# Low Energy Neutrino & Dark Matter Physics using sub-keV Germanium Detectors


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- Overview (Collaboration; Program; History)
- Facilities : KSNL & CJPL
- Detector & Physics Highlights
- Dark Matter Results

# TEXONO-CDEX Collaboration

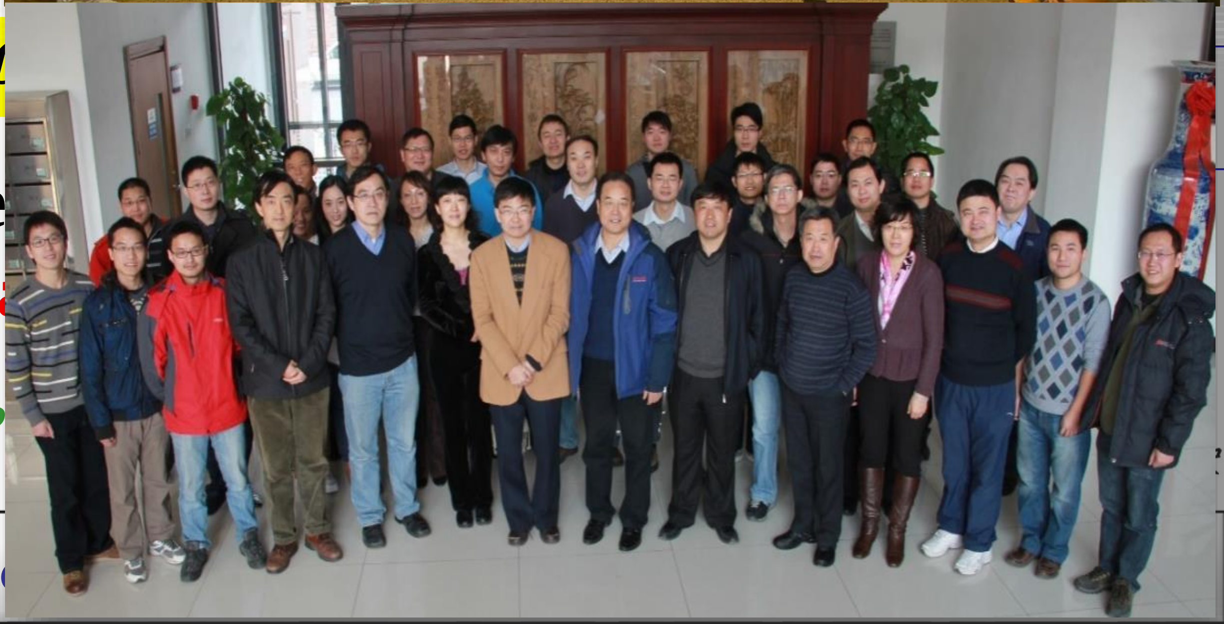
## TEXONO

*Taiwan*

- ⊙ **Neutrino Physic**
  **Laboratory (KS**
  - ➢ **Taiwan (AS,**
  - ➢ **India (BHU)**
  - ➢ **Turkey (MET**

## CDEX

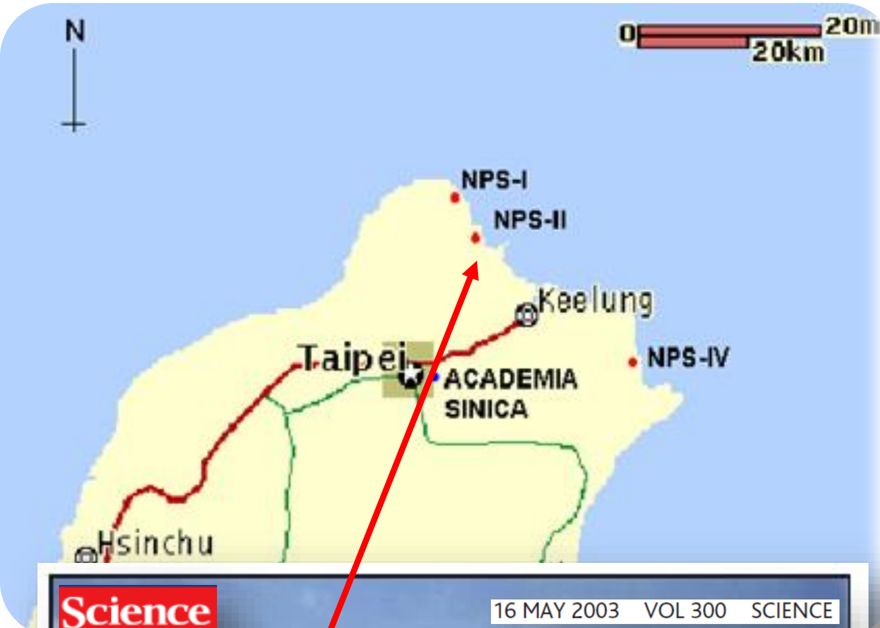
*China Dark M*



- ⊙ **Dark Matter Se**
  **Underground La**
  - ➢ **China (THU,**

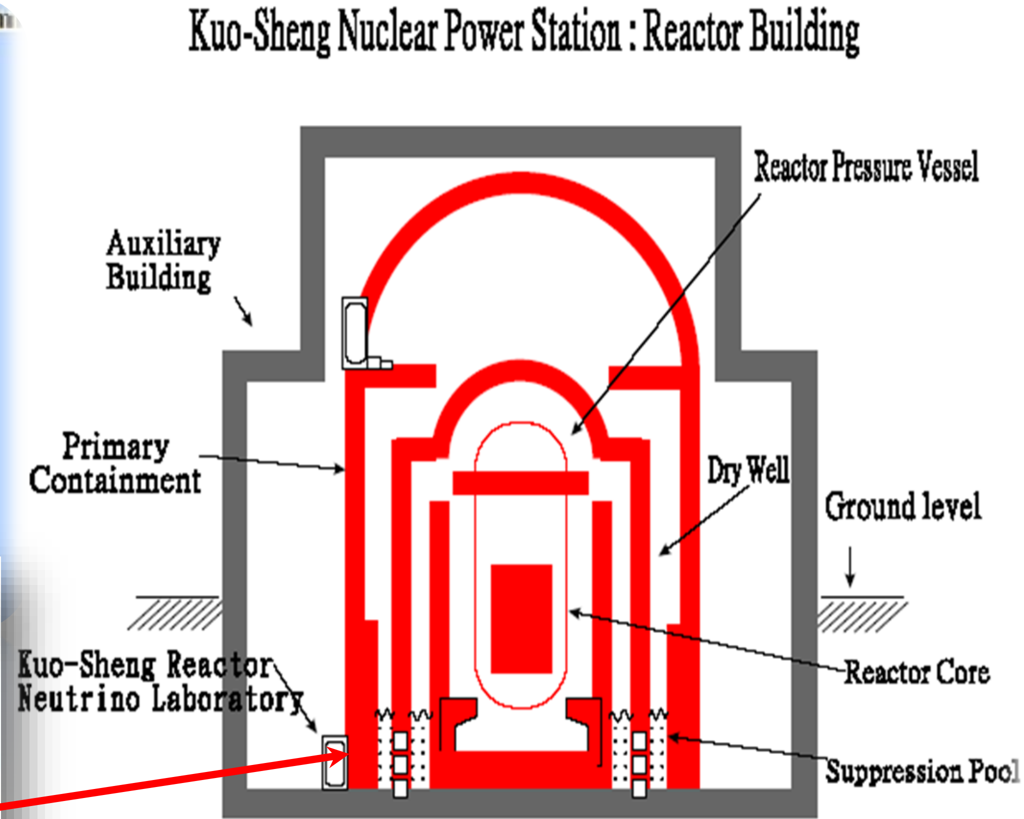
*Research Program:* L

# Kuo-Sheng Reactor Neutrino Laboratory



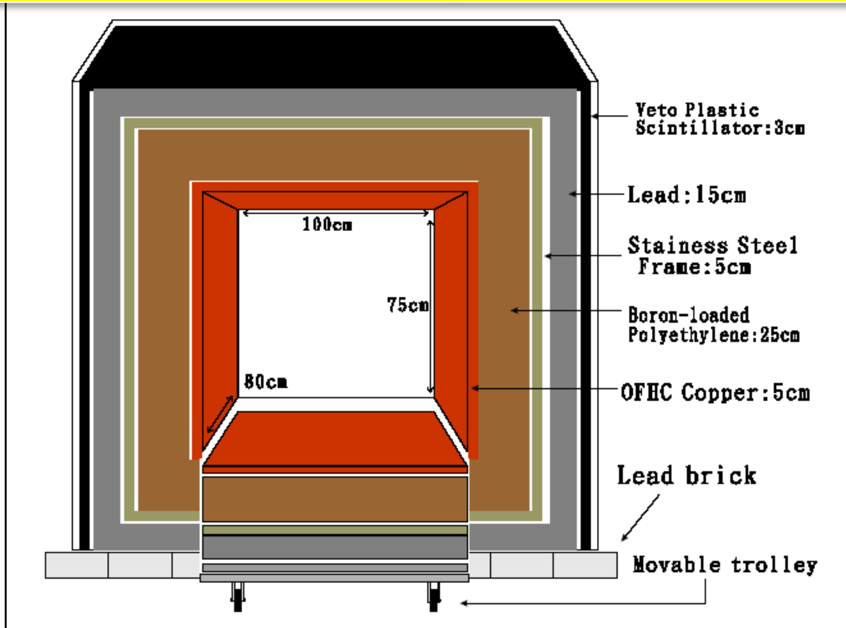


Science
AAAS
16 MAY 2003 VOL 300 SCIENCE
Taiwan-China Collaboration
A Bridge Over Troubled Waters
Researchers from Taiwan and the mainland have hit scientific pay dirt with the first—and so far the only—collaboration between two institutions across the Taiwan Strait

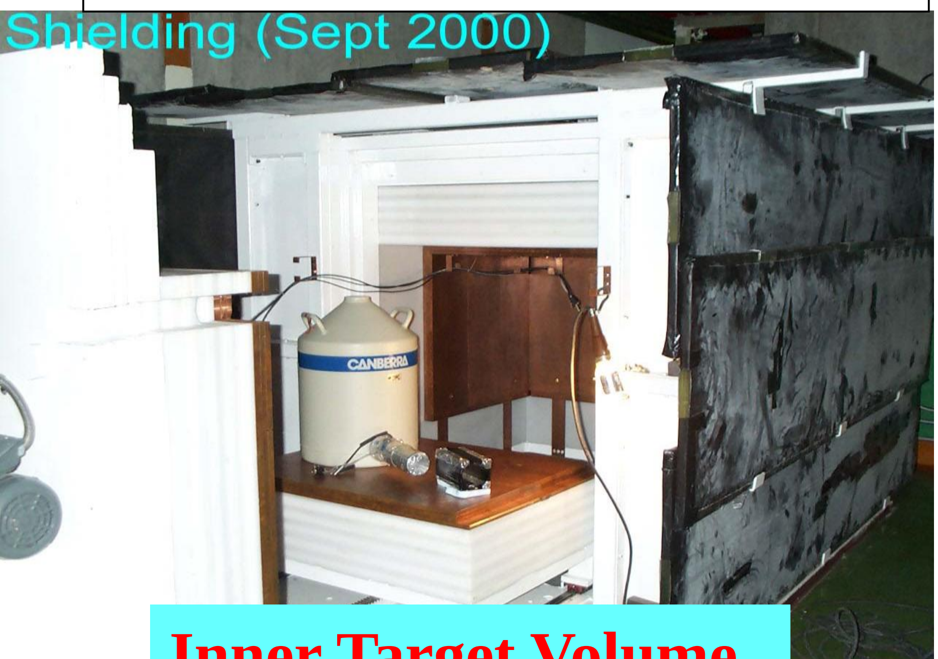



- 28 m from core#1 @ 2.9 GW
- Shallow site : ~30 *mwe* overburden
- ~10 m below ground level
- Neutrino flux $6.35 \times 10^{12} cm^{-2} s^{-1}$

# Kuo-Sheng Reactor Neutrino Laboratory








**Inner Target Volume**

**Front View** *(cosmic vetoes, shielding, control room …..)*

**Configuration:** **Modest yet Unique**

**Flexible Design:** **Allows different detectors conf. for different physics**

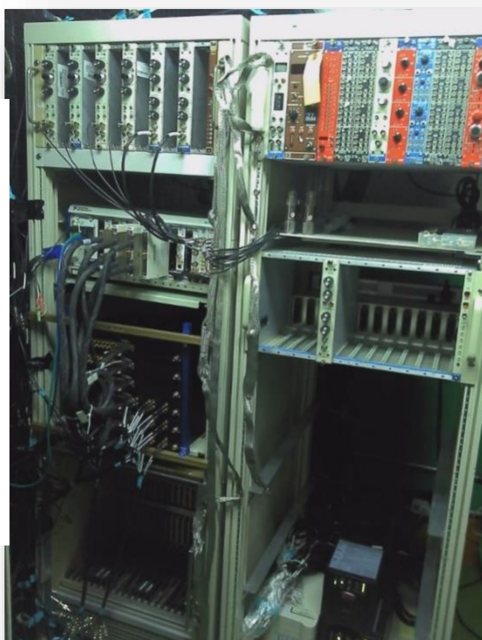
# KSNL: Detector Evolution

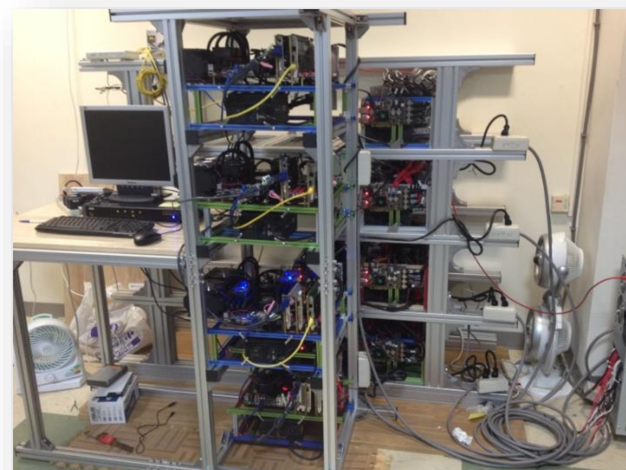
ULB-HPGe [1 kg]

CsI(Tl) [200 kg]

Sub-keV Ge Detectors
(20-1000 g)

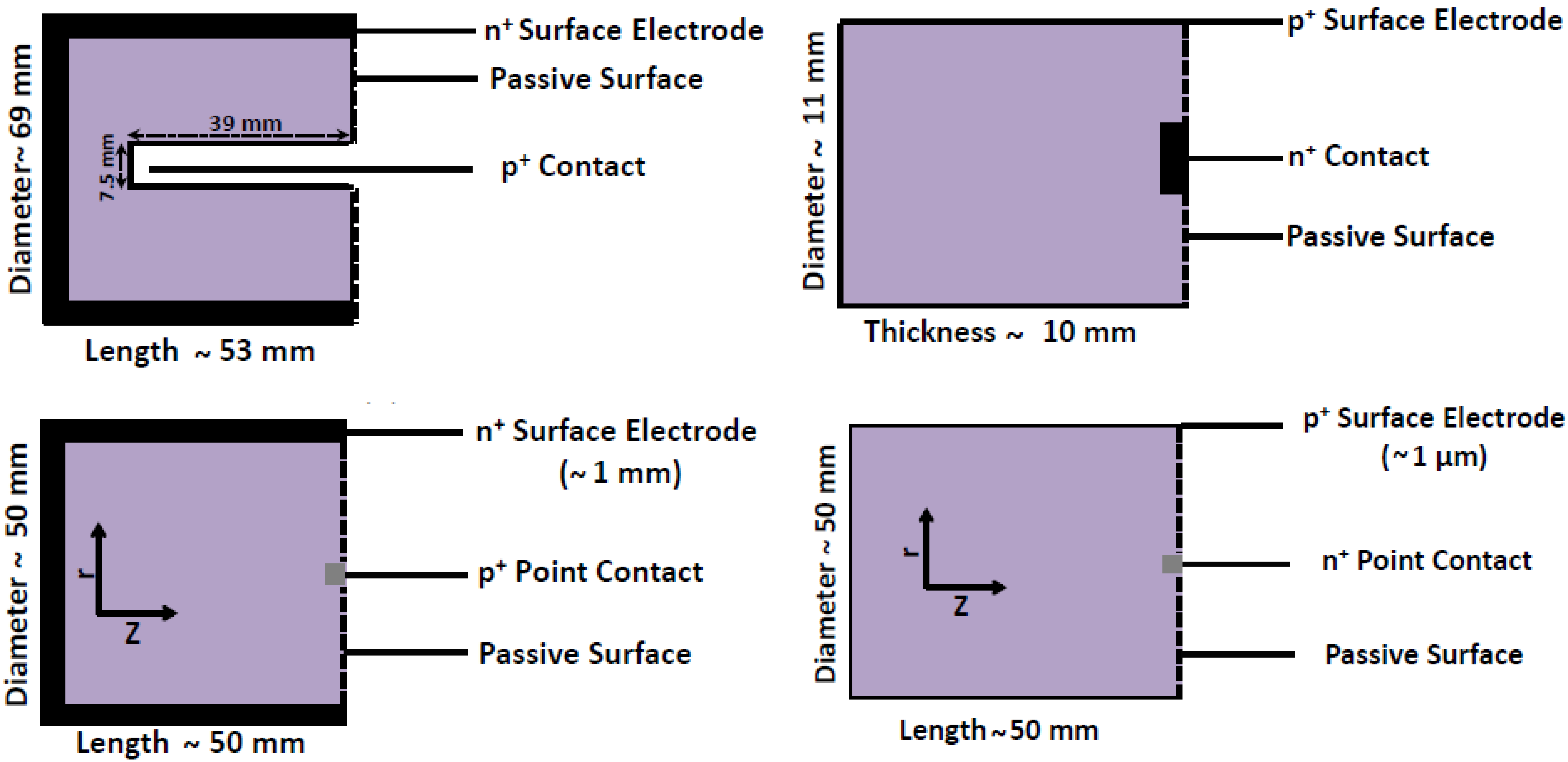
Data
Acquisition with
FADC Readout
& FPGA
Capabilities





Multi-Disks Array [~300 Tb]

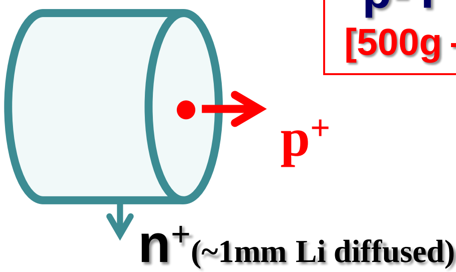
# Sub-keV Germanium Detector




**Schematic crystal configuration of the Ge detectors: (a) CoaxGe at 1 kg mass, (b) ULEGe at 5 g modular mass, (c) pPCGe at 500 g mass, and (d) nPCGe at 500 g mass.**

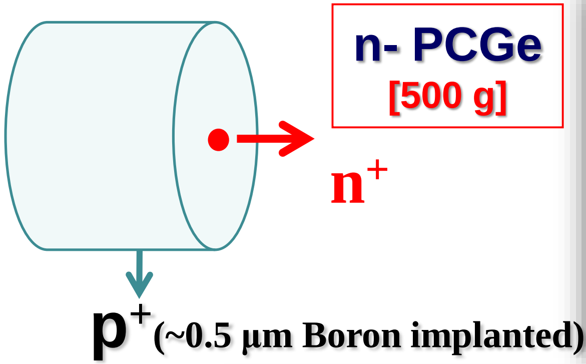
# Baseline Hardware Design

**p- PCGe**
**[500g – 1 kg]**



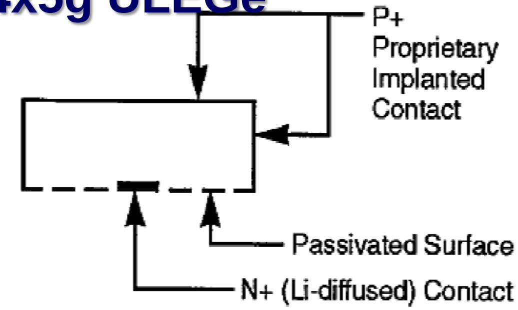


**n- PCGe**
**[500 g]**

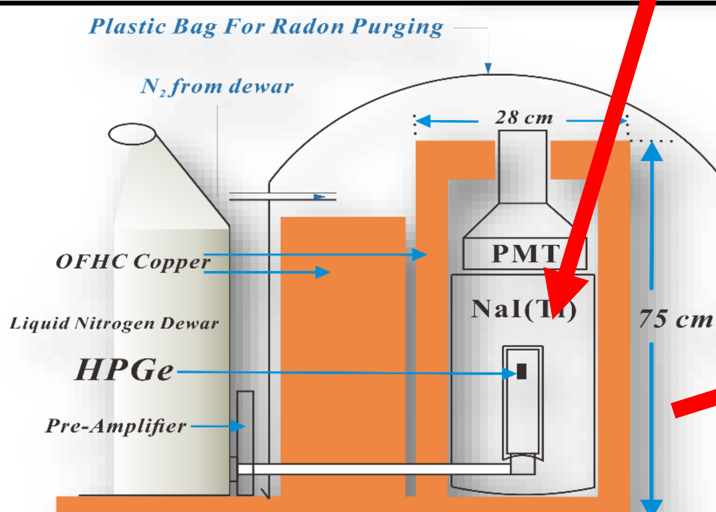


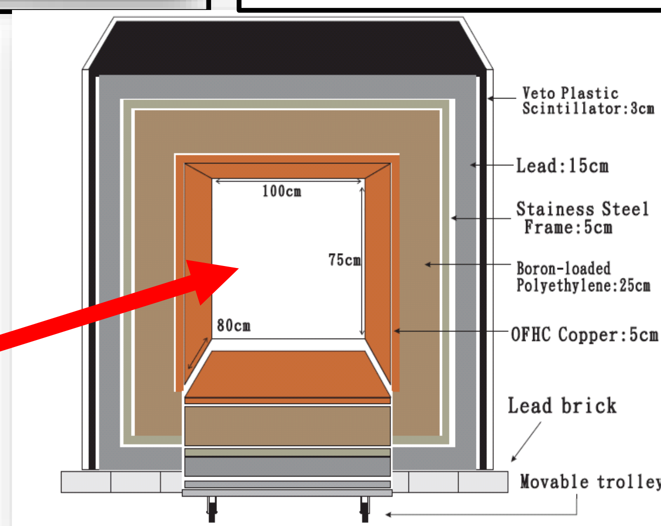


## 4x5g ULEGe





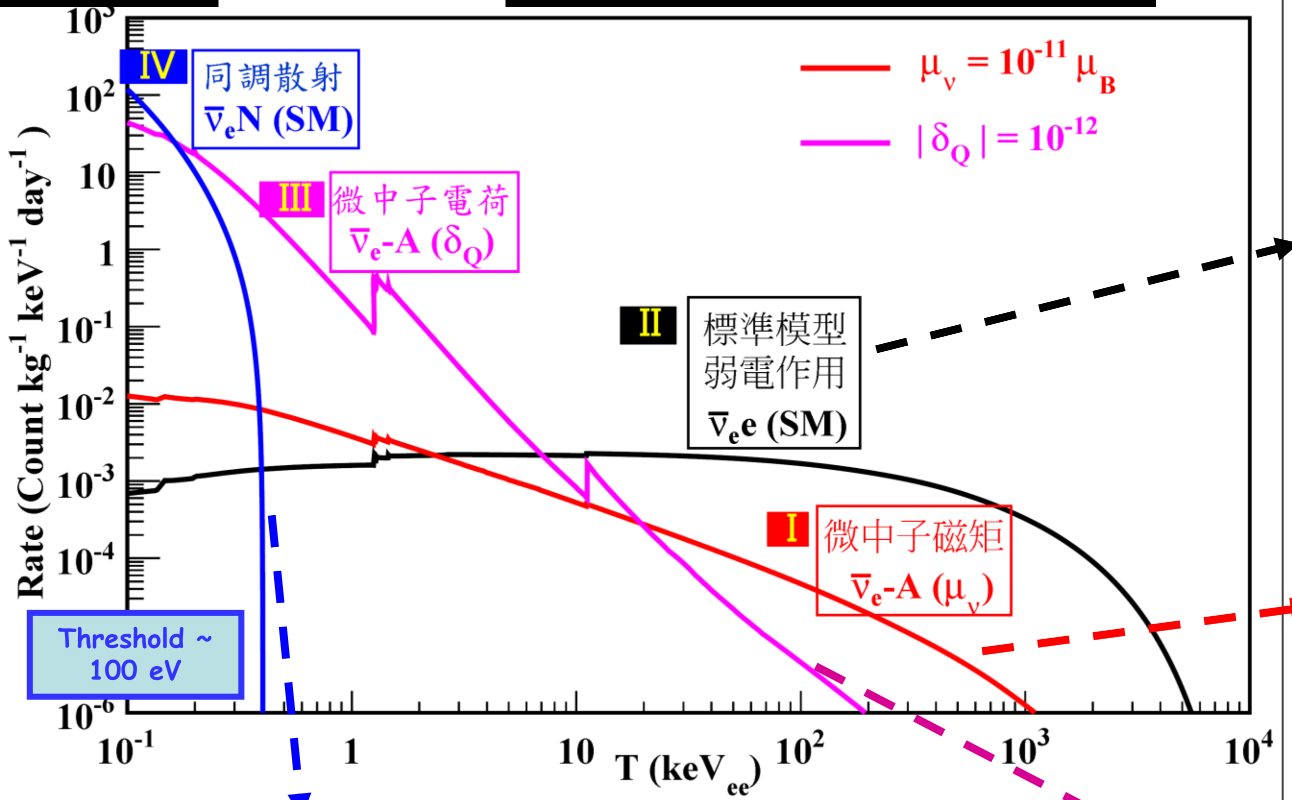


# Neutrino Properties & Interactions at Reactor

## Observable Spectra with Reactor Neutrino

**quality** ← **Detector requirements** → **mass**




**SM & NSI/BSM**

ν-e Scattering

*[PRD10,PRD10,PRD12]*

⇨ 200 kg CsI(Tl)

**Magnetic Moments**

*[PRL03,PRD05,PRD07]*

⇨ 1 kg HPGe

**νN Coherent Scattering**

⇨ sub-keV O(kg) ULEGe / PCGe

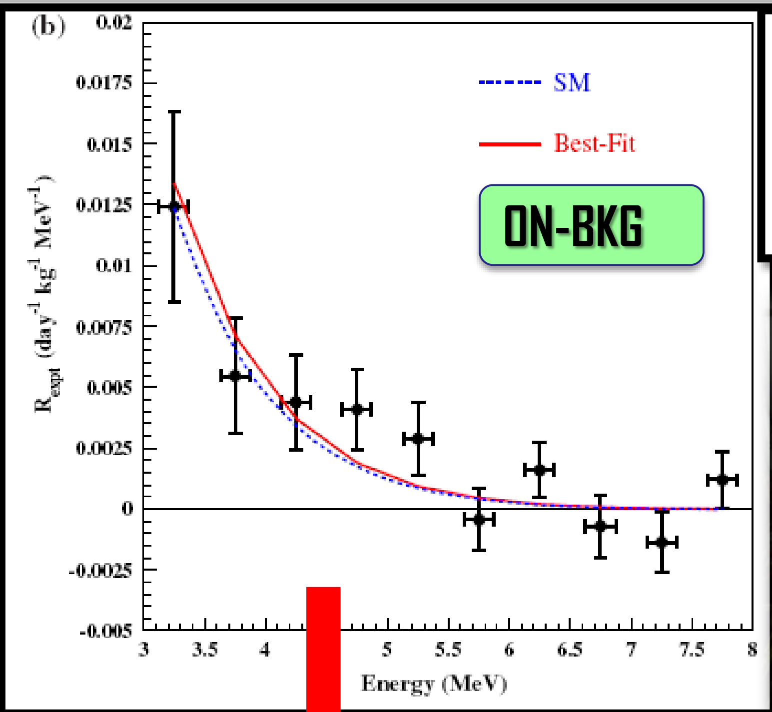
↳ Dark Matter Searches @ KSNL *[PRD09,PRL13,AP14]*

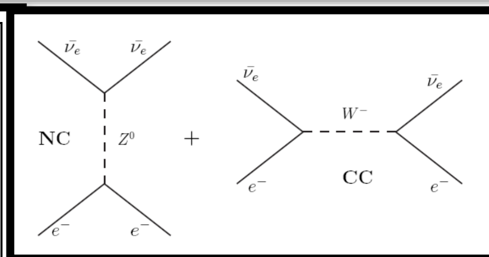
↳ CDEX Program@CJPL *[PRD13,PRD14,PRD14]*

**Neutrino Milli-charge** *[PRD14]*

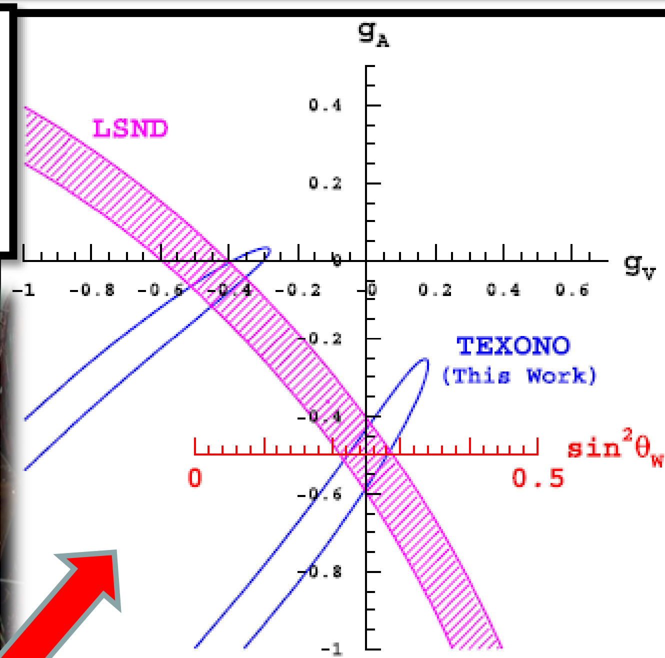
⇨ sub-keV O(kg) ULEGe / PCGe

# CsI(Tl) 200kg: Probe EW Physics [PRD2010]



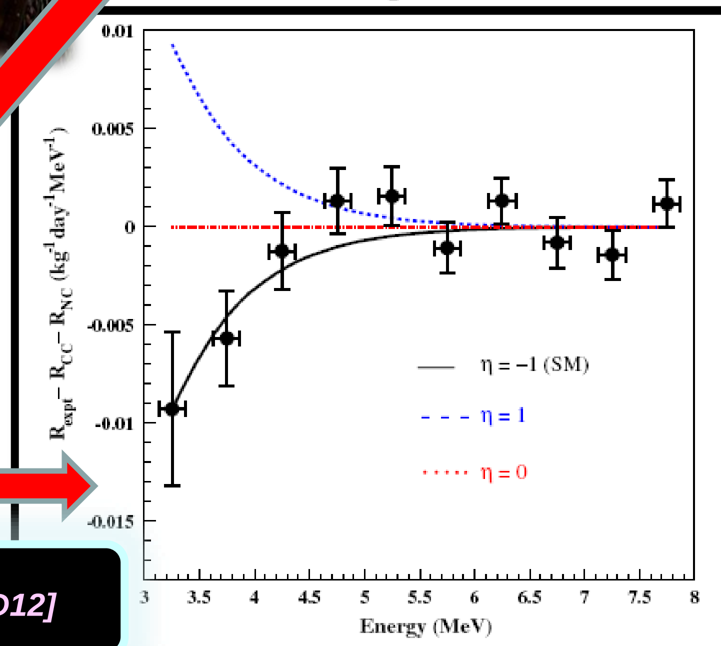





$$R = [1.08 \pm 0.21(stat) \pm 0.16(sys)] \times R_{SM}$$

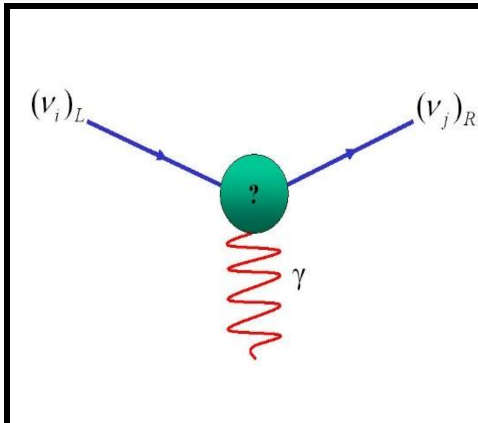
$$\sin^2\theta_W = 0.251 \pm 0.031(stat) \pm 0.024(sys)$$

**Verify SM Destructive Interference**

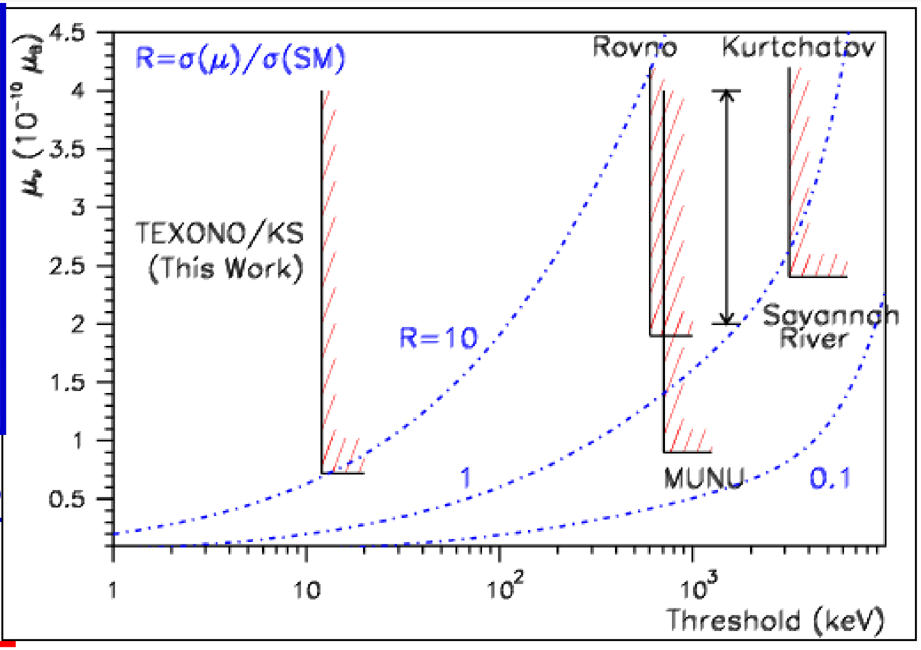



⊕ Constraints on Various Beyond SM Effects *[PRD10; PRD12]*

# Neutrino Electromagnetic Properties: Magnetic Moments




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




$\mu_\nu(\nu_e) < 7.2 \times 10^{-11}\ \mu_B$ [PRL03; PRL07]

**Search of $\mu_\nu$ at low energy with Reactor ν-e scattering**

⇒ high signal rate & robustness:

- $\mu_\nu$>>SM [ decouple irreducible bkg ⊕ unknown sources ]
- T << $E_\nu$ ⇒ dσ/dT depends on total $\phi_\nu$ flux but *NOT* spectral shape [ flux well known : ~6 fission-ν ⊕ ~1.2 $^{238}$U capture-ν per fission ]

Same approach continuing in GEMMA (Kalinin, Russia) $\mu_\nu(\nu_e) < 2.9 \times 10^{-11}\ \mu_B$ *[2013]*

# New (!): Neutrino "Milli-Charge" [+Chen, Liu, Chi; PRD14]

**Neutrino Electromagnetic Form Factors** in CPT conserving theories

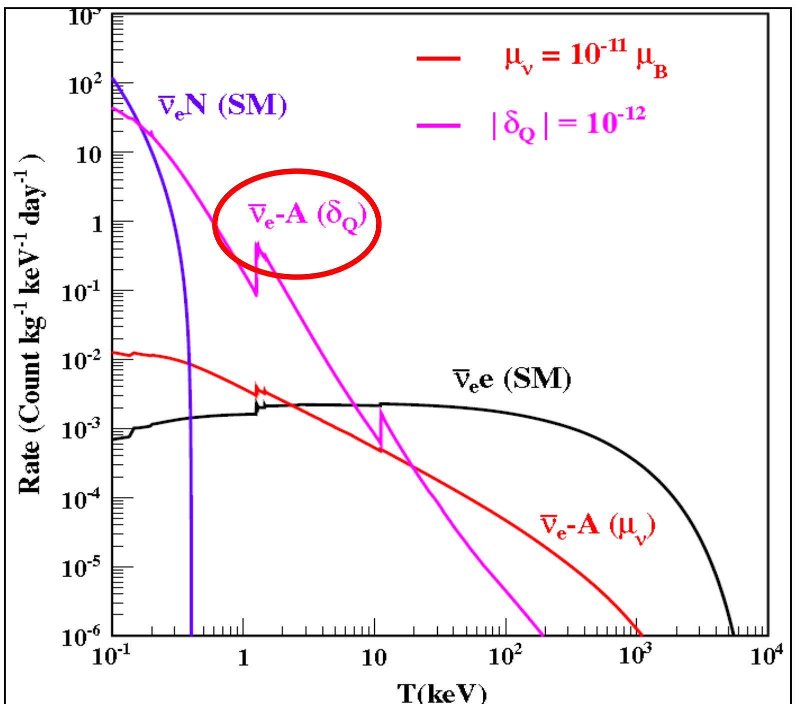
$$\Gamma^{\mu}_{em} \equiv F_1 \cdot \gamma^{\mu} + F_2 \cdot \sigma^{\mu\nu} \cdot q_{\nu}$$

$F_1 = \delta_Q \cdot e_0 + \ldots$   $\ldots \frac{\mu_\nu}{m_e},$

The standard QED matrices

**Atomic Ionization Differential Cross Section with full atomic physics many-body "MCRRPA-multiconfiguration relativistic random phase approximation" calculation [PL13]**

$$\overline{\nu_e} + A \rightarrow \overline{\nu_e} + A^+ + e^-,$$




**The neutrino properties are parameterized by the neutrino fractional charge relative to the electron —commonly referred to as "Neutrino Millicharge".**

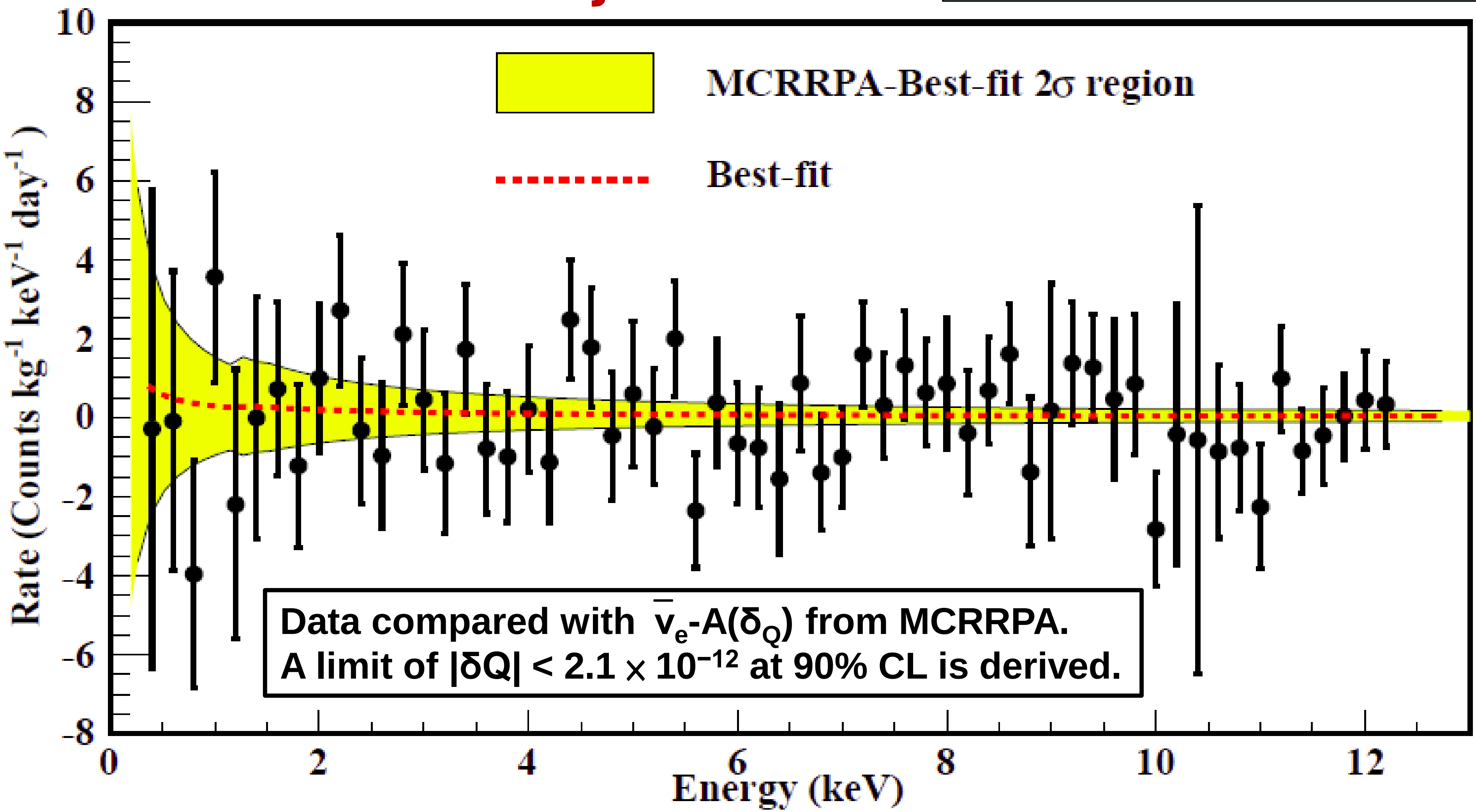
**The $F_1$ and $F_2$ terms characterize neutrino interactions without and with a change of the helicity states.**

threshold): $\delta_Q \sim 10^{-14}$

# Neutrino Electromagnetic Properties: Magnetic Moments

**Data ON/OFF ~ 130days/70days**
**Detector : n-PCGe, p-PCGe**
**Threshold ~ 0.3 keV, 0.5 keV.**

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



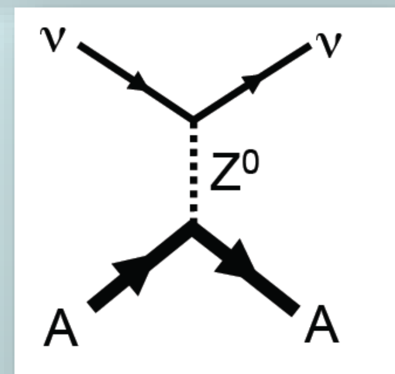
# Current Research Focus: "sub-keV" Ge Detectors

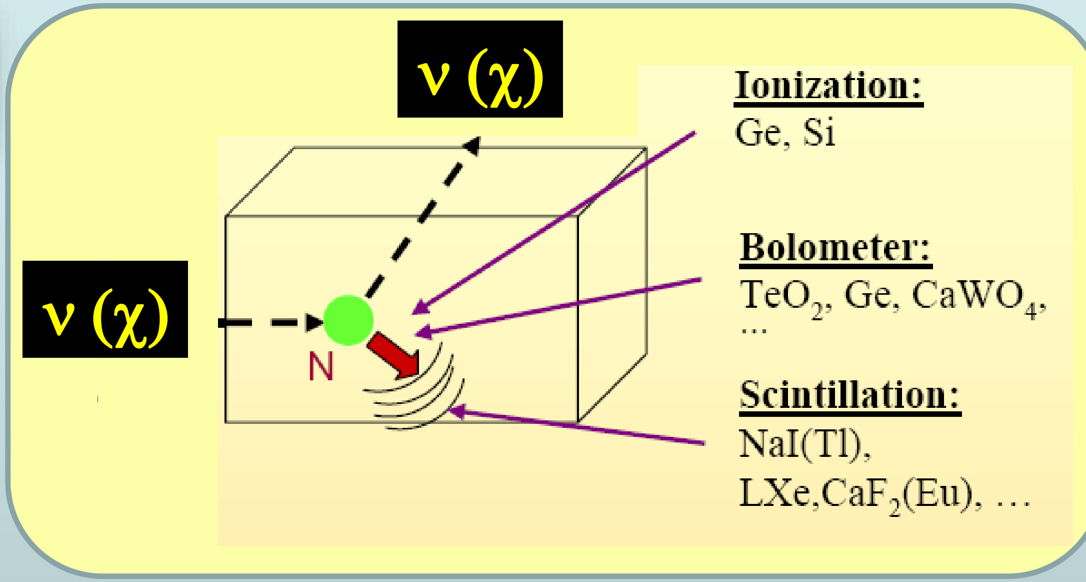
- **Physics Goals for *O[100 eV threhold⊕1 kg mass⊕1 cpkkd]* *detector* :**
  - **νN coherent scattering**
  - **Low-mass WIMP searches**
  - **Improve sensitivities on neutrino electromagnetic properties**
  - **Implications on reactor operation monitoring**
  - **Open new detector window & detection channel available for surprises**
    - HPGe detector with Internal amplification

# Neutrino – Nucleus Coherent Scattering

## ⚐ Standard Model allowed and predicted processes :

$$\nu + A \rightarrow \nu + A$$




- Neutral current process (same for all ν-flavor)
- $\sigma \propto N^2$ @ $E_\nu < 50$ MeV

  ⇒ ***"Coherent"*** *[probe "sees" the whole nucleus]*
- Sensitive probe for BSM; interest in reactor monitoring
- Important process in stellar collapse & supernova explosion
- Analogous interaction used in dark matter detection
- Ge at KSNL @ QF~0.2 : cut-off ~ 300 eV; Rate ~10 $kg^{-1}$ $day^{-1}$ \

  @ threshold~100 eV

# Standard Model Cross - Section at KSNL

[ with Quenching Function for Ge for nuclear recoils ]

$$\nu + N \rightarrow \nu + N$$

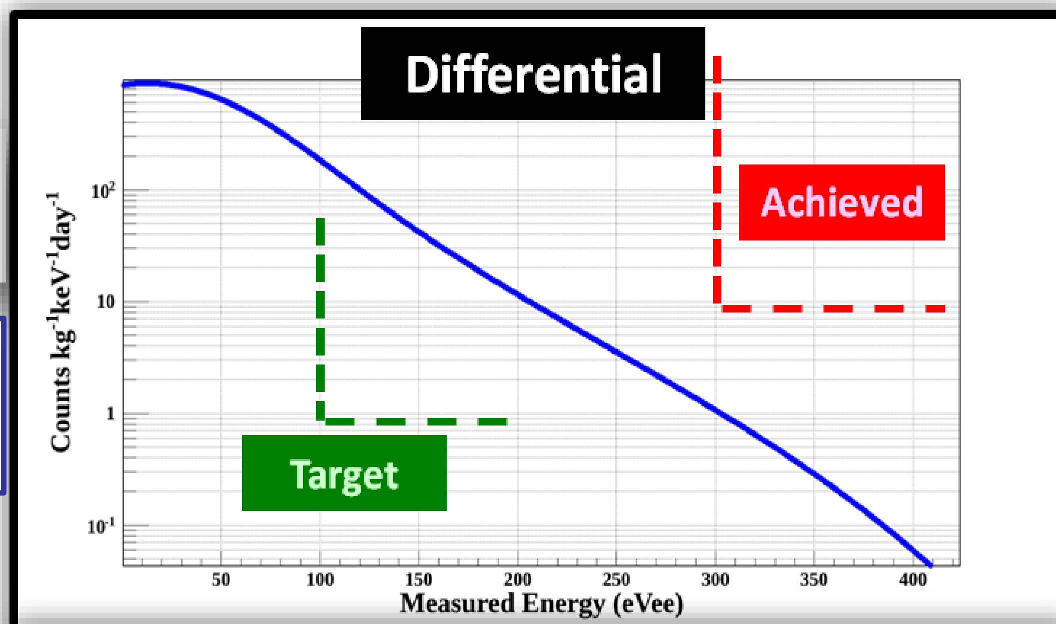
$$\left(\frac{d\sigma}{dT}\right)^{coh}_{SM} = \frac{G_F^2}{4\pi} m_N [Z(1-4\sin^2\theta_W) - N]^2 \left[1 - \frac{m_N T_N}{2E_\nu^2}\right]$$

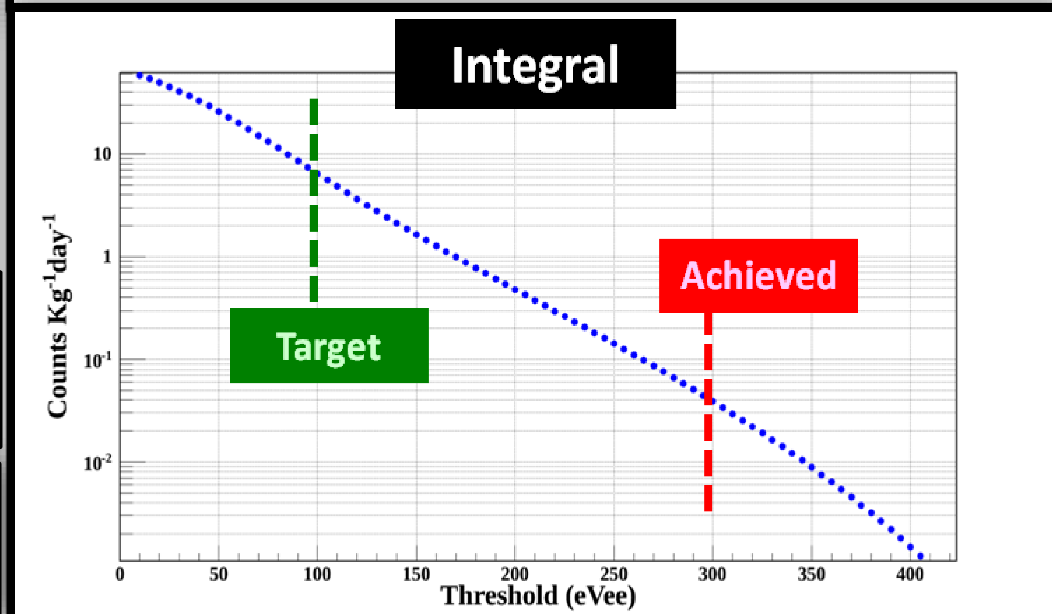
**Needs Background < 10 cpkkd,**
**Target →1 cpkkd**

**Current Focus !!**

**Needs Threshold < 200 $eV_{ee}$,**
**Target → 100 $eV_{ee}$**

$$\sigma_{tot} = \frac{G_F^2 E_\nu^2}{4\pi} [Z(1-4\sin^2\theta_W) - N]^2$$

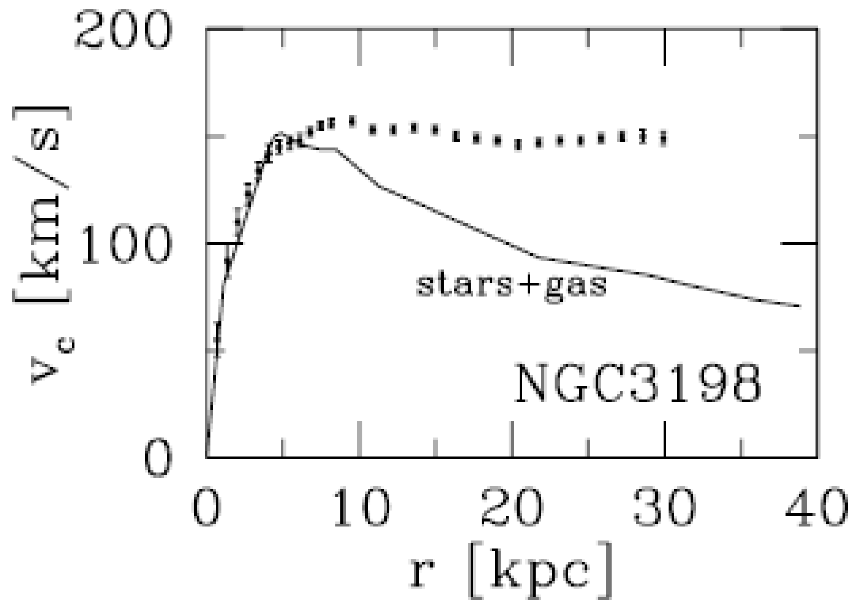


# Origin of the Dark Matter Concept

## Dark Matter rediscovered

In 1970's Vera Rubin found that the rotation curves of galaxies ARE FLAT!




$$\frac{GMm}{r^2} = m\frac{v^2}{r} \Rightarrow v = \sqrt{\frac{GM(r)}{r}}$$

$$v = const. \Rightarrow M(r) \sim r$$

even where there is no light!

1 pc = 3.2 $\ell$y

Dark Matter dominates in galaxies e.g. in NGC3198

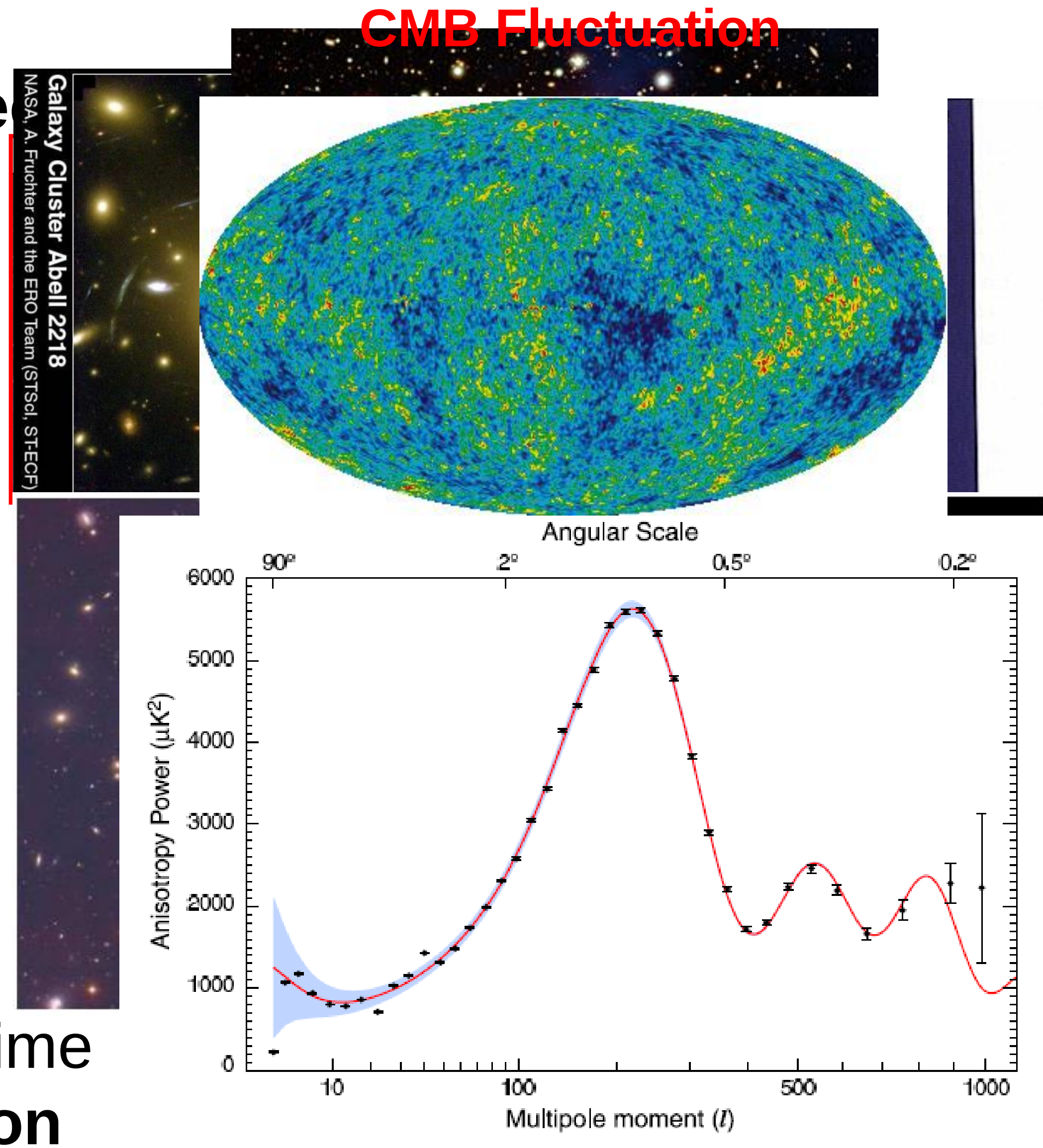
$$M = 1.6 \times 10^{11} M_\odot (r/30\ \mathrm{kpc})$$
$$M_{stars+gas} = 0.4 \times 10^{11} M_\odot$$

$$\frac{M}{M_{vis}} > 4$$

We are going to concentrate on the DM in the Dark Halo of our own galaxy

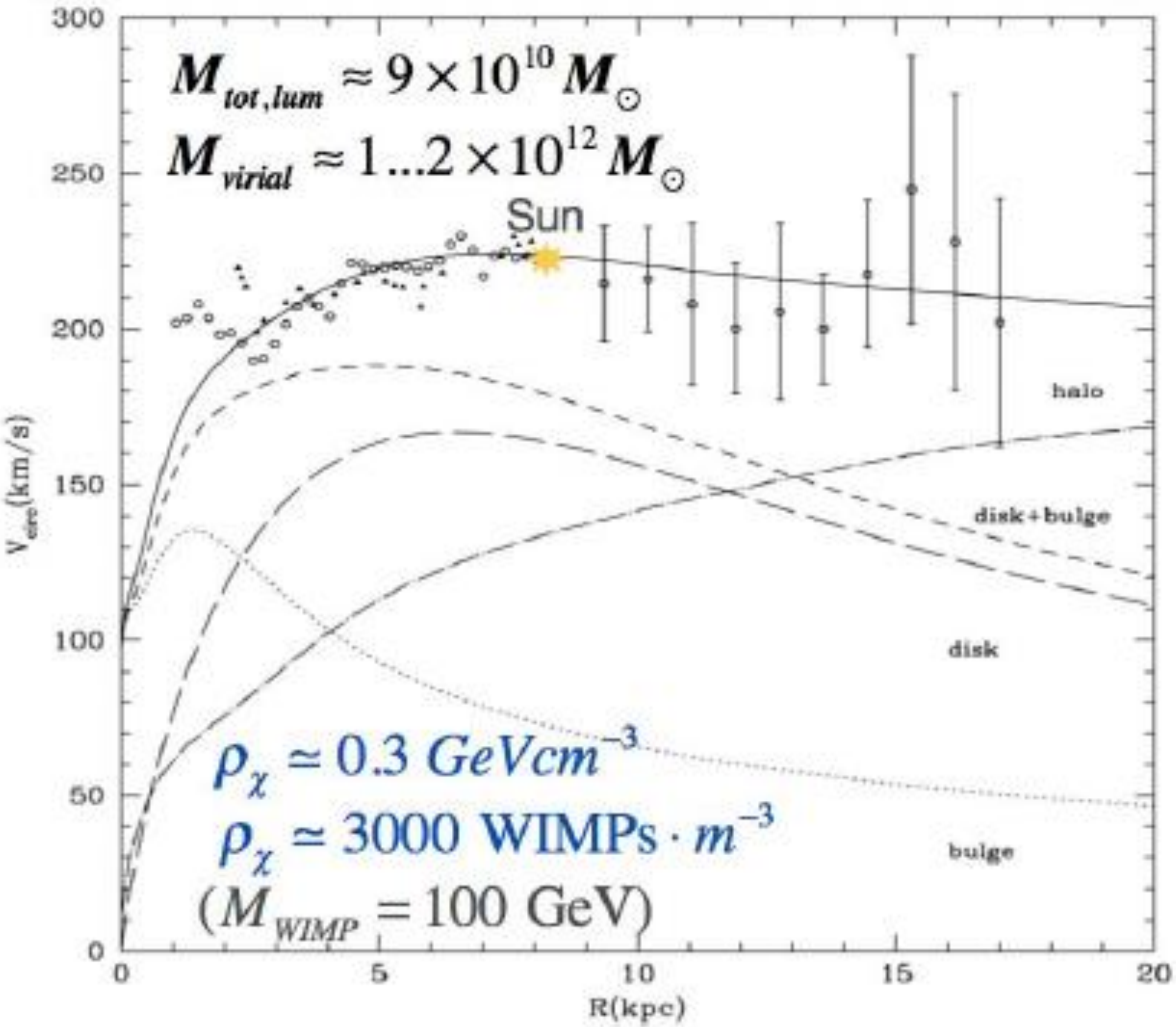
# Astrophysical Evidences

- Dark matter has **already been discovered** through
  - Galaxy clusters
  - Galactic rotation curves
  - Weak lensing
  - Strong lensing
  - Hot gas in clusters
  - Bullet Cluster
  - Supernovae
  - CMB
- We have entered in the regime **of dark matter identification**



# Milky Way's Dark Halo

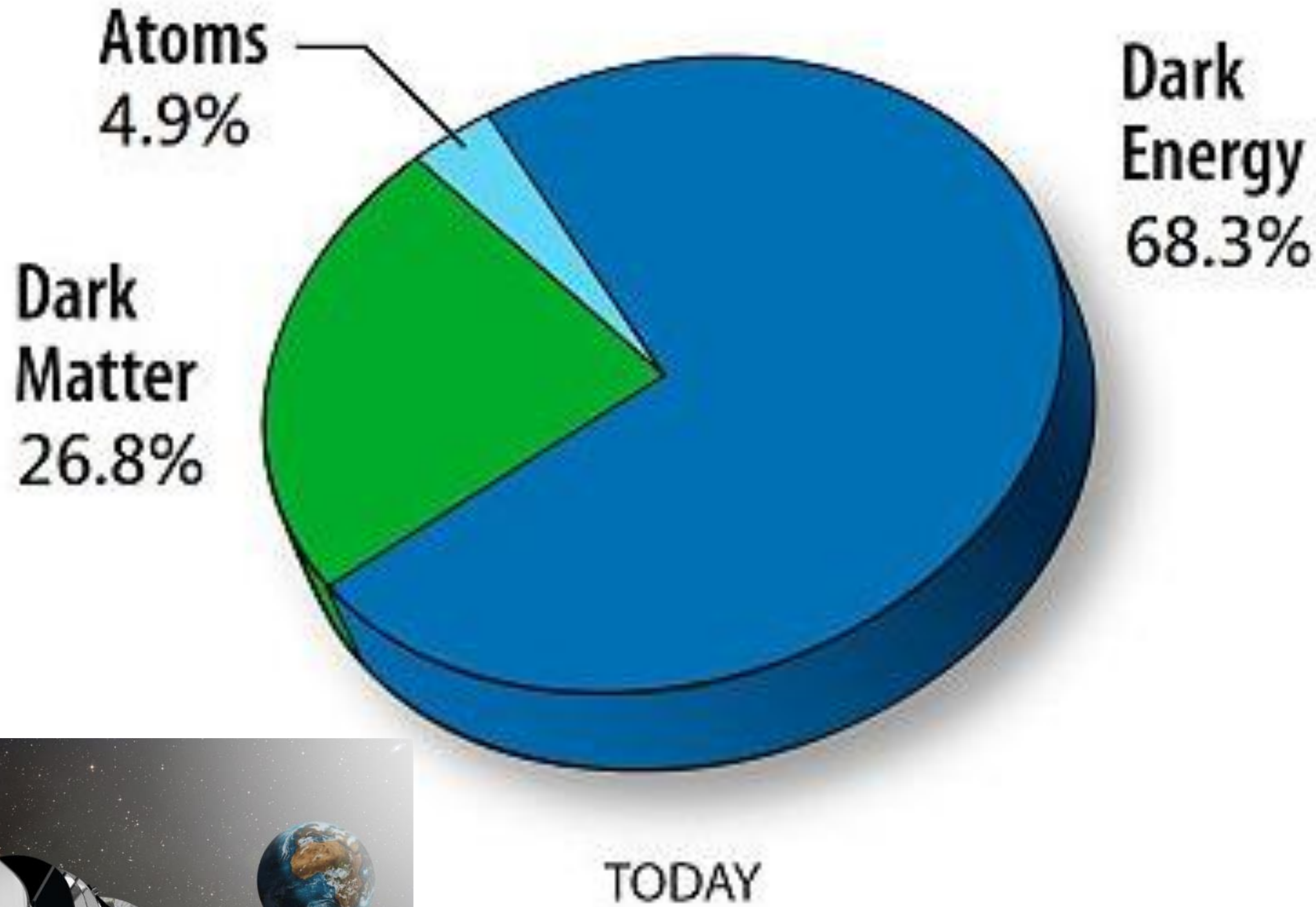
Fig. from L.Baudis; Klypin, Zhao and Somerville 2002

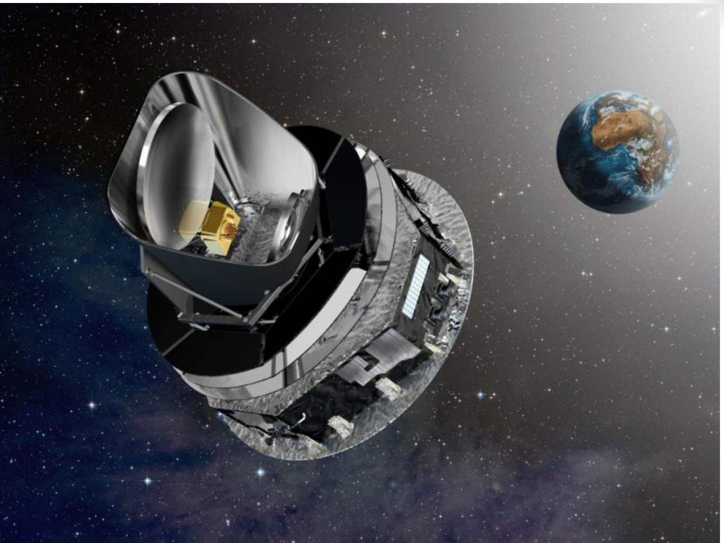



Cold dark matter is present at all scales including galactic halos (rotation curves), including ours (revolution speed of Magellanic Clouds, etc.)
If dark matter particles do not have weak interaction, no hope to detect them, if they do are called **WIMPs**
**NB. Not necessarily only one type**

**$10^{10}$ (GeV/m$\chi$) WIMP's passing through us per cm$^2$ per second !**

# Universe Energy Budget



# What we know about DM?

Know something

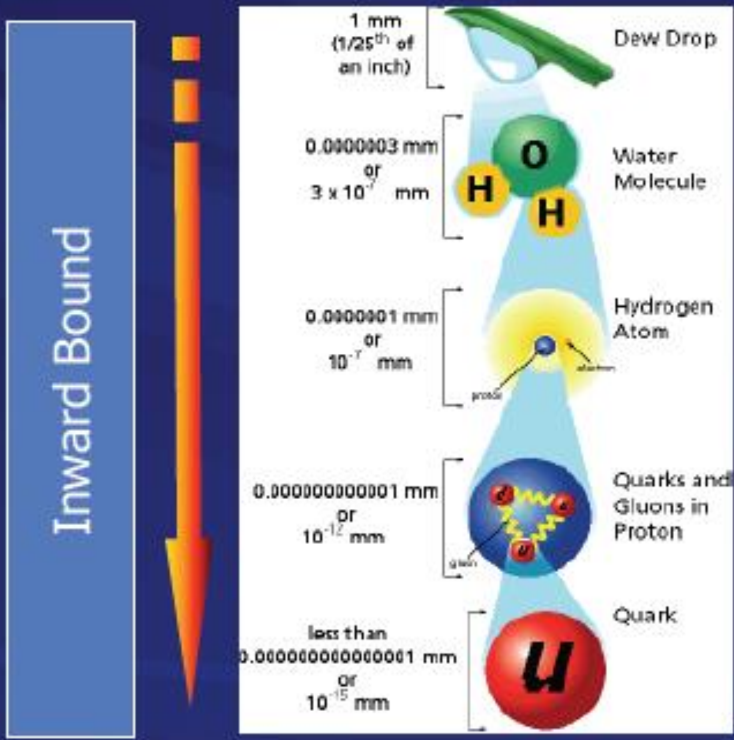
- All we know is that dark matter reacts to gravitation but not to electromagnetism since it does not emit any light i.e. electric charge =0 and colourless
- It should be massive
- Very long lived or absolutely Stable
- Very Weak in nature
- Hot or warm or cold, prefer cold dark matter
- Mass, spin NOT known

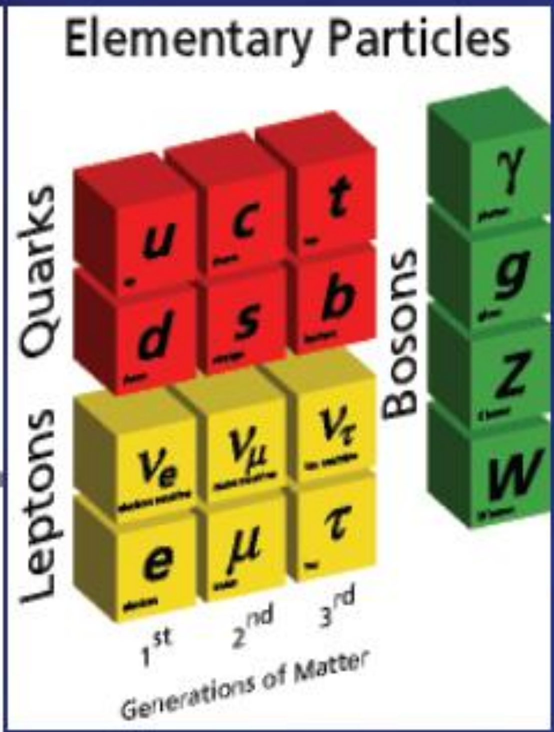
- May be it interacts with ordinary matter through the weak nuclear force, the one responsible for radioactive decays.
- Dark matter would then be made of weakly interacting particles.

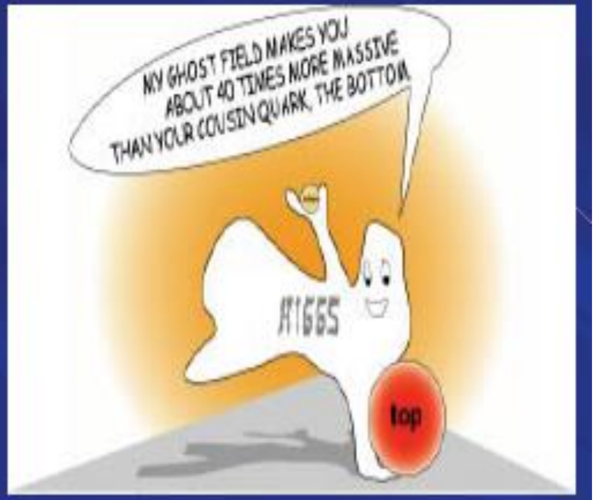
NOTHING ABOUT DARK ENERGY !!!

# Standard Model of Particles

## Standard Model of Particles
## SU(3) x SU(2) x U(1)



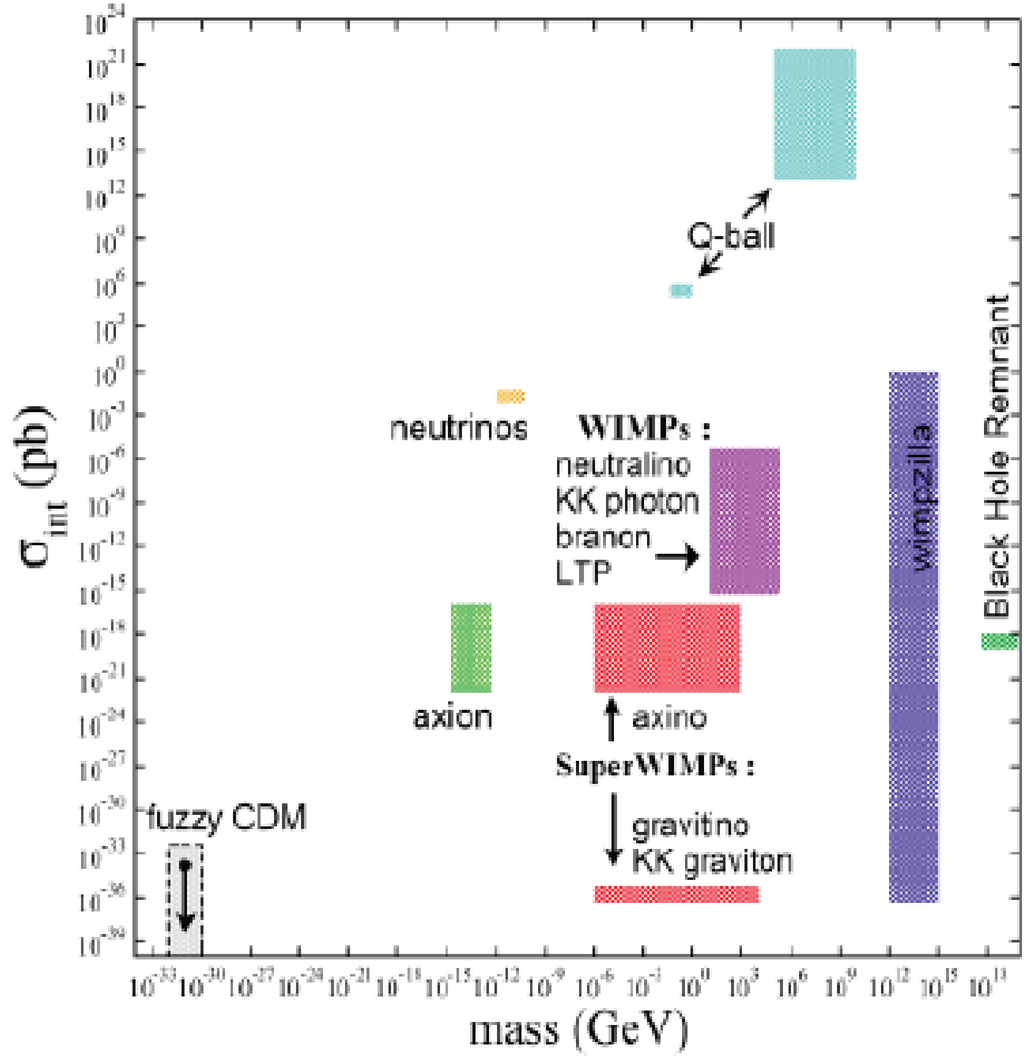




None of the SM particles can play the role of DM

# DM Candidates in Particle Physics

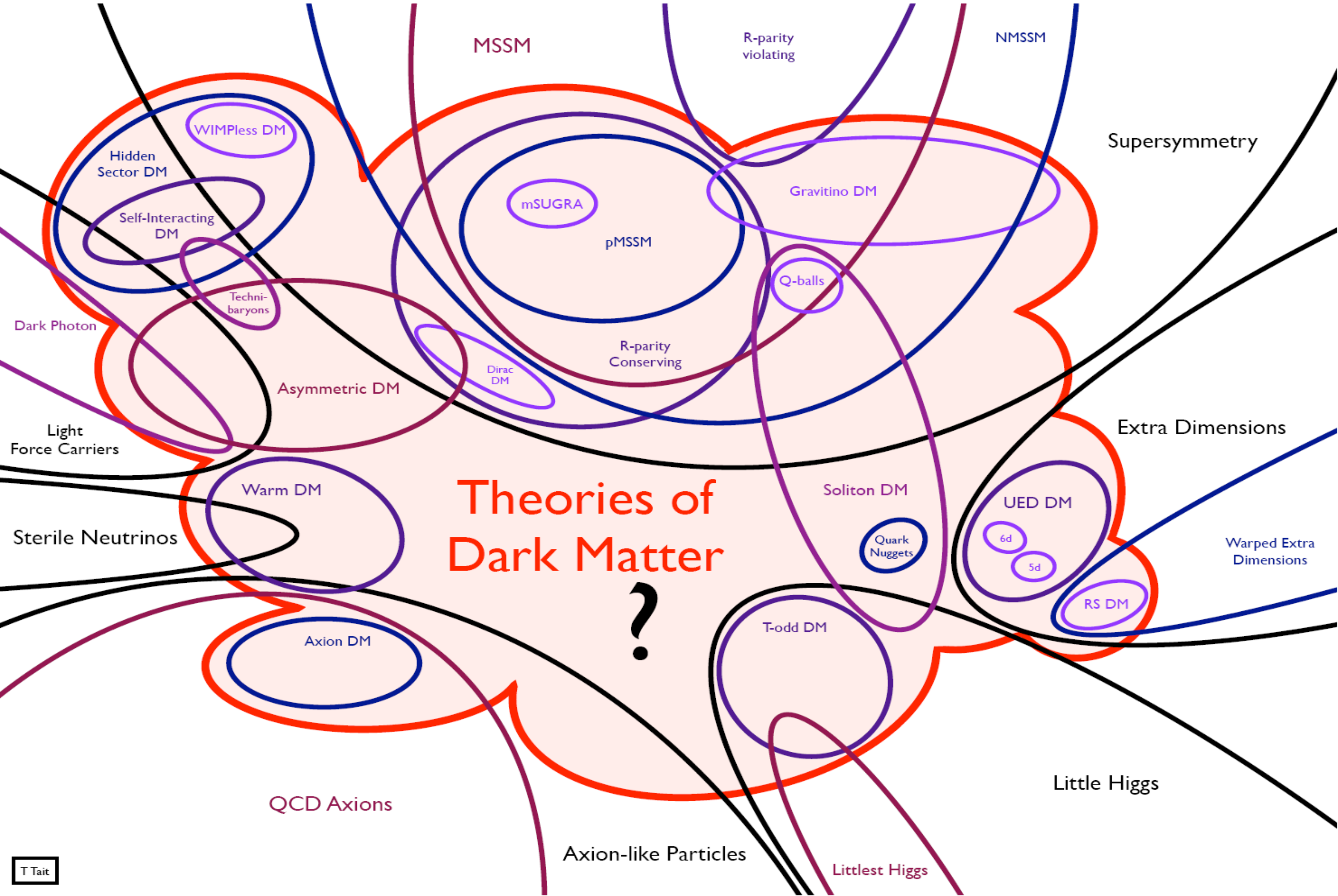
- Many many candidates in fact
- Wide ranges of mass and coupling strengths
- If one tries to solve hierarchy problem, weak scale DM is well motivated
- Strong CP motivated axion




L.Roszkowski (2004)

**Phys. Rev. D 75, 052004 (2007)**

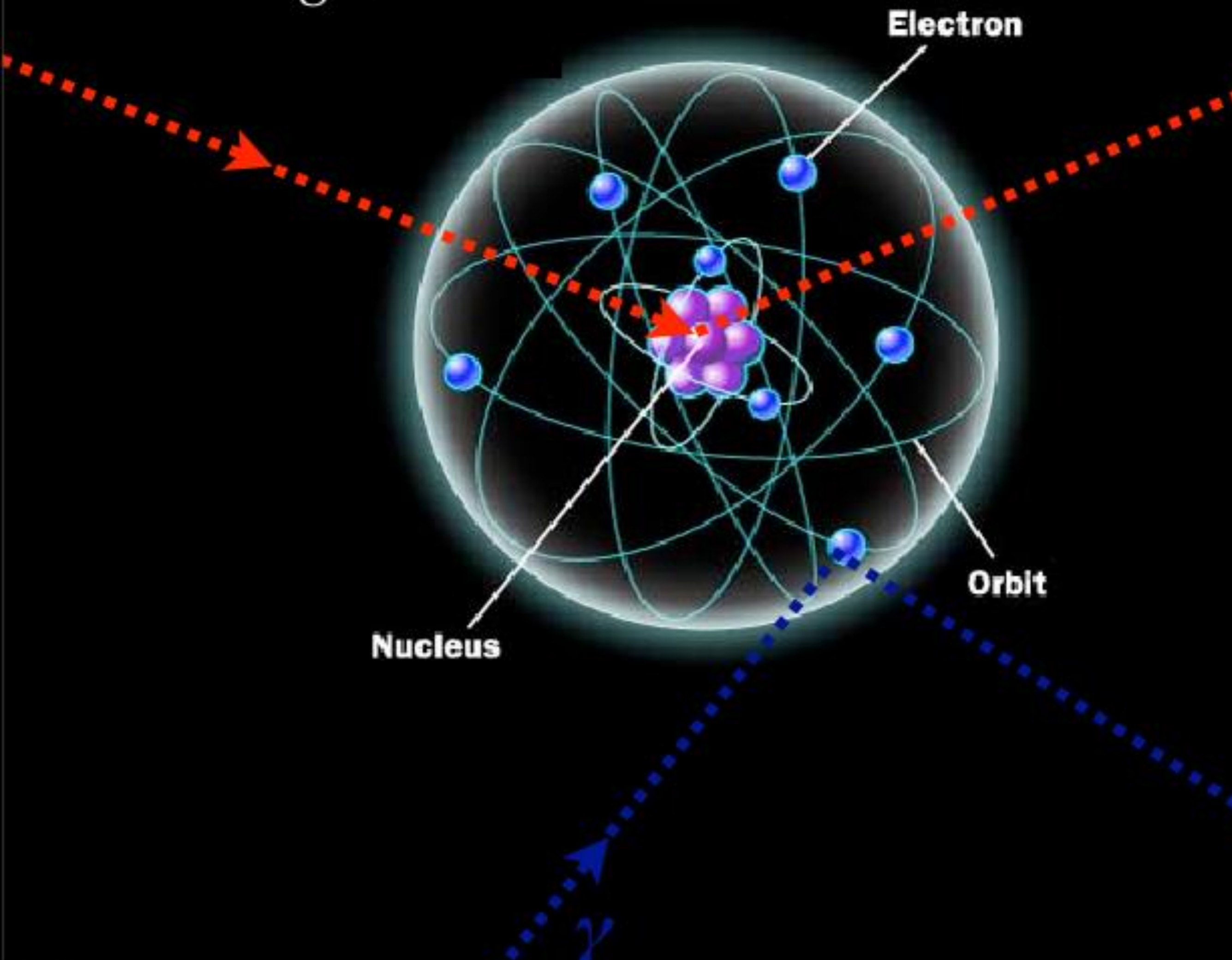
# Non-WIMP Dark Matter



# Dark Matter Searches

## Direct Detection

Signal: N → N'




Backgrounds:

$\gamma\ e^- \rightarrow \gamma\ e^{-\prime}$

$N \rightarrow N'$

$N \rightarrow N' + \alpha, e^-$

$\nu\ N \rightarrow \nu\ N'$

# Dark Matter Searches

$$\chi + N \rightarrow \chi + N$$

WIMP Nucleus Spin Independent cross-section $\sigma_{SI} = \frac{1 + m_\chi^2/m_p^2}{1 + m_\chi^2/m_N^2} \frac{A^2}{\sigma}$

WIMP Nucleon Spin Dependent cross-section $\sigma_{SD} = \frac{1 + m_\chi^2/m_p^2}{1 + m_\chi^2/m_N^2} \frac{4}{3} \frac{\lambda_{p,z}^2 J(J+1)}{\sigma}$

Axion like dark matter particle $R = \frac{1.2 \times 10^{19}}{A} g_{aee}^2 (\frac{m_a}{keV})(\frac{\sigma_{photon}}{bn}) kg^{-1} day^{-1}$

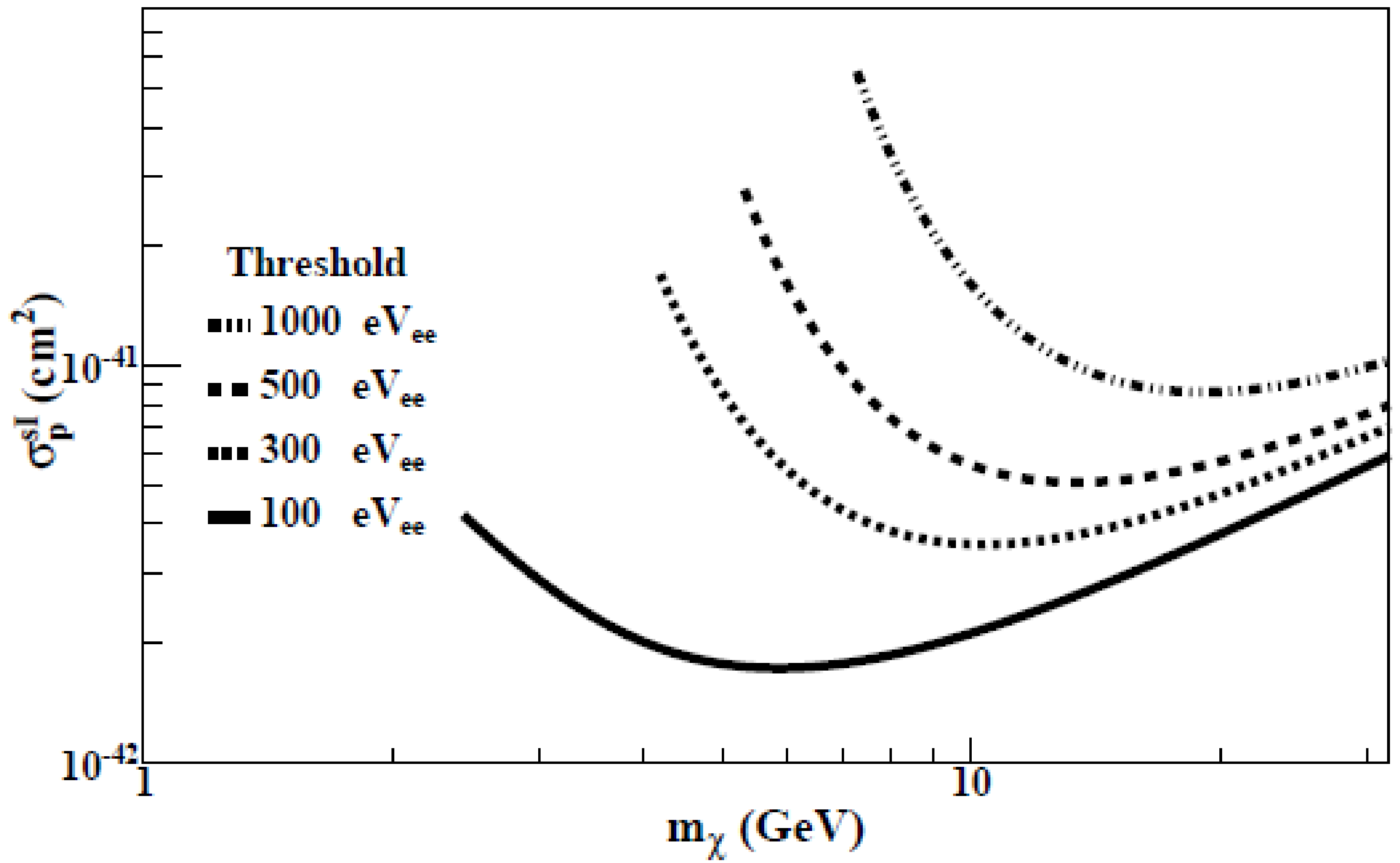
## Low mass (<10 GeV) WIMP / Sub-keV Recoil Energy

- Not favored by the most-explored specific models on galactic-bound SUSY neutralinos as CDM; *still* allowed by generic SUSY
- *Solar-system bound* WIMPs require lower recoil energy detection
- Other candidates favoring low recoils exist: e.g. non-point like SUSY Q-balls; Models e.g. pseudo-scalar axion-like particles.
- Less explored experimentally

# The World Wide WIMP Search


Many experiments are collecting more data and new ones are being built. With theorists and experimentalists being hard at work, hopefully there will soon be a breakthrough.

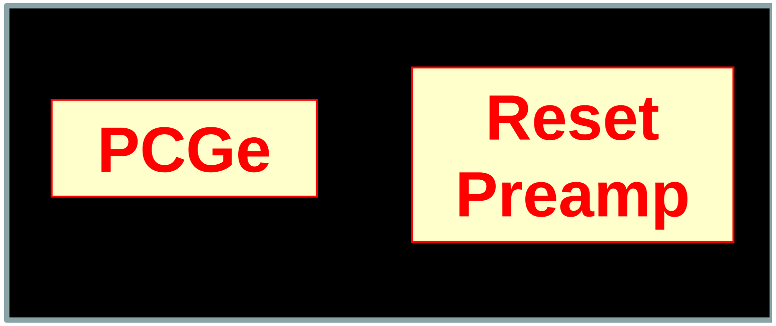
# Dark Matter Searches



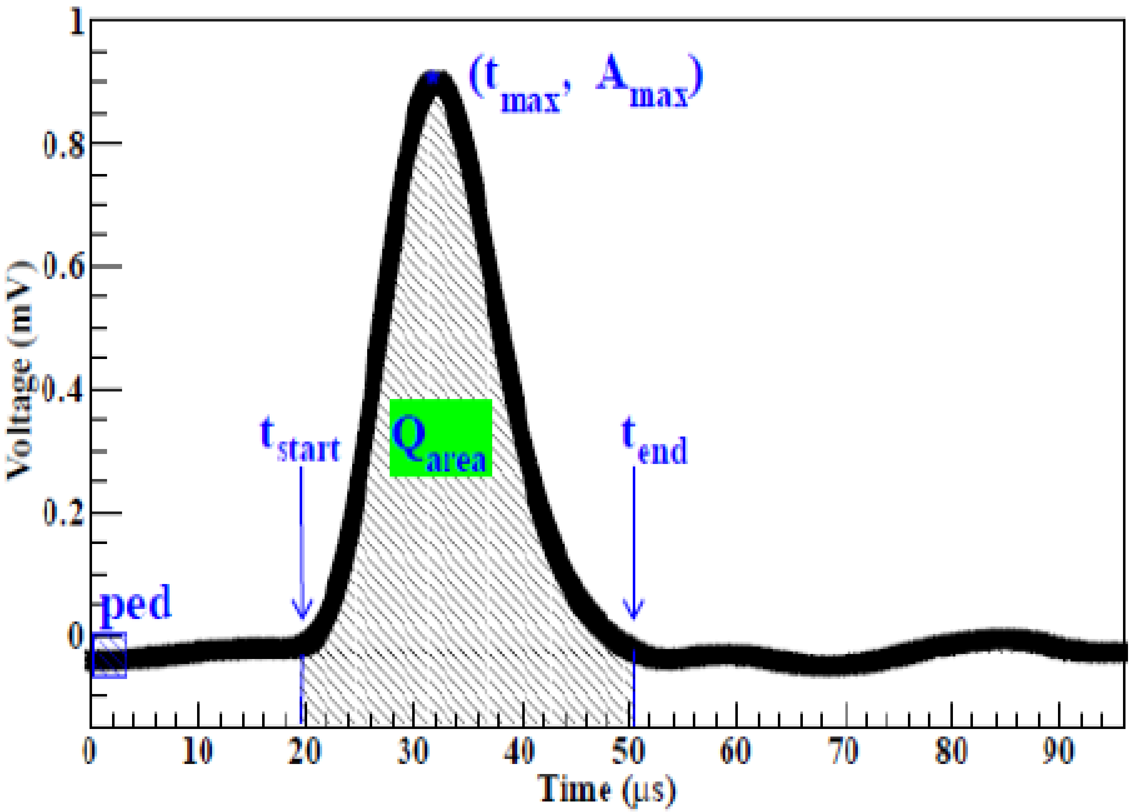

Sensitivity reach of the same configuration at different detector threshold, showing the relative improvement in cross-section as a function of $\chi_m$.

at various values of $\chi_m$. The lower bounds of $\chi_m$ as a function of physics threshold is also shown, assuming 1 kg-yr of data and a background level of 1 $kg^{-1}keV_{ee}^{-1}$ $day^{-1}$. Quenching effects of nuclear recoils are taken into account.

# Energy Measurement: Energy Calibration



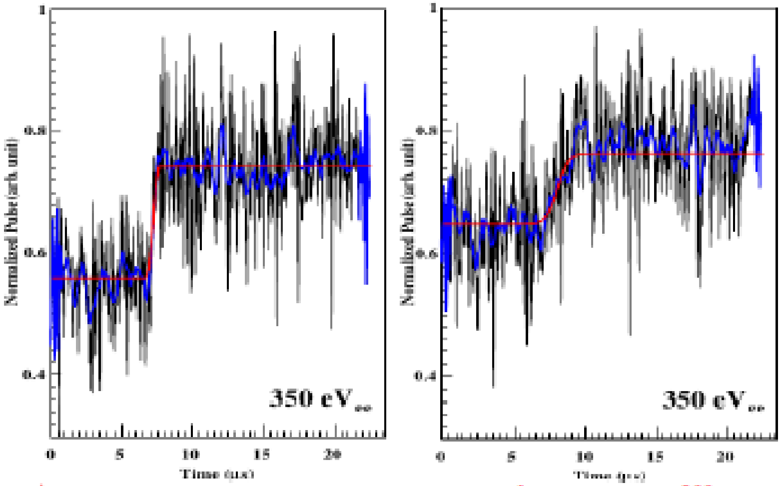

SA: Shaping time 0.5 μs to fit in frame ; Typical operation in




Typical SA6 pulse at 6 μs shaping time. The various key parameters for analysis and calibration purposes are shown.

# Bulk and Surface event Identification

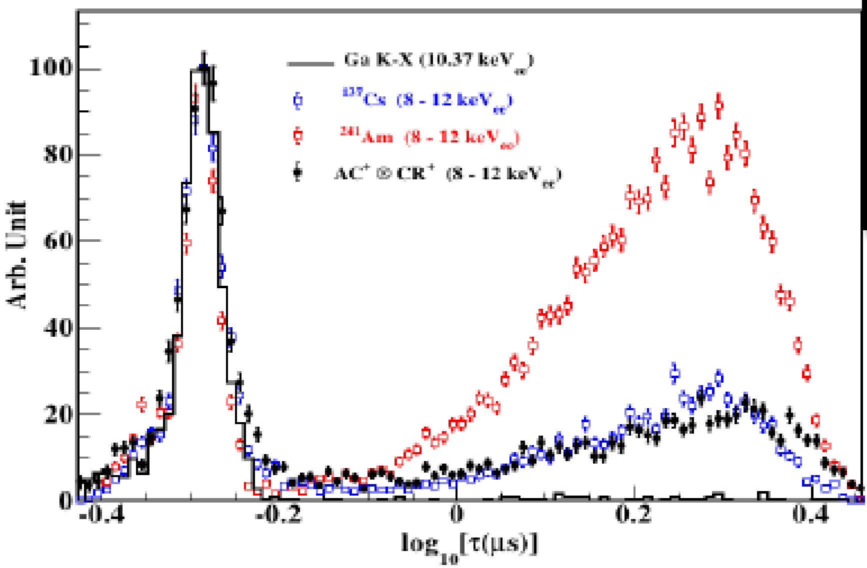
## Timing Amplifier Output

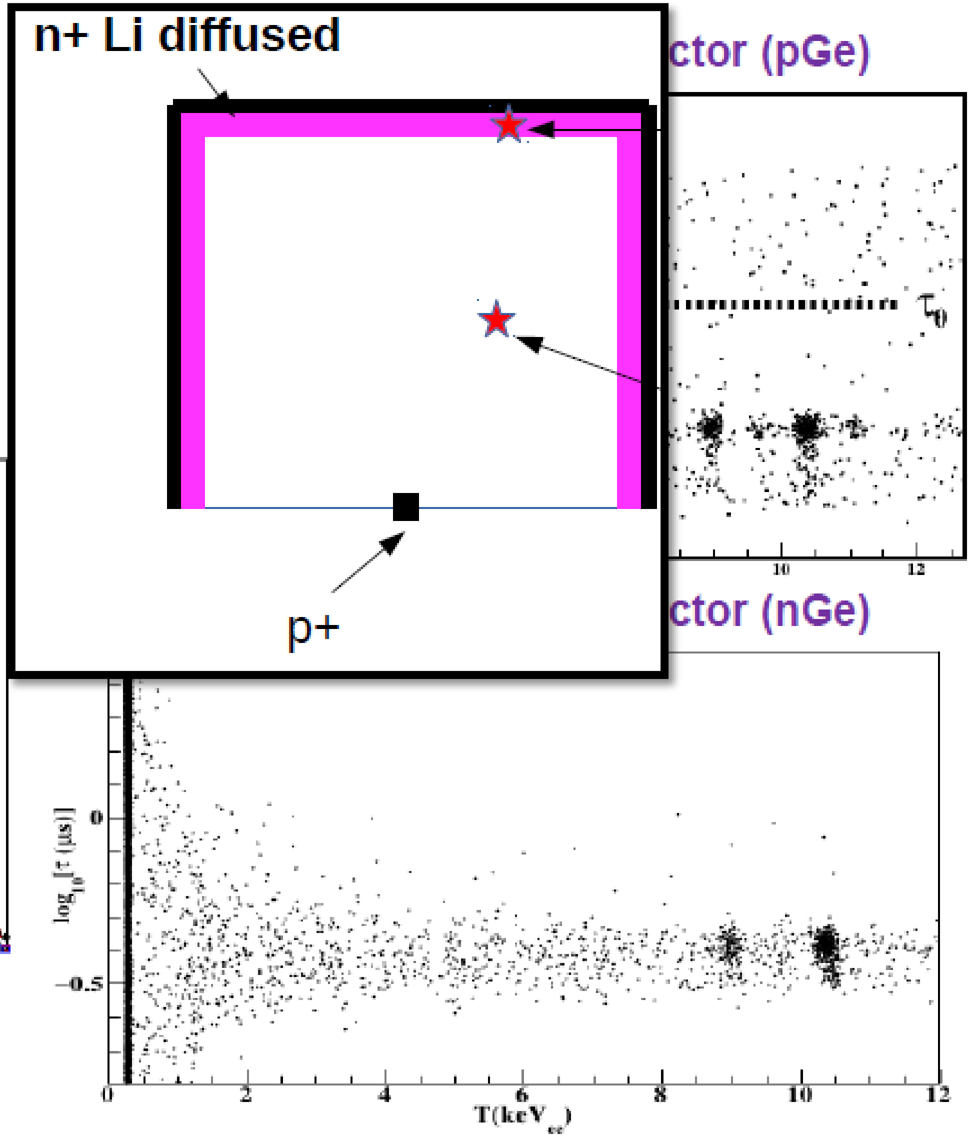



**Savitzky – Golay Filter**

$$\frac{1}{2}A_0 \times \tanh\left(\frac{t - t_0}{\tau}\right) + P_0$$

⇨ Thickness of Dead Layer = 1.16 ± 0.09 mm ( $^{133}$Ba Source)




⇨ Different Background Sources give Identical TA-risetime in Bulk but Varying in Surface.

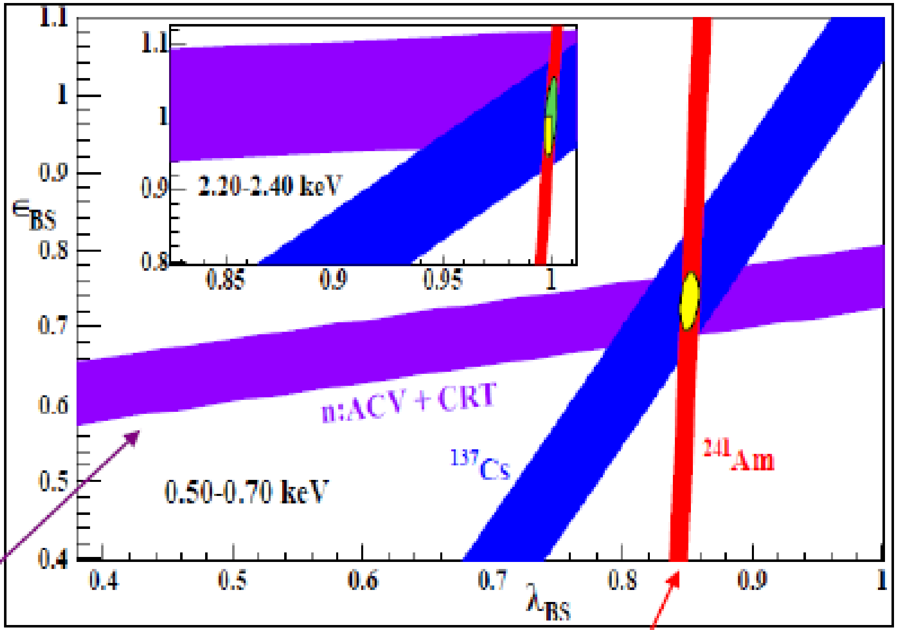
# Bulk and Surface event selection efficiency

$$B = \epsilon_{BS} \cdot B_0 + (1 - \lambda_{BS}) \cdot S_0$$
$$S = (1 - \epsilon_{BS}) \cdot B_0 + \lambda_{BS} \cdot S_0$$
$$B_0 + S_0 = B + S$$

B = Observed Bulk, S = Observed Surface
$B_0$ = Actual Bulk, $S_0$ = Actual Surface
$\varepsilon_{BS}$ = Efficiency of bulk signal retaining
$\lambda_{BS}$ = Efficiency of surface signal suppression

**To obtain ($\varepsilon_{BS}$, $\lambda_{BS}$) requires at least two measurements of (B,S) where ($B_0$,$S_0$) are known:**

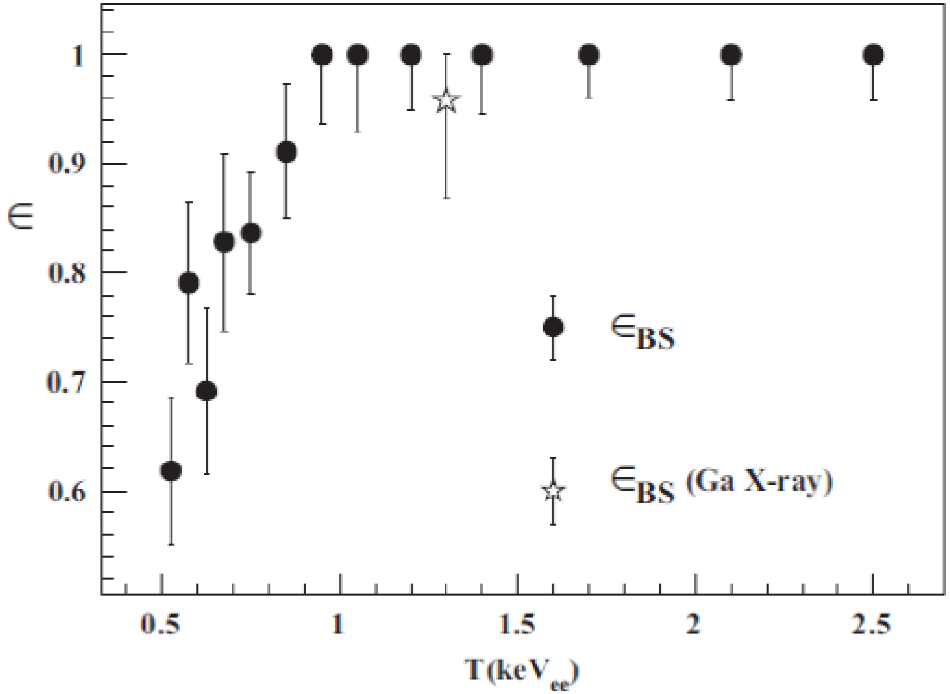
- Very Surface Rich events with γ-ray sources ($^{241}$Am); $B_0$ from MC.
- Surface Rich events with γ-ray sources ($^{137}$Cs); $B_0$ from MC.
- Bulk Rich Cosmic-ray induced high energy neutrons; $B_0$ from n-PCGe detector (no anomalous Surface-Bulk events).

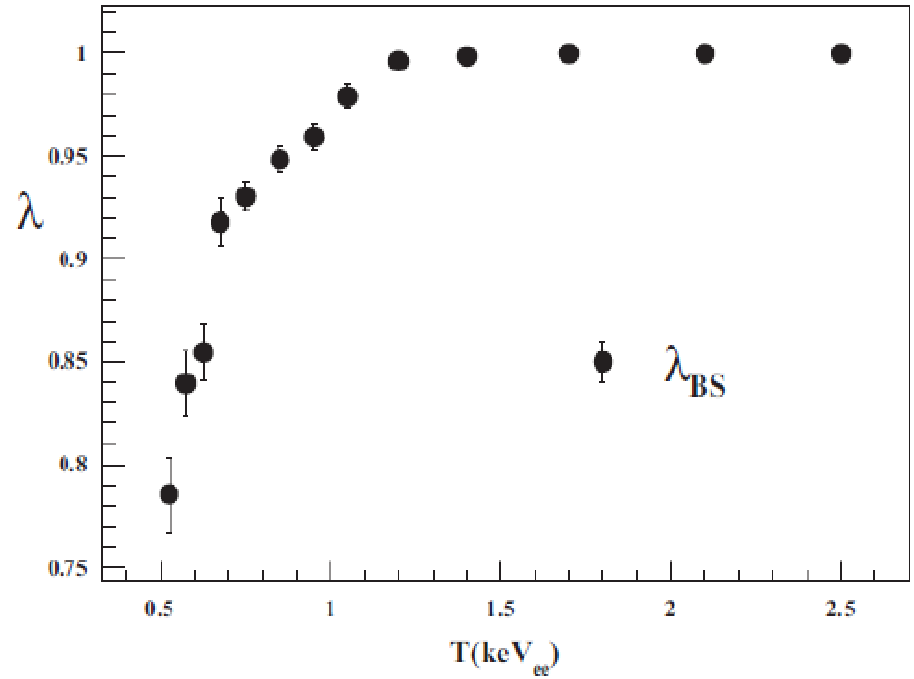



Bulk-Rich high-energy neutrons constrain $\varepsilon_{BS}$

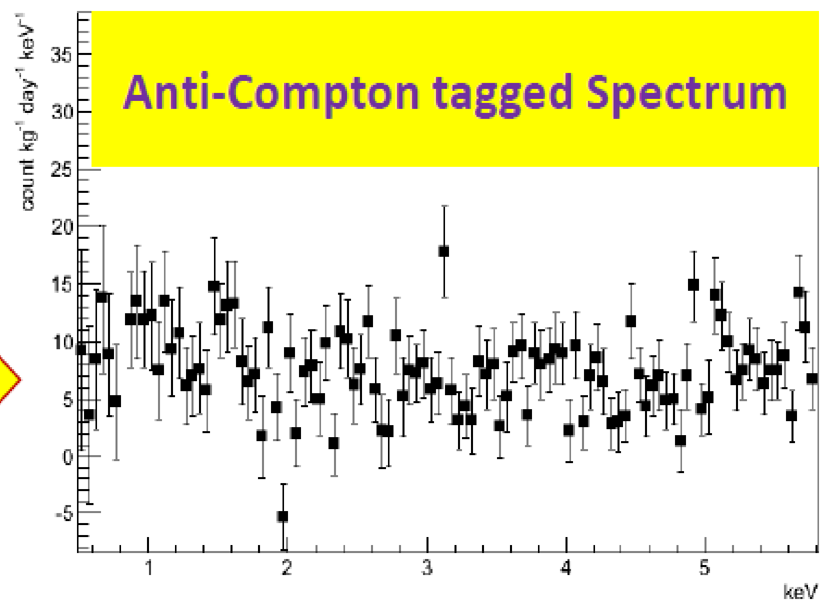
Surface-Rich γ-rays constrain $\lambda_{BS}$

# Bulk and Surface event selection efficiency

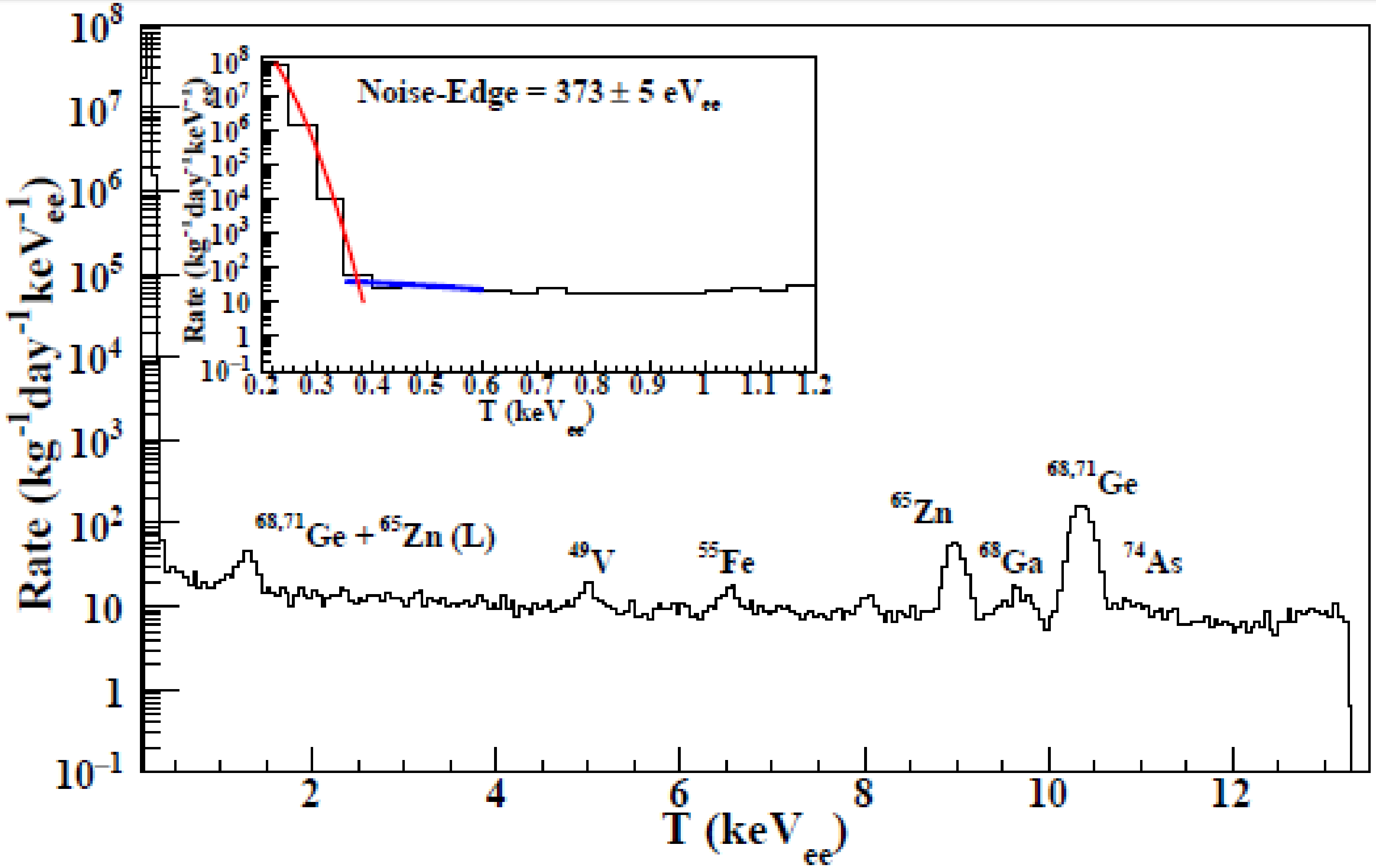



Cross-Check Consistent with flat MC expectation



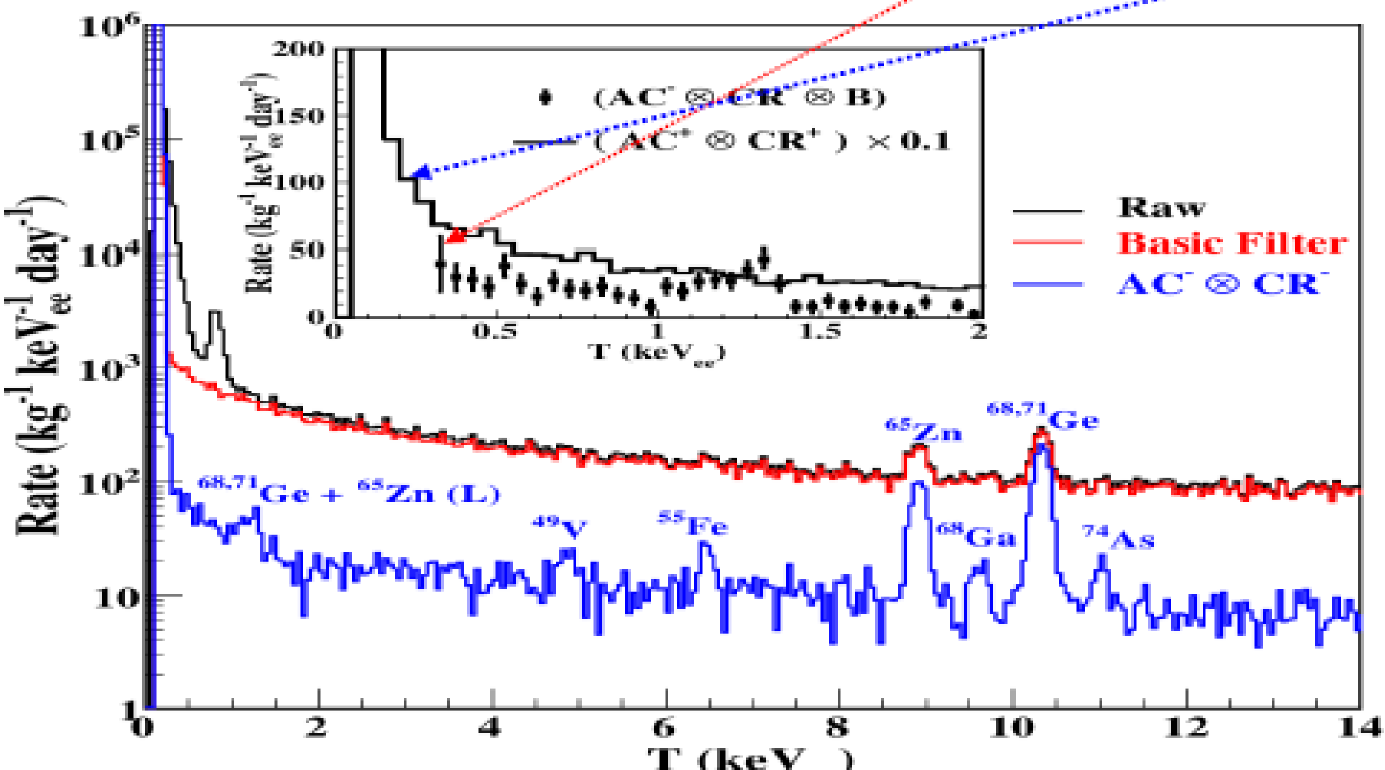
# Energy Measurement: Energy Calibration




Typical ULEGe, pPCGe and nPCGe spectra showing X-ray peaks and noise-edge. **The lines in all cases are used in energy calibration**. The peaks are due to electron capture of cosmogenic activated isotopes producing X-rays inside the detectors. The noise-edge is defined **as the energy when physics events would take over from the self-trigger electronic noise spectra**.

# Summary table of Ge detector performance

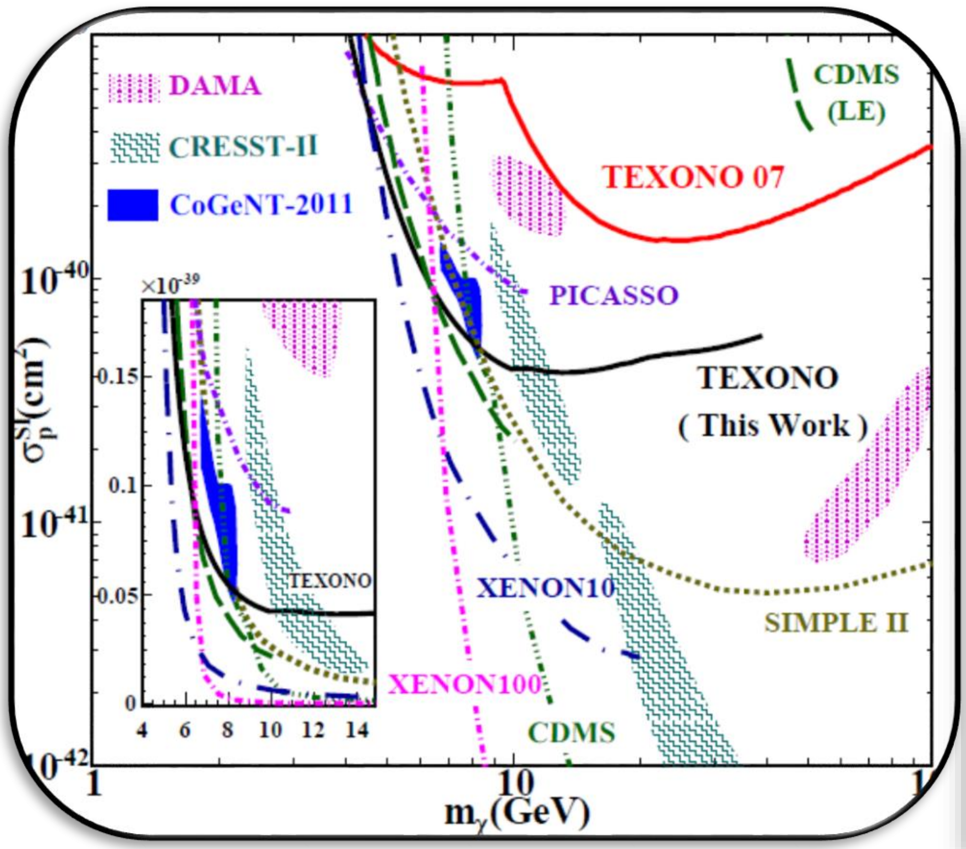
| Items | CoaxGe | pPCGe | nPCGe | pPCGe |
|---|---|---|---|---|
| Modular Mass (g) | 1000 | 900 | 500 | 500 |
| Pedestal Noise RMS(eV) | 812 | 56 | 49 | 41 |
| Pulser FWHM (eV) | 1566 | 124 | 133 | 110 |
| Noise Edge (eV) | 5600 | 400 | 373 | 311 |
| Noise Edge with Double Co-incidence (eV) | N/A | 300 | 237 | 197 |



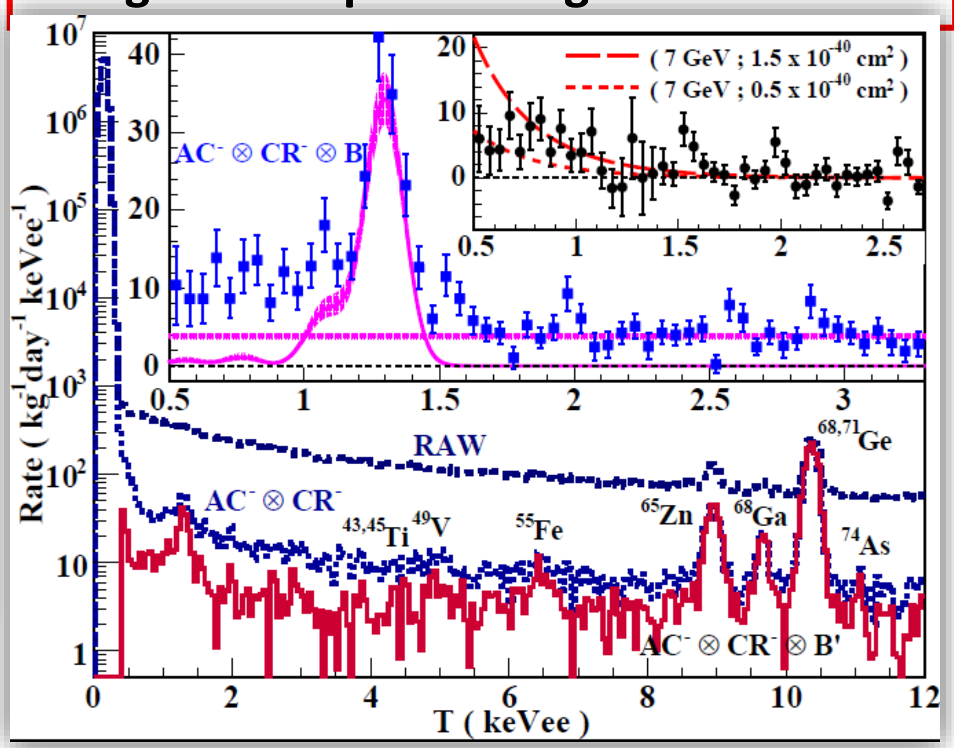
# Light WIMP Searches with Ge @ KSNL

TEXONO@KSNL *[PRL13,AP14]* :

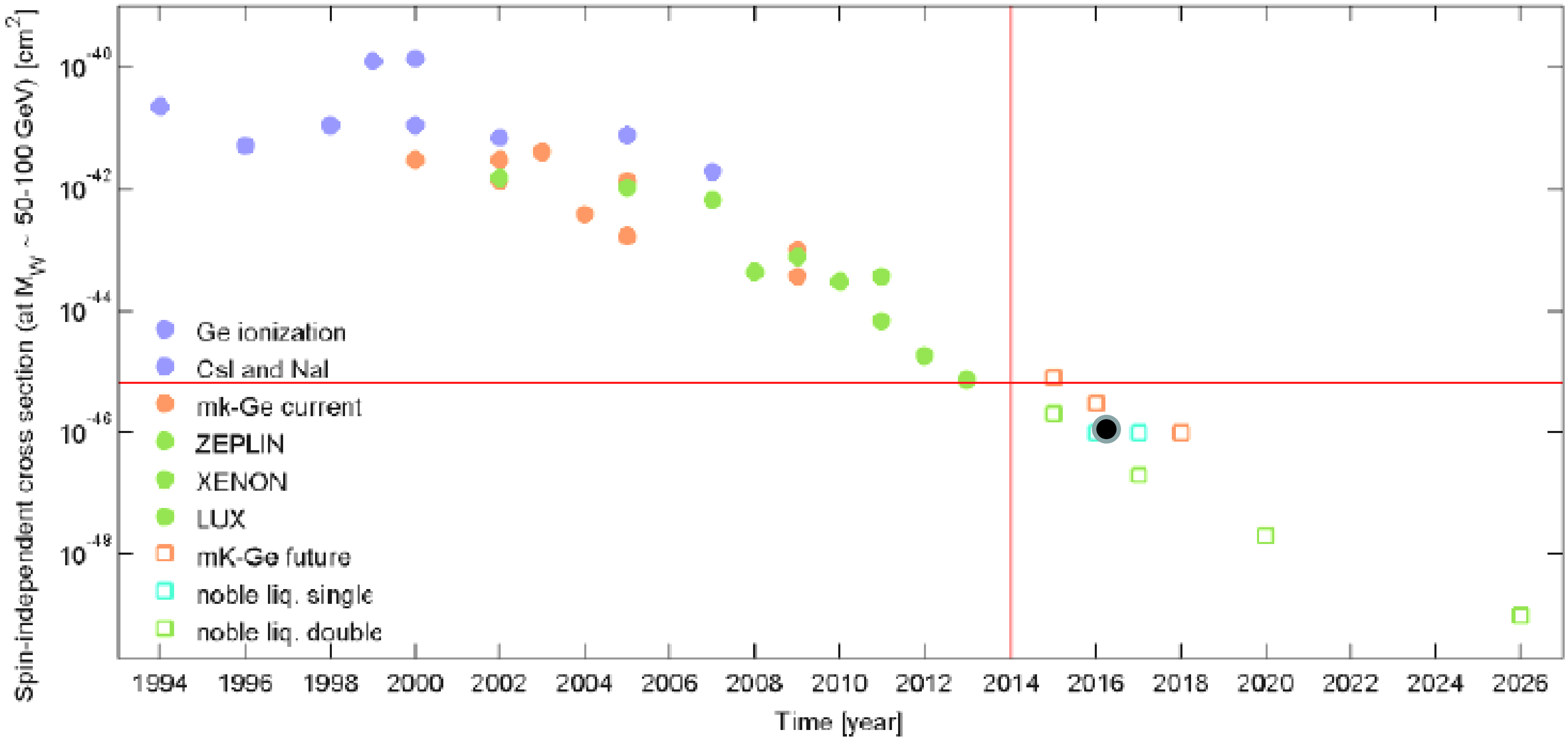
- Learn & Establish Techniques
- Catalyze CDEX-1 @ CJPL
- Produce Physics Results !




- 500 eV threshold; FM 0.84 kg; DS 39.5 kg-days
- devised schemes for B/S separation & efficiencies
- probed and excluded some light WIMP allowed regions
- Indicated: leakage of “Surface” background to “Bulk” samples can give false positive signals.



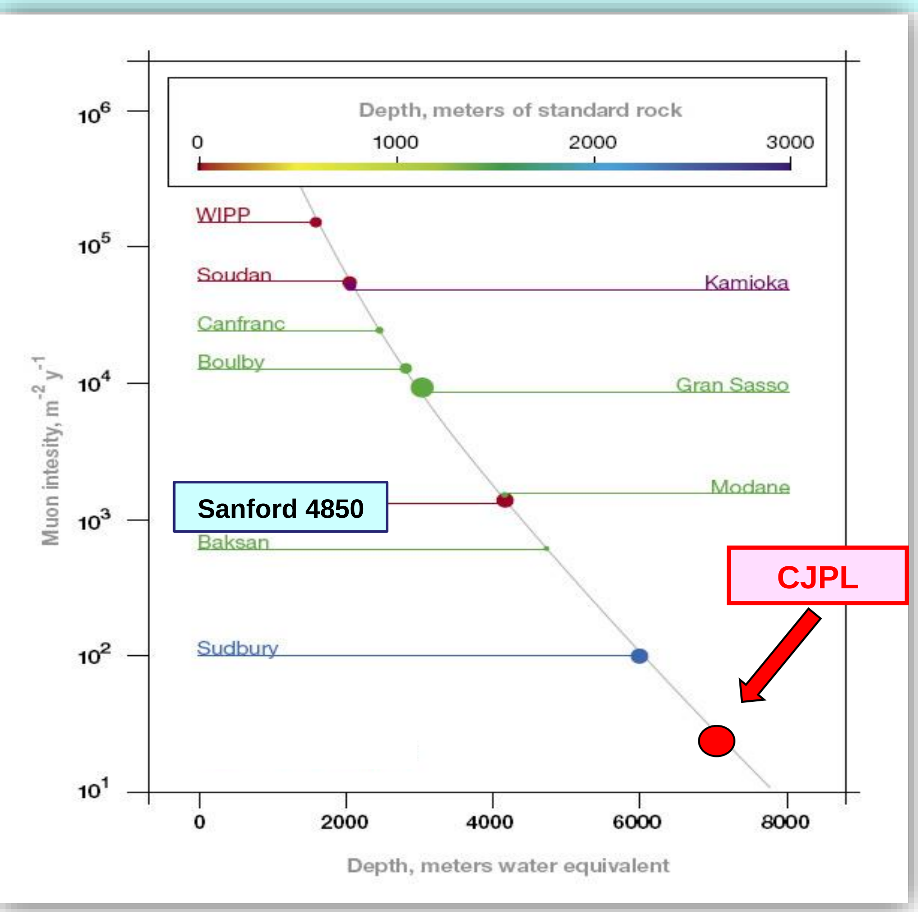
# Light WIMP Searches Sensitivity




L. Baudis, arXiv:1408.4371

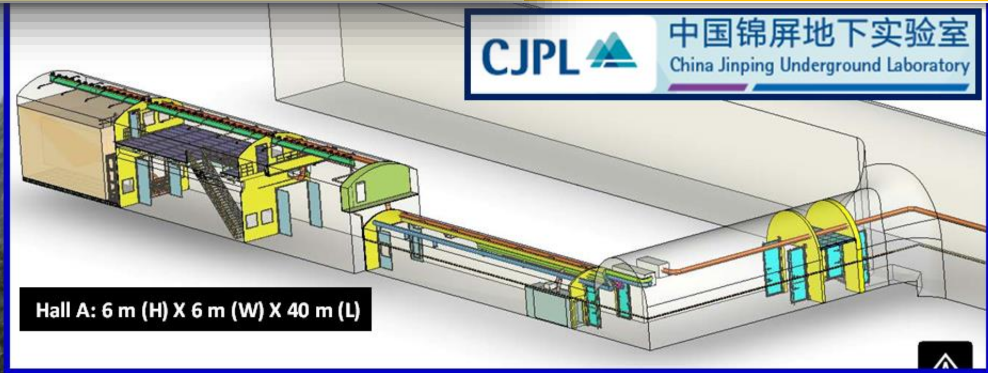
**Limits are getting better and better ....**
**So be positive and wait for positive claim....**

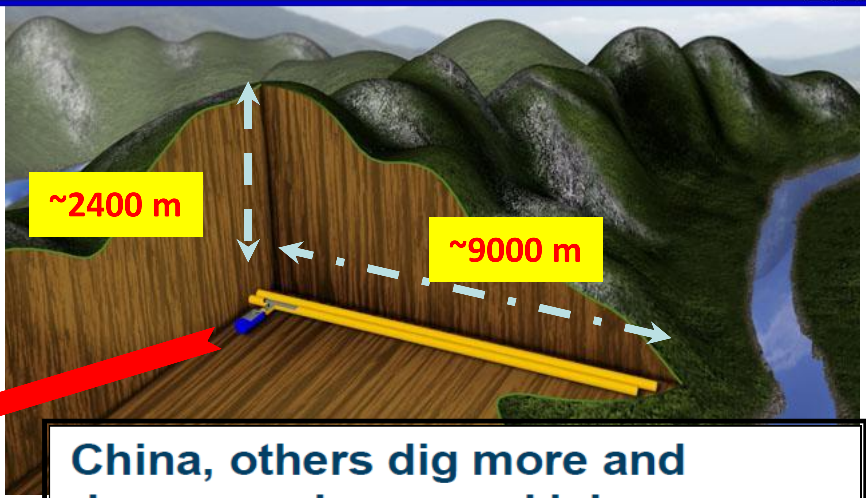
- ◎ 2400+ m rock overburden, drive-in road tunnel access
- ◎ ~6 muon/m²-month (cf sea-level 100 Hz/m²)
- ◎ 6X6X40 m cavern constructed [managed by THU & YLJHDC]
- ◎ CDEX-1 Dark Matter Program

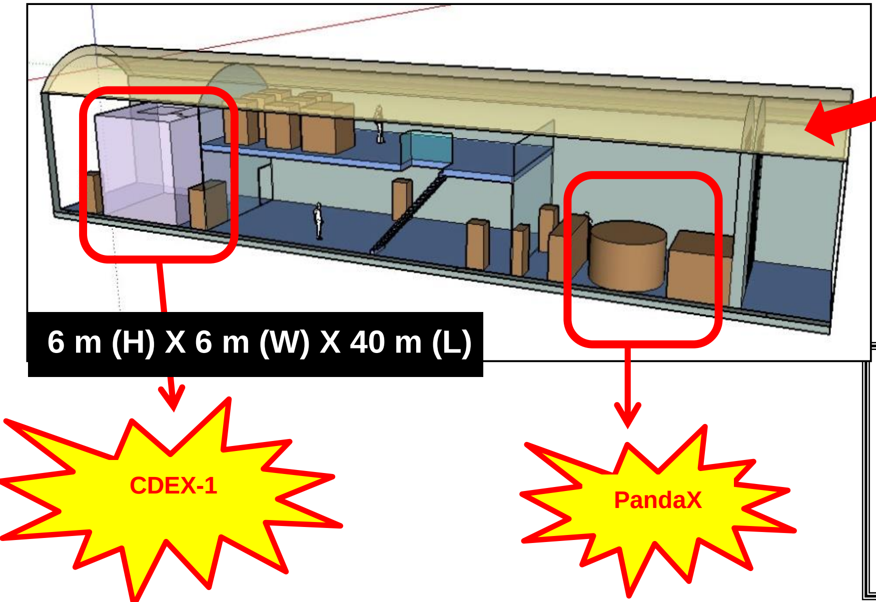



中国锦屏地下实验室

CJPL China Jinping Underground Laboratory


## China, others dig more and deeper underground labs

From tiny to gargantuan, experiments are in the works to exploit the shielding from cosmic rays that being deep underground offers

Physics Today September 2010

PARTICLE PHYSICS:

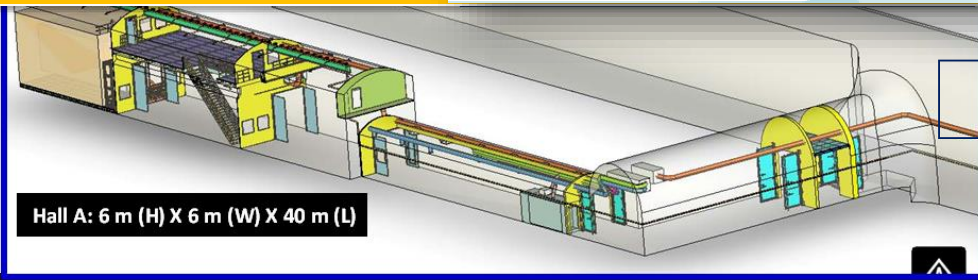
## Chinese Scientists Hope to Make Deepest, Darkest Dreams Come True

Dennis Normile

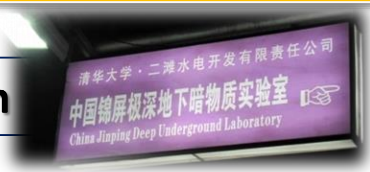
Science AAAS


*Science* 5 June 2009:
Vol. 324. no. 5932, pp. 1246 - 1247
DOI: 10.1126/science.324_1246

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

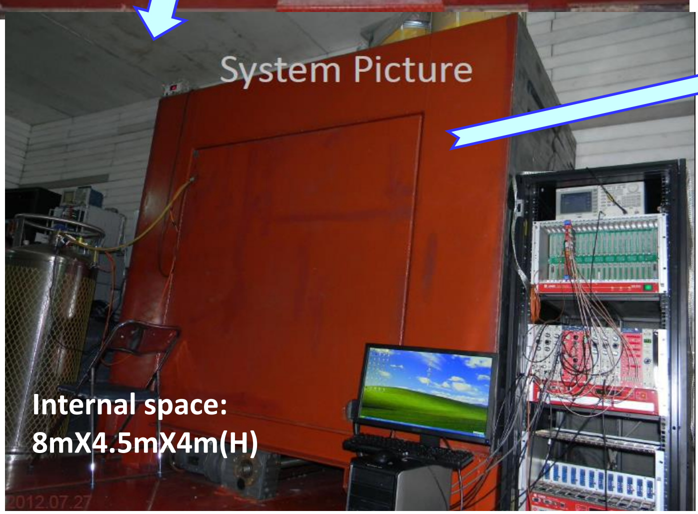


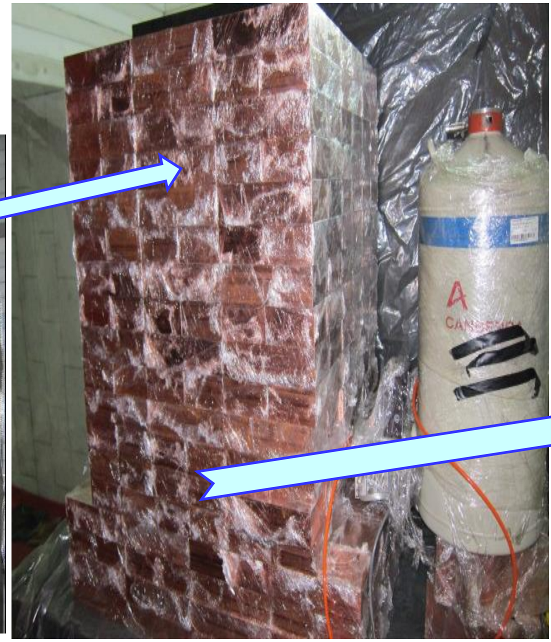

μ-rate ~ 6 per $m^2$ per month

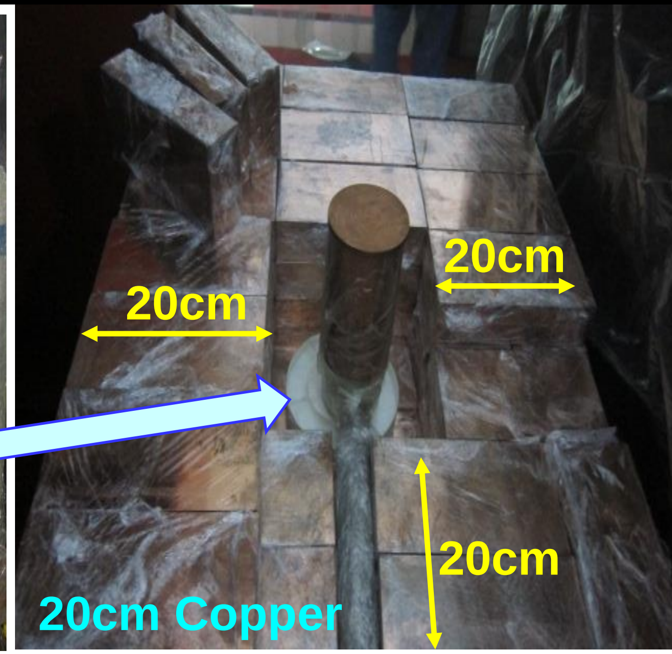



## CDEX-1 @ CJPL :

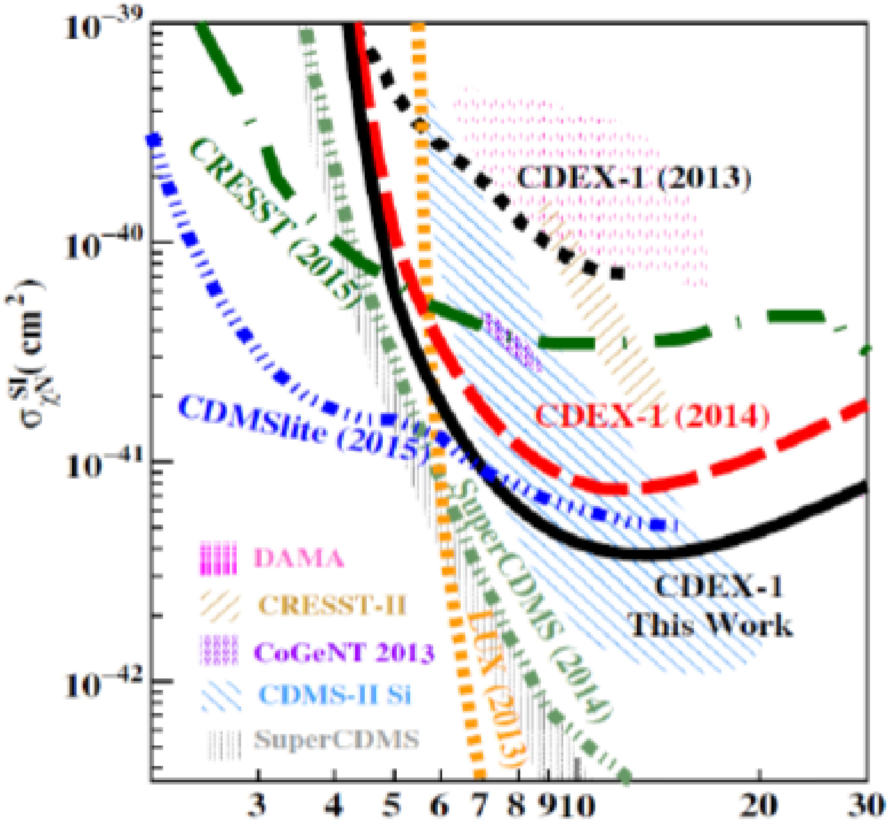
- Adopt KSNL Baseline Design
- Engineering Run 2011
- Physics Run June 2012
- First Results 2013

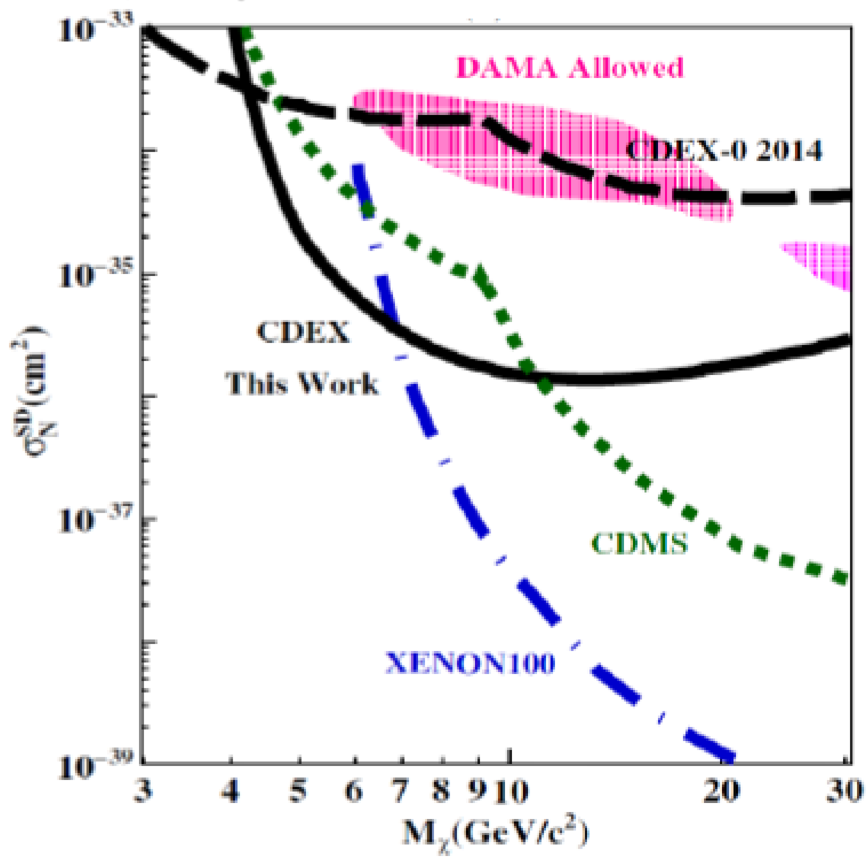





- All events quantitatively accounted for ; No Residual Excesses at sub-keV
- Exclude CoGeNT-2013 excess as WIMP-induced, independent of interaction channels




**Configurations:**

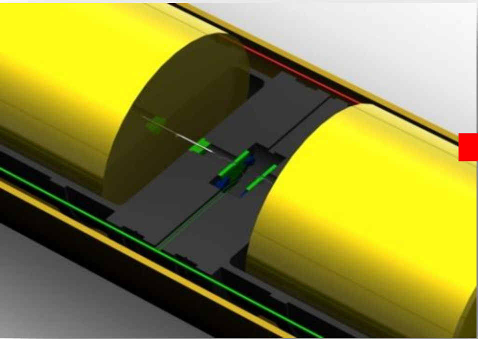
- 335 kg-days of data @ CJPL (2016)
- Baseline design with NaI(Tl)
- Fiducial mass : 915 g
- Analysis above : 475 eV
- Q.F. adopted by TRIM software with 10% systematic uncertainty

*Reference: PRD 93 092003 (2016) ; PRD(R) 90 091701(2014); PRD 90 032003 (2014); PRD 88 052004 (2013)*

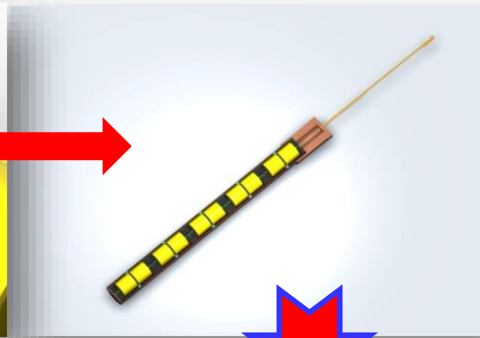
# Design of CDEX-10: LAr as anti-Compton

- 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

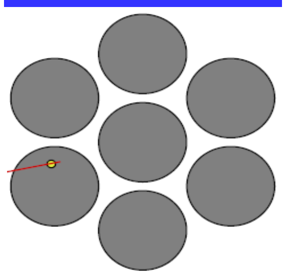
Ge + JFET

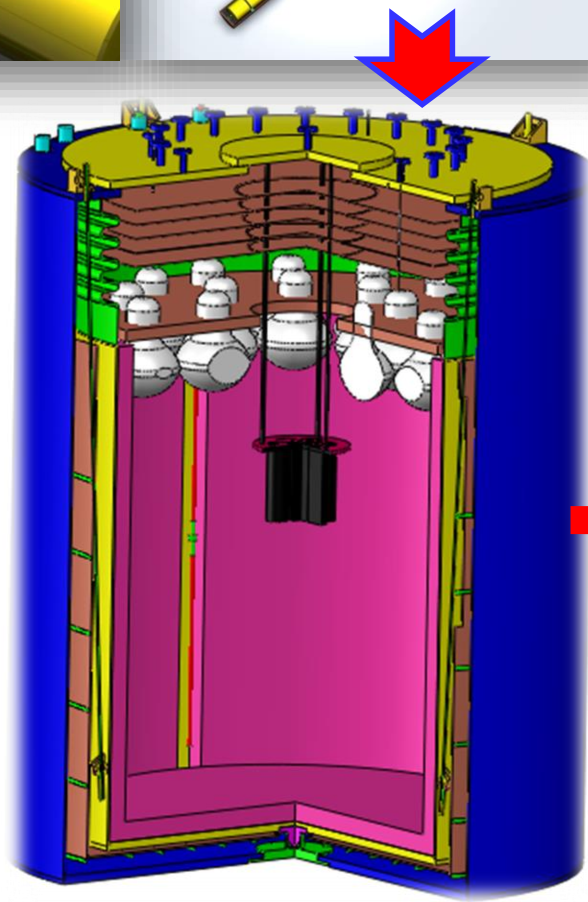


Ge Array in String

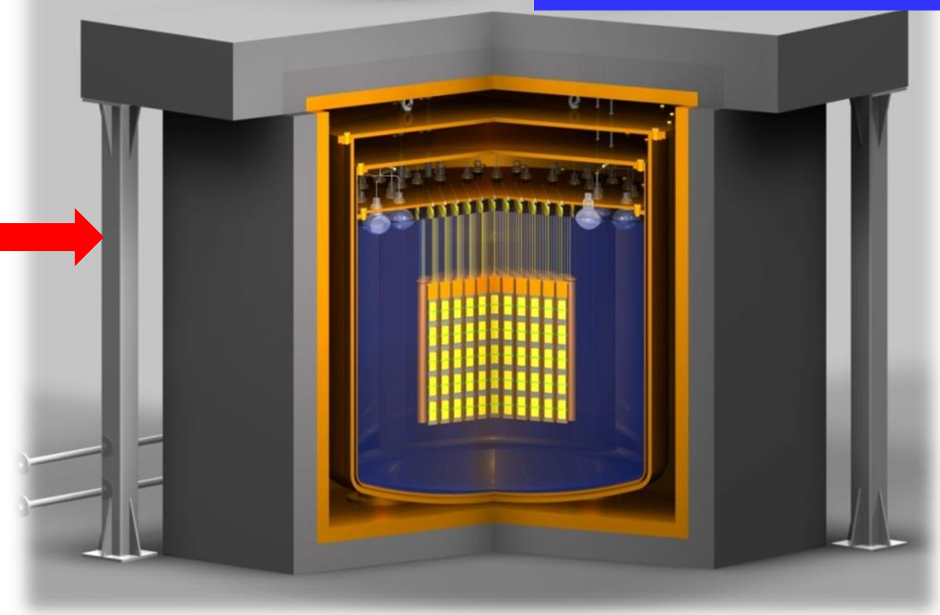


CDEX-10 (2015+)

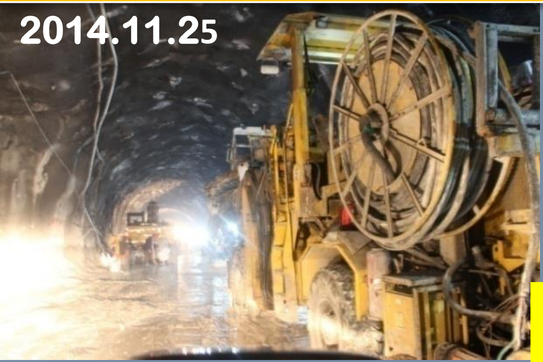


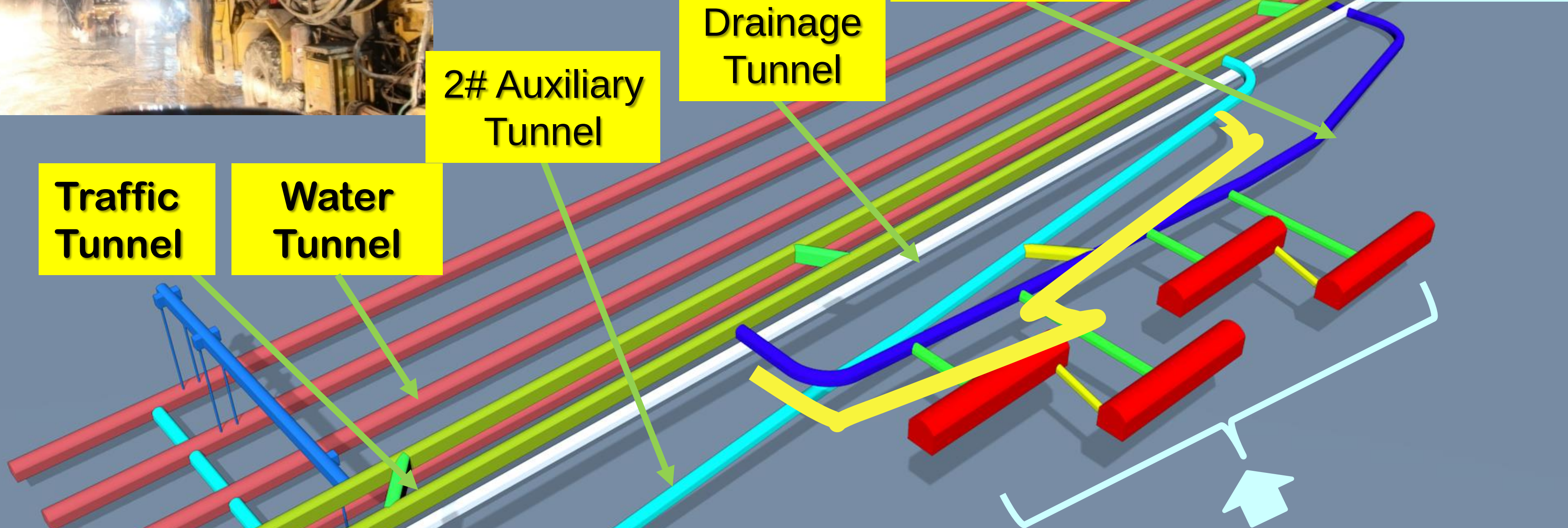


CDEX-(1 ton) Artist's Conception



# New Lab: CJPL - II




- **Four 14m*14m*130m Lab Halls [30×> CJPL-I]**
- **Construction Started end 2014**

PHYSICS

Science V346, Nov 2014

## China supersizes its underground physics lab

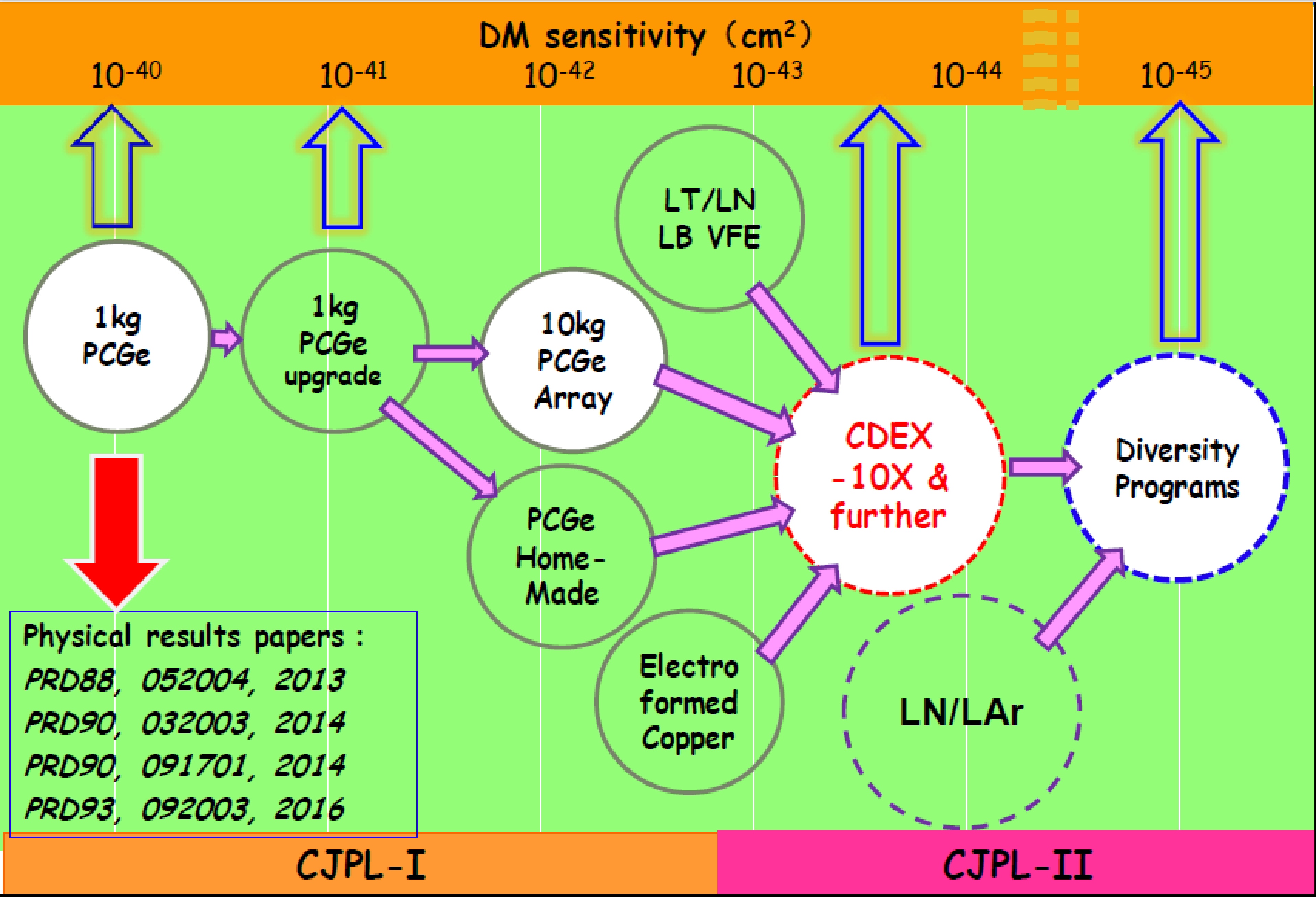
Planned expansion could pave way for "ultimate dark matter experiment"

## China carves out larger role in underground science

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

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

# Plans of CDEX



# Summary & Prospects

- Improved sensitive bounds on low energy neutrino parameters.
- Competitive results on light WIMPs with sub-keV Ge, *even at* a surface TEXONO@KSNL; further improved with underground CDEX-1@CJPL
- Surface leakage to Bulk samples is important to PPCGe at low energy, origin of earlier "WIMP signal".
- CJPL-2: 30 times more space, being built
- Ge R&D + technology acquisition ⇨ next generation DM (+DBD) experiment @CJPL
- KSNL: more matured to return to original goal
  - $\nu$N coherent scattering

# Thank you !!

# Back Up
# Technical Materials

# Direct Detection

1. Large mass 2. Low cost 3. Low threshold
4. As pure as possible 5. Deeper is the better

- **Standard assumption** → Galactic WIMP Halo
- **WIMP "wind"** with ~220 km/s relative velocity, or $\beta = v/c \sim 7\times10^{-4}$
- **Direct detection attempts to measure**: $E_{recoll} \sim \frac{1}{2} M_{nucleus}\, c^2 \beta^2$
  $\sim$ 10 to 20 keV
- **Event rate** ∝ detector size, ∝ WIMP flux, & ∝ cross section
- More specifically, **sensitivity** depends on detector composition, WIMP mass, detection threshold, and halo model


Very roughly:

Rate = N [atoms] x φ [cm$^{-2}$day$^{-1}$] x σ [cm$^2$/atom]

N = $8.3\times10^{24}$ [atoms in a 1 kg Ge detector]

$$N = \frac{M}{A}\times N_A = \frac{1000\ [g]}{72.61\ [g/mole]}\times 6.02\cdot 10^{23}\ [atoms/mole]$$

φ = $6.1\times10^{8}$ [cm$^{-2}$day$^{-1}$]

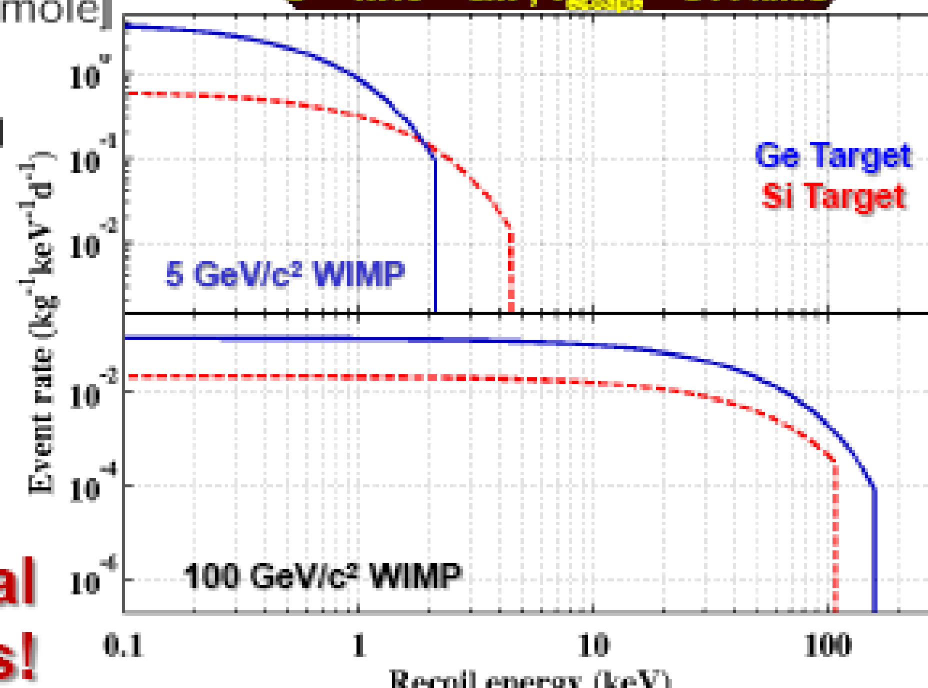
$$\phi = \frac{\rho}{M_\chi c^2} vT = \frac{1/3\ [GeV/cm^3]}{100\ [GeV]}\times 0.7\cdot10^{-3}\times 3\cdot10^{10}[cm/s]\times 86400[s/day]$$

σ = $1\times10^{-43}$ [cm$^2$/atom] (weak scale cross section)

Rate = $5.1\times10^{-9}$ [kg$^{-1}$day$^{-1}$]… totally hopeless rate per nucleon

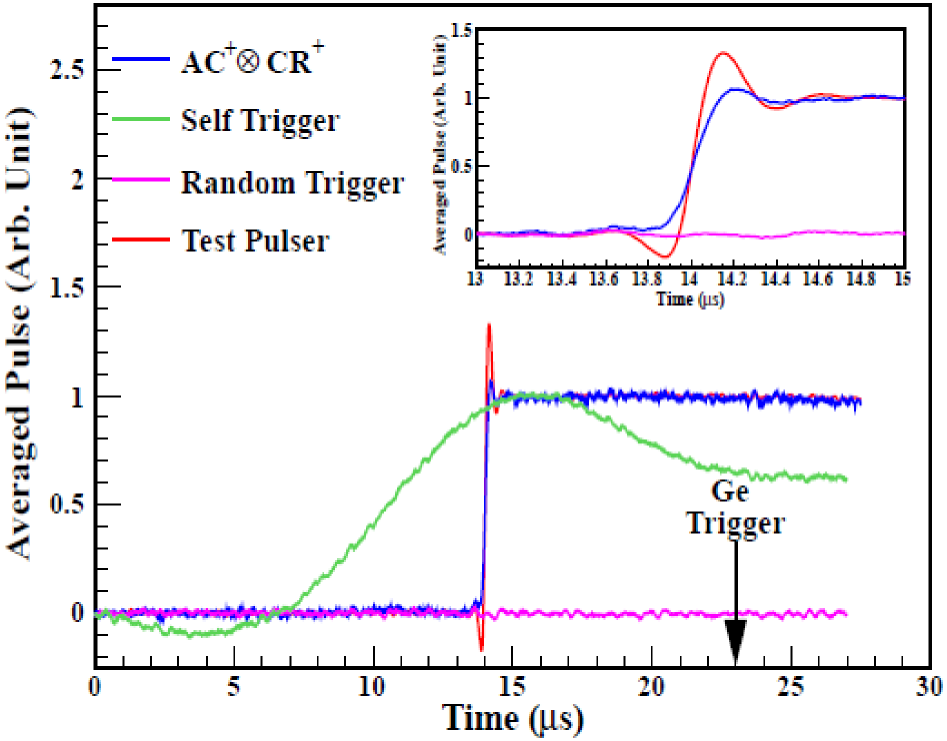
But $\beta \ll 1$ → Coherent scattering from entire nucleus
→ ~$A^4$ enhancement

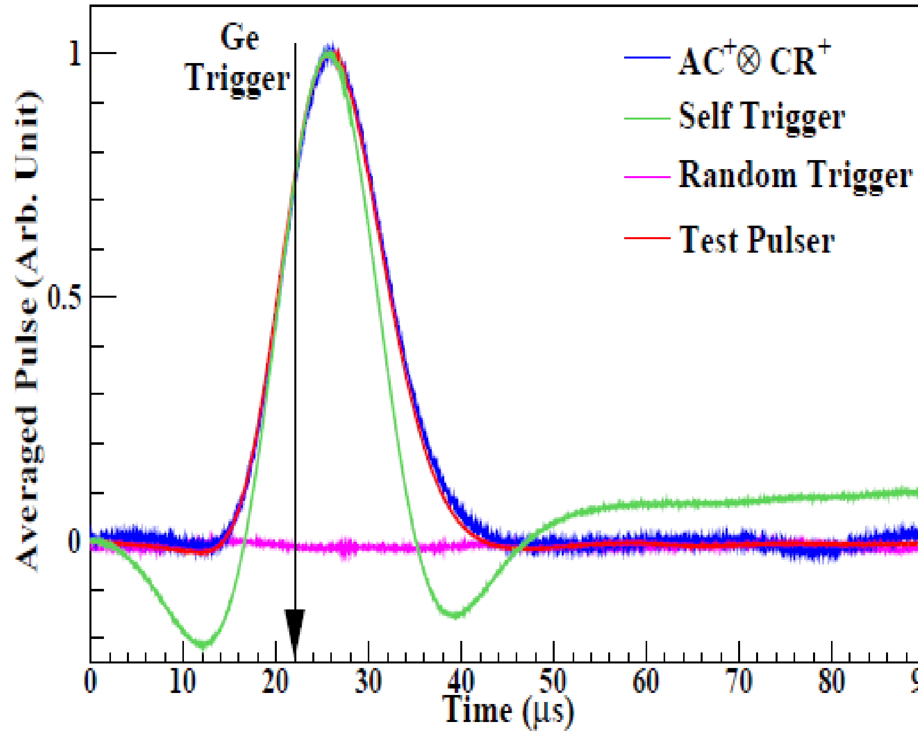
Rate ~ $(72.61)^4 \times 5.1\times10^{-9}$ [kg$^{-1}$day$^{-1}$]
~ 0.1 events [kg$^{-1}$day$^{-1}$]… much more approachable




**A low-energy threshold is critical for detecting LOW MASS WIMPs!**

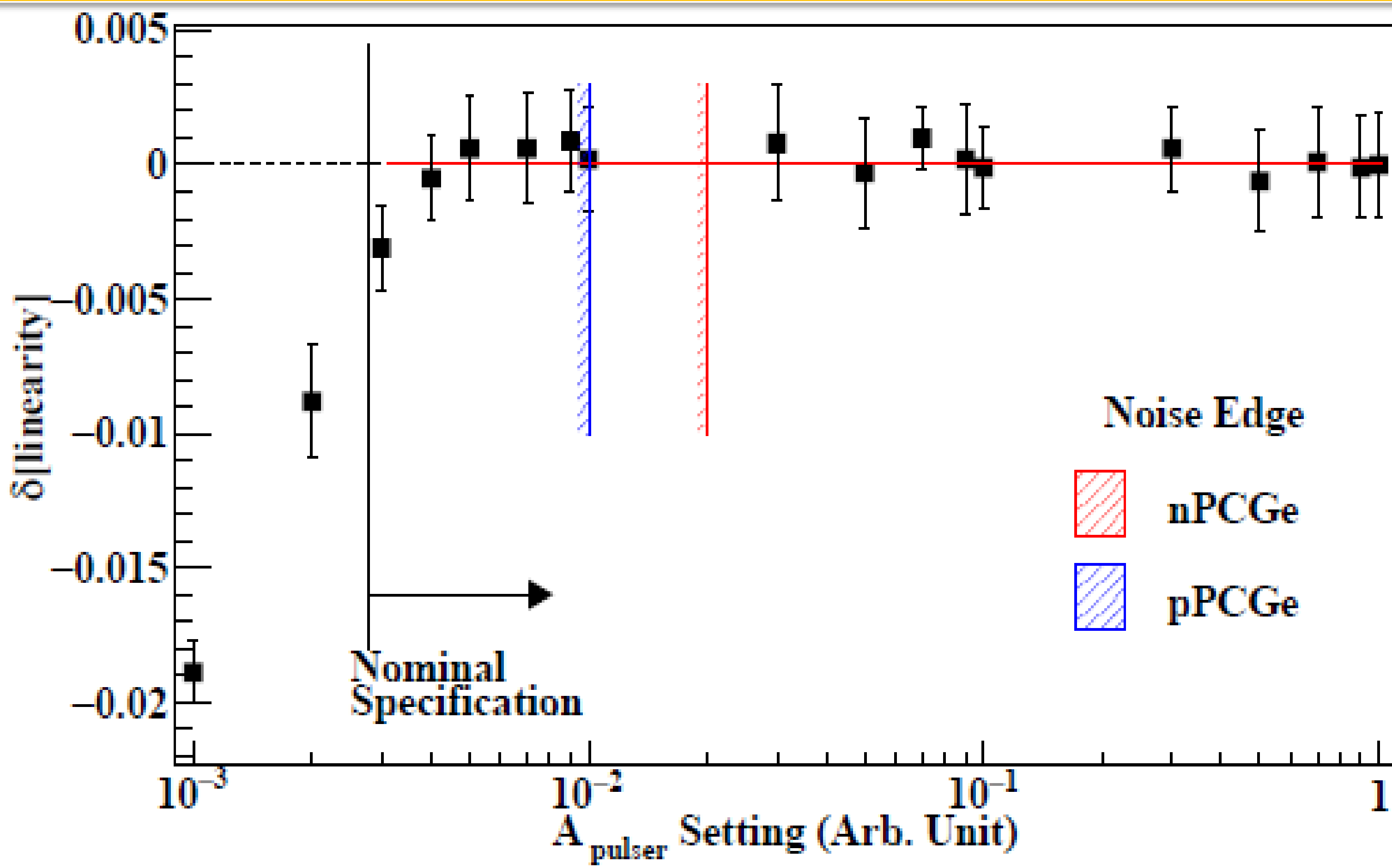
# Energy Measurement: Energy Calibration



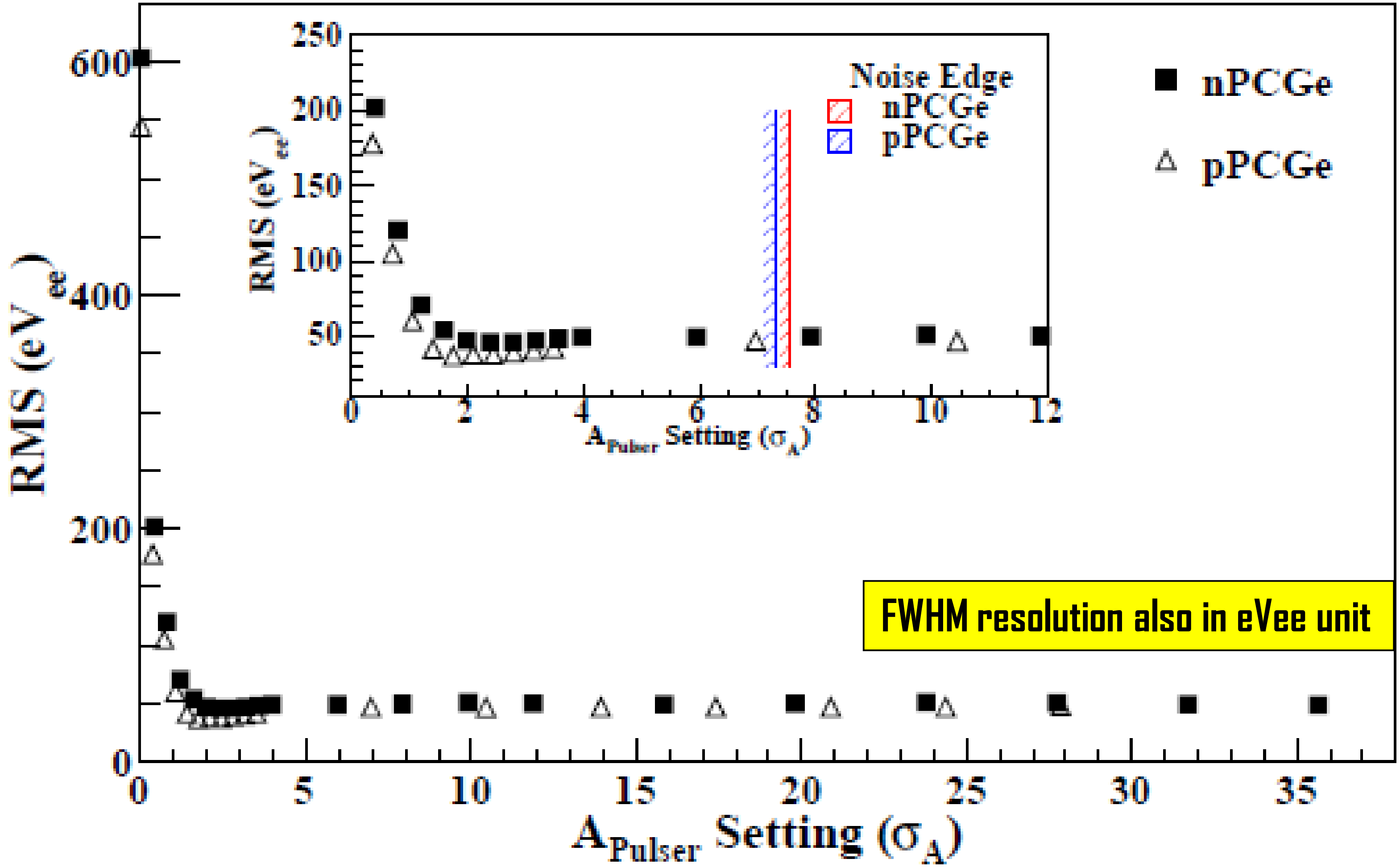

**Comparison of averaged pulse shaped from timing amplifier (TA) and shaping amplifier $SA_6$ for events due to random-trigger, self-trigger pedestal electronic noise, test-pulser and physics interaction.** The selected events except those of random-trigger are of effective energy near noise-edge ( 300eVee). Their amplitude is normalized to unity in the display, except for the random-trigger whose normalization follows that of the self-trigger. **The physics samples are from bulk events tagged with "$AC^+ \otimes CR^+$" and after basic criteria.** The trigger instants defined by Ge-$SA_6$ signals are shown.

# Energy Measurement: Energy Response




Energy response near threshold with the test-pulser which provides precise and linear input signals.
Superimposed are the nominal specification, as well as the settings corresponding to the electronic noise-edges of the pPCGe and nPCGe.

# Energy Measurement: Energy Response




Response of the pPCGe and nPCGe detectors versus energy when the test-pulser amplitude (displayed in $\sigma_A$ unit) is comparable to pedestal noise fluctuations.

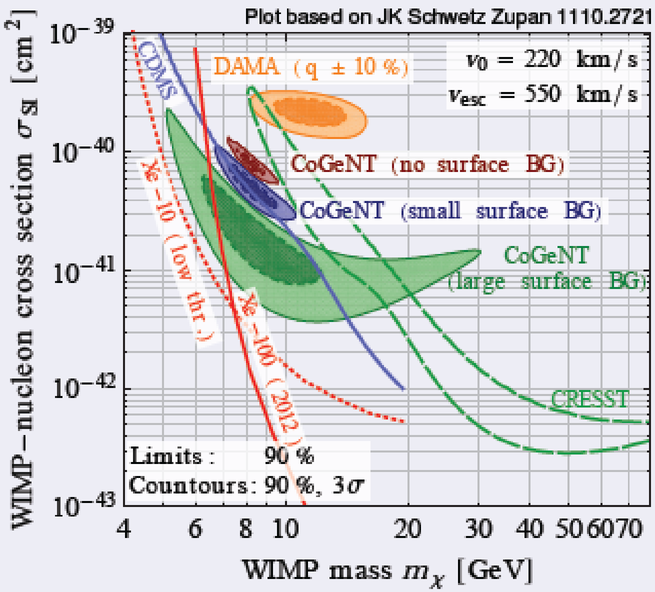
**It can be seen that the detectors are well-behaved in the physics regions of interest.**

- **TEXONO @ KSNL (2007):** 220 eV threshold with 20 g ULEGe ; Opened window for "Light WIMPs" searches **[PRD09]**
- **2010—2013:** Claimed evidence of GeV WIMPs from terrestrial experiments and astrophysics data **[strength diminished by now]**

## Hints for light dark matter

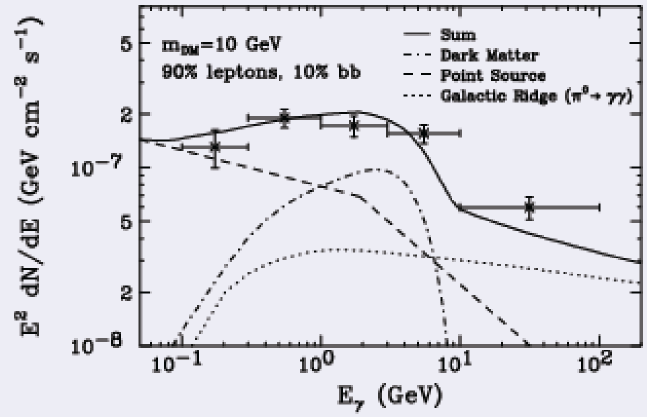
J. Kopp @ IDM12

### On the Earth . . .




- Several intriguing direct detection signals
- But severe tension with null results

### . . . and in the skies



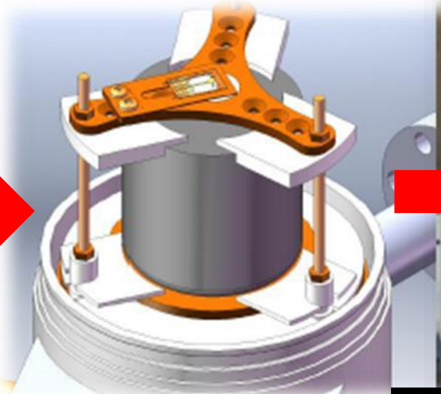

- An tentative $\gamma$ ray excess from the Galactic Center
  Hooper Goodenough 0912.2998, 1010.2752, 1201.1303
  - Morphology ≠ point source
- Radio filaments
  Linden Hooper Yusef-Zadeh 1106.5493
- Isotropic radio background
  Hooper Belikov Jeltema Linden Profumo Slatyer 1203.3547

# Ge Processing & Assembly Facility at THU

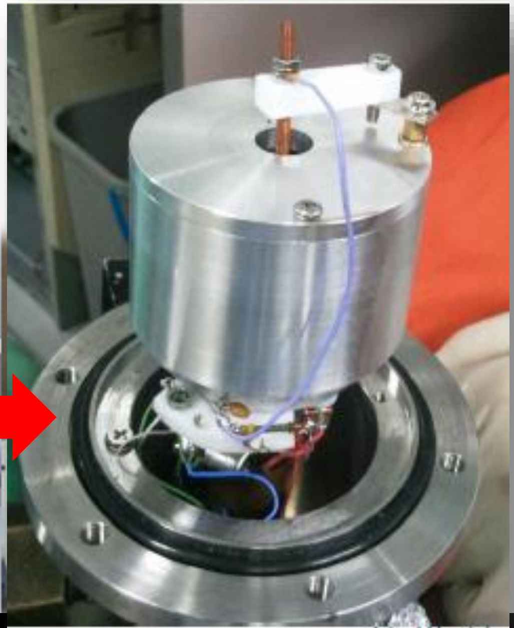
Czochralski machine


- Growth & Processing of raw Ge crystal
- Application-specific optimized assembly
- R&D on JFETs & Preamps & ASICs

Crystal



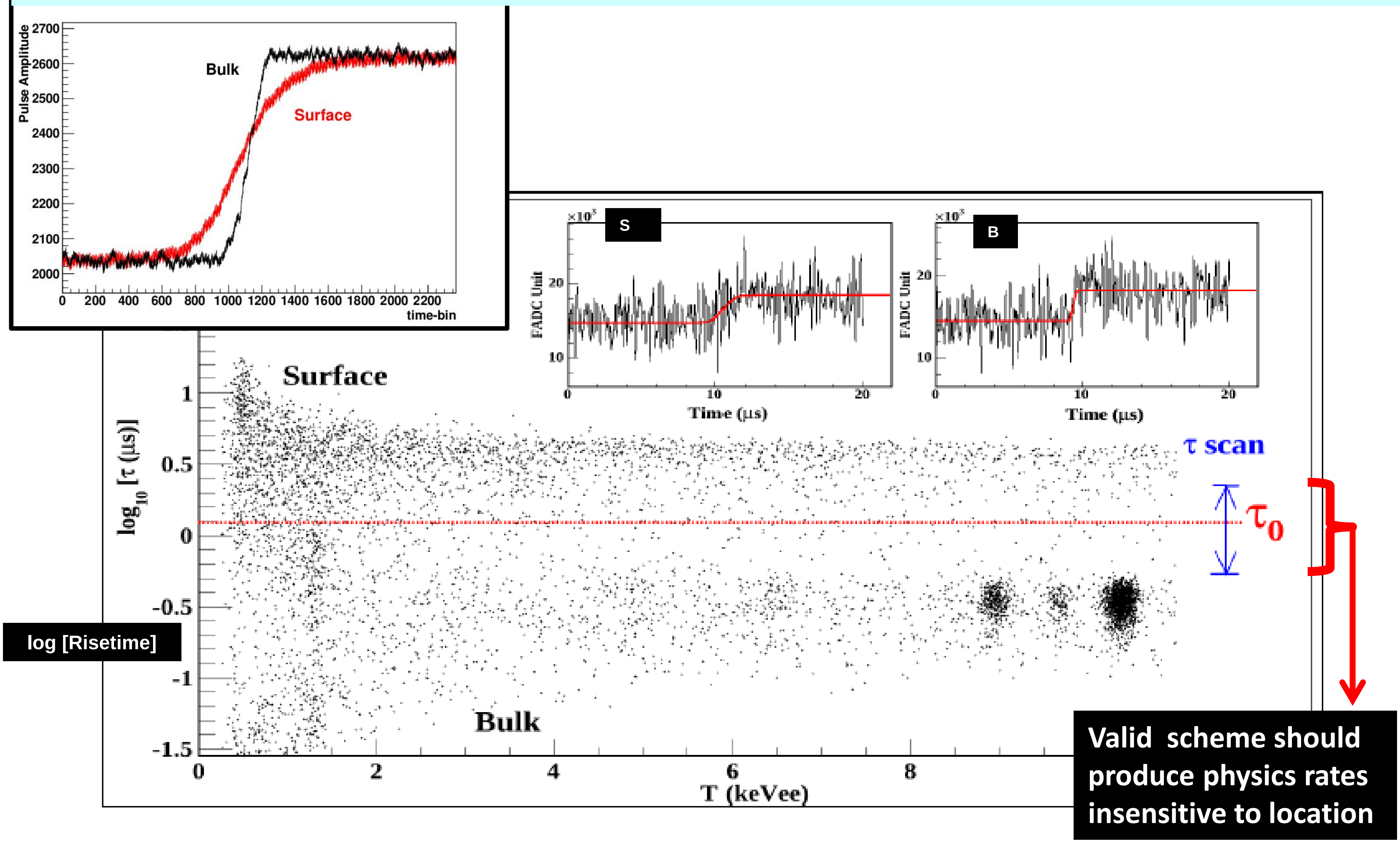
Processing & Assembling



Detector & Cryogenics

# PSD for Surface Vs Bulk Events @ PCGe *[AP14]*

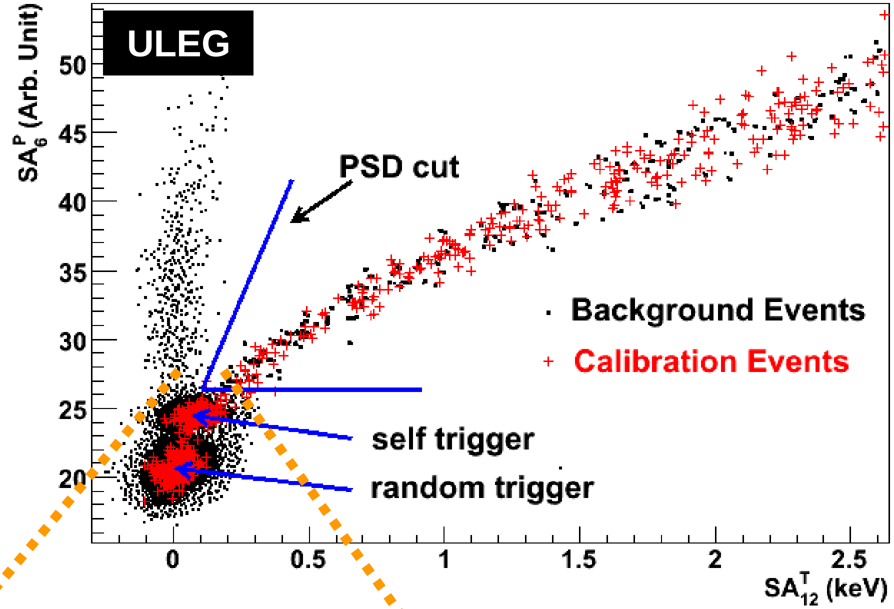
- n+ "inactive layer" is not totally dead; signals finite but slower rise time
- ACV+CRT tag (cosmic-induced high energy neutrons) ⇨ no surface band
- n-type PCGe ⇨ no surface band



# PSD Selection to Suppress Electronic Noise

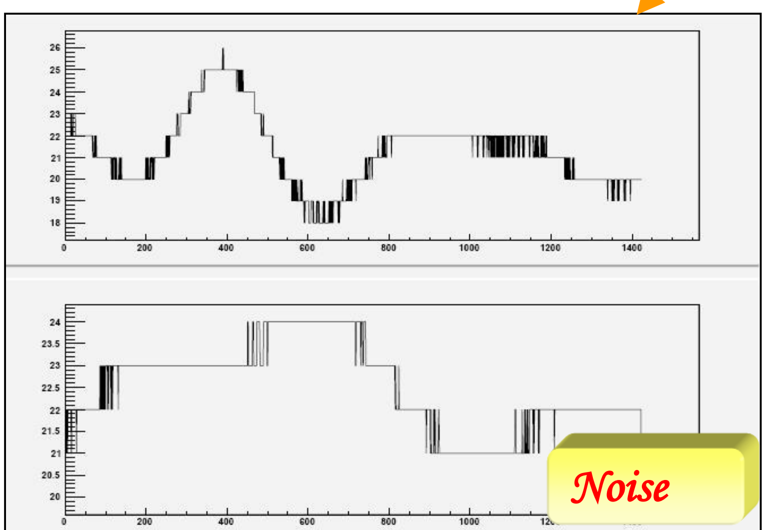
## E.g. 1 ⇨ correlations in two readout of different gains & shaping times

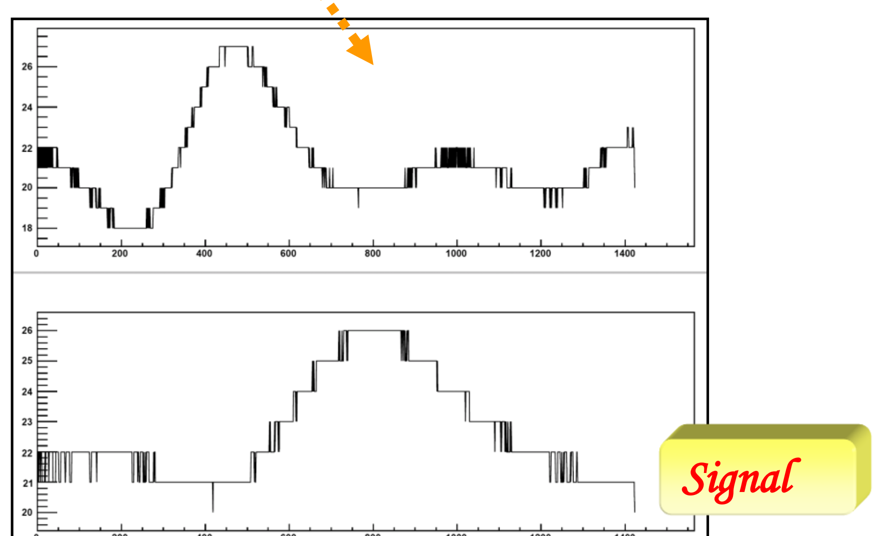
◎ **look for specific +ve pulse fluctuations at specific & known timing**




*6μs*

*12μs*



# Phys-Vs-Noise Selection Efficiency