

Neutrino and Dark Matter Physics with sub-KeV Germanium Detectors

- Overview
- Facilities
- Physics programs
- Challenge for sub-keV
- Summary

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TEXONO-CDEX Collaboration

TEXONO Taiwan **EX**periment **ON** Neutrino (since 1997)

Neutrino Physics at **Kuo-Sheng Reactor Neutrino Laboratory (KSNL)**

- **Taiwan** (AS, INER, KSNPS)
- **Turkey** (METU, DEU)
- **India** (BHU)



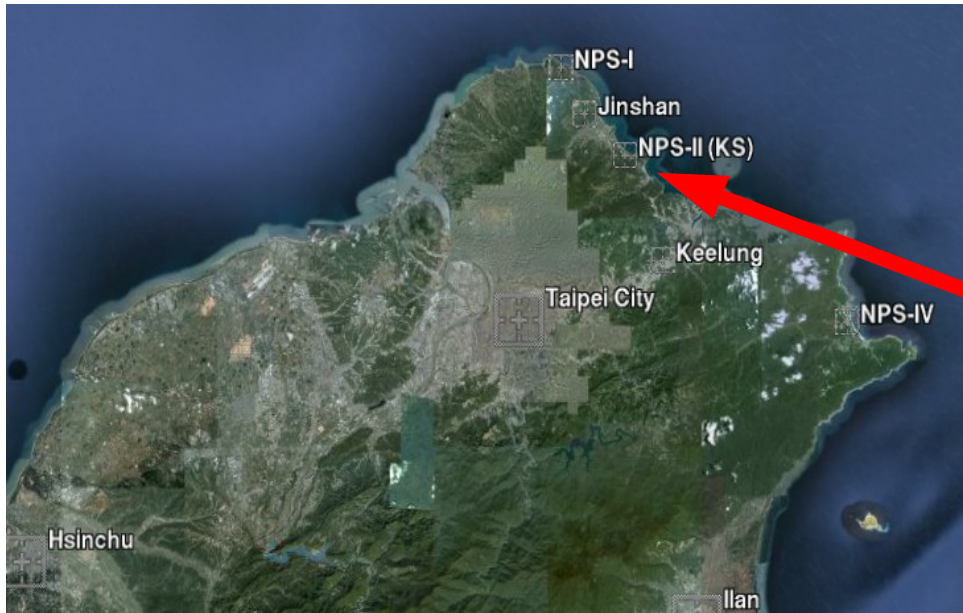
CDEX China **D**ark Matter **EX**periment (birth 2009)

Dark Matter Searches at **China Jin-Ping Underground Laboratory (CJPL)**

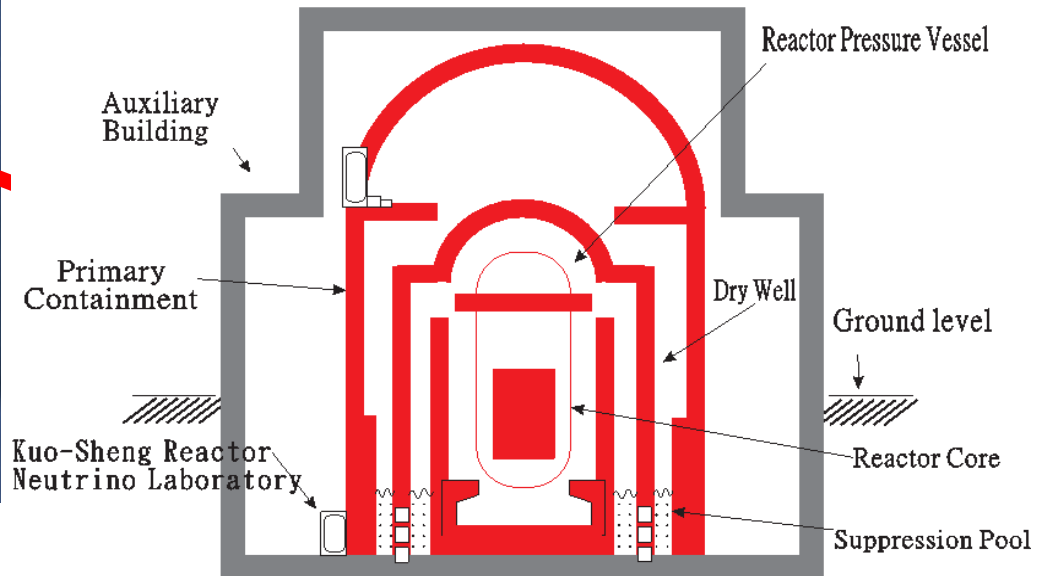
- **China** (THU, CIAE, NKU, SCU, YLJHD)



Kuo Sheng Reactor Neutrino Laboratory



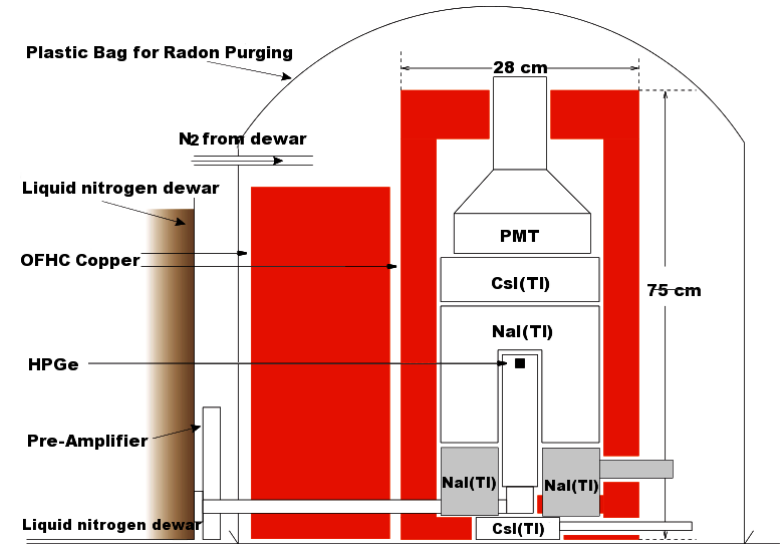
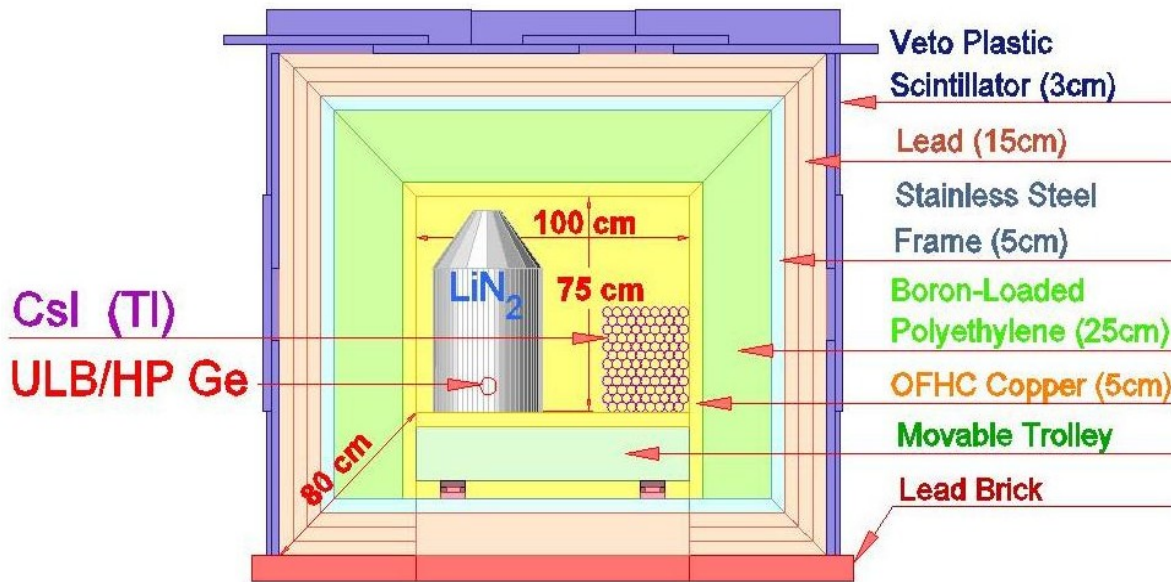
Kuo-Sheng Nuclear Power Station : Reactor Building



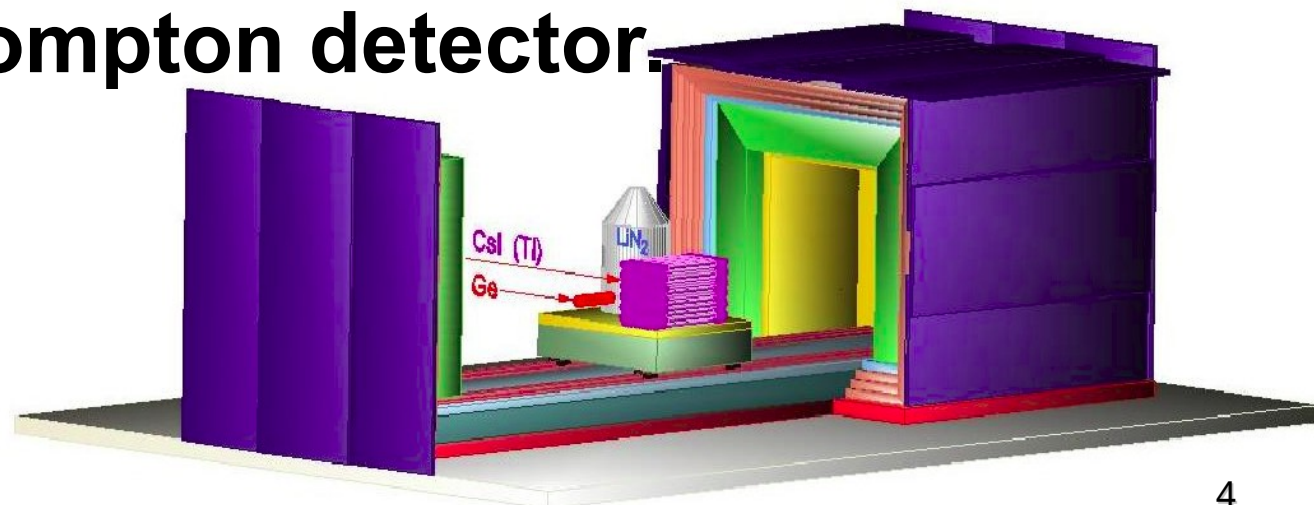
- **2 reactor core, 2 GW.**
- **Lab. : 28 m from nearest core.**
- **30mwe concrete over burden.**

see Jianmin Li's talk at
Dark Matter session on
CJPL present and future

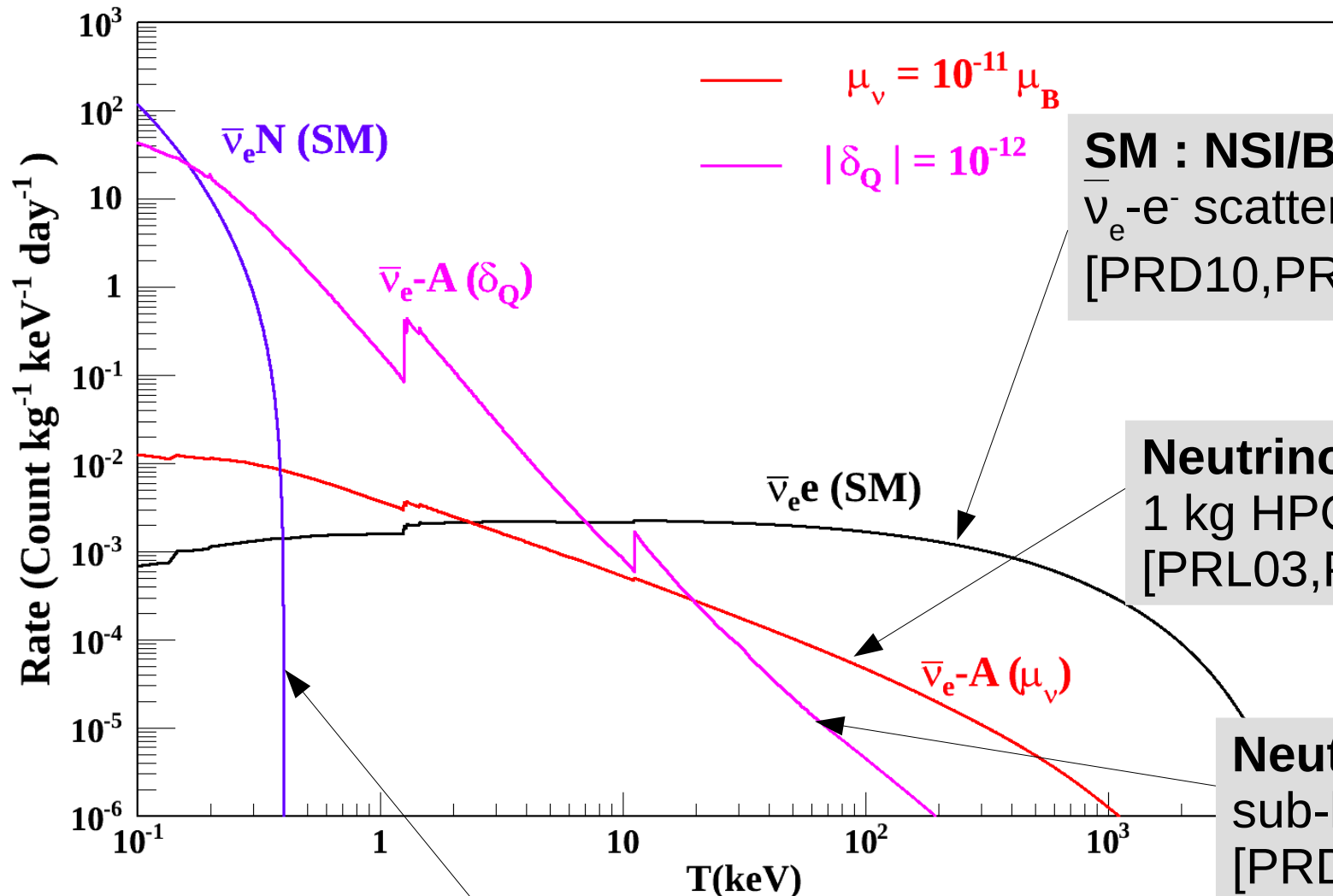
Kuo Sheng Reactor Neutrino Laboratory



- Active cosmic shielding with plastic scintillator.
- NaI(Tl) as anti-Compton detector.
- Flexible design.



Physics Program



SM : NSI/BSM
 $\bar{\nu}_e$ -e scattering with 200 kg CsI
 [PRD10,PRD10,PRD12]

Neutrino Magnetic Moment
 1 kg HPGe
 [PRL03,PRD05,PRD07]

Neutrino milli-charge
 sub-keV ULEGe, PCGe
 [PRD14]

ν -Nuclei Coherent Scattering [goal]
 sub-keV ULGe, PCGe
 Dark Matter Searches at KSNL [PRD09,PRL13,AP14]
 CDEX at CJPL [PRD13,PRD14,PRD14]

see Cheng-Pang Liu's talk
 at Neutrino session
 on detail calculation of
 the cross-section

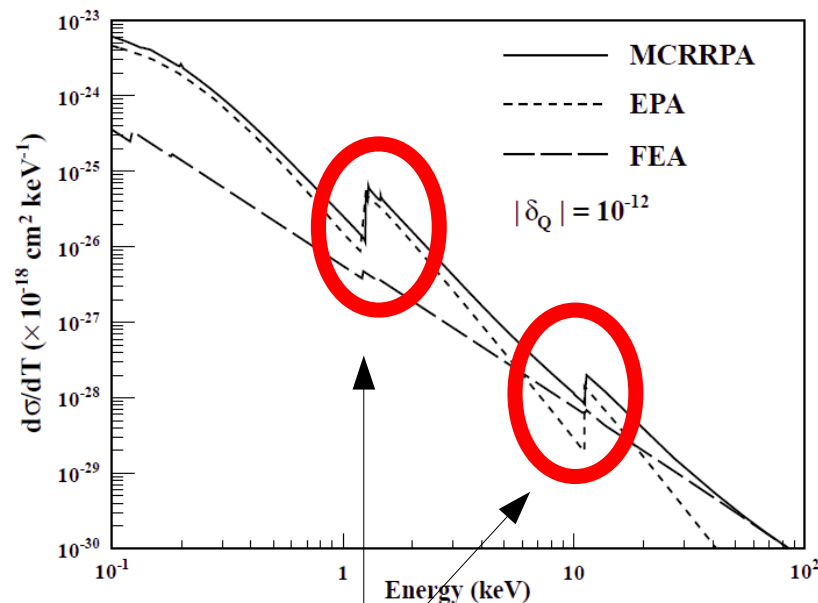
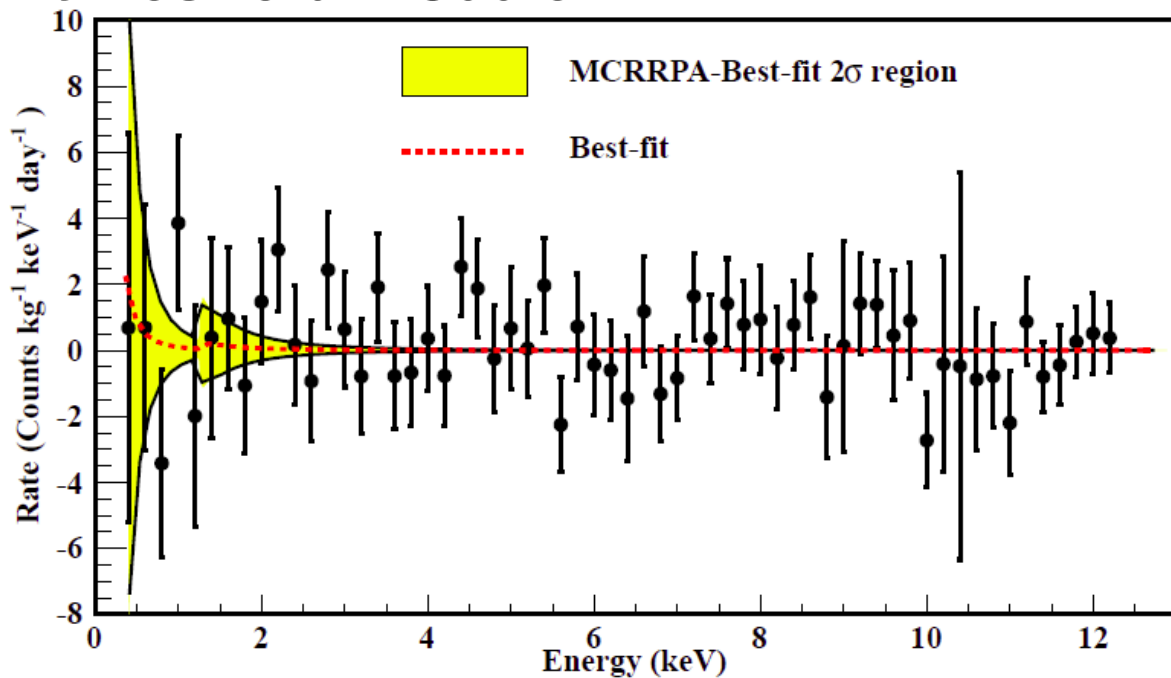
Neutrino milli-charge

free electron :

$$\left(\frac{d\sigma_{\delta_Q}}{dT}\right)_{FEA} = \delta_Q^2 \left[\frac{2\pi\alpha_{em}^2}{m_e}\right] \frac{1}{T^2},$$

Atomic Ionization Differential Cross-Section
with full atomic physics many-body “MCRRPA” calculation
enhancement at sub-keV

best-fit results on 0.5 kg PCGe
threshold = 300 eV



positive signals : known K/L ratio
(different from cosmic-activation
electron-capture background)

• goal $\delta_Q \sim 10^{-14}e$ at 100 eV threshold

→ $\delta_Q < 2.1 \times 10^{-12}e$ at 90 % C. L.

νN coherent scattering

- $\nu + A \rightarrow \nu + A$: Never been experimental observed.

- $$\frac{d\sigma}{dT} = \frac{G_F^2}{m_N} \left[(1 - 4\sin^2\theta_W) - N \right]^2 \left[1 - \frac{m_N T_N}{2E^2} \right]$$

- Neutral current process.

- $\sigma \propto N^2$ for $E_\nu < 50 \text{ MeV}$ (Coherent)

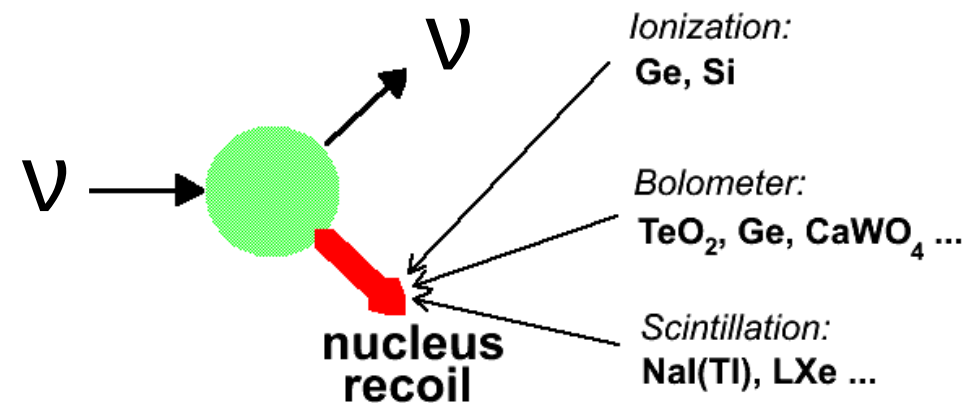
- sensitive probe for BSM

- reactor monitoring

- important process in stellar collapse & supernova explosion

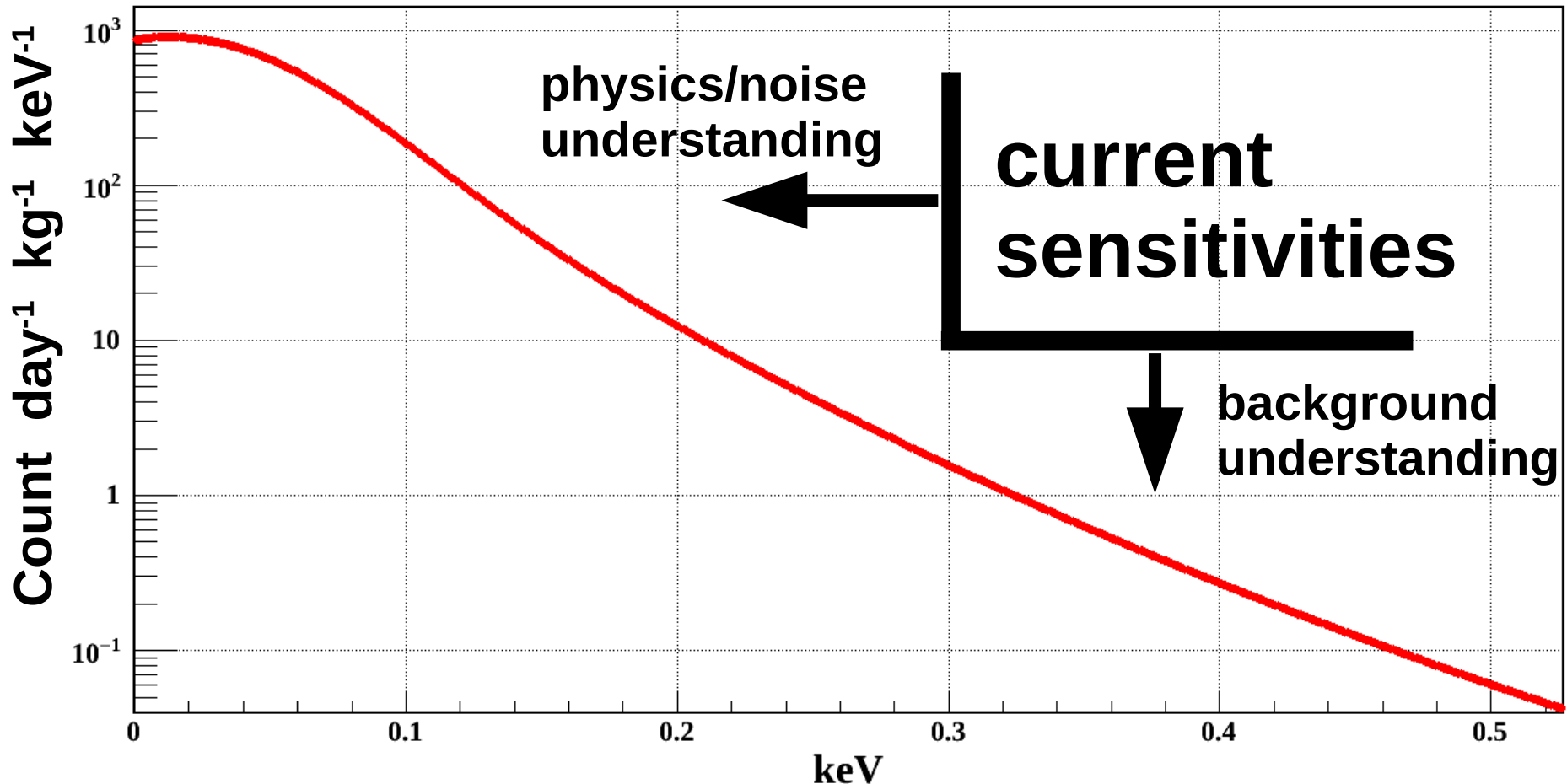
- for reactor neutrino on Ge, $T_{\max} \sim 2 \text{ keV}$

$T_{\max} \sim 500 \text{ eV}$ after Q. F. ~ 0.2



ν N coherent scattering

estimated events rate at KSNL



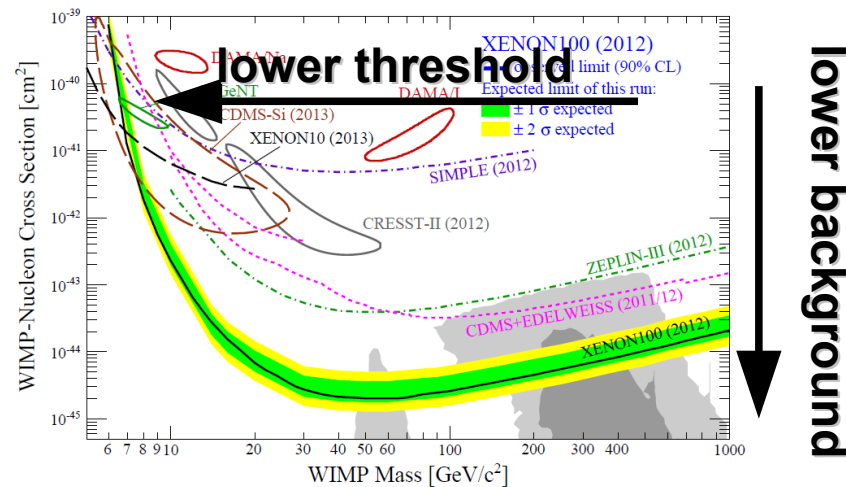
integral events rate(with energy resolution) :

6.6 $\text{count day}^{-1} \text{ kg}^{-1}$ at 100 eV threshold

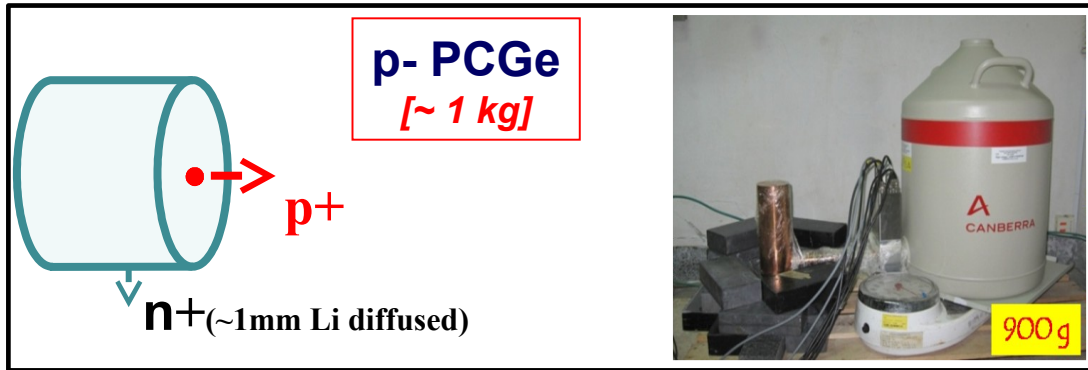
0.59 $\text{count day}^{-1} \text{ kg}^{-1}$ at 200 eV threshold

Ge detector

- Neutrino physics at sub-keV :
neutrino magnetic-moment,
 ν N-coherent scattering, reactor-monitoring.
- Low-mass (~ 10 Gev) **WIMP Search.**
- Allow Low Threshold Measurements(~ 100 eV).
- However, no γ /nuclei recoil separation.



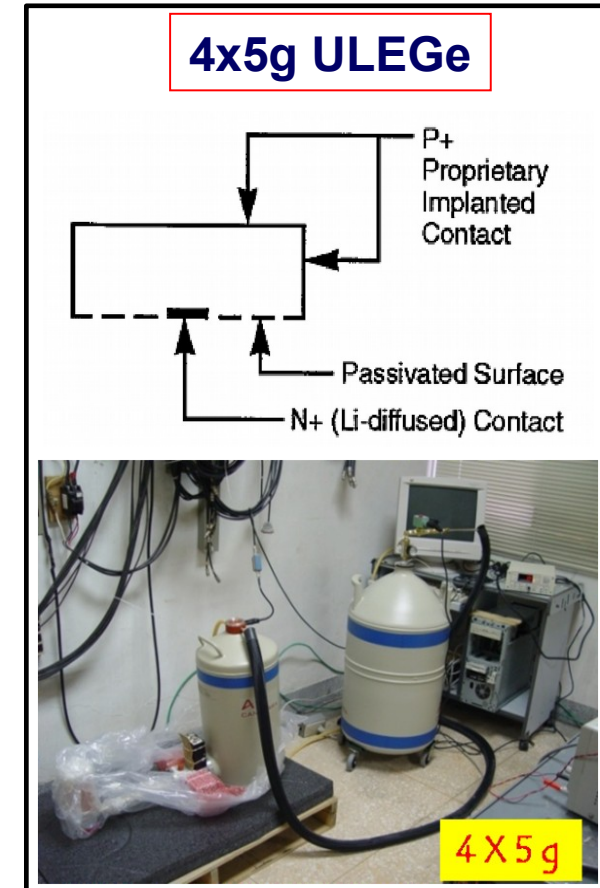
Various Ge detectors



**p-PCGe : ~kg, threshold ~300 eV
with bulk/surface feature**



**n-PCGe : ~kg, threshold ~300 eV
without bulk/surface feature**



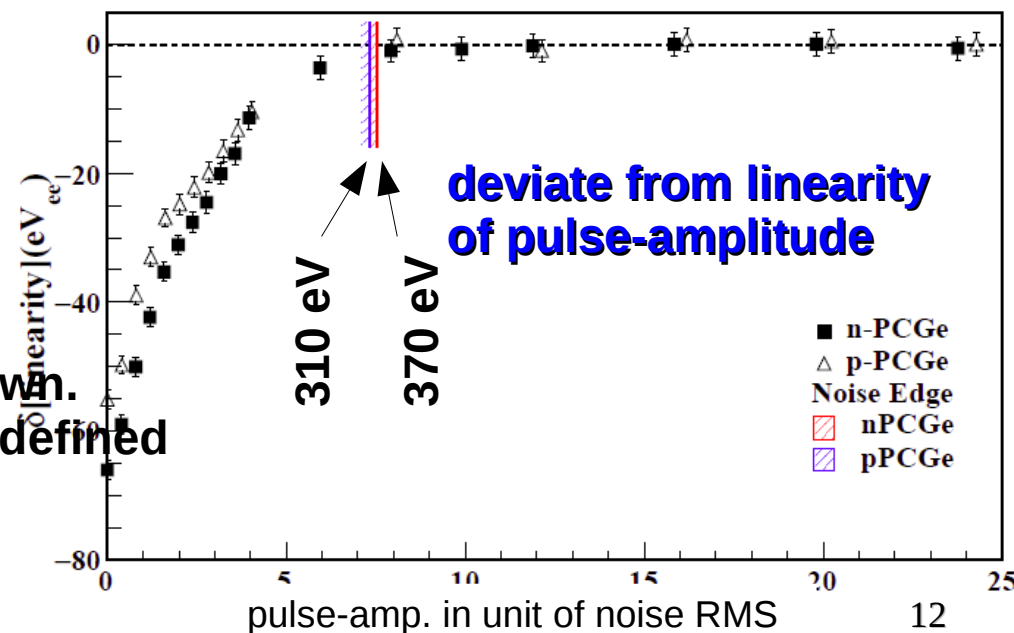
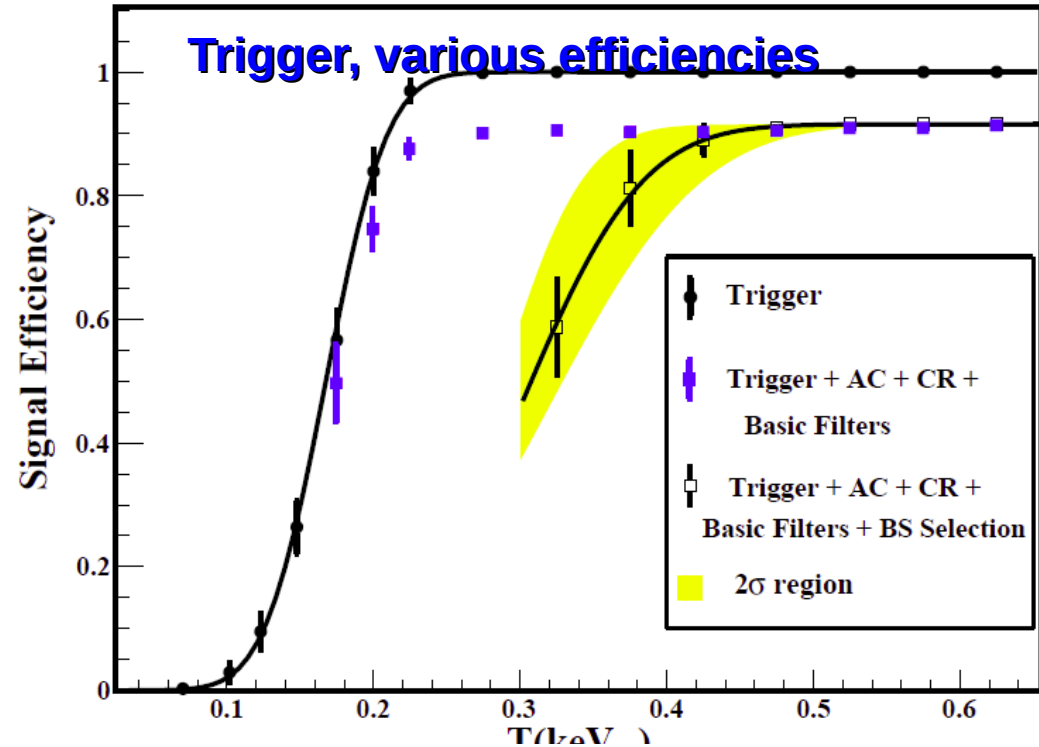
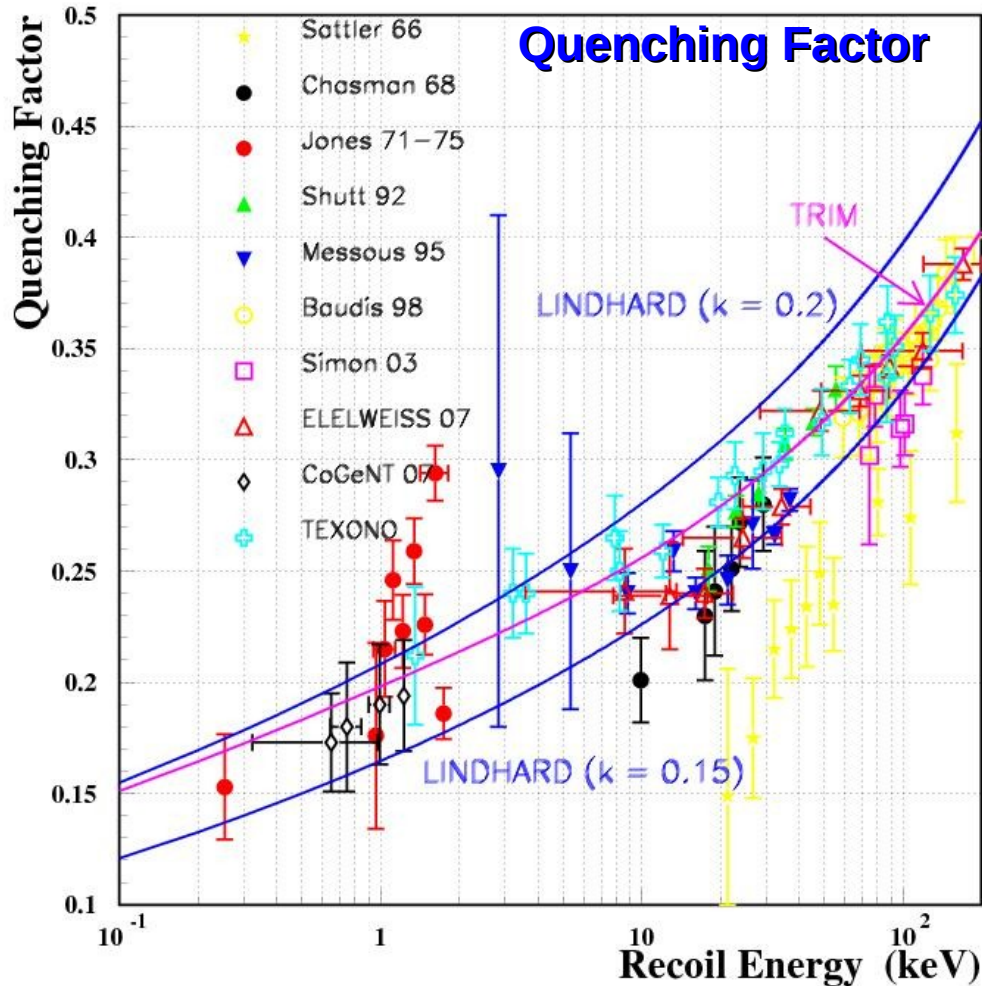
**ULEGe : ~g,
threshold ~100 eV**

Physics goals/challenge for sub-keV Ge Detectors

mass ~1kg : threshold ~few \times 100 eV : bgk ~few cpkkd

- Quenching Factors.
- Energy Definition & Calibration.
- Trigger Efficiencies near threshold.
- Physics vs. Noise Pulse-Shape Selection :
algorithms & efficiencies.
- Bulk vs. Surface Events Selection :
algorithms & efficiencies.
- Background understanding

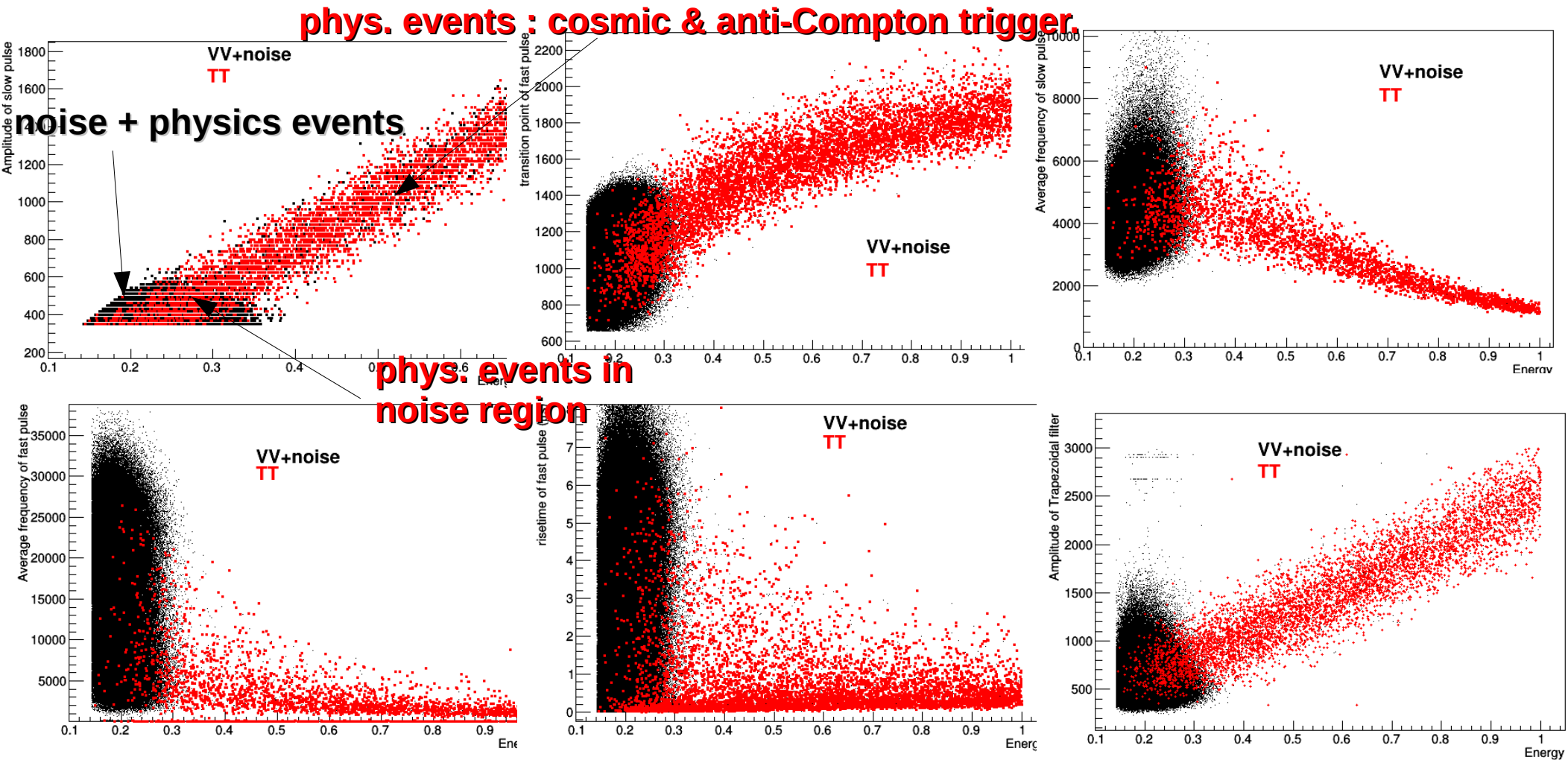
Challenge for sub-keV Ge



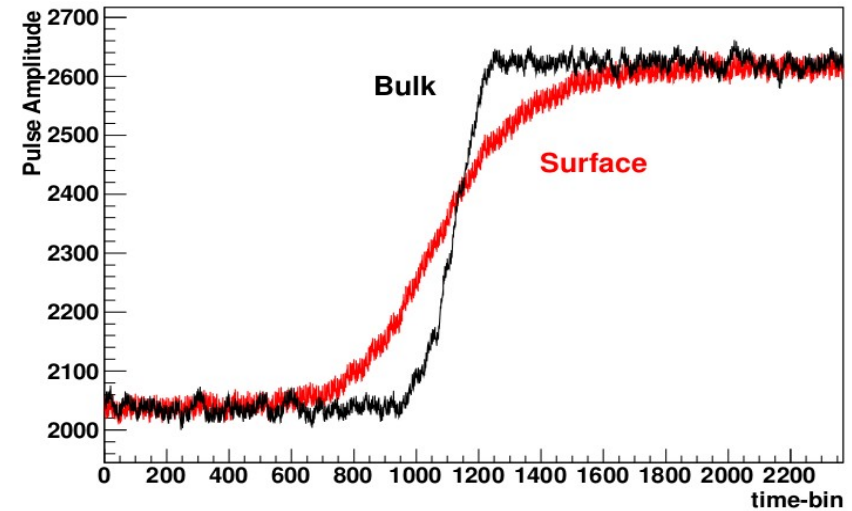
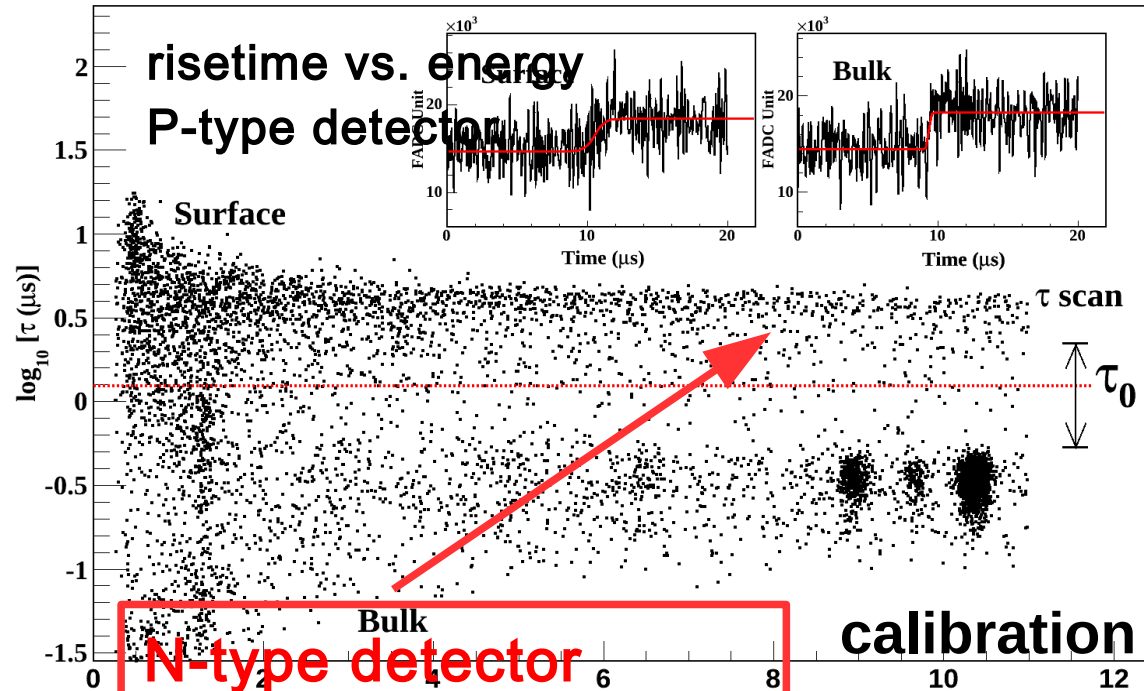
- Quenching factor at sub-keV are not well known.
- Energy and efficiencies should be measured/defined carefully at sub-keV range.
- non-linearity had been checked.

Challenge for sub-keV Ge

Physics events inside the noise region :
Machine Learning → physics/noise separation



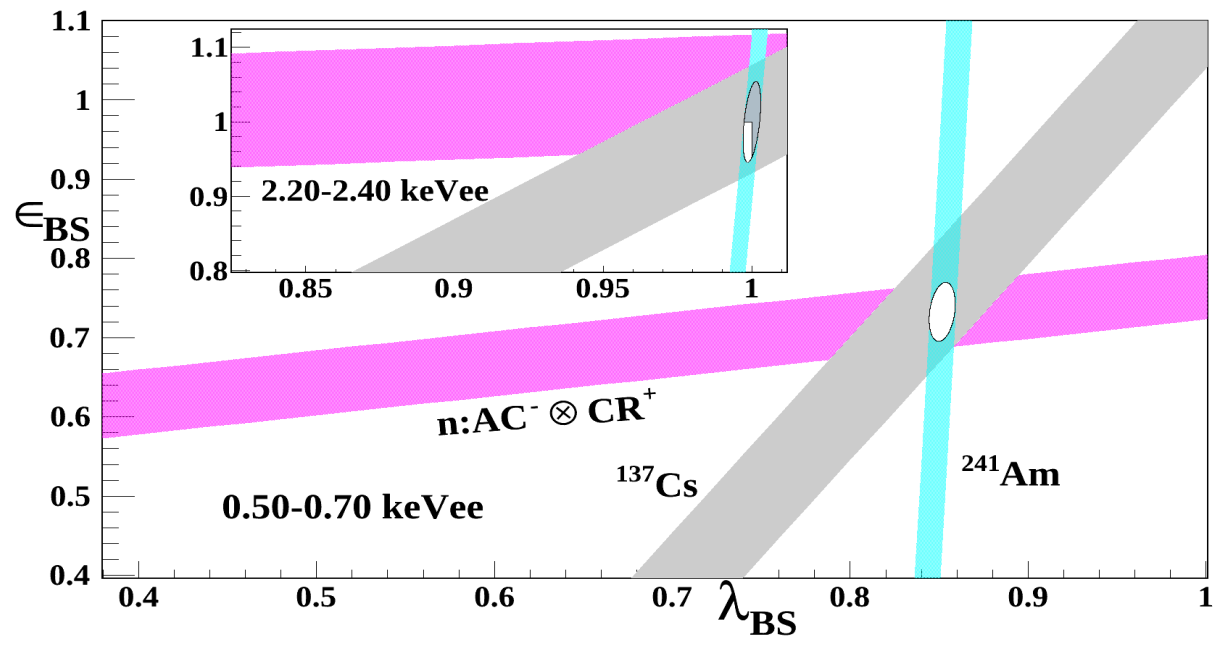
Bulk/Surface



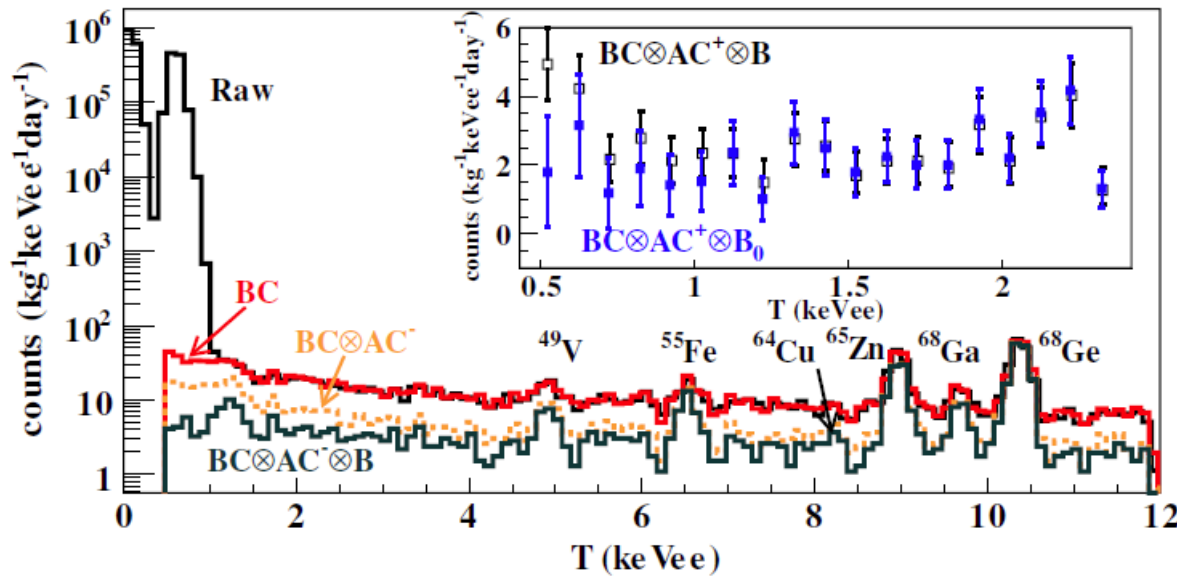
N-type detector
(submicron inactive surface layer)
do not show these
anomalous surface events

calibration : AC⁻ ⊗ CR⁺ in N-type, ²⁴¹Am, ¹³⁷Cs

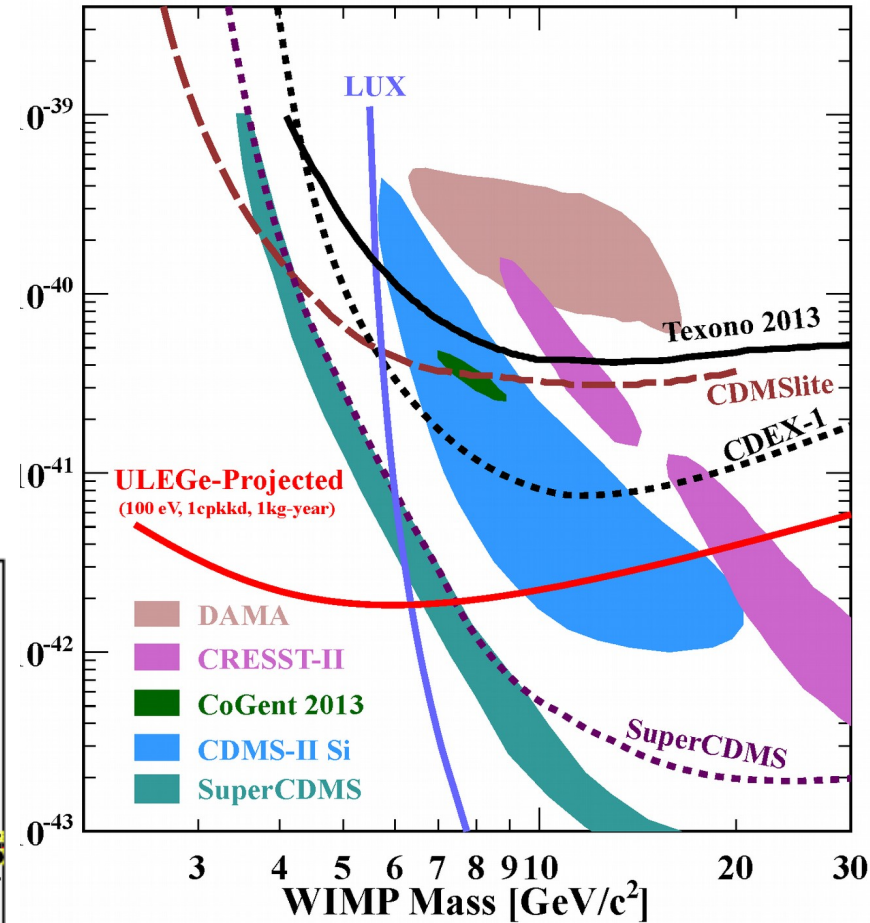
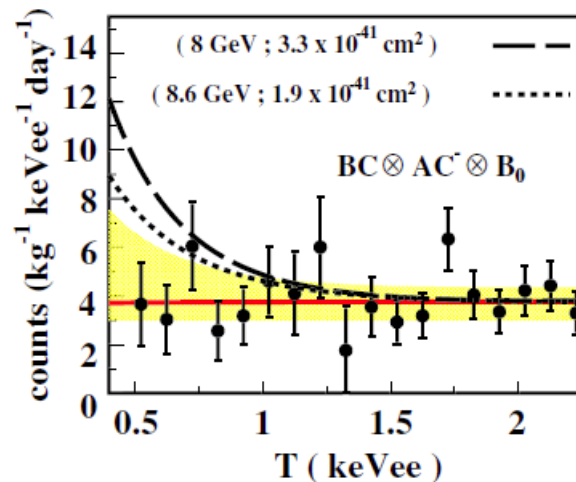
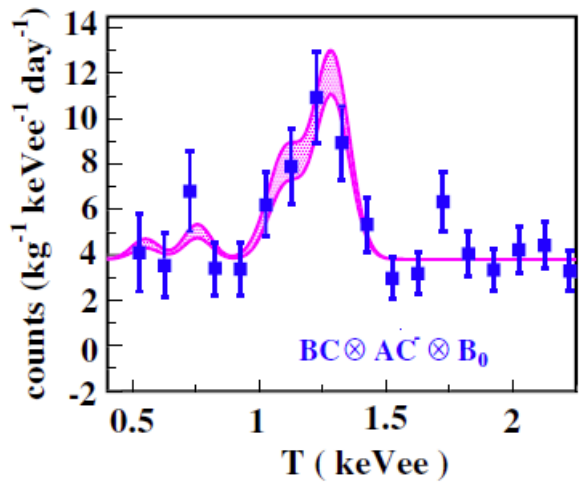
- efficiency ε
- leakage $1-\lambda$



Dark Matter Results at CJPL



(a)



see Qian Yue's talk
at Dark Matter session
for details.

- Establish a working scheme for B/S correction.
- Stable within different B/S cut, normalization scheme :
contribute to <5 % of total errors.

summary

- **Competitive results on light WIMPs with sub-keV Ge, even at a surface KSNL**
(same hardware underground gain x10 sensitivities)
- **Results on neutrino electromagnetic properties.**
- **Establish B/S calibration schemes.**
ongoing :
- **Background understanding.**
- **Detector properties near noise edge.**
- **Goal : νN coherent scattering,**
 ~ 100 eV threshold & \sim cpkkd