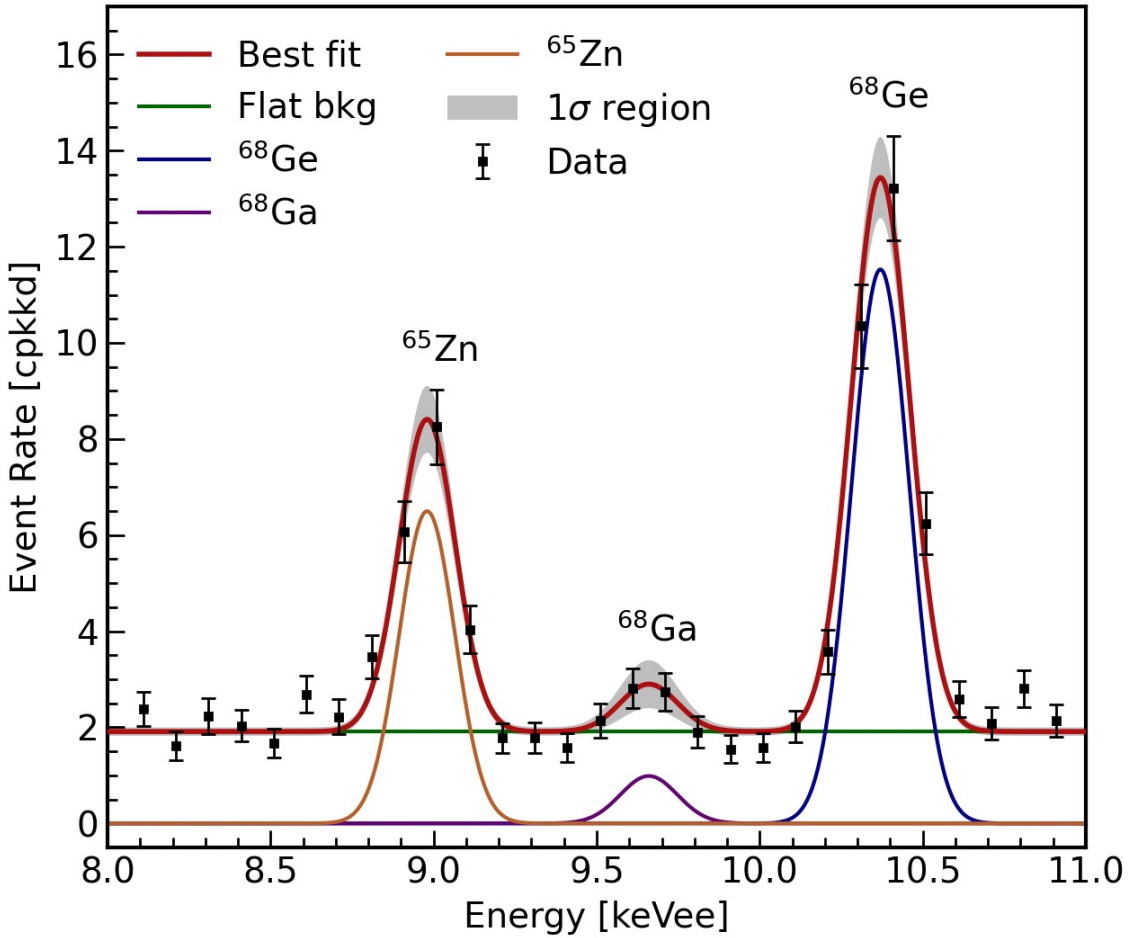


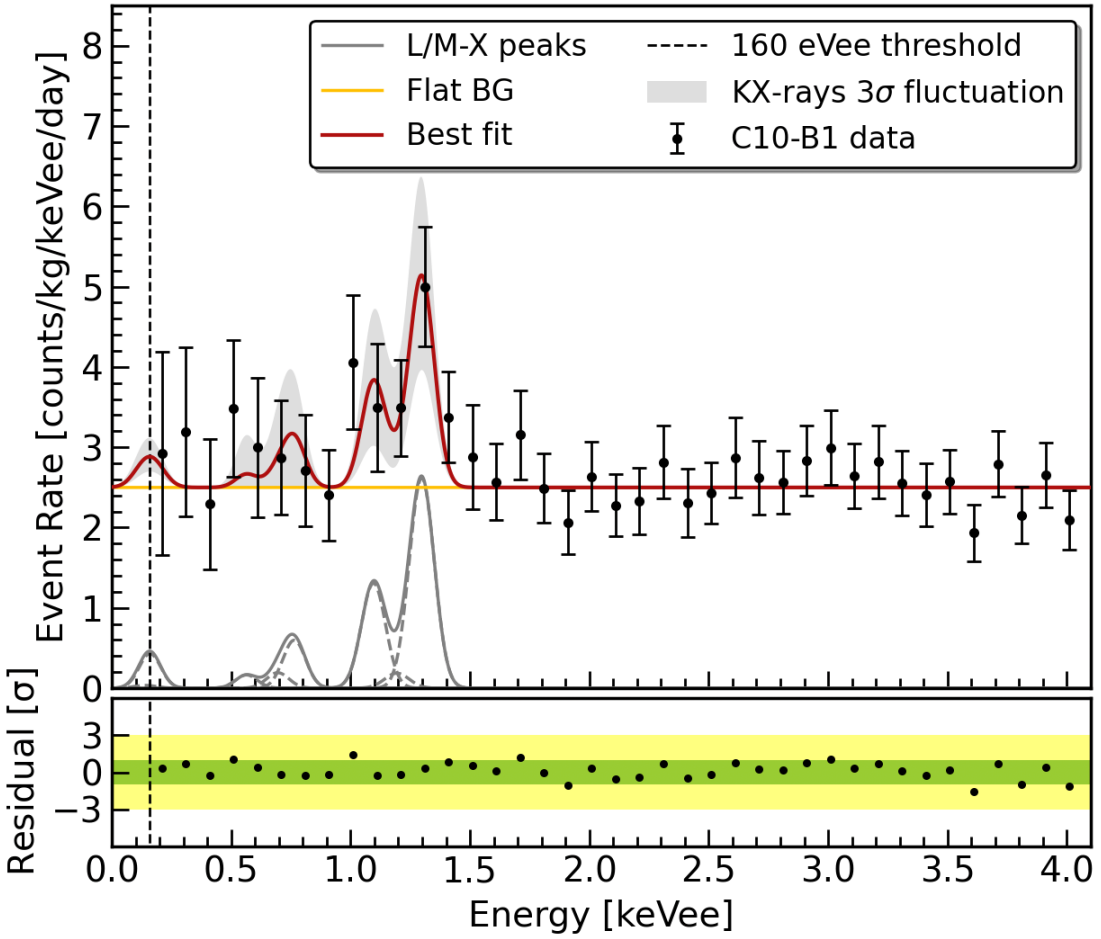


CDEX-10 data: experiment background

- Fit the high energy region spectrum to get the background model
  - Linear background
  - K/L X-ray peaks

$$B_{Model}(E) = kE + b + \sum \frac{A_K \cdot R_{L/K}}{\sqrt{2\pi}\sigma_L} e^{\left(\frac{-(E-E_L)^2}{2\sigma_L^2}\right)}$$

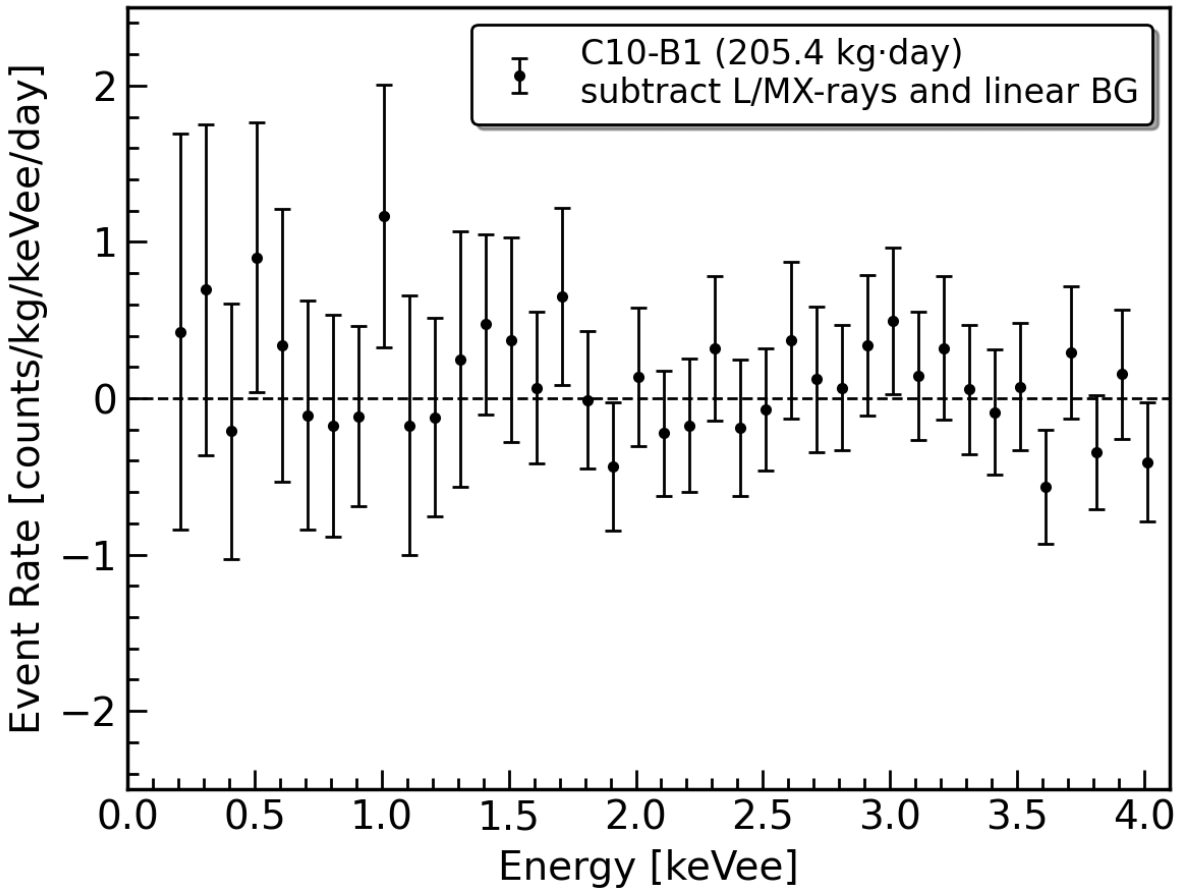


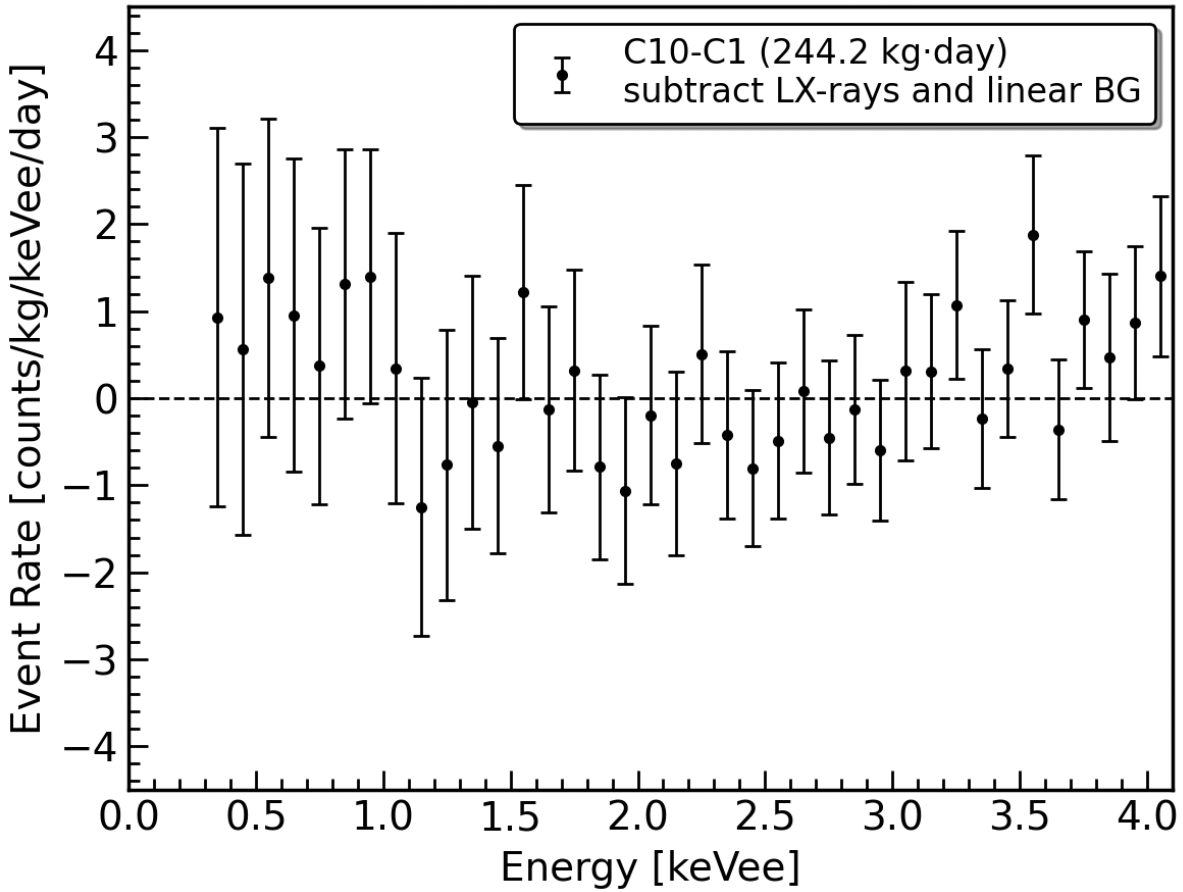


CDEX-10 data: experiment background

The residual spectra

- Subtract the background contribution





Constraints with CDEX-10

The analysis method

- χ^2 minimizing + Feldman-Cousins method, using the full dataset of CDEX-10

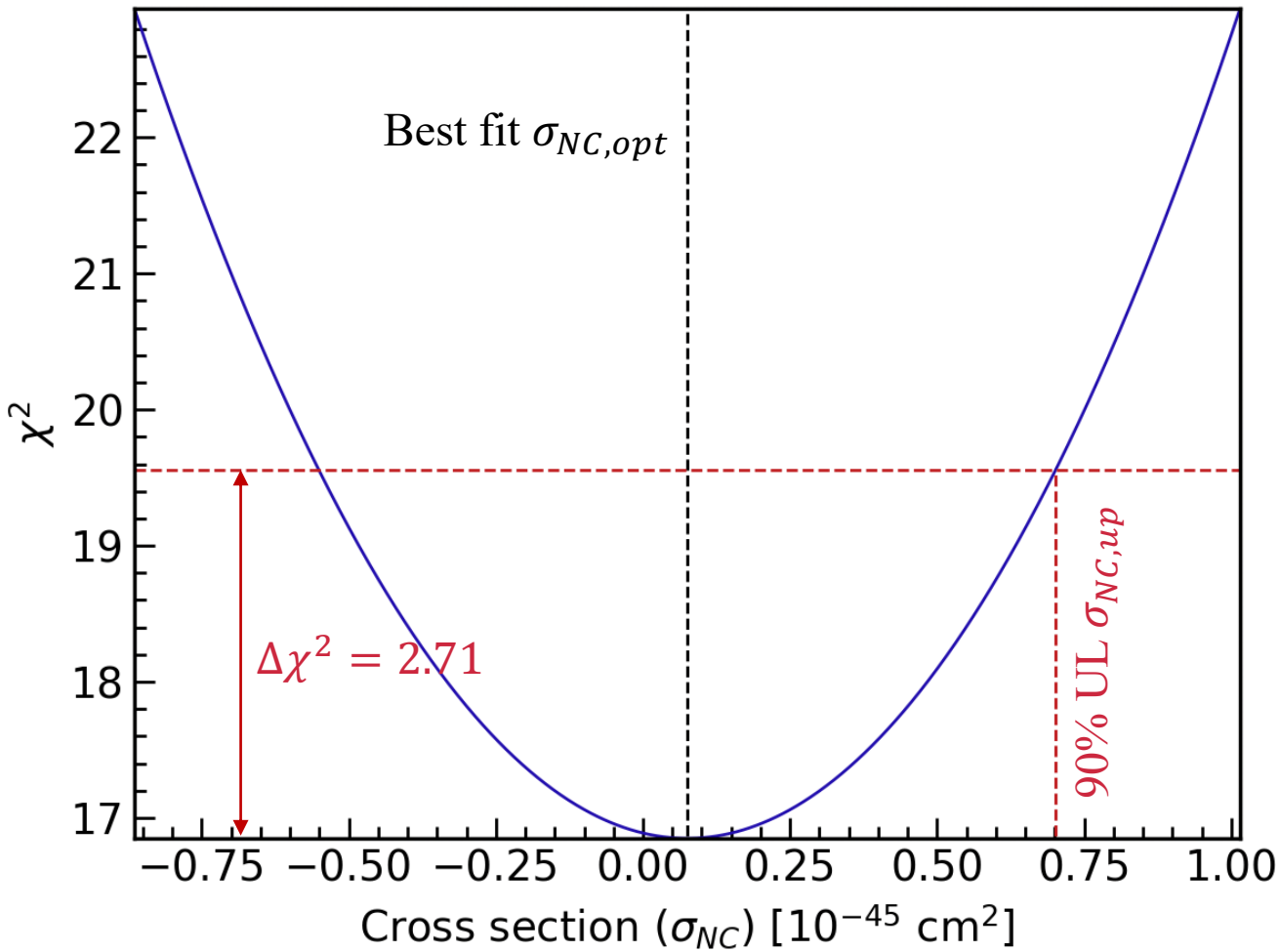
$$\chi^2(\sigma_{NC}) = \sum_{k=1}\sum_{i}\frac{\left[S_{k,i}(\sigma_{NC}) - D_{k,i}\right]^2}{\sigma_{k,i,stat}^2 + \sigma_{k,i,sys}^2}$$

$$\chi^2(\sigma_{NC,up}) = \chi^2_{\min}(\sigma_{NC,opt}) + \Delta\chi^2$$

$D_{k,i}$: bkg count rate of k-th detector in i-th bin
$\sigma_{k,i,stat}$: the statistical uncertainty
$\sigma_{k,i,sys}$: the systematic uncertainty
$S_{k,i}$: signal count rate of k-th detector in i-th bin

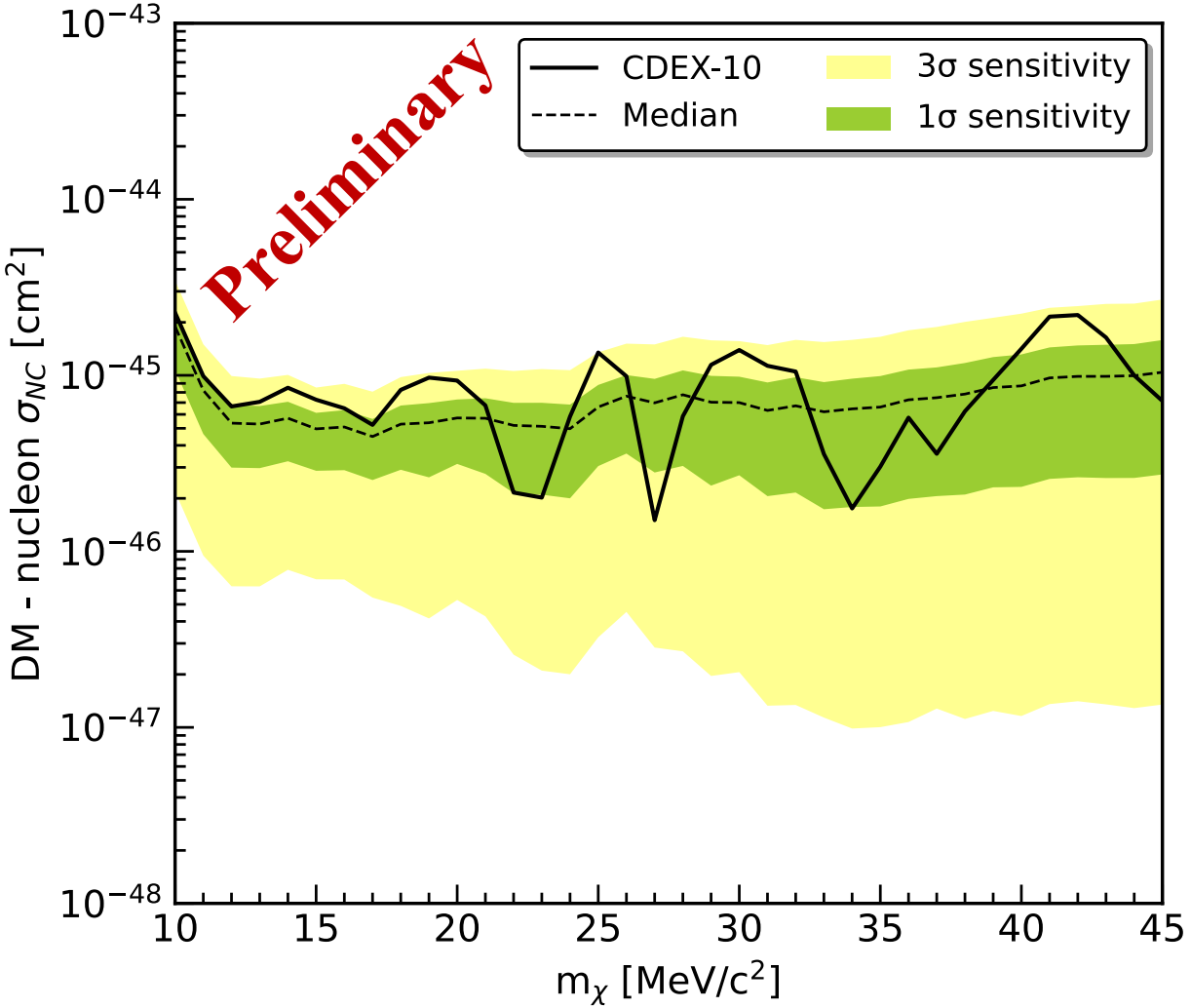
$\sigma_{NC,opt}$: the best fit
$\chi^2_{\min}$: the minimized χ^2 of the best fit
$\sigma_{NC,up}$: the 90% upper limit of the cross section

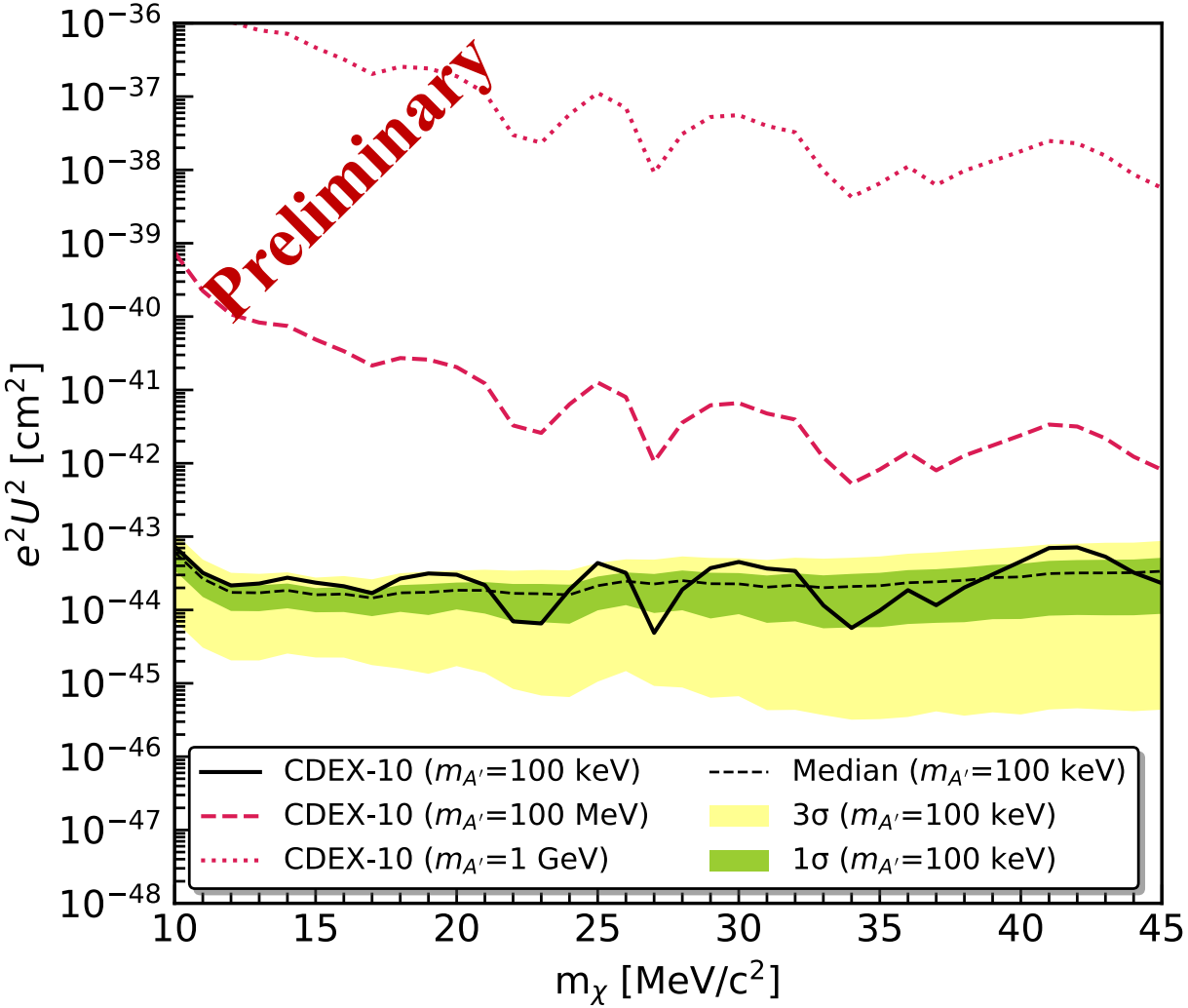
$$\Delta\chi^2 = \begin{cases} 2.71 & \sigma_{NC,opt} \geq 0 \\ use\ \text{FC}\ method & \sigma_{NC,opt} < 0 \end{cases}$$



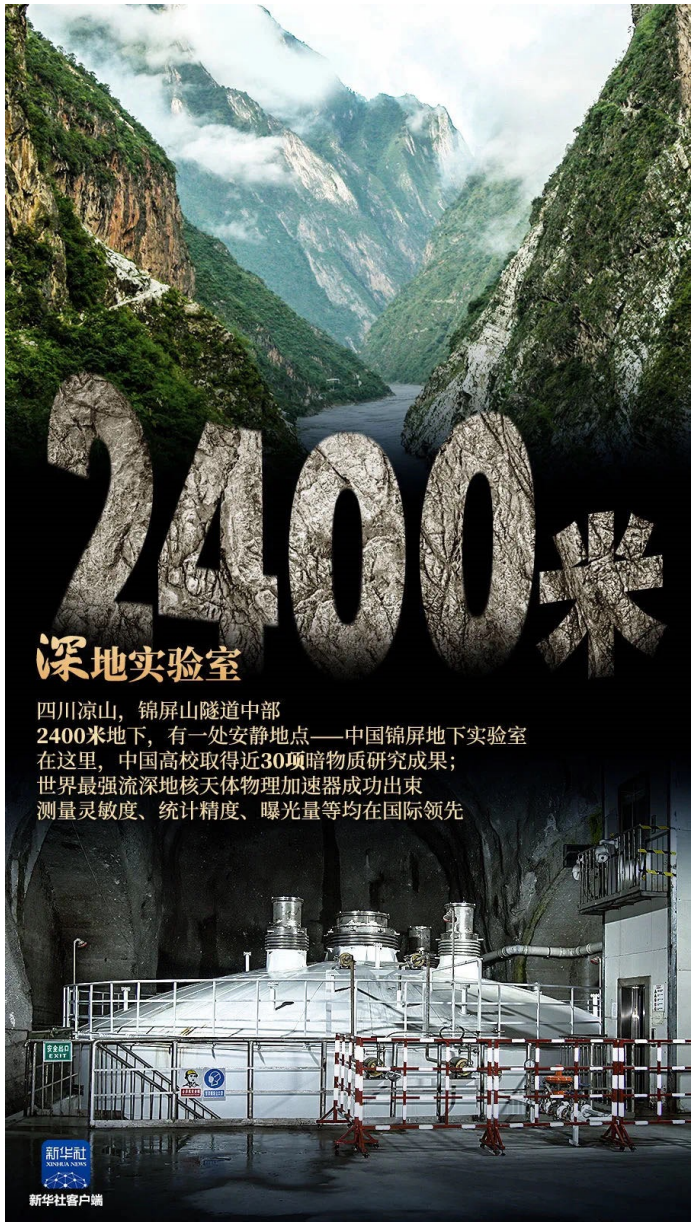
Constraints with CDEX-10

- Constraints on the cross section and coupling coefficient





Summary



- Constraint on the cross section of the magnetic dipole-base light fermionic dark matter using the full CDEX-10 experiment data (~1E-45 cm2)
- Constraint on the coupling coefficient with different dark photon masses

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THANK YOU!