TEXONO program on Neutrino and Dark Matter Physics

- Overview
- Physics programs
- Challenge for sub-keV
- Dark Matter search.
- Summary

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on behalf of TEXONO Collaboration

2016 Mar 29

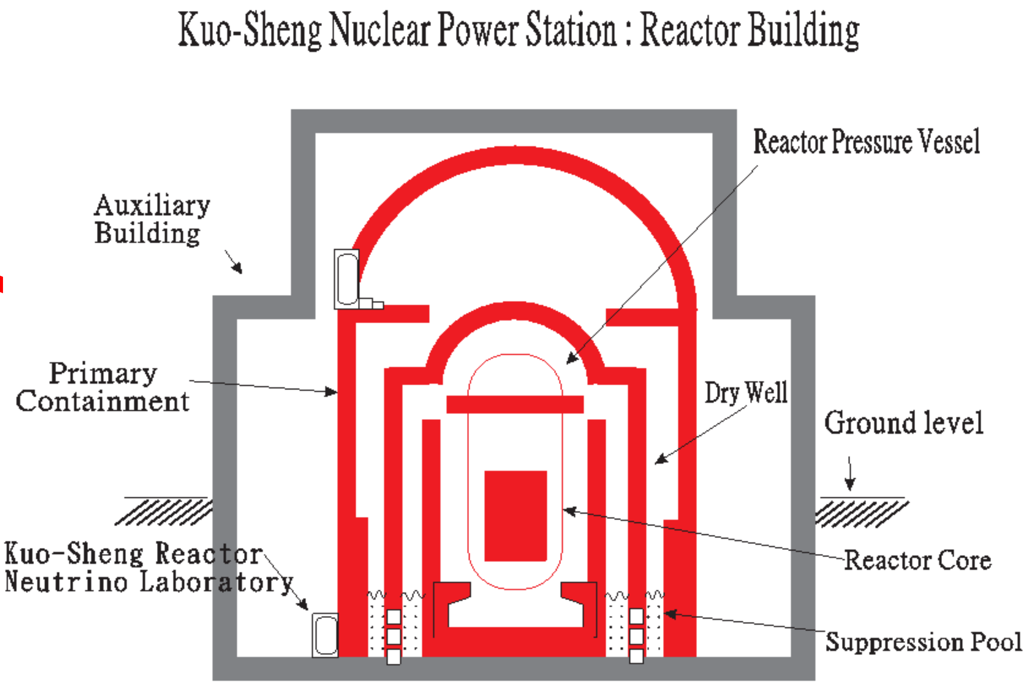
TEXONO Collaboration

TEXONO Taiwan EXperiment On NeutrinO (since 1997)

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

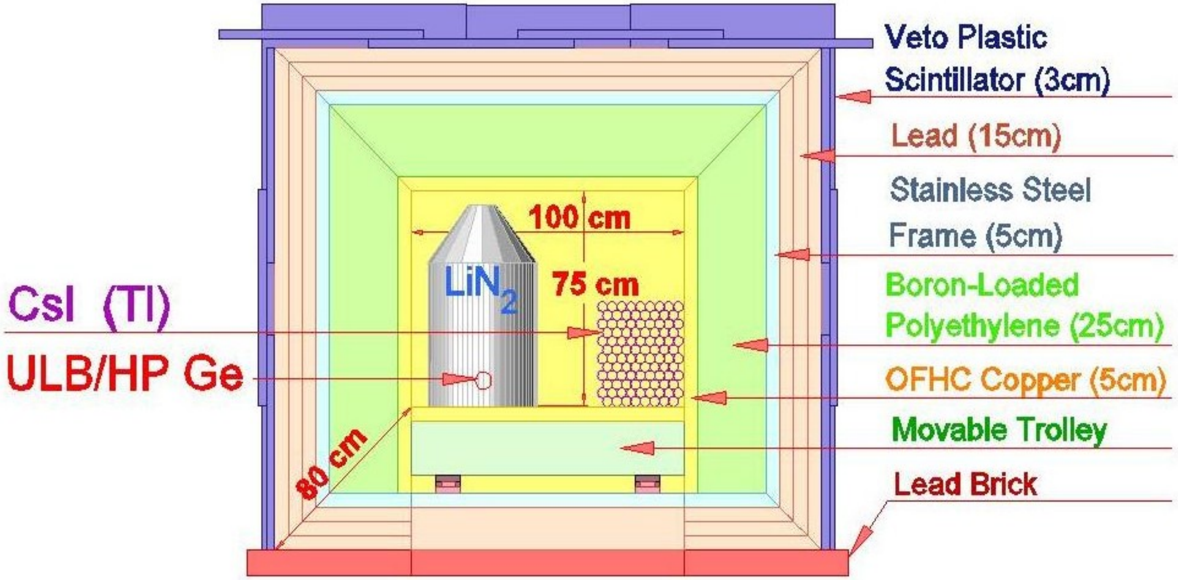
- **Taiwan (AS, INER, KSNPS)**
- **Turkey (METU, DEU)**
- **India (BHU)**

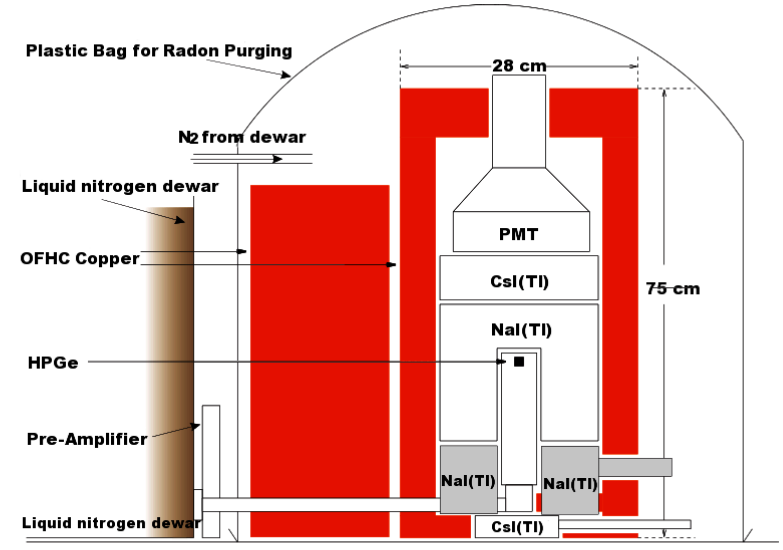
Kuo Sheng Reactor Neutrino Laboratory



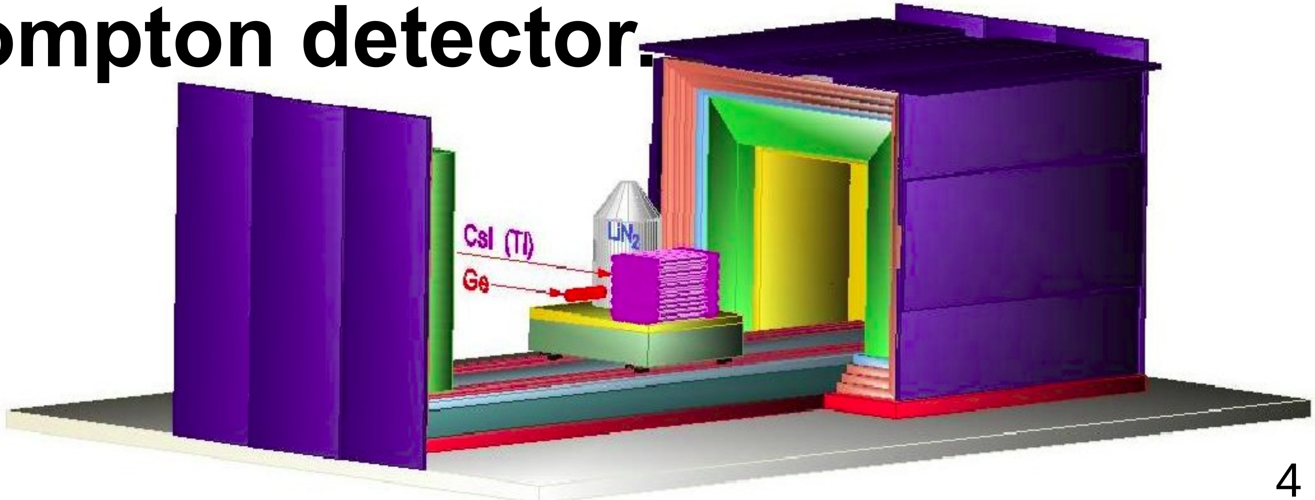
- 2 reactor core, 2 GW.
- Lab. : 28 m from nearest core.
- 30mwe concrete over burden.

Kuo Sheng Reactor Neutrino Laboratory

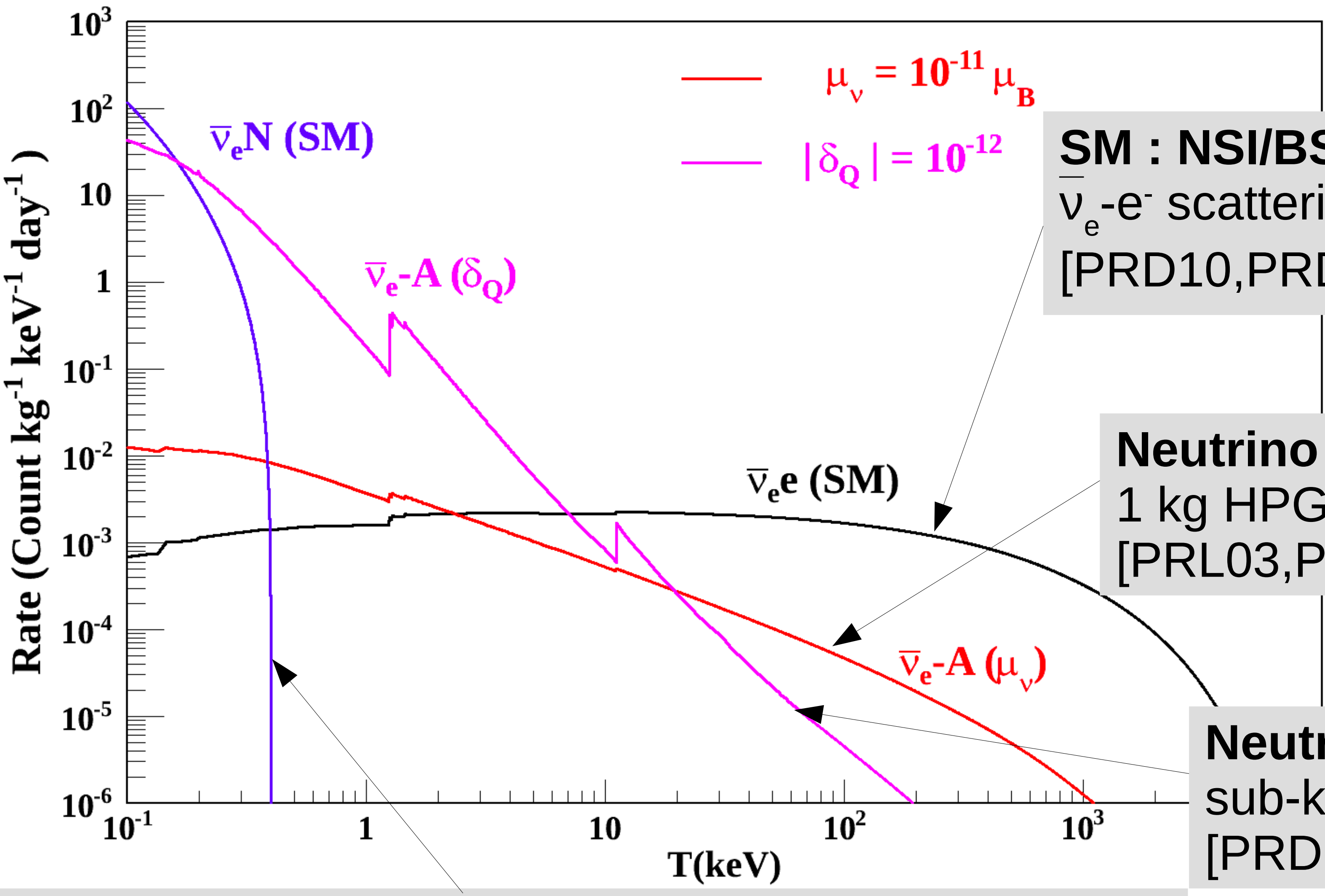




- Active cosmic shielding with plastic scintillator.
- NaI(Tl) as anti-Compton detector.
- Flexible design.



TEXONO 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]

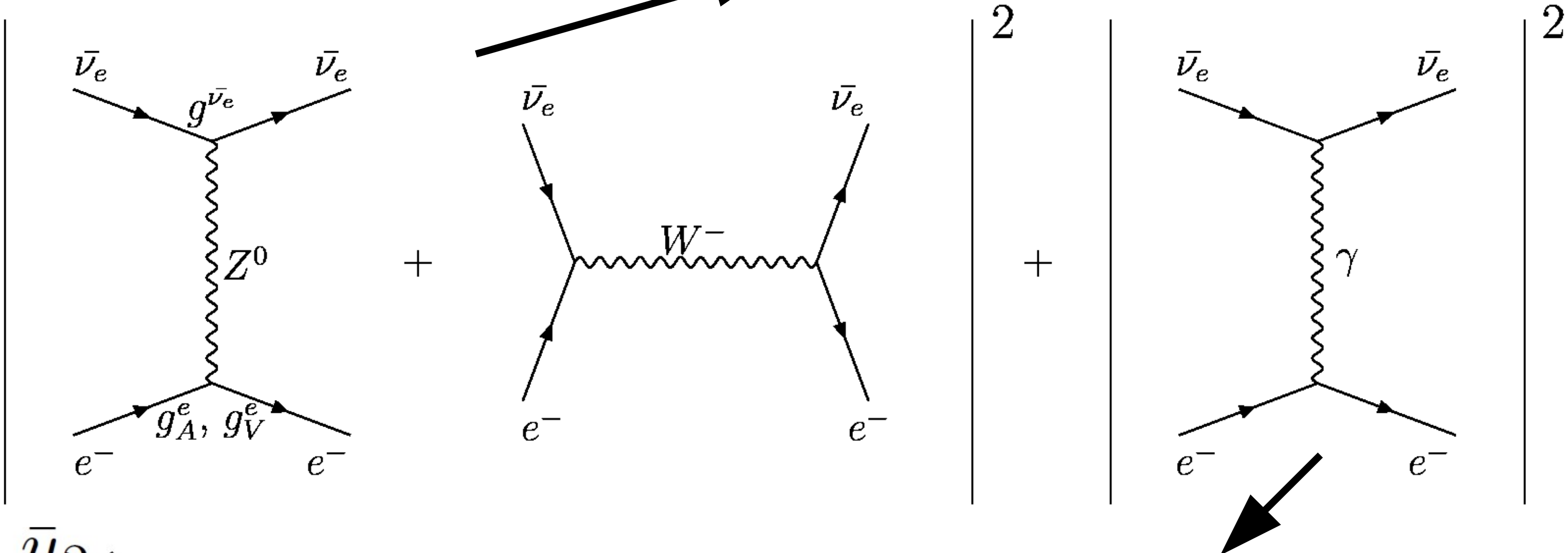
Neutrino milli-charge
sub-keV ULEGe, PCGe
[PRD14]

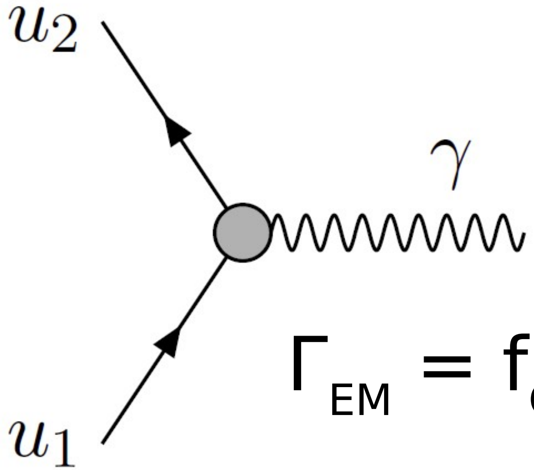
ν-Nuclei Coherent Scattering [goal]
sub-keV ULGe, PCGe
Dark Matter Searches at KSNL [PRD09,PRL13,AP14]
CDEX at CJPL [PRD13,PRD14,PRD14]

neutrino electron scattering

differential cross-section for $\bar{\nu}_e e^-$ scattering(standard model)
(T: recoild e^- energy):

$$\left(\frac{d\sigma}{dT}\right)_{SM}=\frac{G_F^2 m_e}{2\pi}\left[(g_V-g_A)^2+(g_V+g_A)^2\left(1-\frac{T}{E_\nu}\right)^2+(g_A^2-g_V^2)\frac{m_e T}{E_\nu^2}\right]$$





f_Q : charge
f_M : magnetic dipole moment
f_E : electric dipole moment

$$\Gamma_{EM} = f_Q\gamma_\mu + f_M i\delta_{\mu\nu}q^\nu + f_E\delta_{\mu\nu}q^\nu\gamma_5 + f_A(q^2\gamma_\mu - q_\mu \not{q})\gamma^5$$

neutrino magnetic moment

magnetic moment $\mu_{\nu e}$= flavors mixing of $|f_M - f_E|^2$

minimum extended standard model:

$\mu_\nu \sim 10^{-19}$ $(m_\nu/1eV)$ μ_B

present lab. sensitivities ~ 10^{-12}-10^{-11} μ_B

differential cross-section for magnetic moment(free electron):

$$\left(\frac{d\sigma}{dT}\right)_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left(\frac{1}{T} - \frac{1}{E_\nu}\right)$$

~ 1/T while (dσ/dT)SM ~ constant.

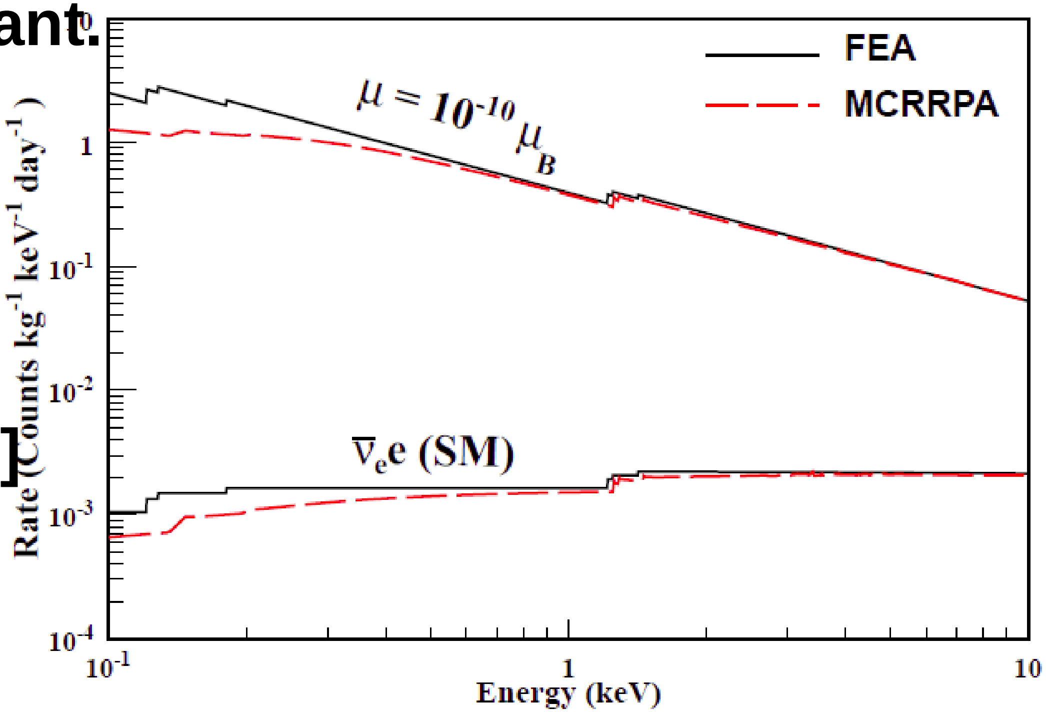
<u>enhanced in low recoil energy</u>

<u>FEA</u> : free electrons

<u>MCRRPA</u> (atomic electrons):

multi-configuration relativistic

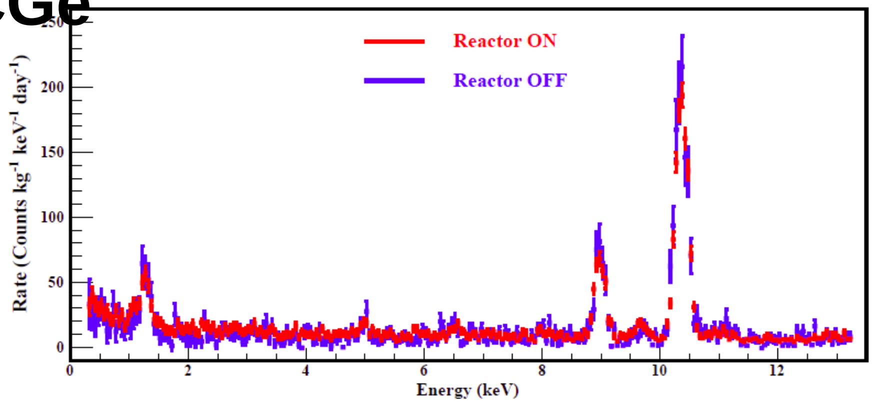
random-phase approx. [PRD14]

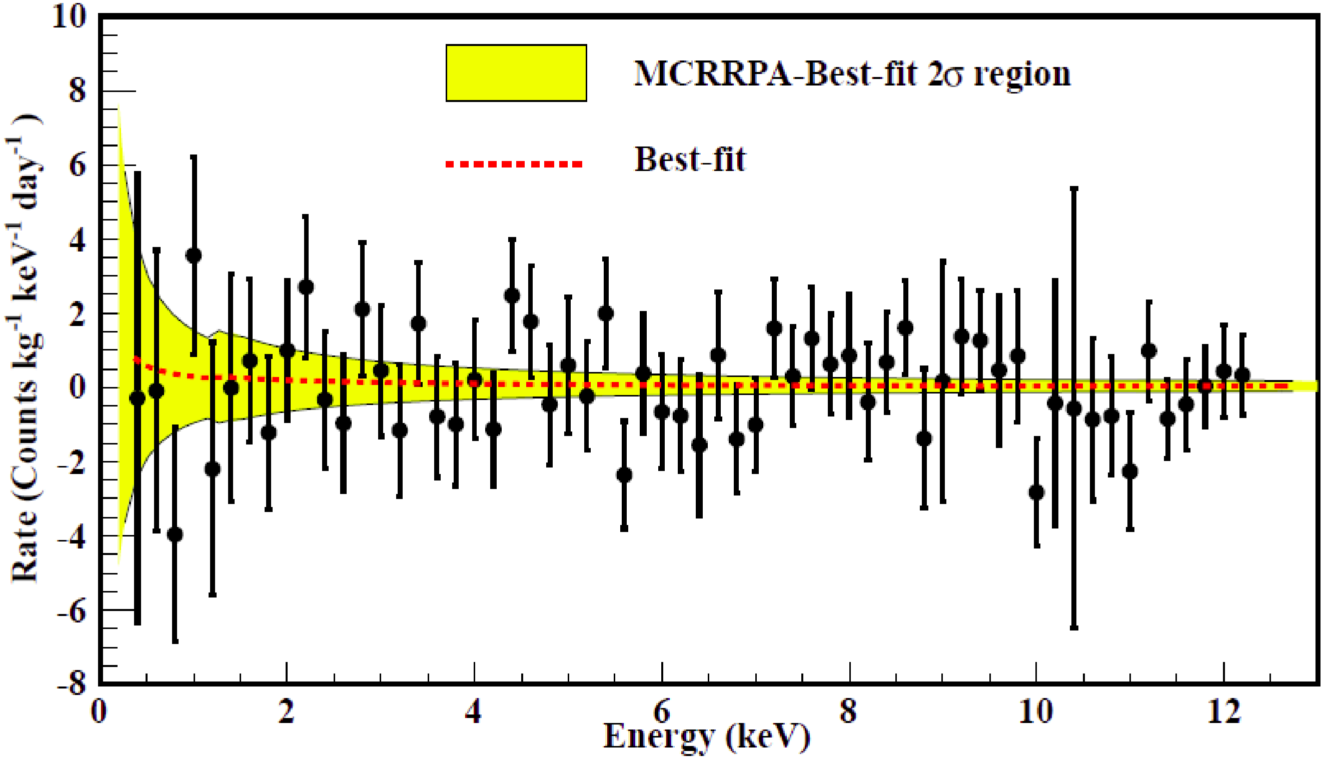


neutrino magnetic moment

data ON/OFF ~ 130days/70days
detector : 3 Ge detector, n-PCGe, p-PCGe
threshold ~ 0.3 keV, 0.5 keV.

$\mu_\nu < 1.7 \times 10^{-10}\ \mu_B$
(at 90 % C. L.)



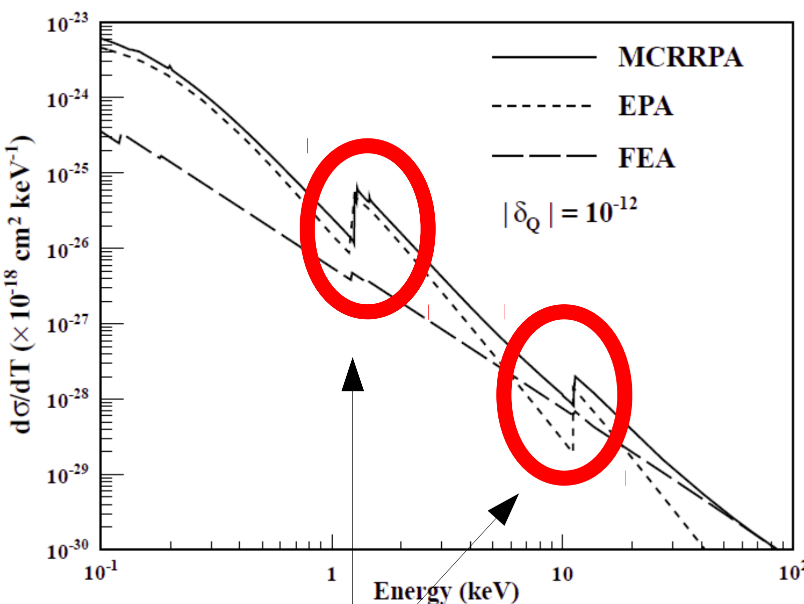


neutrino milli-charge

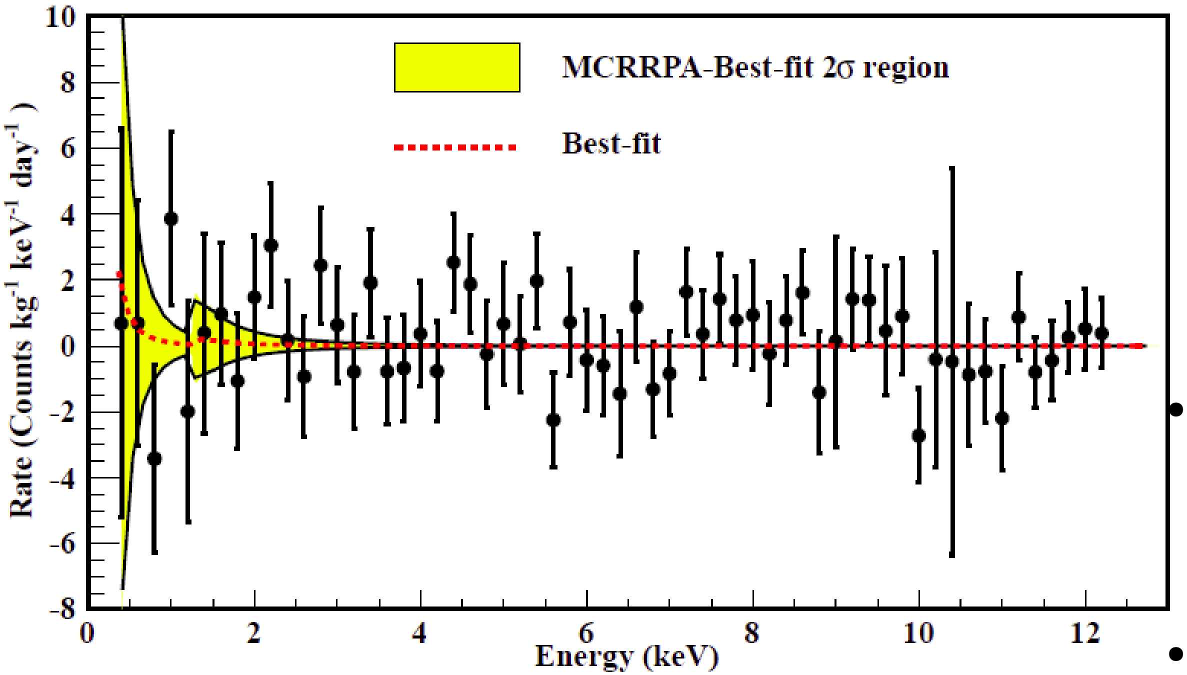
free electron :

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

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



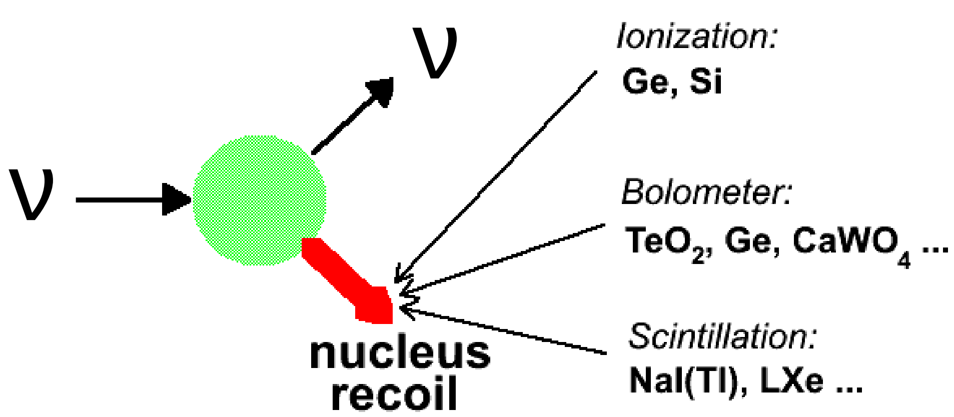
- positive signals : known K/L ratio (different from cosmic-activation electron-capture background)
- goal $\delta_Q \sim 10^{-14}$e at 100 eV threshold

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

νN coherent scattering

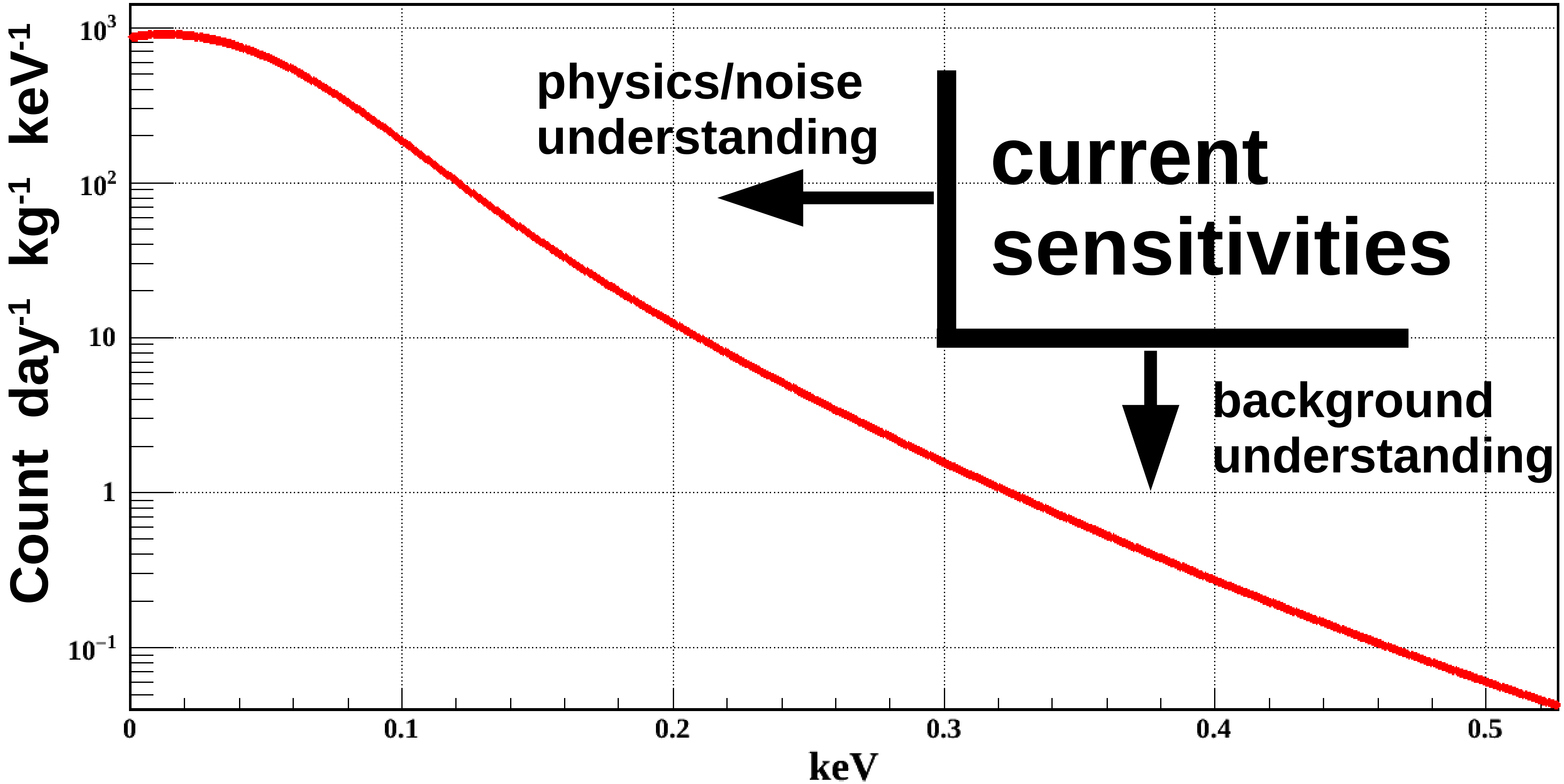
- ν+A→ν+A : Never been experimental observed.
- $$\frac{d\sigma}{dT} = \frac{G_F^2}{m_N}\left[\left(1 - 4sin^2\theta_W\right) - N\right]^2\left[1 - \frac{m_N T_N}{2E^2}\right]$$
- Neutral current process.
- $\sigma \propto N^2$ for E_ν<50MeV (Coherent)
- sensitive probe for BSM
- reactor monitoring
- important process in stellar collapse & supernova explosion
- for reactor neutrino on Ge, T_{max} ~ 2 keV

  T_{max} ~ 500 eV after Q. F. ~ 0.2



νN coherent scattering

estimated events rate at KSNL



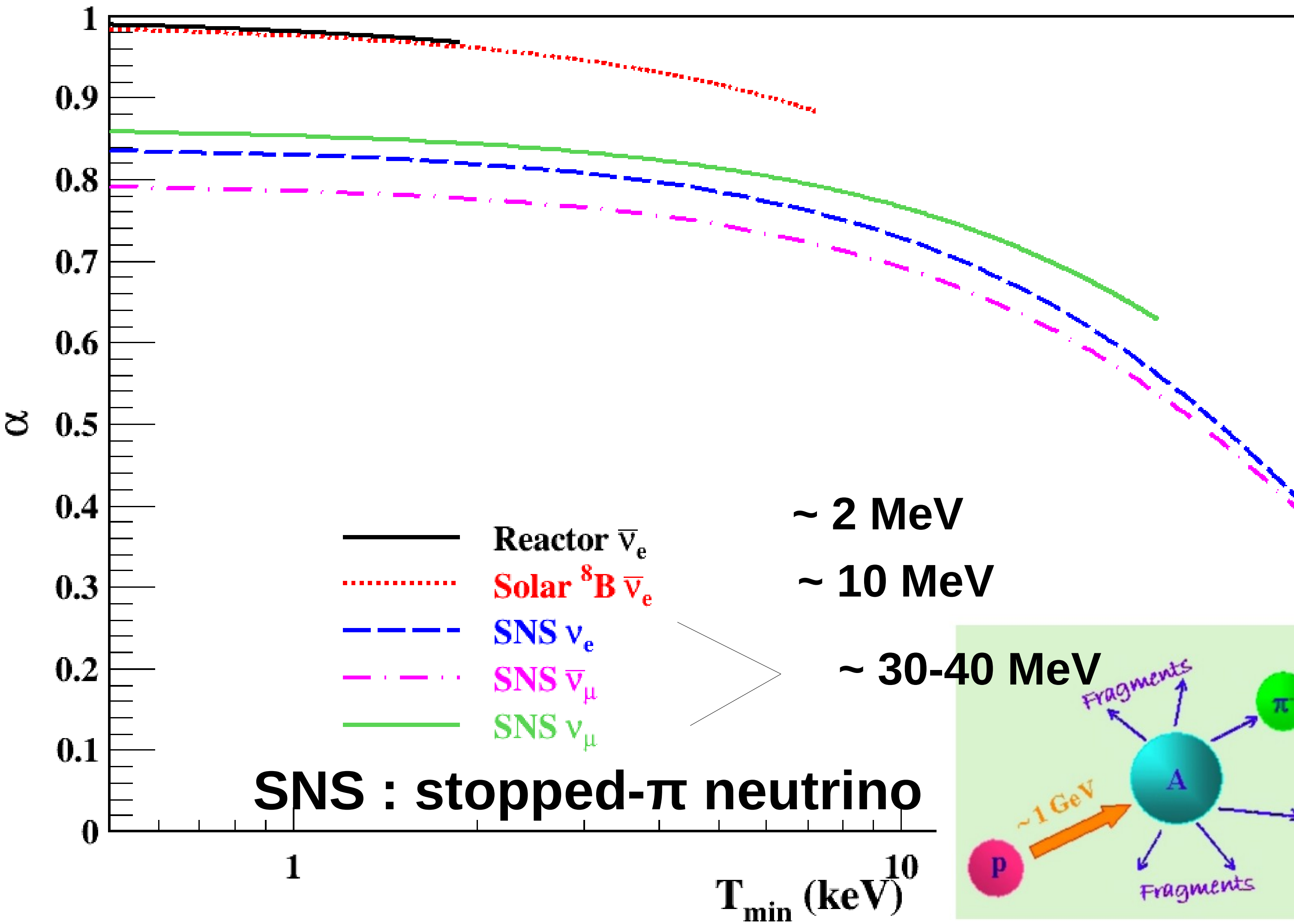
integral events rate(with energy resolution) :

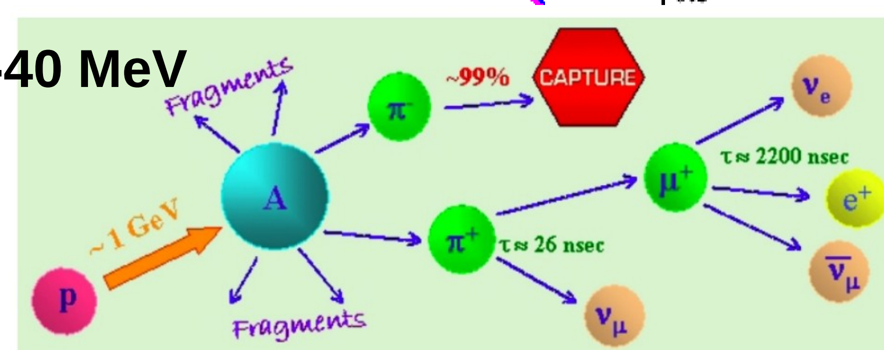
6.6 count day^{-1} kg^{-1} at 100 eV threshold

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

coherency of νN scattering

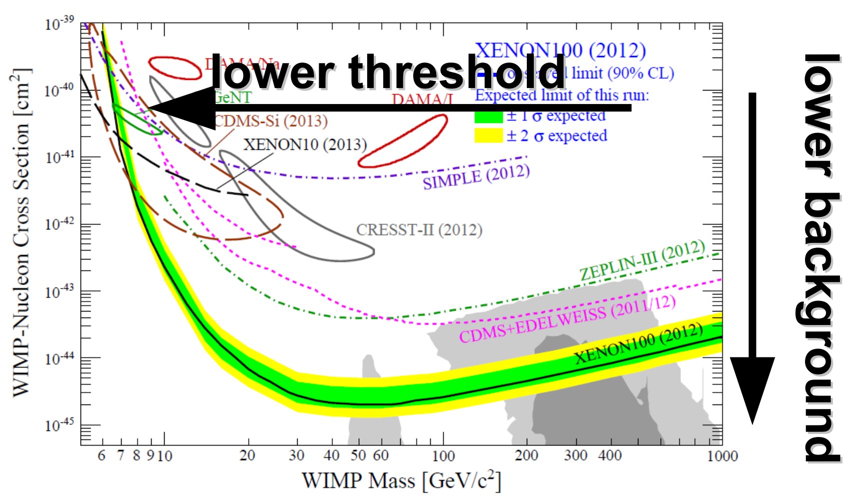
when wavelength of ν > nuclei size, σ ∝ N^2
when wavelength < nuclei size, σ ∝ N
$\sigma(Z,N)/\sigma(\text{neutron}) \sim \ \ldots + (1-\alpha)N + \alpha N^2$



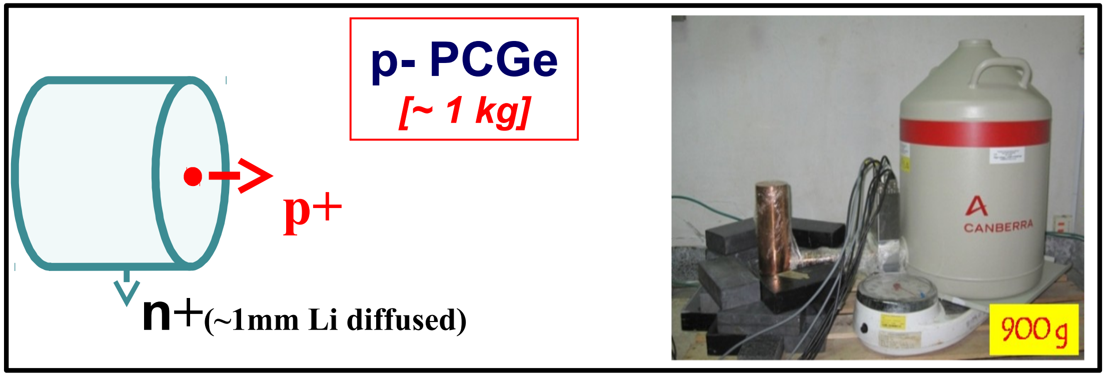


why Ge detector?

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

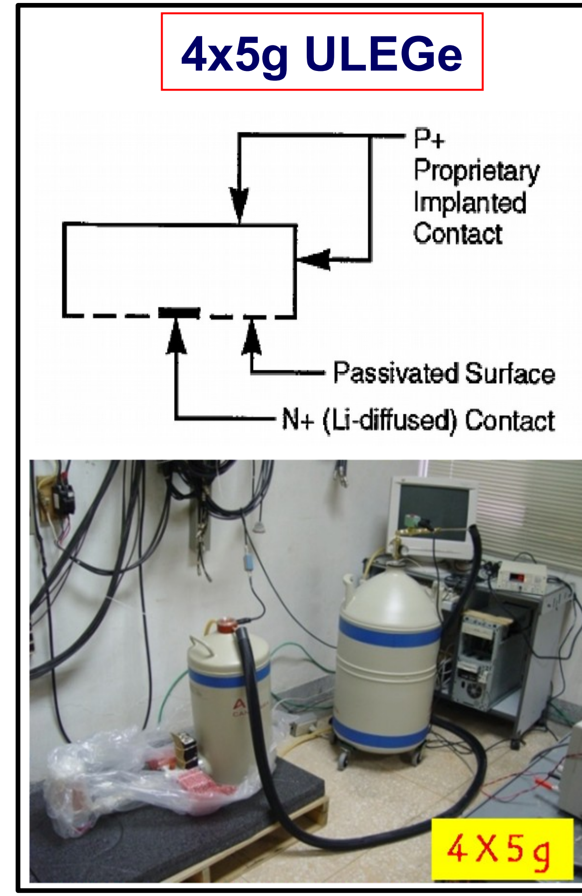


Various Ge detectors



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

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



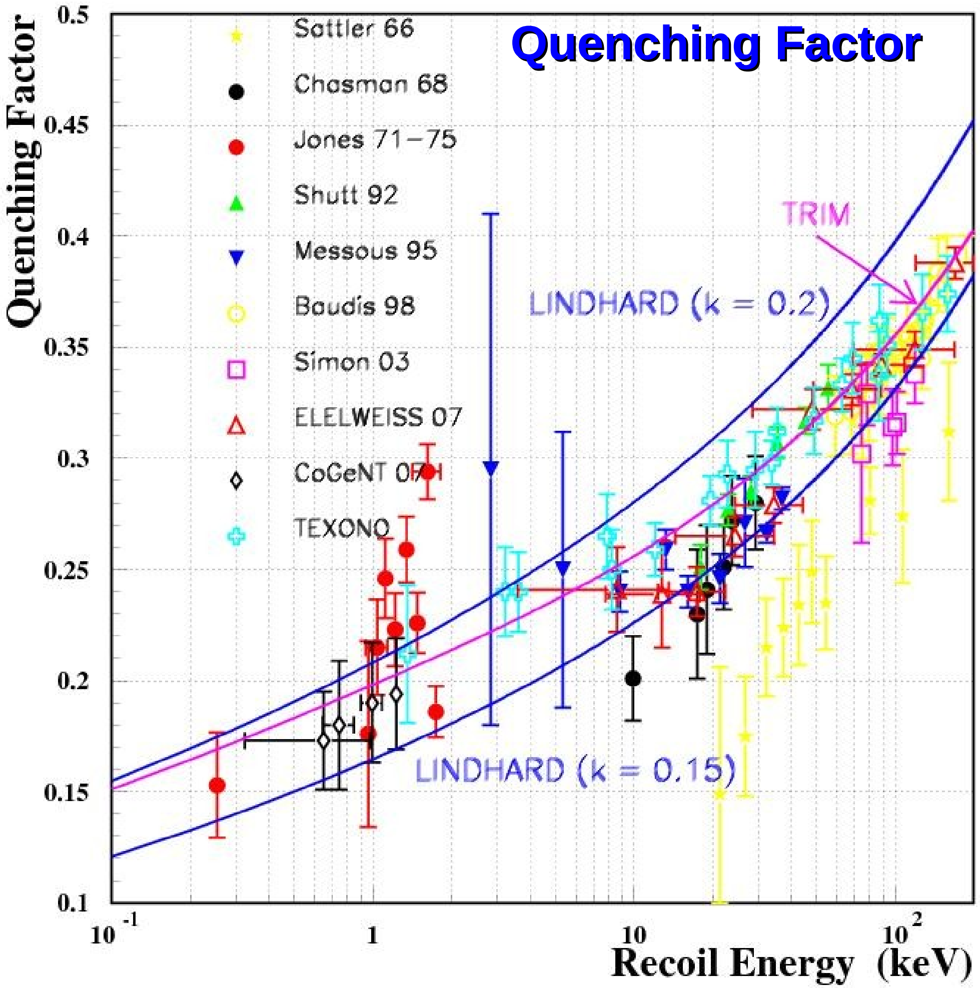
ULEGe : ~g, threshold ~100 eV

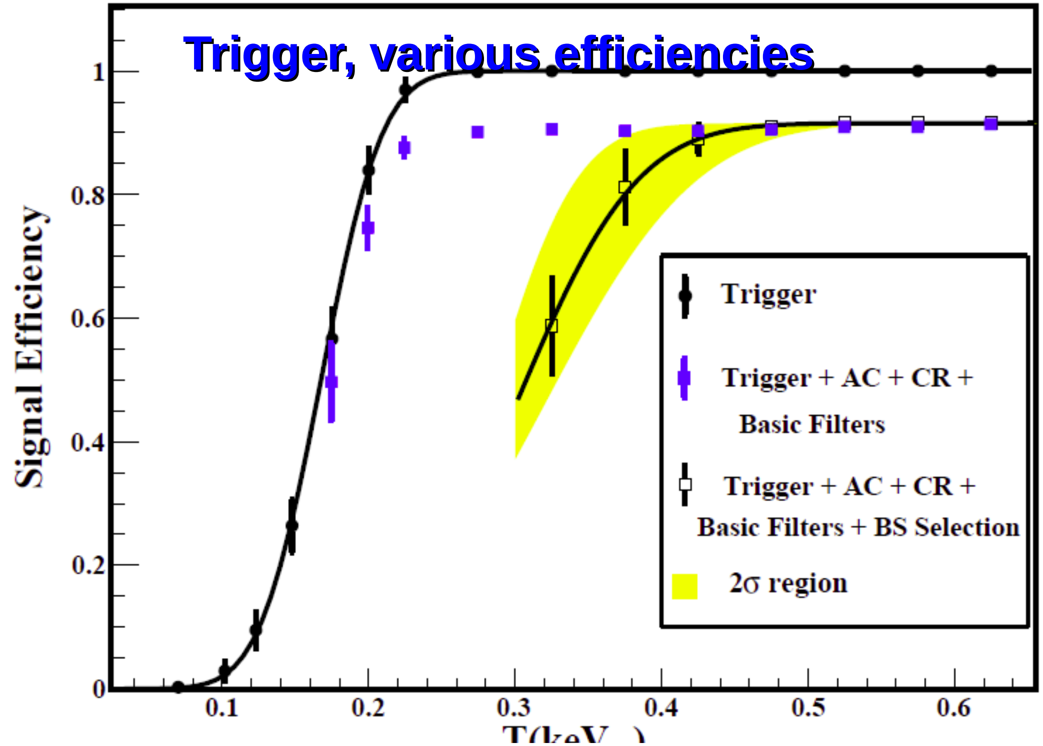
Physics goals/challenge for sub-keV Ge Detectors

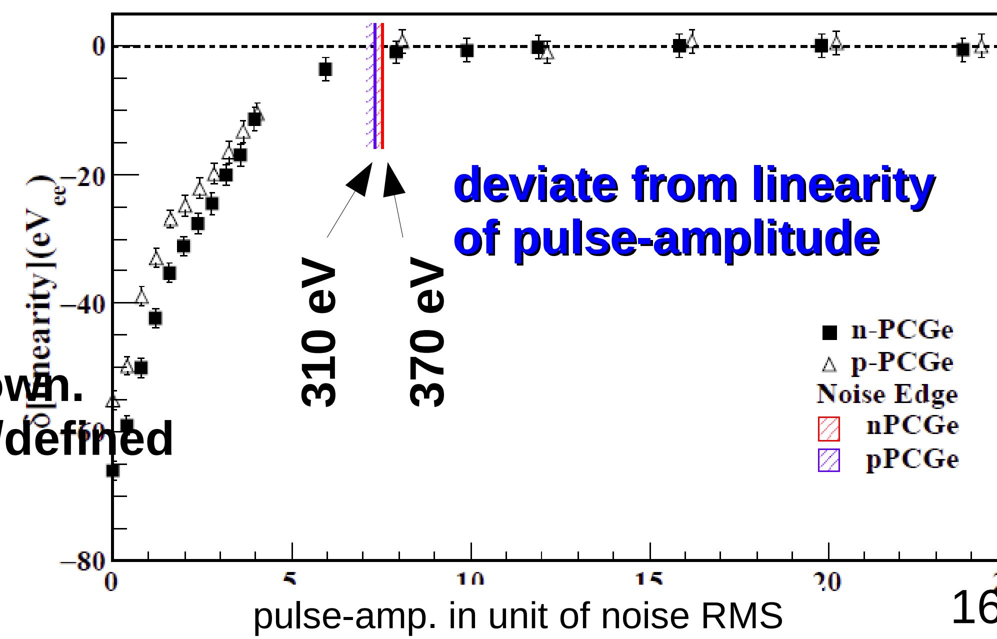
mass ~1kg : threshold ~few×100 eV : bgk ~few cpkkd

- 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





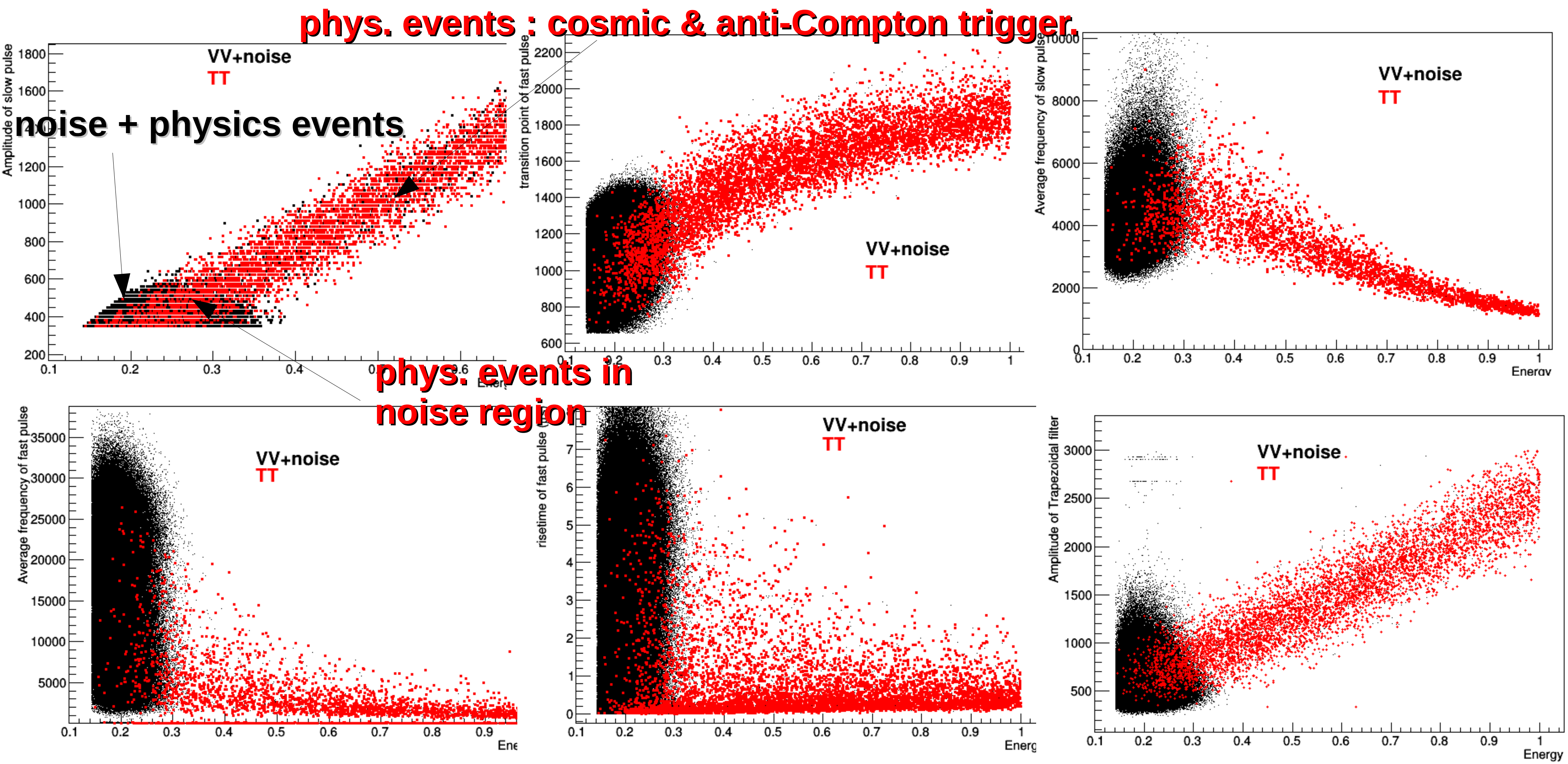


- Quenching factor at sub-keV are not well known.
- Energy and efficiencies should be measured/defined carefully at sub-keV range.
- non-linearity had been checked.

Challenge for sub-keV Ge

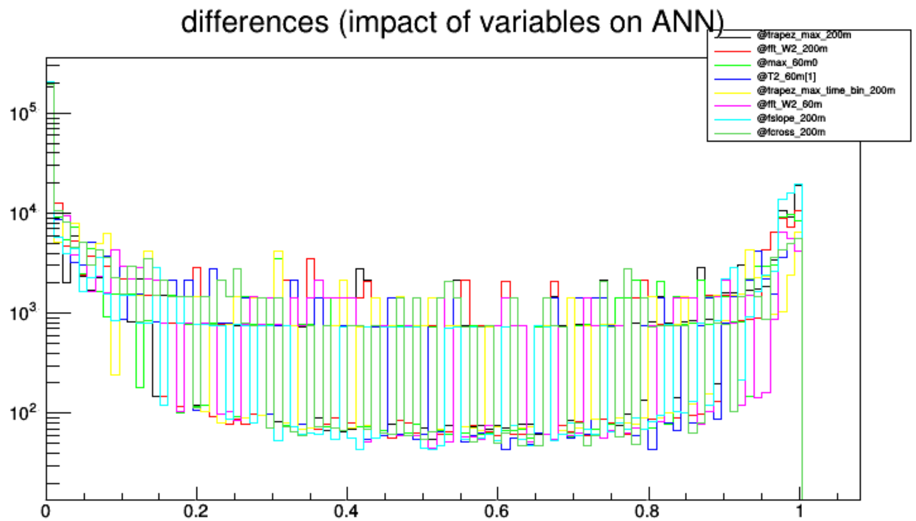
Physics events inside the noise region :

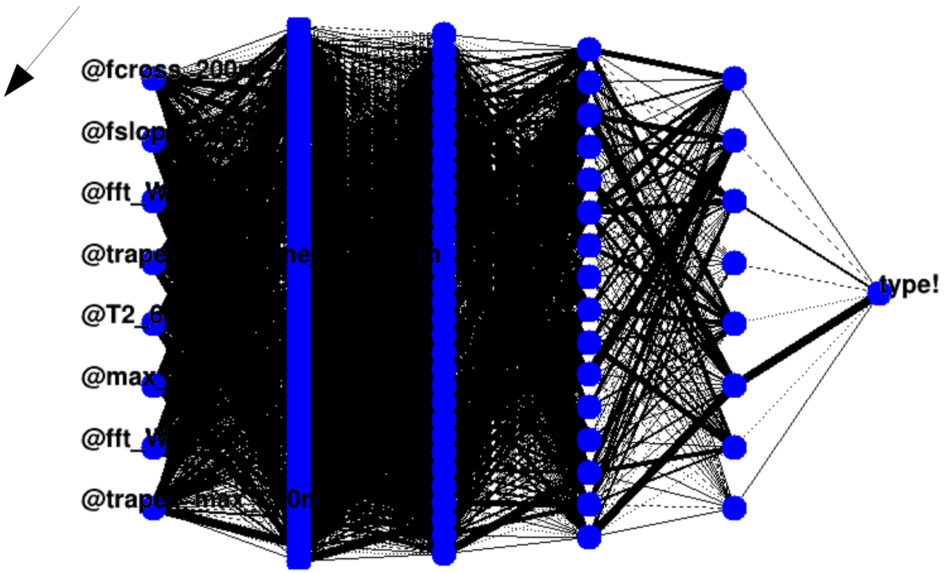
Machine Learning →physics/noise separation

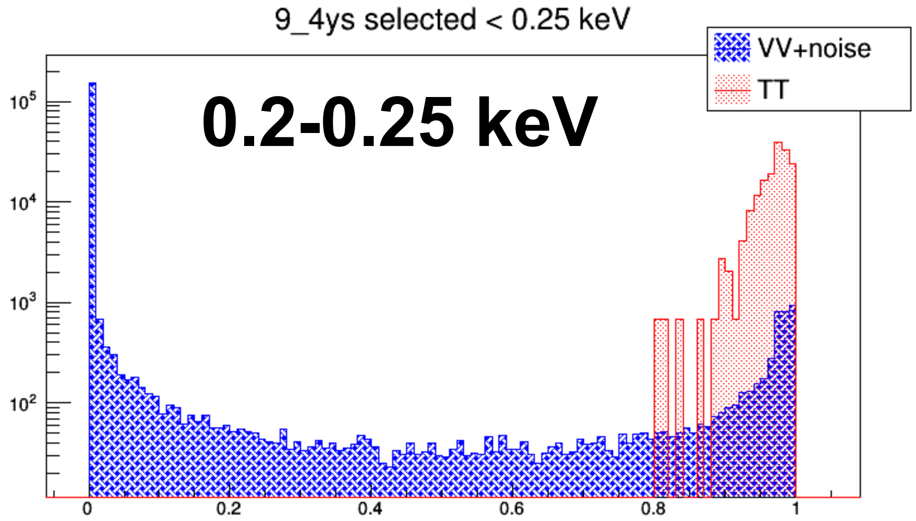


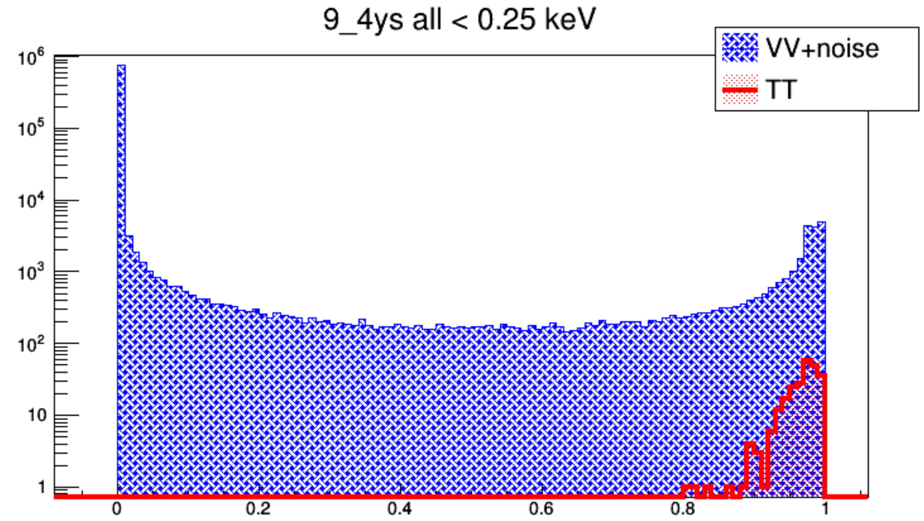
neural-network : n-PCGe

one of the NN results

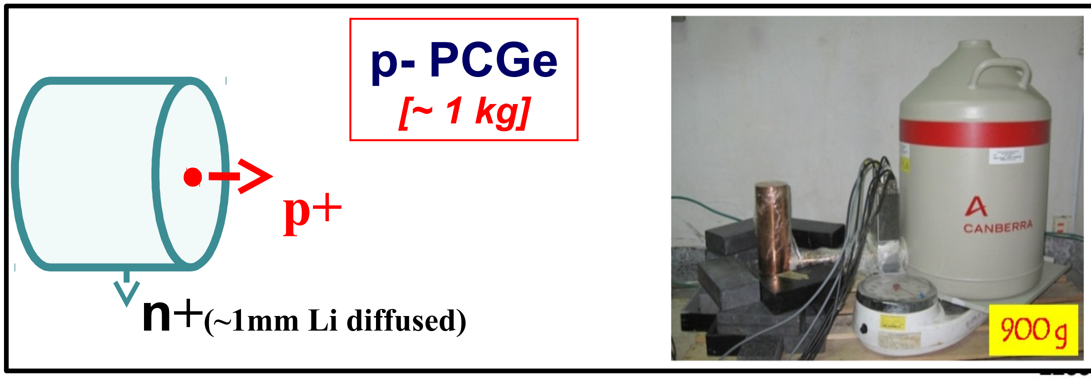


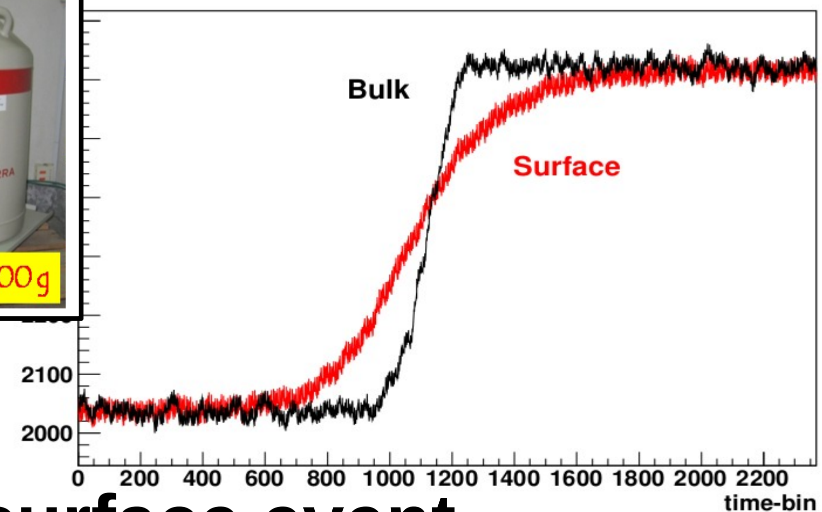




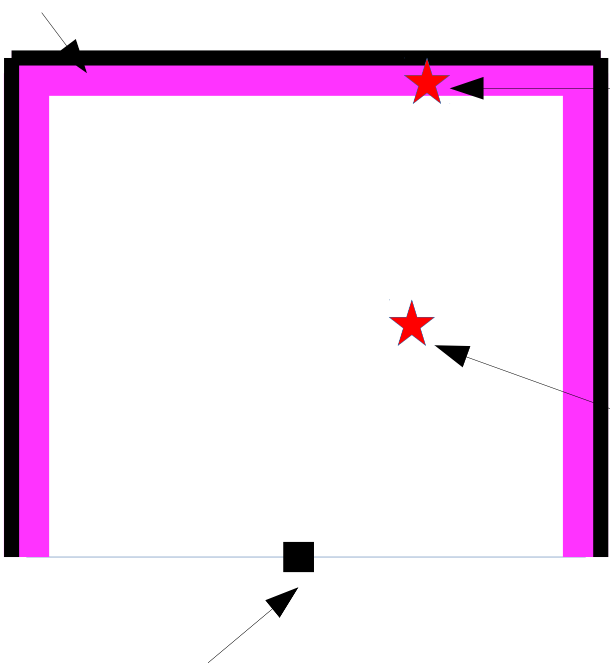


ppc-Ge detector





n+ Li diffused



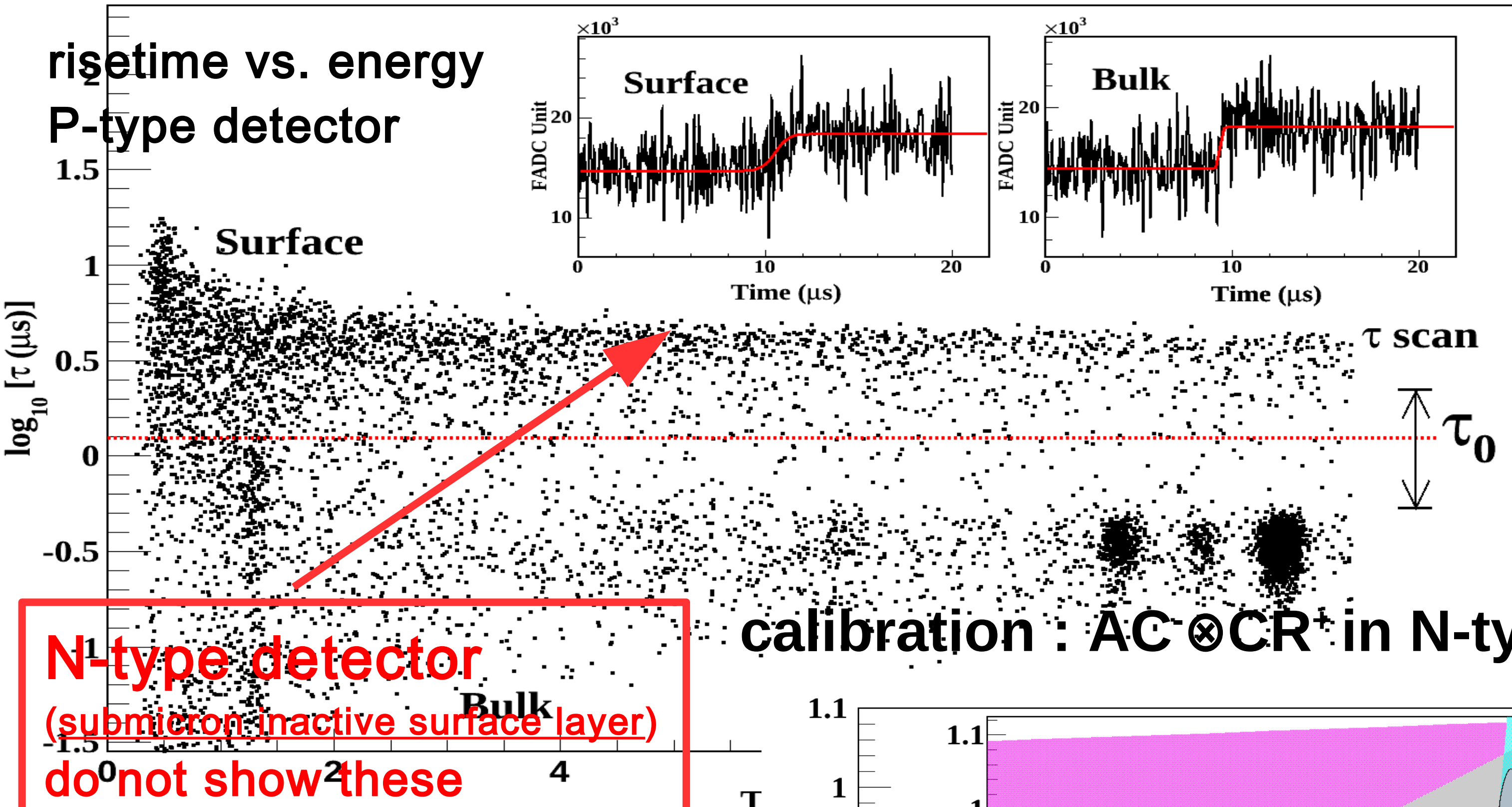
p+

surface event
slow pulse
partial energy deposit

bulk event
fast pulse
full energy deposit

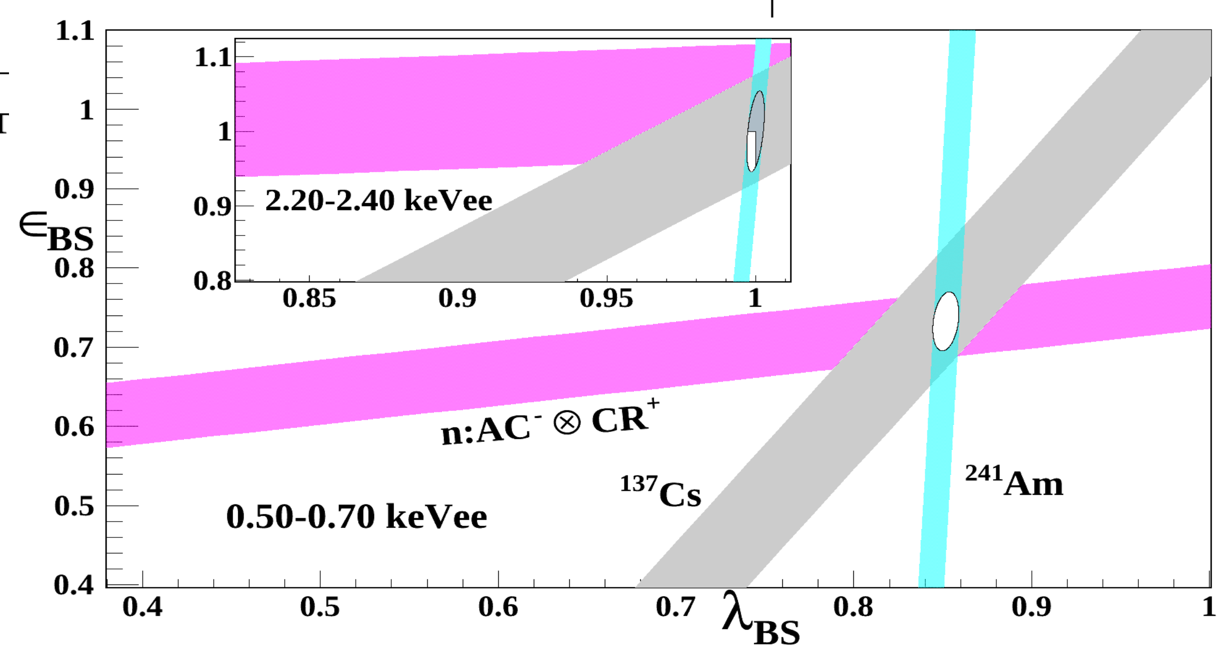
Bulk/Surface

risetime vs. energy
P-type detector



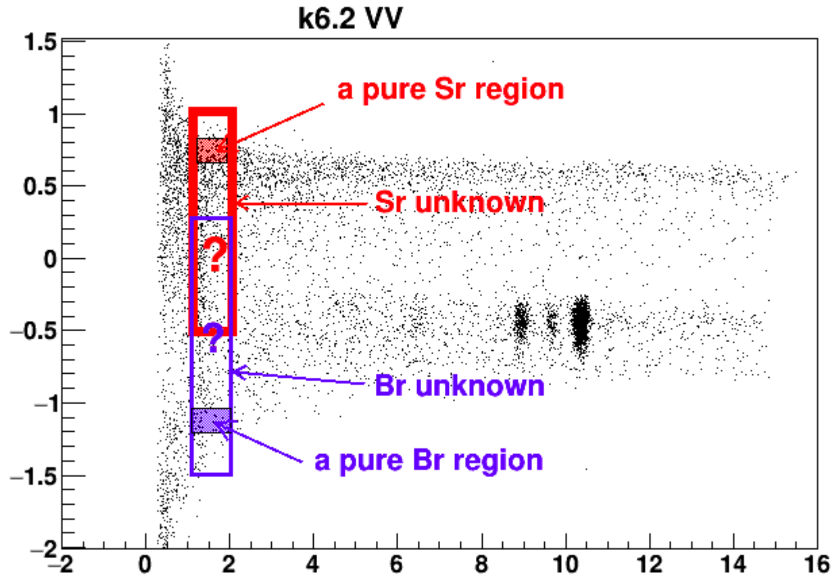
N-type detector
(submicron inactive surface layer)
do not show these anomalous surface events

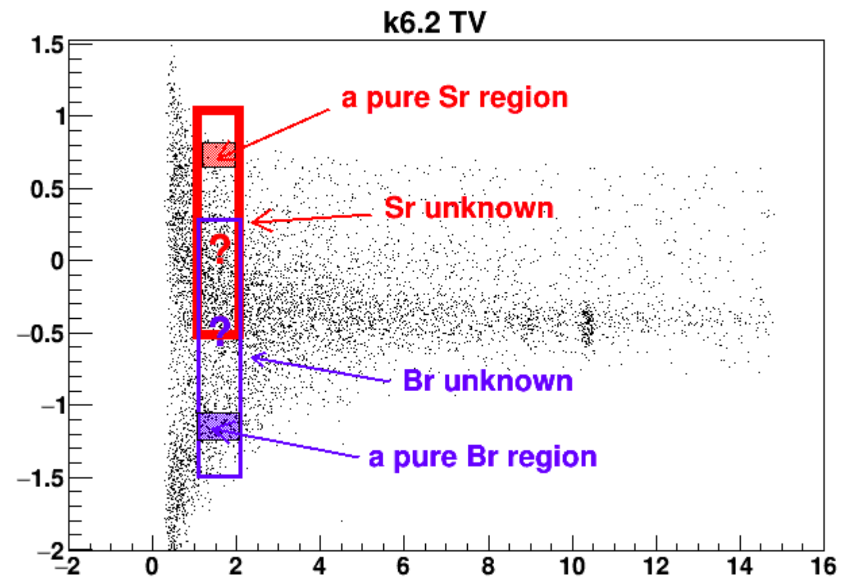
calibration : $AC^- \otimes CR^+$ in N-type, ^{241}Am, ^{137}Cs



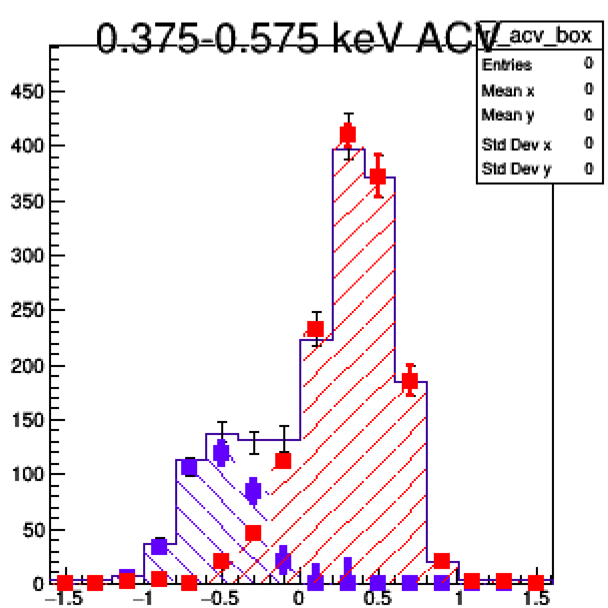
- efficiency ε
- leakage 1-λ

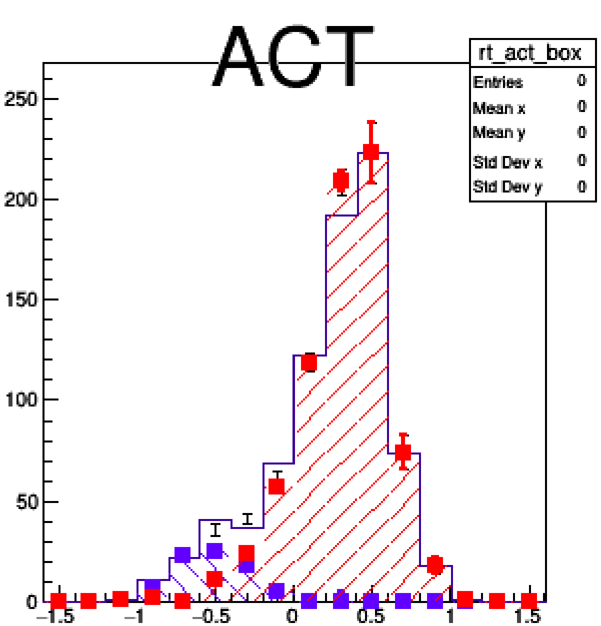
Bulk/Surface : a better way (developing)

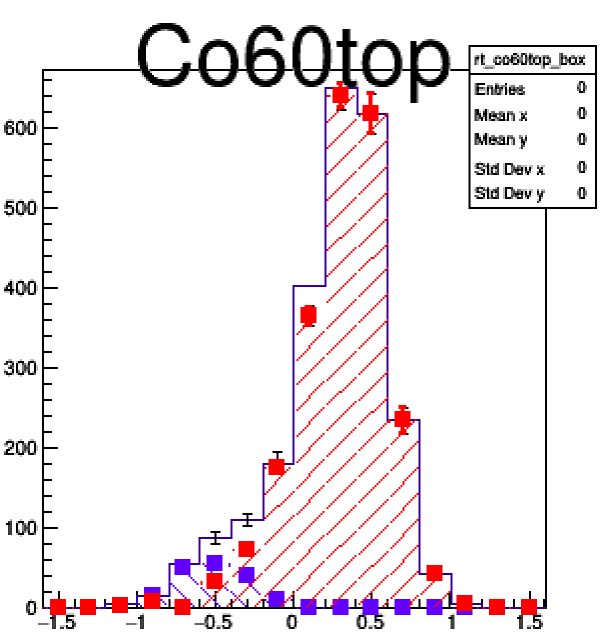




using bulk-ratio and surface ratio to solve the distribution :

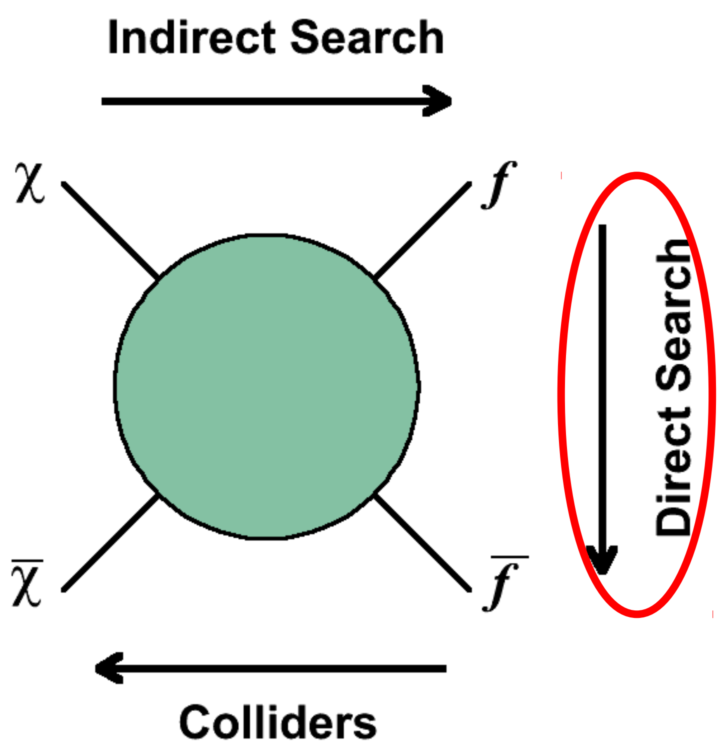


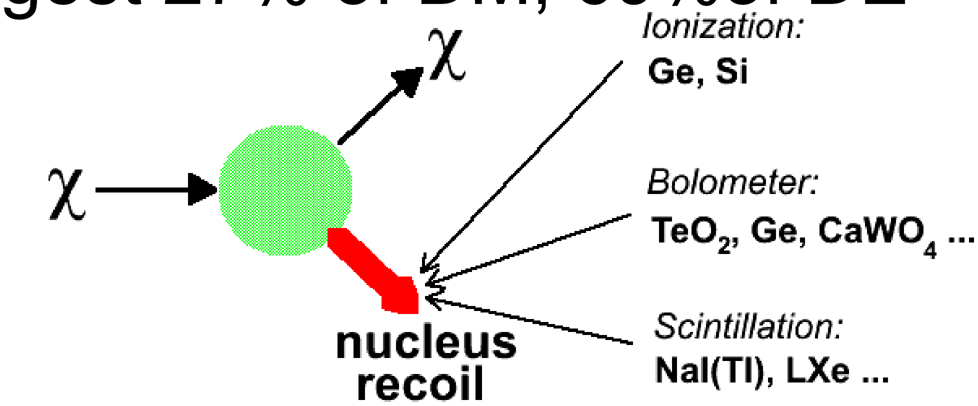




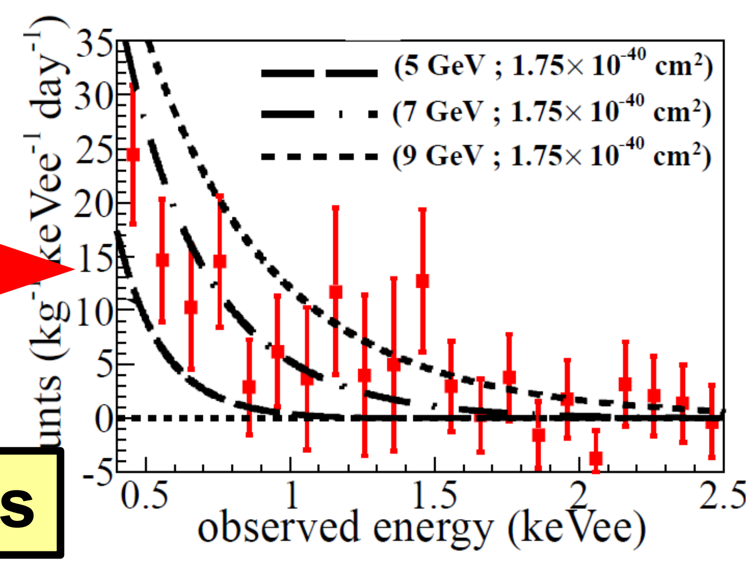
Dark Matter : Direct Search

- Various astronomical/cosmological observations suggest Dark Matter, Planck-2013 suggest 27% of DM, 69%of DE





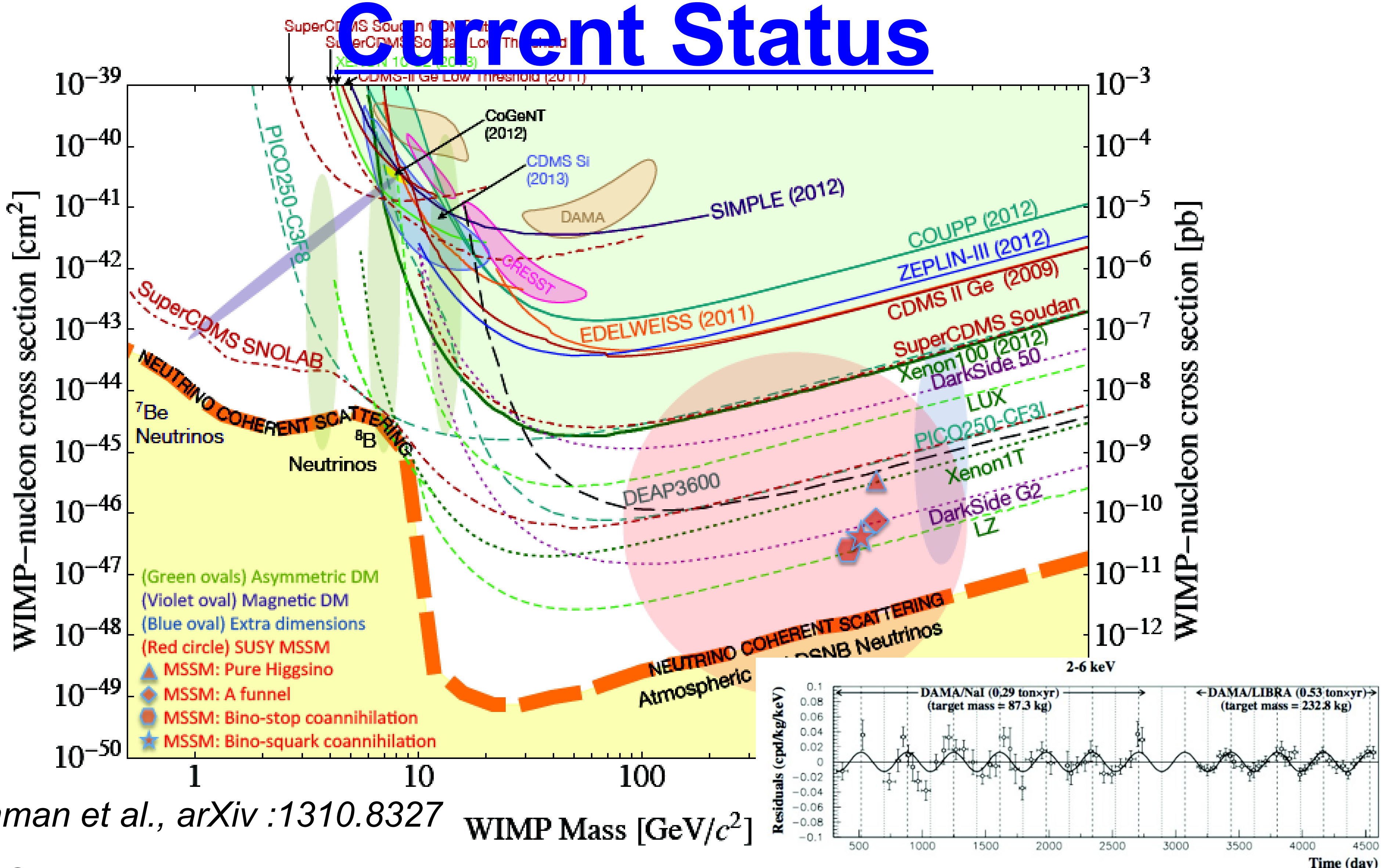
Examples of WIMP recoil spectrum



Recoil Rate = **χN Cross-Section** × **Astrophysics**

χN Cross-Section = **Spin-Independen, σ_{SI}** + **Spin-Dependen, σ_{SD}**

Current Status



P. Cushman et al., arXiv :1310.8327

Positive Claim :

CoGeNT (Ge) Excess background & annual modulation (~1000 kg-day ; 3.4 y)

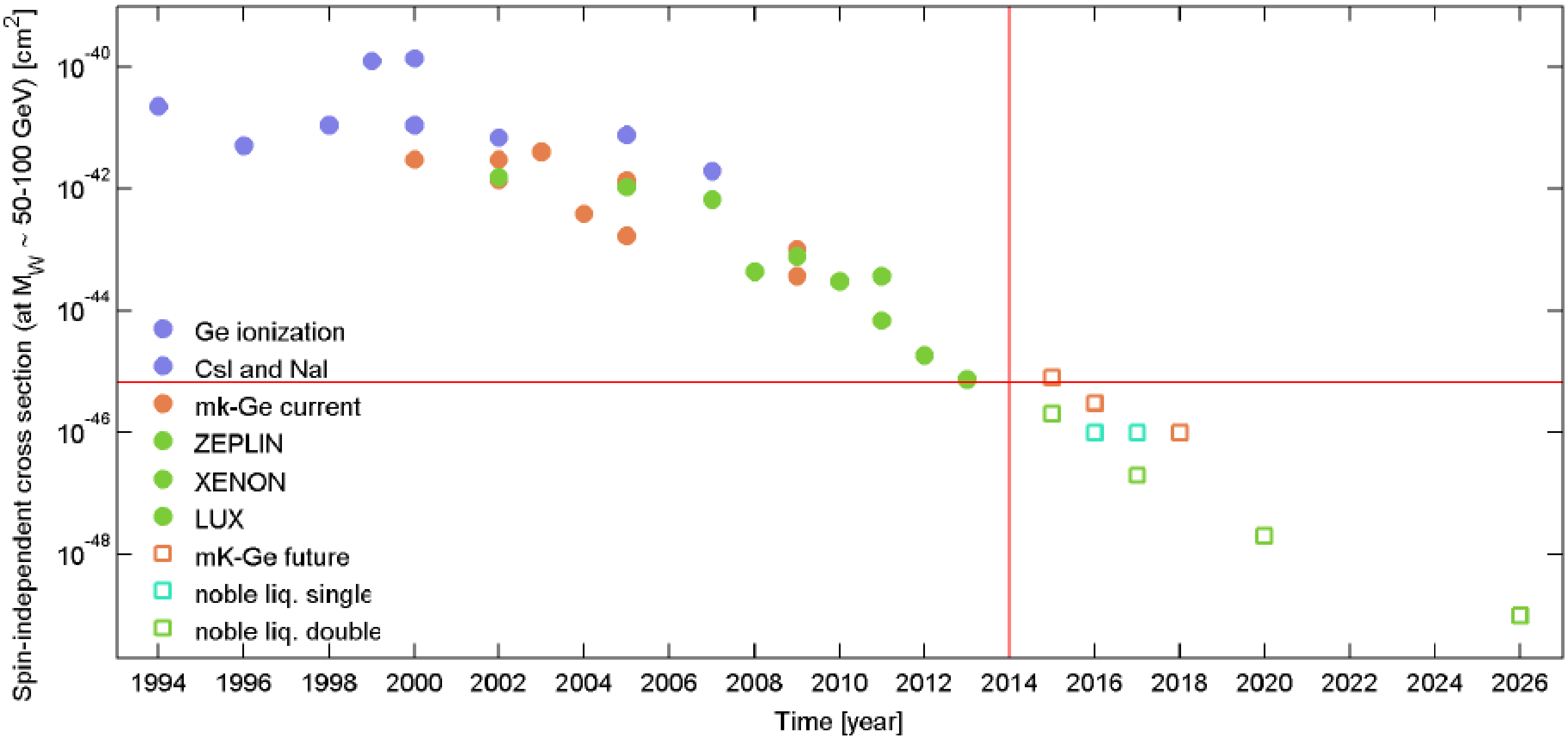
CDMS-II(Si) 3 out of 0.7 expected bkg (140 kg-day)

<u>Inconsistence with others.</u>

DAMA/LIBRA (NaI) Annual modulation (~ 430 ton-day; 13 y)

CRESST-II(CaWO4) Excess background (730 kg-day)

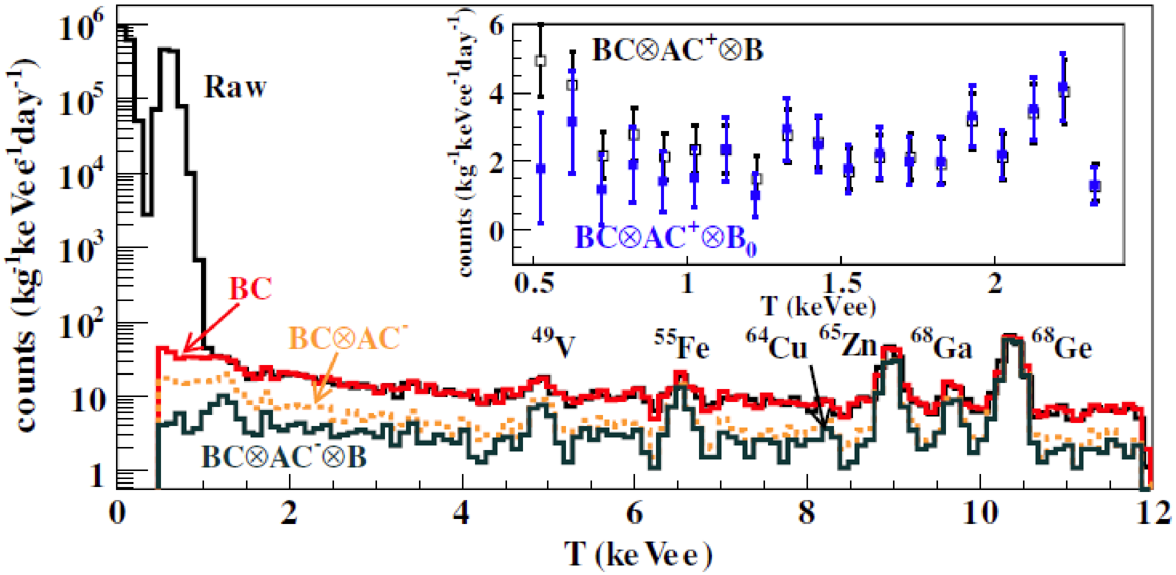
Sensitivities



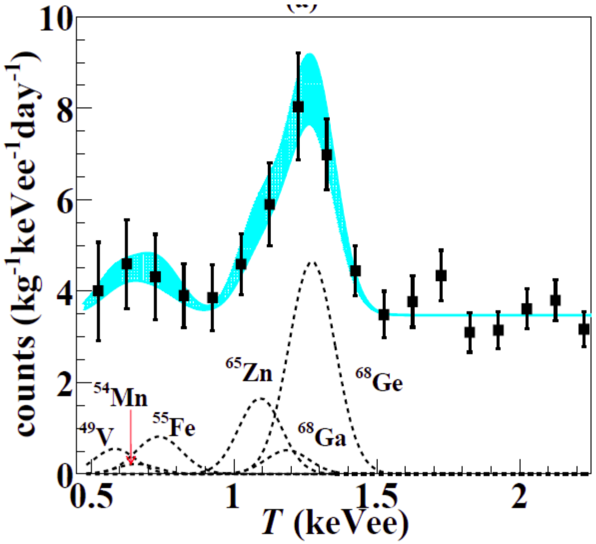
L. Baudis, arXiv :1408.4371

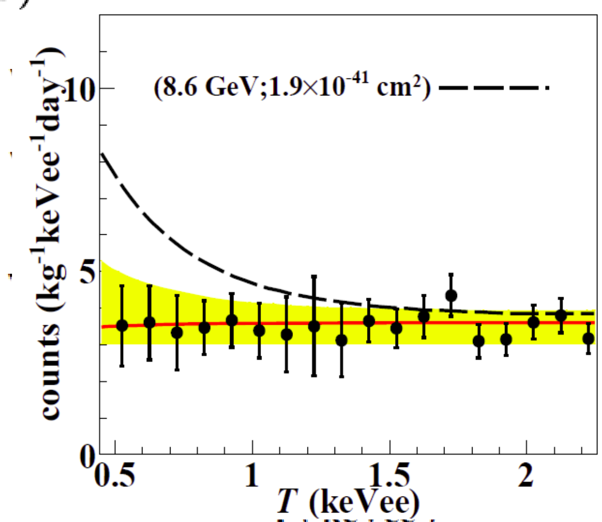
Limits are getting better and better,
So are positive claims ...

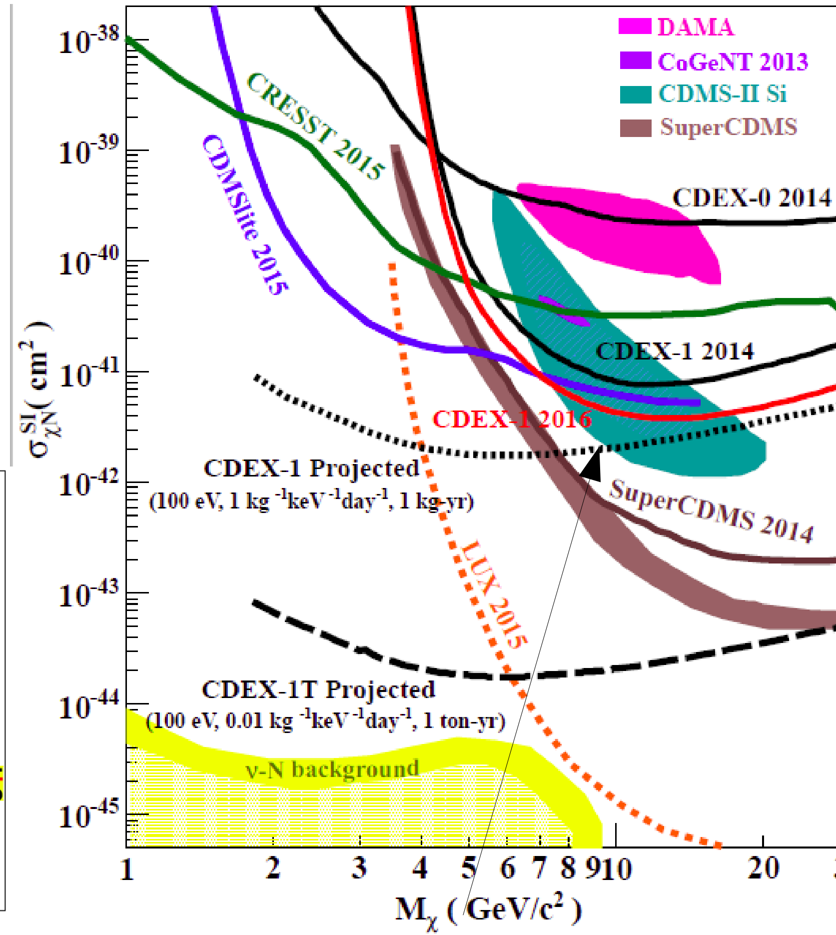
Dark Matter Results at CJPL



(a)







CJPL : underground

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

Partner : CDEX Collaboration

CDEX China Dark Matter Experiment (birth 2009)

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

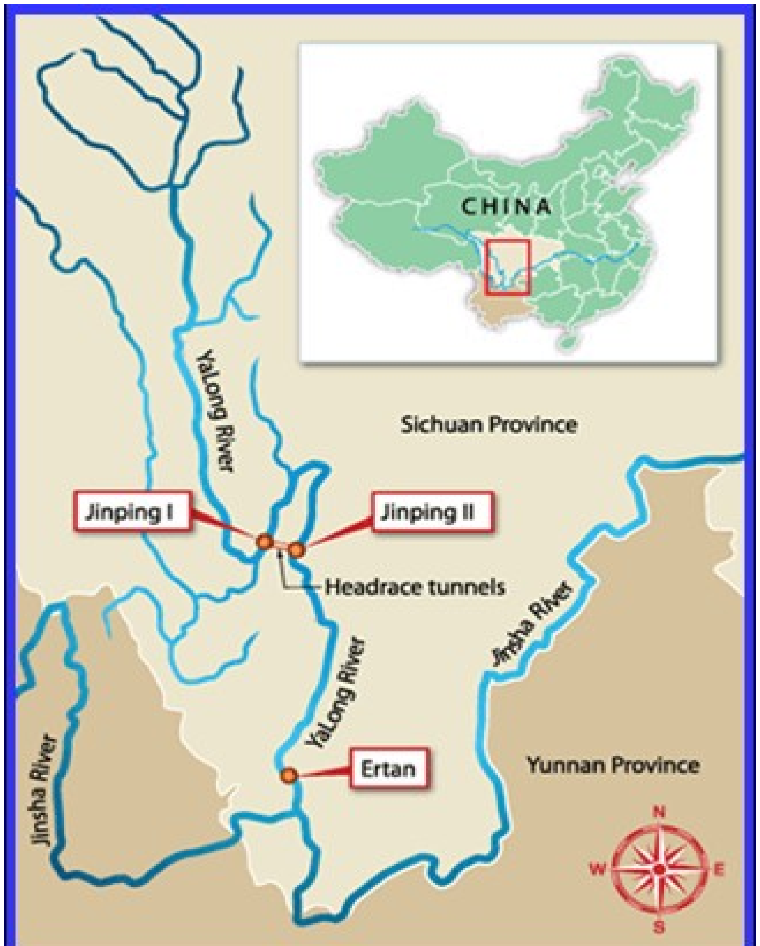
- **China (THU, SCU, CIAE, NKU, ,YLJHD)**

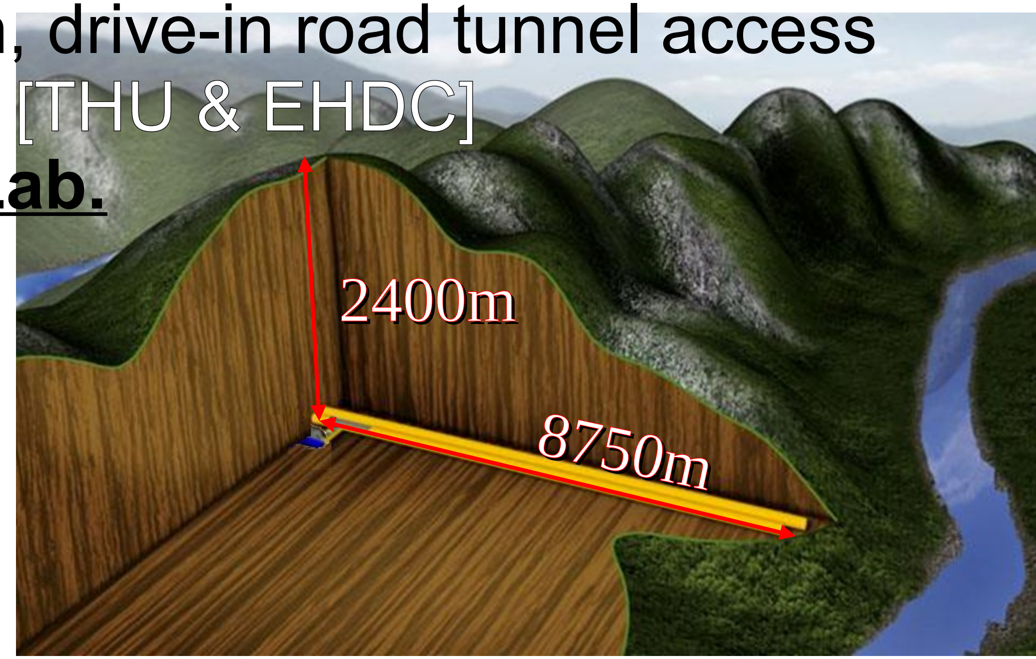
- **Ge as primary detector.**
- **same detector technique, bulk/surface seperation, phys/noise seperation.**

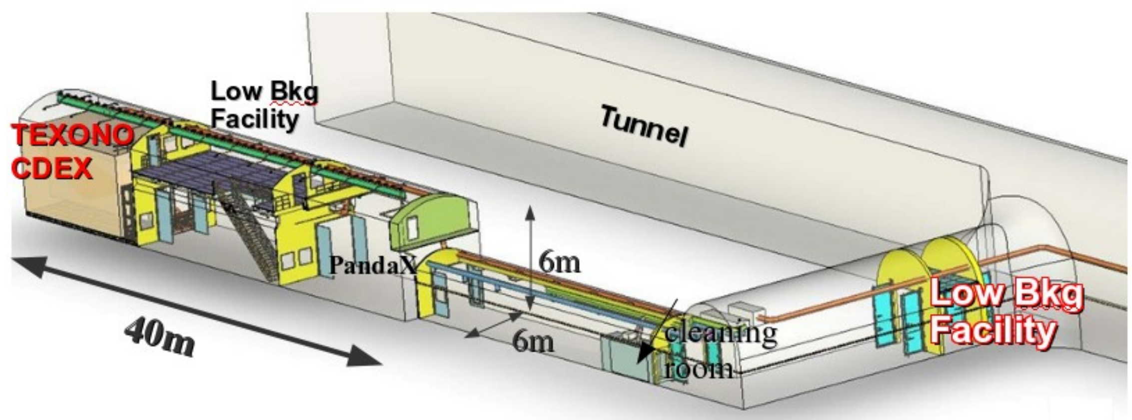
China Jin-Ping Underground Laboratory (CJPL)

CJPL 中国锦屏地下实验室 China Jinping Underground Laboratory

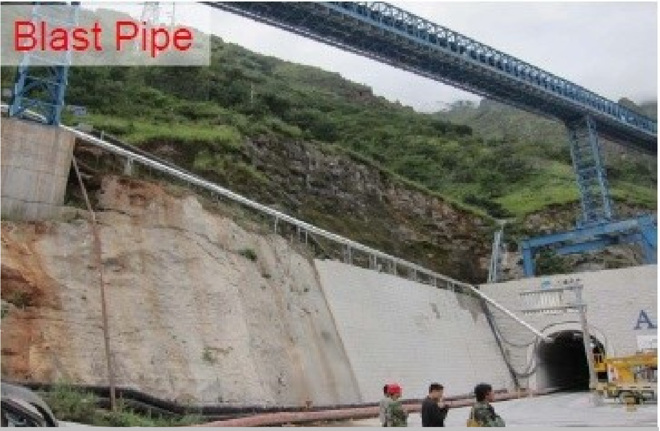
- 2400+ m rock overburden, drive-in road tunnel access
- 6x6x40 m cavern ready [THU & EHDC]
- **Deepest Underground Lab.**



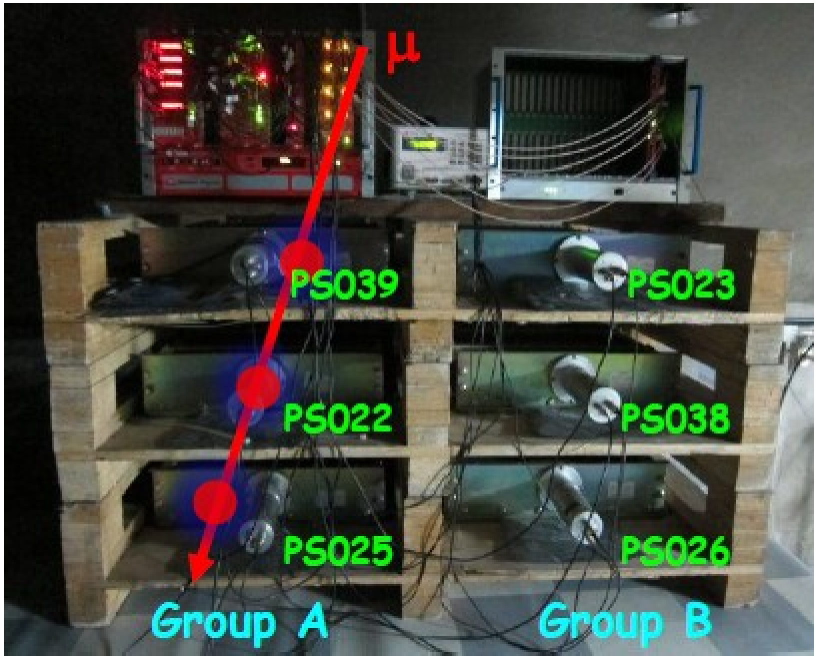




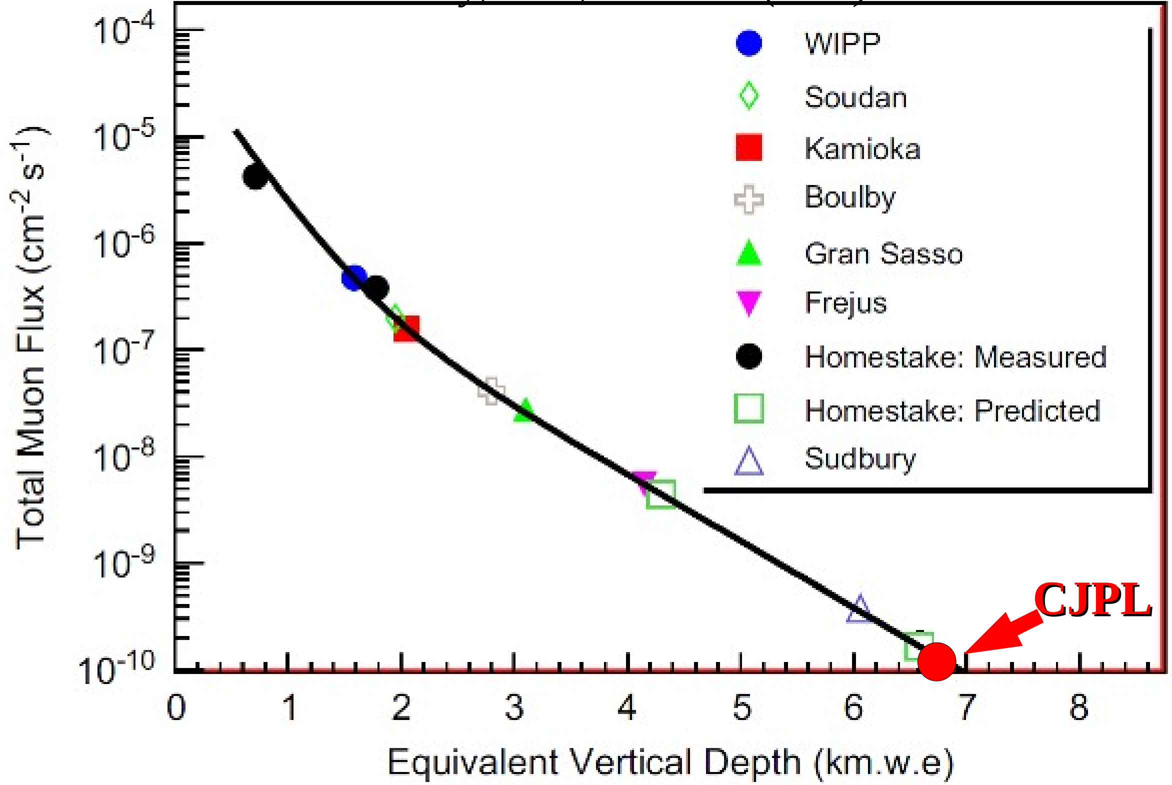
CJPL internal layout



Cosmic flux at CJPL



F.E. Gray, et al., NIMA638 (2011)



- 61.7 ± 11.7 /(m^2·yr) [~8000/(m^2·yr) at Gran Sasso, ~950 /(m^2·yr) at Homestake]

  ref : *arXiv:1305.0899*

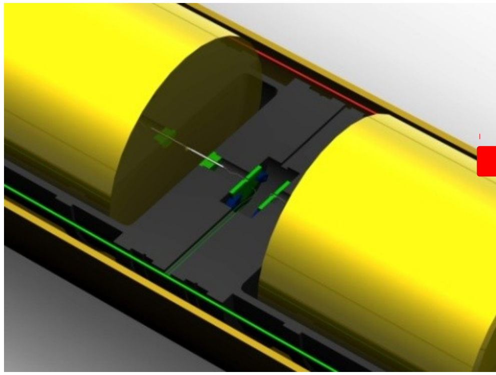
- Consistent with expectation : $10 cm^{-2}s^{-1}$

  ≈ 10^{-8} of ground level

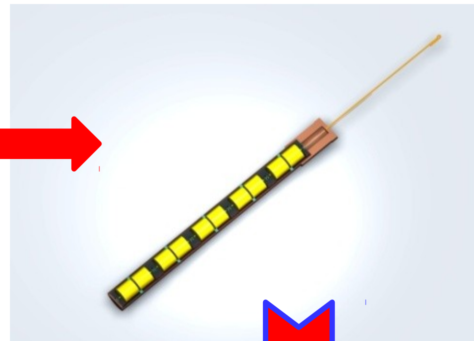
(Unit : Bq/kg)	K-40	Ra-226 (609keV)	Th-232 (911keV)
Rock Sample	< 1.1	1.8±0.2	< 0.27
Ground Level (Beijing)	~600	~25	~50

Design of CDEX-10 : with LAr Anti-Compton

Ge + JFET

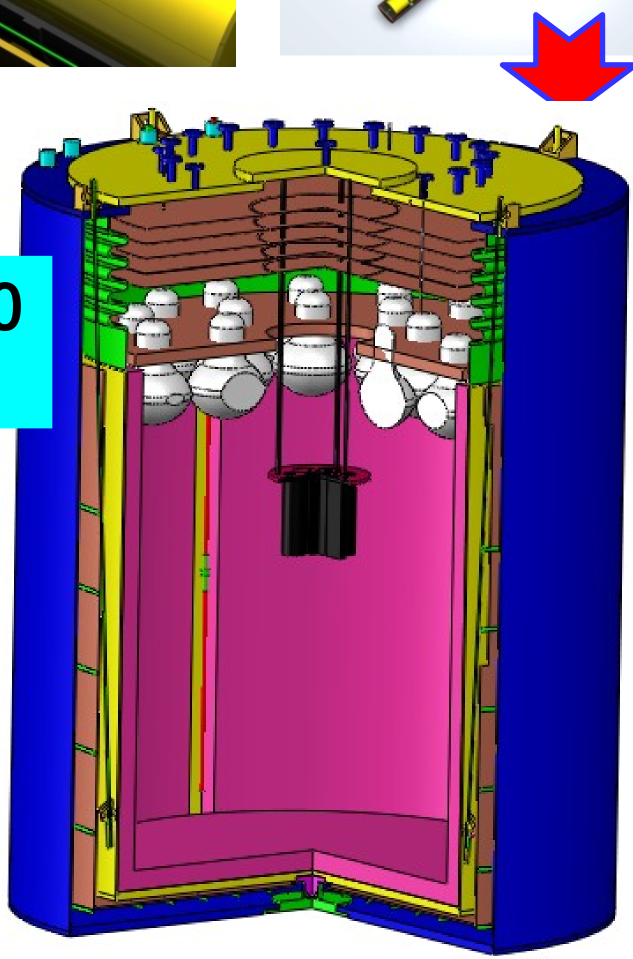


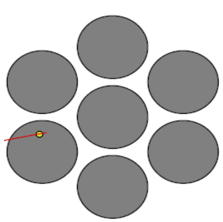
Ge Array in String



- PCGe in Arrays & Strings
- LiqN (LiqAr) as both cryogenics (& active anti-Compton)
- ~30-40 cm 4π shielding range
- Prototype 2014
- Baseline Design for Future O(1 ton) Expt for DM+0νββ

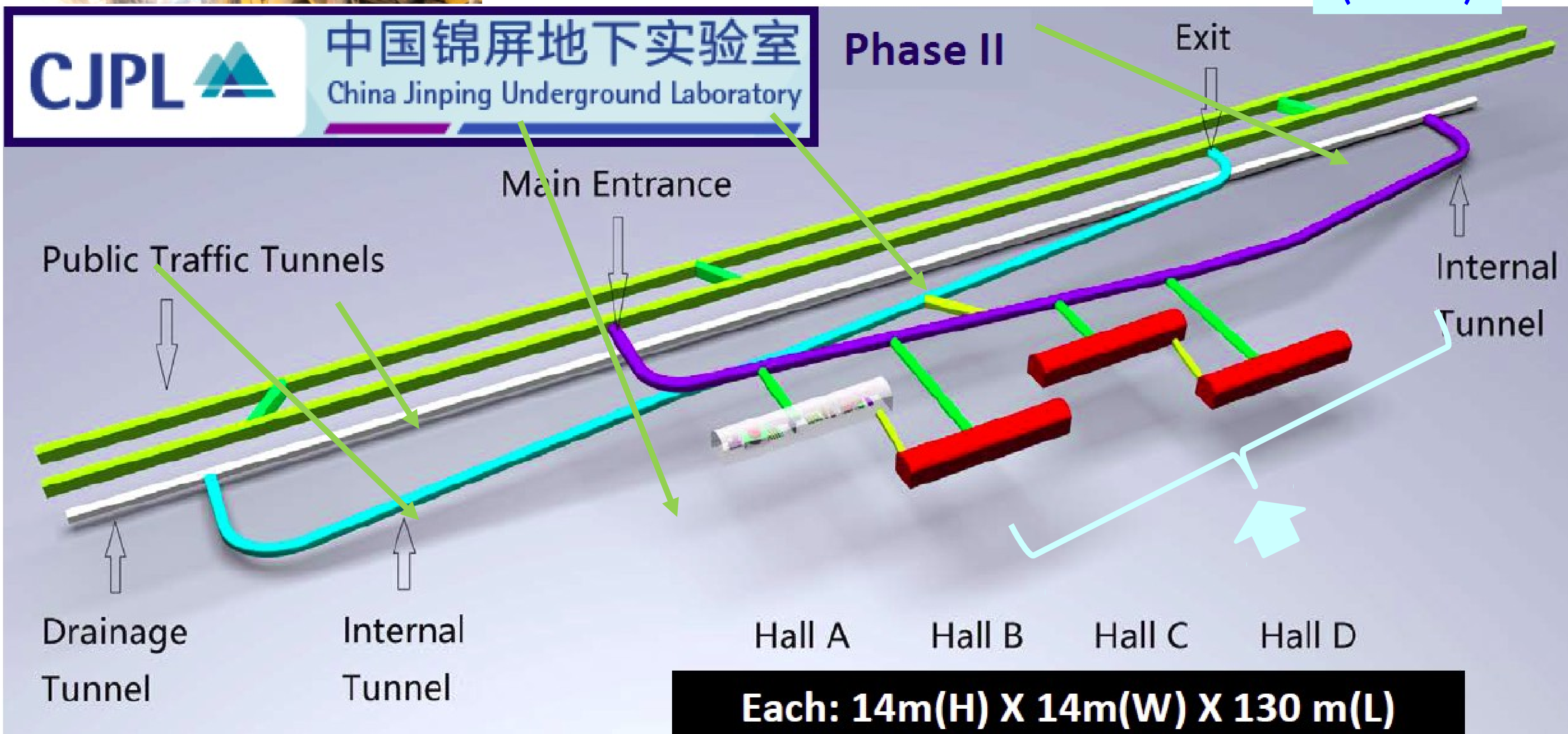
CDEX-10 (2015+)





CDEX-(1 ton)
Artist's Conception

NEW Lab： CJPL-II



Science V346, Nov 2014

PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

China carves out larger role in underground science

As it is doing in so many areas of science, China is racing onto the world stage of underground astroparticle physics.

Physics Today **68**(1), 23 (2015)

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 & ~ cpkkd
- Dark matter sensitivities improvement.