Search of exotic physics with low threshold Germanium detector

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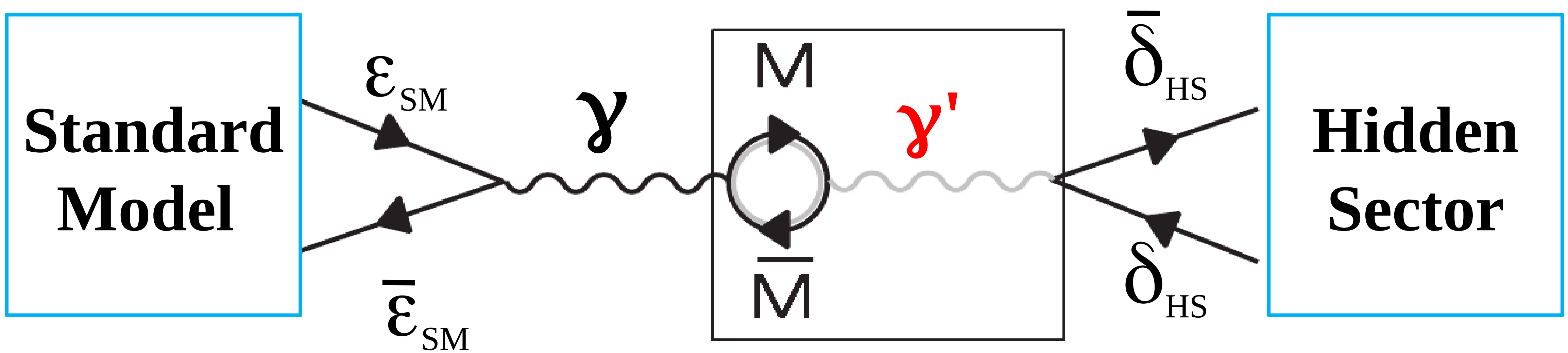
- **Motivation and Production of Millicharged Particles**
- **Experimental Setup**
  - **TEXONO @ Kuo-Sheng Reactor Neutrino Laboratory (KSNL),Taiwan**
- **Point Contact Germanium Detectors**
- **Constraints on Millicharged Particles**
- **Summary**

Millicharged Particles

Models with extra U(1) gauge group predict the existence of new particle with small electric charge,

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{\xi}{2}F_{\mu\nu}X^{\mu\nu}$$

$F_{\mu\nu}$ Field strength tensor in SM , $X_{\mu\nu}$ Field strength tensor in HS



ε_{SM}, and $\bar{\varepsilon}_{SM}$ are particle and antiparticle of SM , δ_{HS}, $\bar{\delta}_{HS}$ are particle and antiparticle of HS,

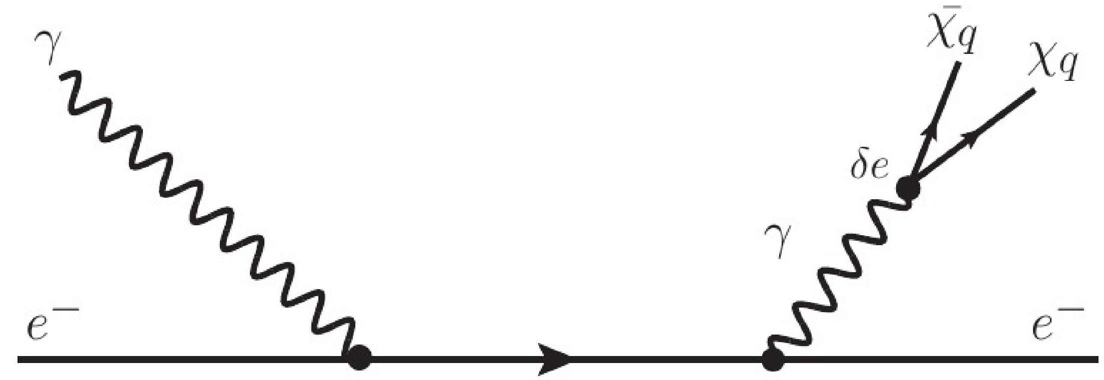
(R. Holdom et. al. Phys. Lett. B, vol. 166, pp. 196 -198 (1986).)

Reactor Millicharged Particles

Nuclear reactor cores may powerful sources of millicharged particles.

The production of millicharged particles (χ_q) via Compton-like mechinesm

$$\frac{d\sigma}{dE_{\chi_q}}(\gamma e \to \chi_q \bar{\chi}_q e) \simeq \frac{4}{3}\frac{\delta^2\alpha^3}{m_e^2 E_\gamma^3}\left[(3(E_{\chi_q}^2 + E_{\bar{\chi}_q}^2)+ 2E_{\chi_q}E_{\bar{\chi}_q})\right]\log\left(\frac{2E_{\chi_q}E_{\bar{\chi}_q}}{E_\gamma m_{\chi_q}}\right)$$



The total prompt γ-ray spectrum for reactor core is approximated:

$$\frac{dN_\gamma}{dE_\gamma} = 0.581 \times 10^{18} e^{-1.1E_\gamma(\mathrm{MeV})} \times \mathrm{Power(MW)}$$

The differential flux of millicharged particles :

$$\frac{d\phi_{\chi_q}}{dE_{\chi_q}} = \frac{2}{4\pi R^2}\int \frac{1}{\sigma_{tot}}\frac{d\sigma}{dE_{\chi_q}}\frac{dN_\gamma}{dE_\gamma}dE_\gamma$$

L. Singh et al, arXiv:1808.02719

Dark Cosmic Rays

The dark sector particles may have both neutral and ionized components.

The ionized component: incomplete recombination of primordial DM gas and re-ionization by sources such as starlight and supernova explosions

First-order Fermi acceleration (diffusive shock acceleration):

$$E_{max} \simeq \delta e_0 \, B \, t_A \, V_S^2$$

Suppose dark cosmic rays and cosmic ray protons are both driven by Fermi acceleration and from the same source: → SNR near Galactic Center

Dark cosmic ray flux by using results of ion acceleration in shocks:

$$\frac{d\phi_{\chi_q}}{dE_{\chi_q}} = 30 \, \delta^{\alpha-1} \left(\frac{\text{GeV}}{m_{\chi_q}}\right) \left(\frac{E_{\chi_q}}{\text{GeV}}\right)^{-\alpha} \text{cm}^{-2} \text{ s}^{-2} \text{ sr}^{-1} \text{ GeV}^{-1}$$

Phys. Lett. B 768, 18, 2017.

Atmospheric Millicharged Particles

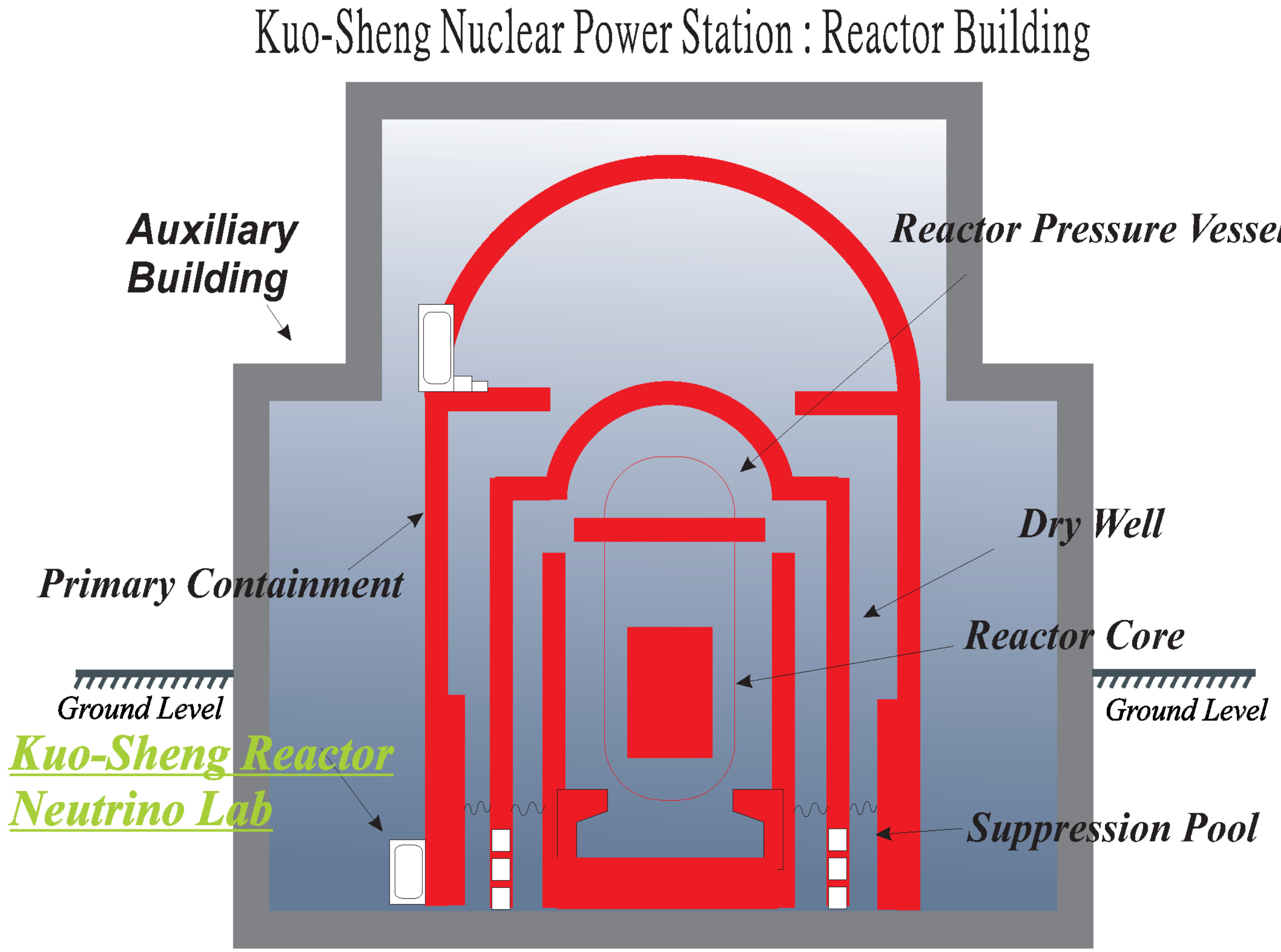
- The high energy cosmic-rays are capable of creating massive millicharged via interaction with nucleus in the earth's atmosphere.

- Experimental sensitivity is usually expressed in terms of the integral incoming flux (I) in the units of cm^{-2} s^{-1} sr^{-1} as a function of δ.

- Direct searches for atmospheric millicharged particles, including MACRO, Kamiokande-II, and LSD placed stringent limits on the millicharged flux for $\delta > 0.1$

- The Majorana Demonstrator placed limits on for these exotic particles $\delta > 10^{-3}$.

Kuo-Sheng Nuclear Power Plant

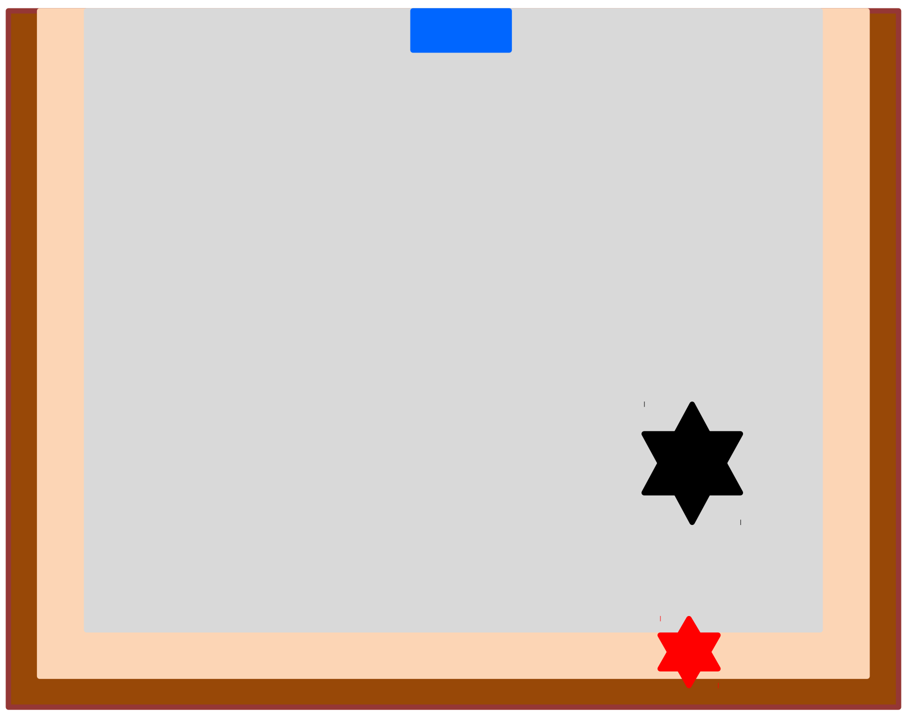


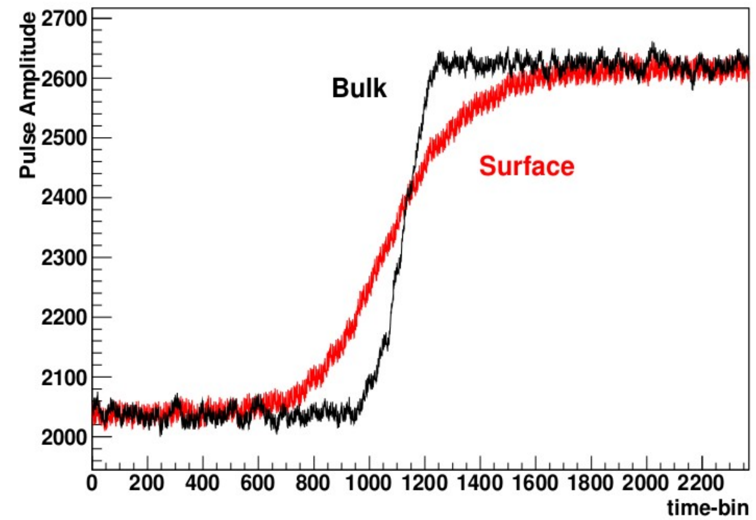
$\Phi\nu = 6.4\times10^{12}\ cm^{-2}\ s^{-1}\ sr^{-1}$

- *Lab: 28 m from core #1,*
- *30 MWE overburden concrete*

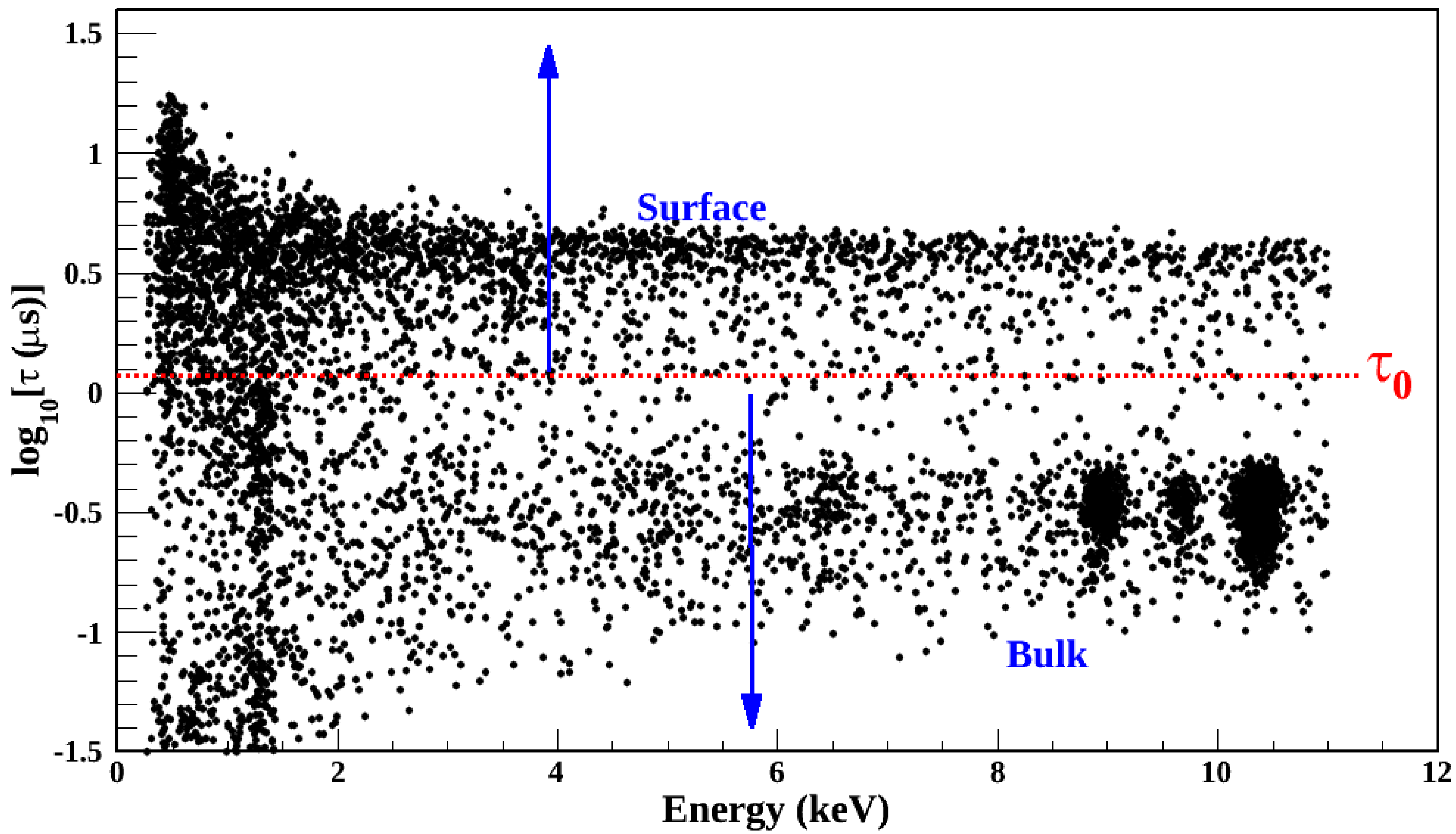
Point Contact Ge-Detectors

P-type Point Contact Germanium Detectors





- n+ dead layer (mm)
- transition region
- active volume



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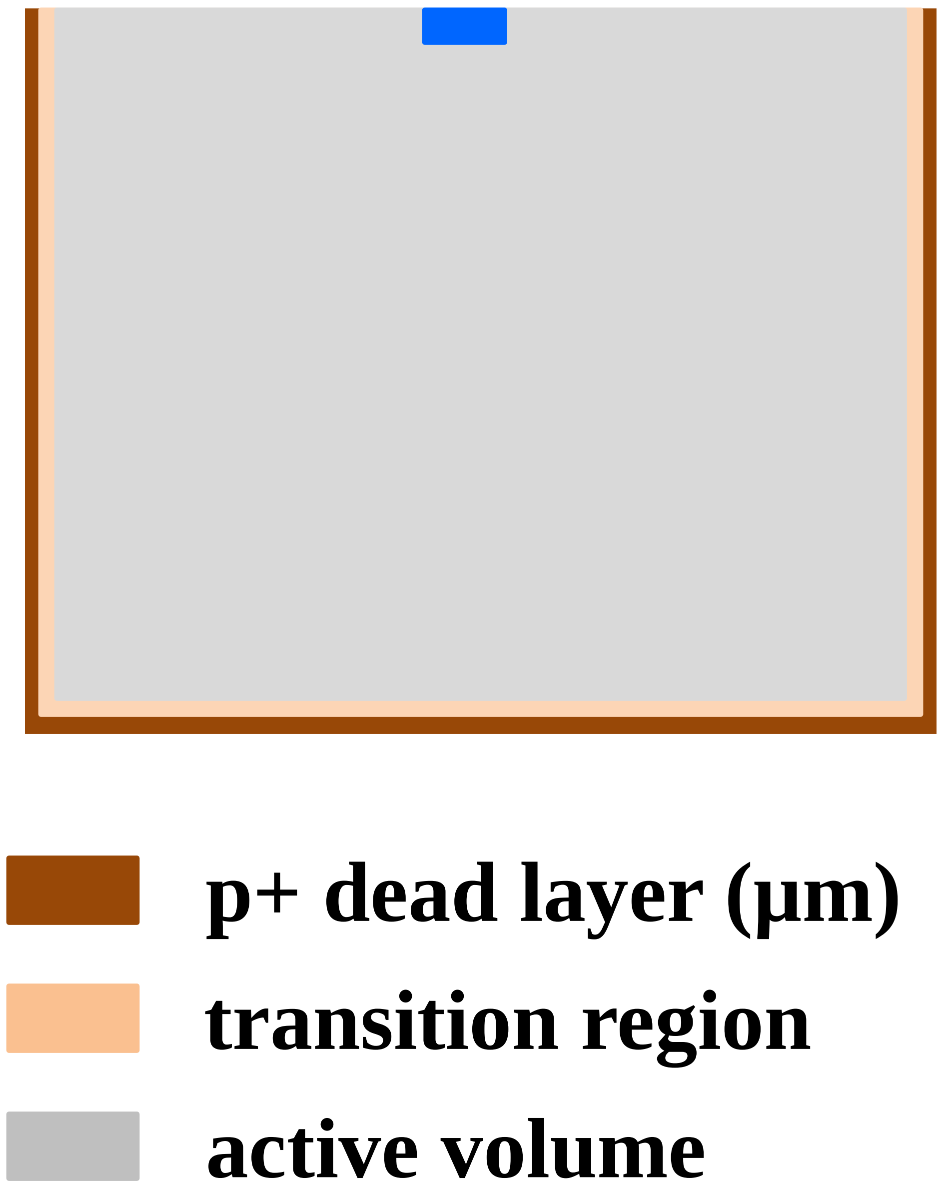
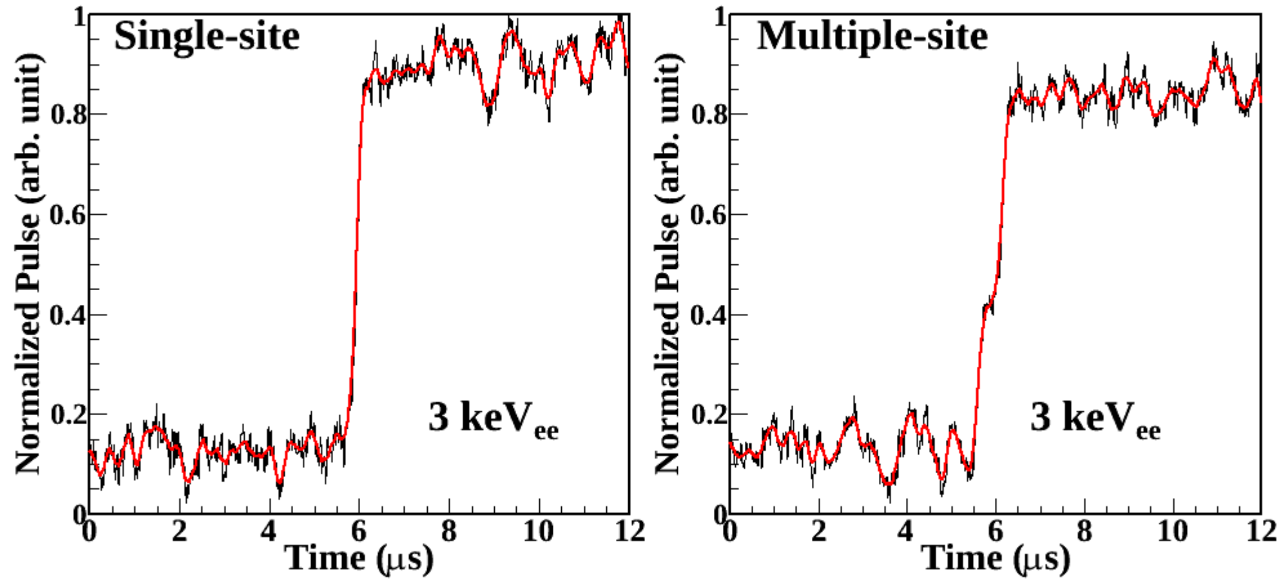
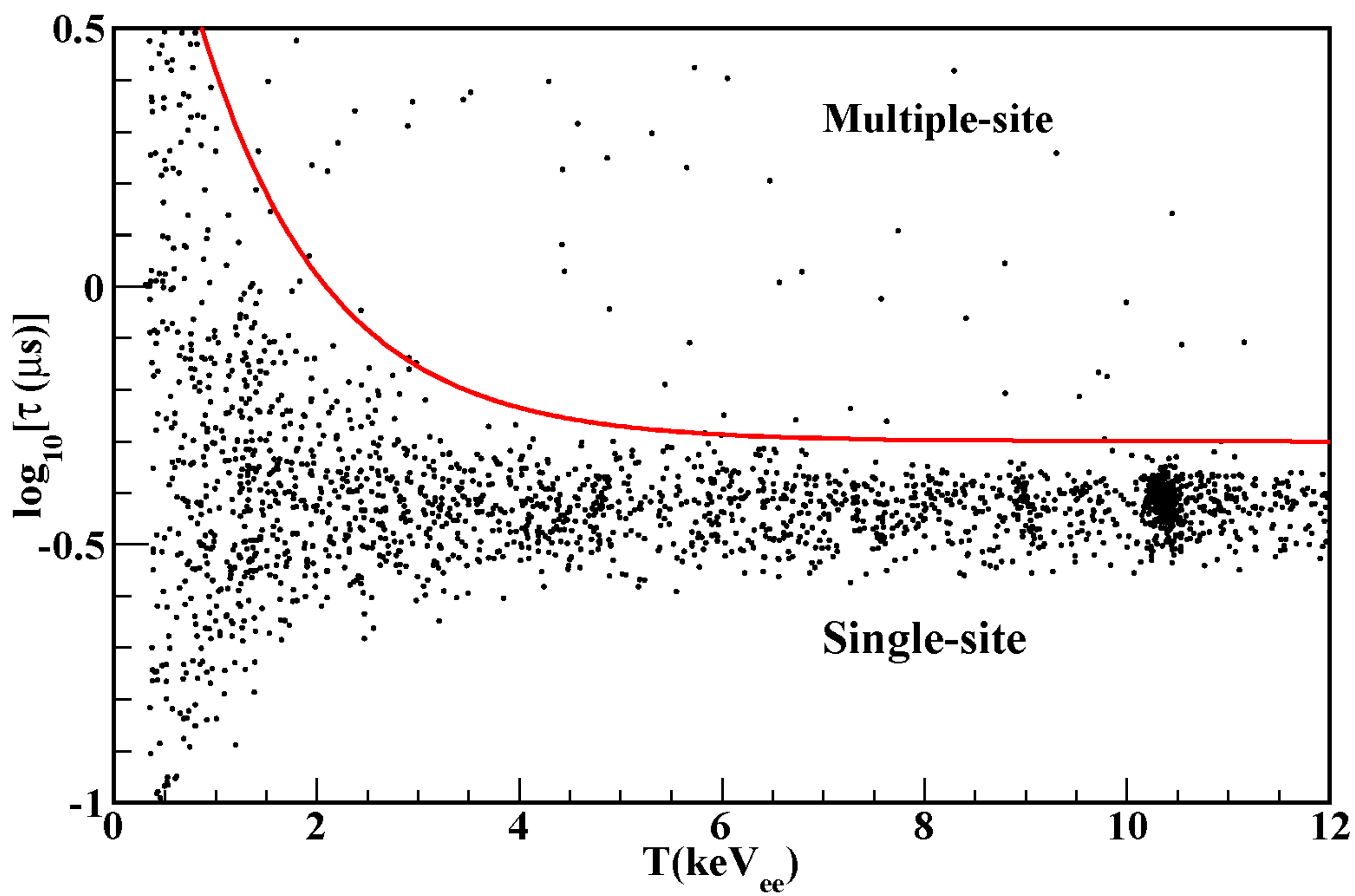
Point Contact Ge-Detectors

N-type Point Contact Germanium Detectors



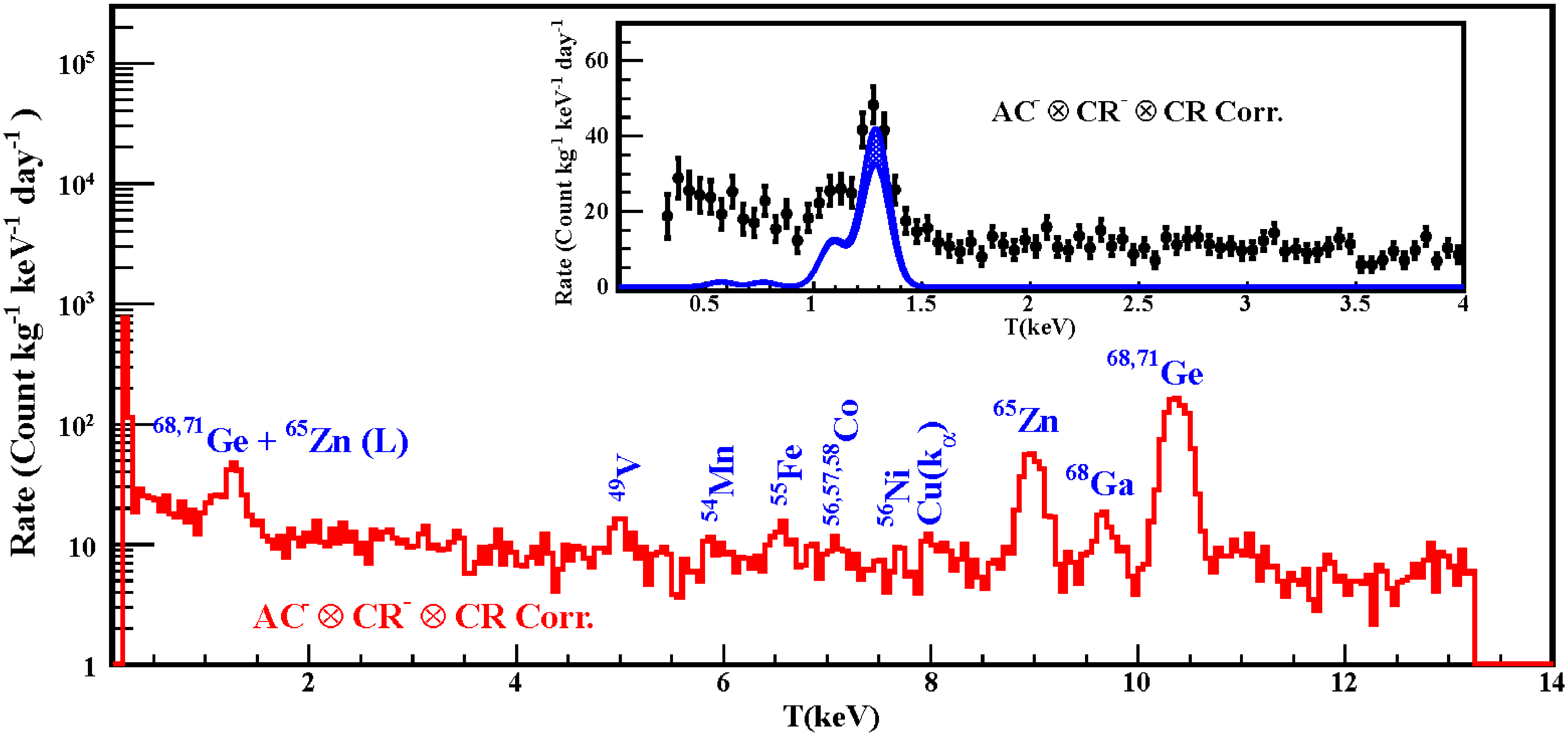




Calibrations

Residual Energy Spectrum

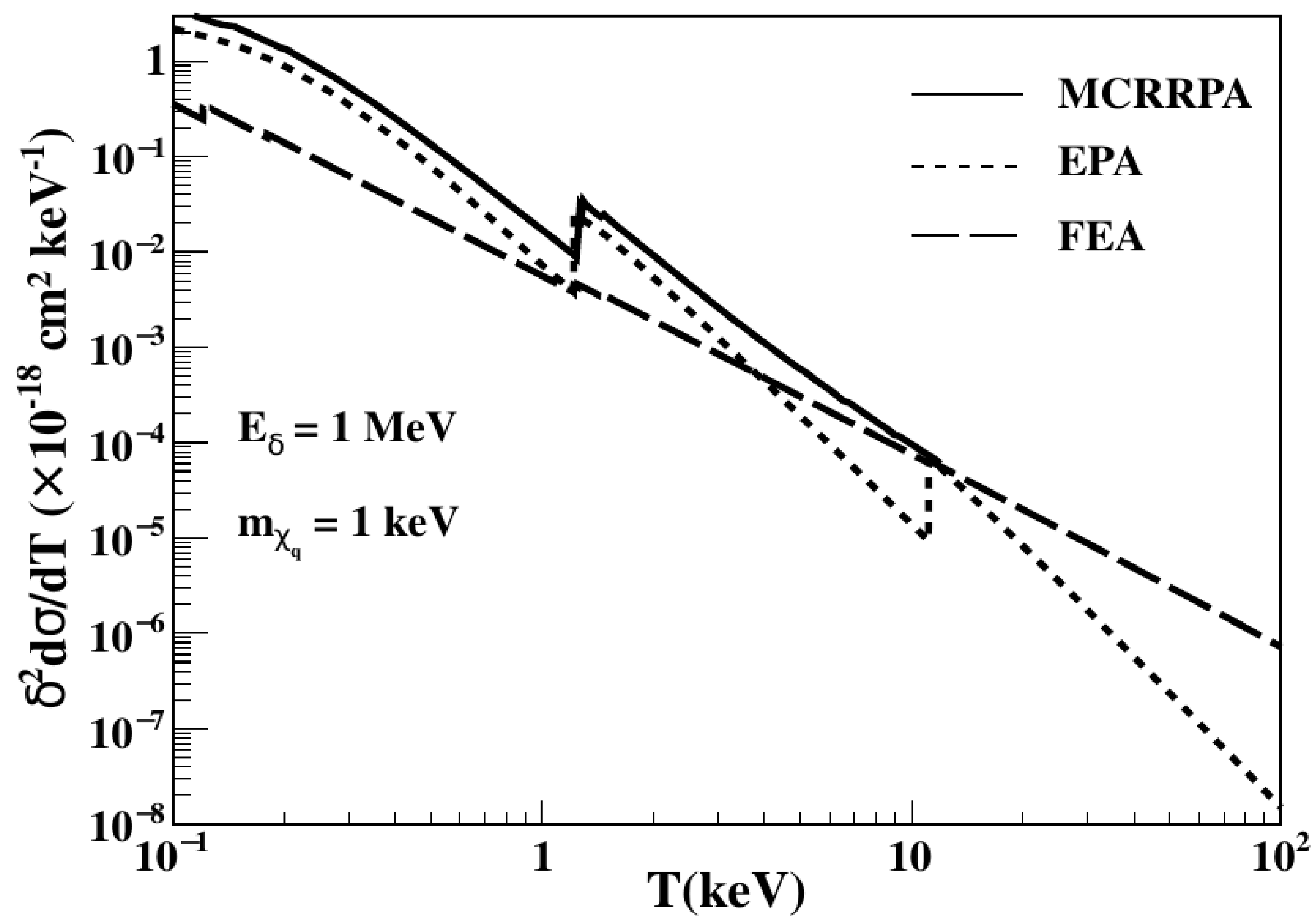
L/K ratio of Ge and Zn is experimentally and theoretically well known



Differential Cross Sections

$$\chi_q + A \rightarrow \chi_q + A^+ + e^-$$

MCRRPA: **M**ulti **C**onfiguration **R**elativistic **R**andom **P**hase **A**pproximation



Free Electron Approximation (FEA):

➔ FEA is a good approximation at high momentum transfer

Equivalent Photon Approximation (EPA):

➔ EPA is a good approximation at low momentum transfer

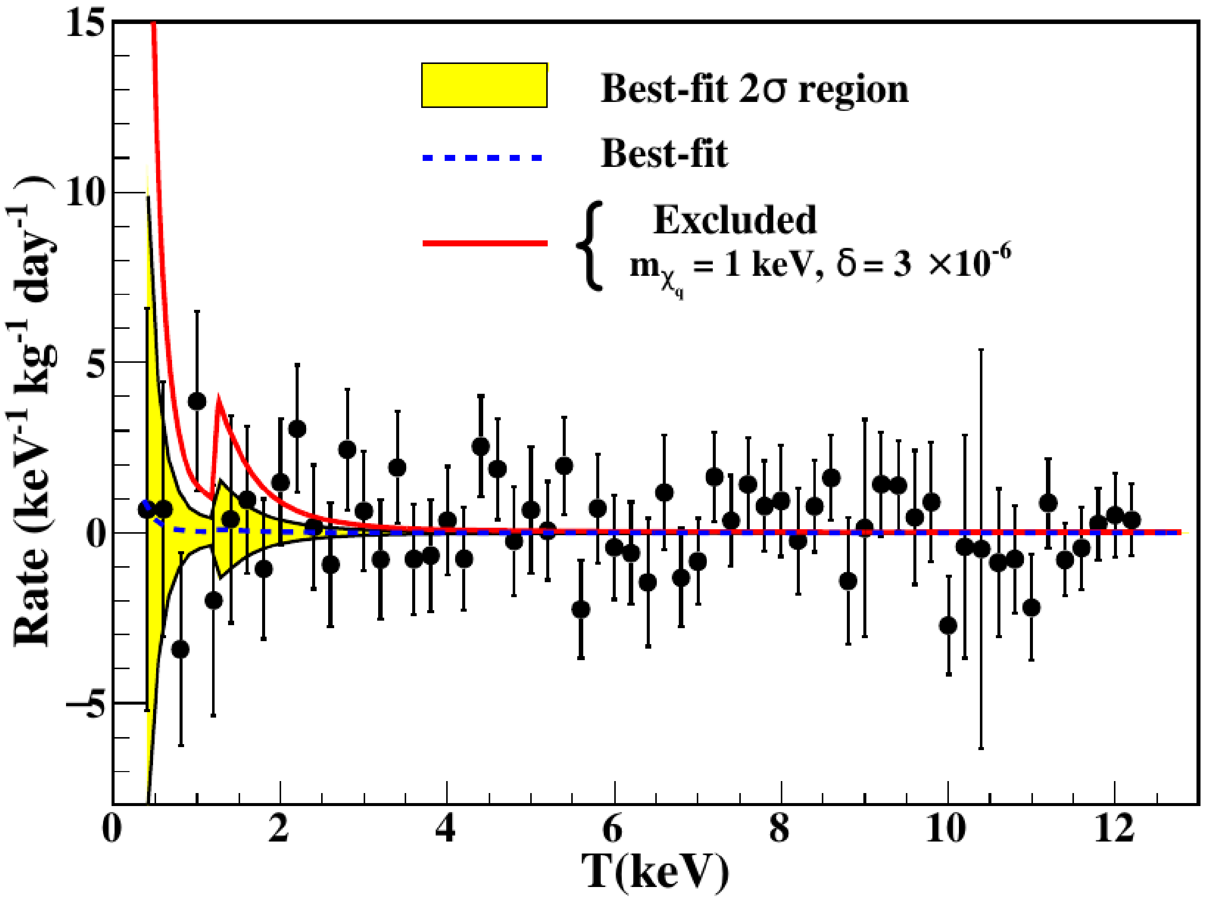
The EPA and FEA schemes serve as conservative approximations in the region near and away from ionization thresholds,

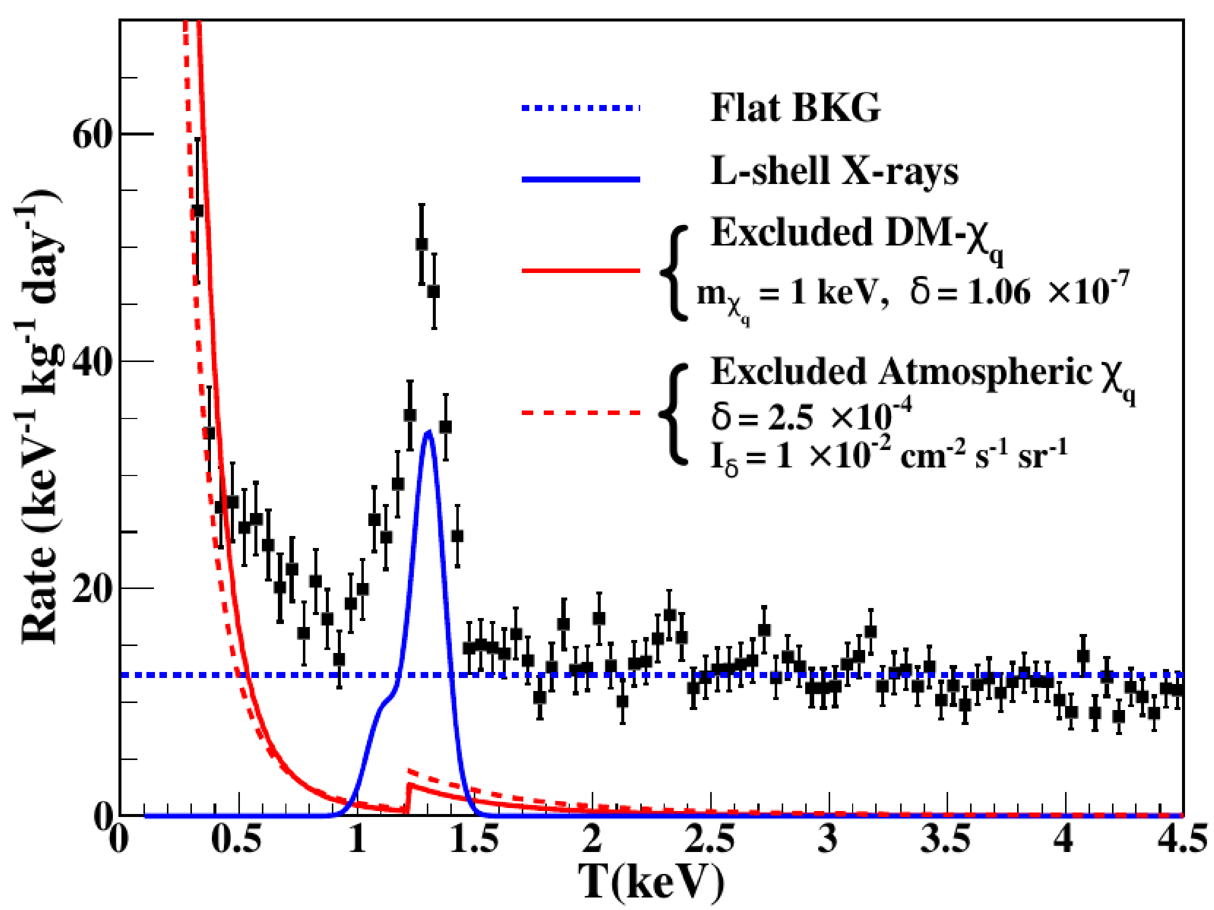
$$\sigma^{\text{tot}} = max(\sigma^{\text{EPA}}, \ \sigma^{\text{FEA}})$$

Constraints on Millicharged Particles

Reactor ON - OFF (124.2/70.3 kg day) residual spectrum of nPCGe detector.

Energy distribution of the events remaining in the data set after all data selection cuts. Excluded Dark Cosmic Ray spectrum for low mass is also shown.





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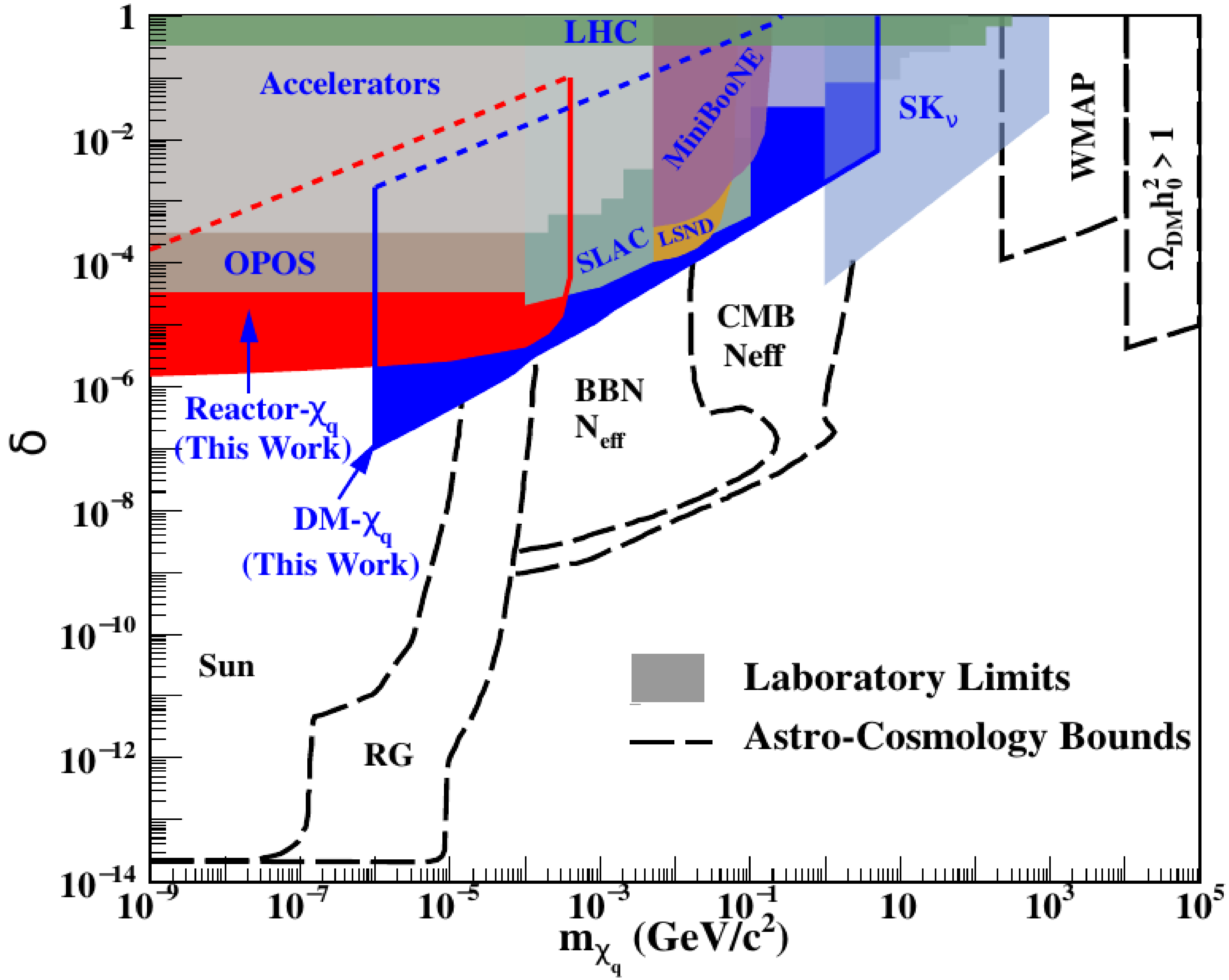


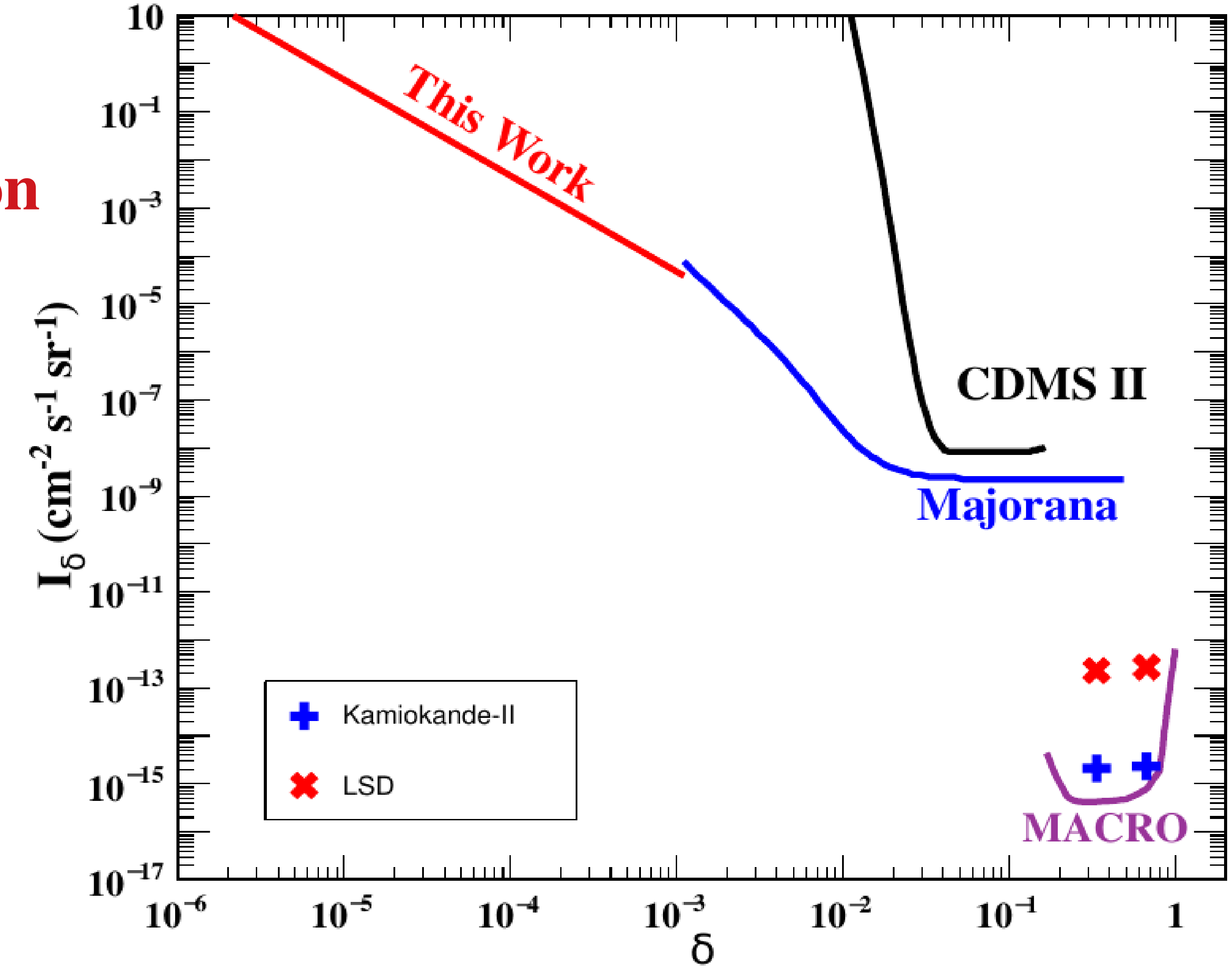
Atmospheric Millicharged Particles

Attenuation of millicharged particle between source and detector is estimated via radation length of high energy electron ($X0_e$) :

$$\frac{X0_\chi}{X0_e} \simeq \frac{1}{\delta^4}\left(\frac{m_\chi}{m_e}\right)^2$$

where m_e is the mass of electron, m_χ and $X0_\chi$ is the mass and radiation length of millicharged partilces.

Reactor: 10 m of water,
10 m of concrete,
and 50 cm of lead



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Summary

- ✓ **Hidden sector with massless gauge boson allows possibilities of multicomponent dark matter.**
- ✓ **Ultra low energy threshold : 300 eV (nPCGe-500g)**
- ✓ **The sub-keV sensitivity of the PCGe leads to improve direct limits of δ at low mass and extend the lower reach of δ to 10^{-6} .**
- ✓ **Demonstrated application of nPCGe Detectors technology in order to study millicharged particles.**
- ✓ **Efforts on understanding sub-keV background.**
- ✓ **R&D on reducing threshold via hardware & software.**

Thanks