Neutrino & Dark Matter Physics with sub-keV Germanium Detectors

- Overview (Collaboration; Laboratory; Program)
- Highlights of Reactor Neutrino Program
- Neutrinos & Dark Matter with sub-keV Ge Detectors
- Status & Plans

Henry T. Wong /王子敬

Academia Sinica /中央研究院

March 2011 @

TEXONO-CDEX Collaboration

🏆研究主軸: 低能區微中子與暗物質物理

TEXONO

Taiwan EXperiment On NeutrinO *[since 1997]*

- ⊙ 台灣國聖核電廠微中子實驗室(KSNL)
  - ➢ 台灣（中研院, 清大, 核能所, 核二廠）
  - ➢ 土耳其（METU,KTU)
  - ➢ 印度（Banaras Hindu U）

CDEX

China Dark Matter EXperiment *[birth 2009]*

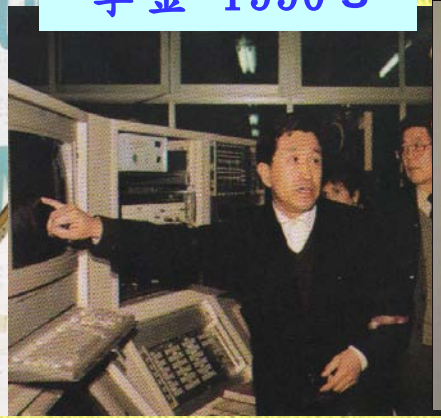
- ⊙ 中國錦屏地下實驗室(CJPL)
  - ➢ 中國（清大, 原子能院, 南開大, 川大, 二灘水利）

歷史與里程

- ~1990: 台灣中研院高能組(李世昌)與北京高能所(鄭志鵬)啟動交流、互訪
- 1996/4: 探討合作策略架構 *[Who,Where,What]* (張仲澐、李世昌、鄭志鵬、李金)
- 1997/1: 王子敬加入、與李金共同推動、內容與細節*[How's]* 定案、組織兩岸團隊

鄭志鵬 1989

李金 1990's



張仲澐 2010

李世昌2010

創新精神 (時、空、人、事):

- 國聖實驗(KSNL): 首次於台灣本土執行的大型粒子物理實驗
- 錦屏地下實驗室(CJPL): 中國首個、世界最深的地下實驗室
- TEXONO-CDEX 團隊: 台灣與中國大陸重點科研單位首次合作

16 MAY 2003 VOL 300 SCIENCE www.sciencemag.org

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

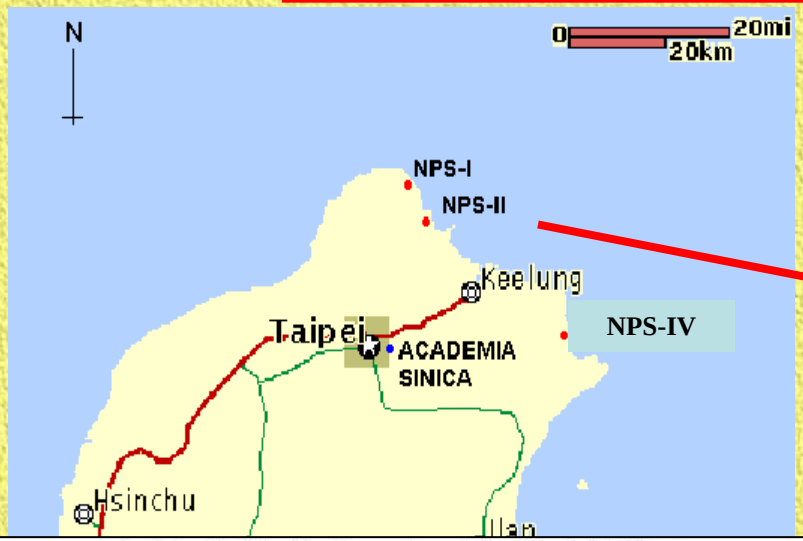
TOKYO—A hot campaign issue in Taiwan's presidential election in March 1996 was whether the island should drop its long-held objective of reuniting with the mainland and formally declare its independence. As a

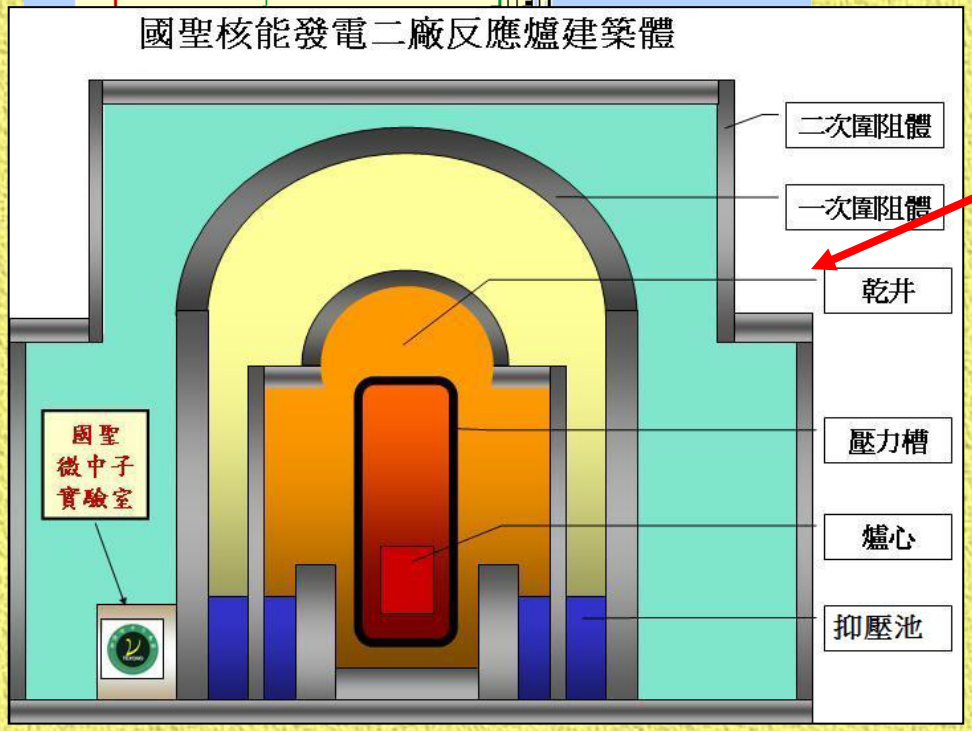
the mainland but is now a U.S. citizen. It was his idea to get Taiwanese scientists together with researchers at the Chinese Academy of Sciences' Institute of High Energy Physics (IHEP). That month, the two

Neutrino Physics *at (L~0)* Reactor ??
Rationale :

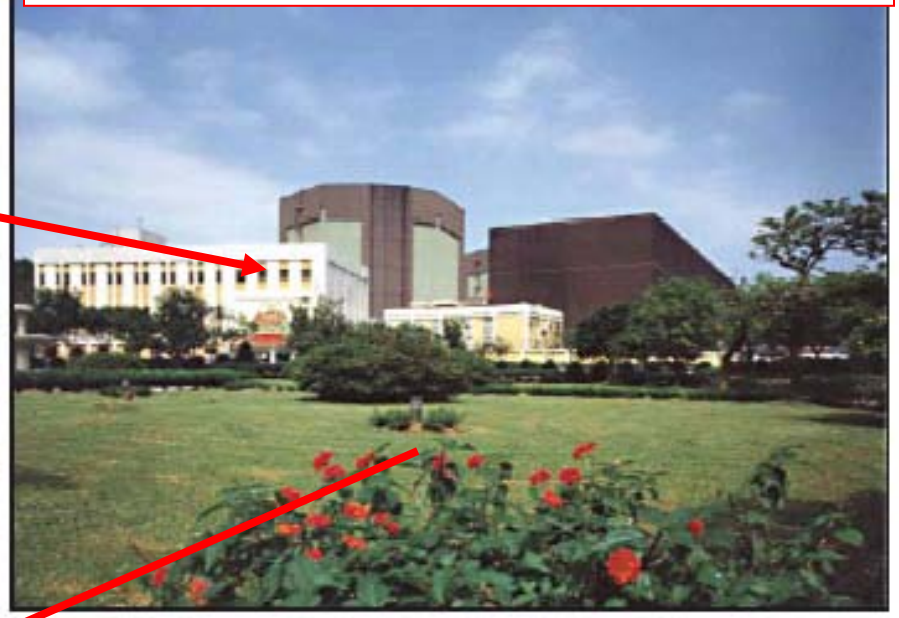
- Need neutrino source to do neutrino physics : reactor is a high-flux, understood and controlled source ⇒ *AND* free as well !!
- oscillation expts. ⇒ $m_\nu \neq 0$ ⇒ anomalous ν properties & interactions
- Experimental neutrino physics has been full of surprise
- Worth exploring any experimentally accessible parameter space
- May place constraints to interpretation of precision oscillation data
- Explore new neutrino sources & detection channels for future studies

國聖微中子實驗室





Science Magazine 2003年 專文報導



Powerful collaboration. Scientists from Taiwan and mainland China are studying neutrino emissions from this nuclear power plant outside Taipei.

* 距離爐心 28 m
* 微中子通量 ~10^{13} cm^{-2} s^{-1}
  （比太陽微中子高）

實驗室外觀（宇宙線探測器、屏蔽體、控制室…..）

屏蔽體內

KS Laboratory : Detectors

ULB-HPGe [1 kg]

CsI(Tl) [200 kg]

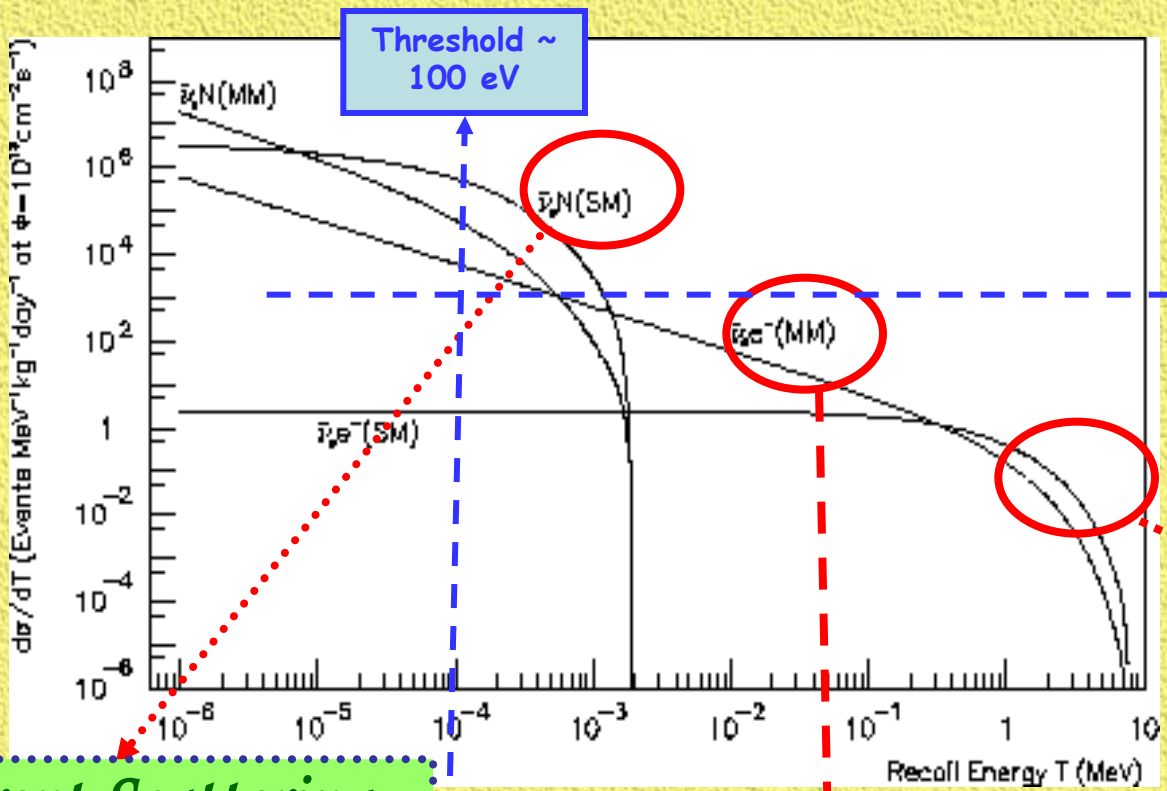
ULE-ULB-HPGe Prototype [20 g]

FADC Readout
[16 ch., 20 MHz, 8 bit]

Multi-Disks Array [600 Gb]

Neutrino Properties & Interactions at Reactor

quality ← Detector requirements → mass

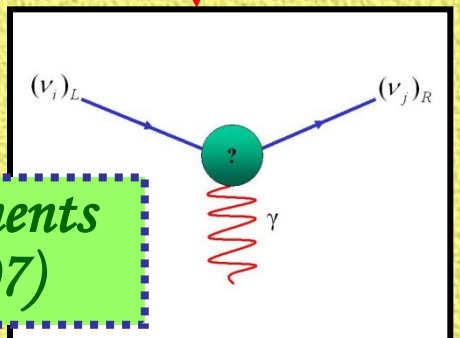


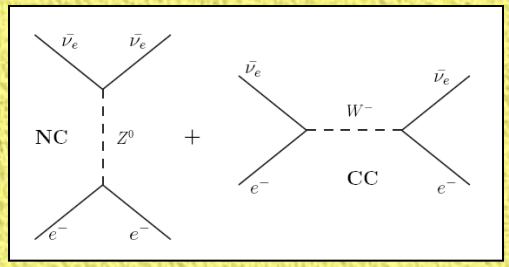
Standard Model νe Scattering (2 ⊗ PRD10)

νN Coherent Scattering

Dark Matter Searches (PRD-RC09)

Magnetic Moments (PRL03,PRD07)



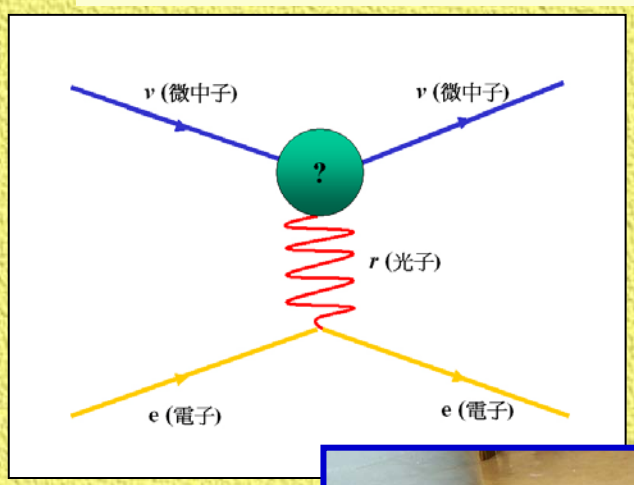


重點研究成果：於低能區開啟觀察視窗

微中子與光子可能交互作用的研究

[Phys.Rev.Lett. 2003 ; Phys.Rev.D 2007]

- 靈敏度世界水平前沿



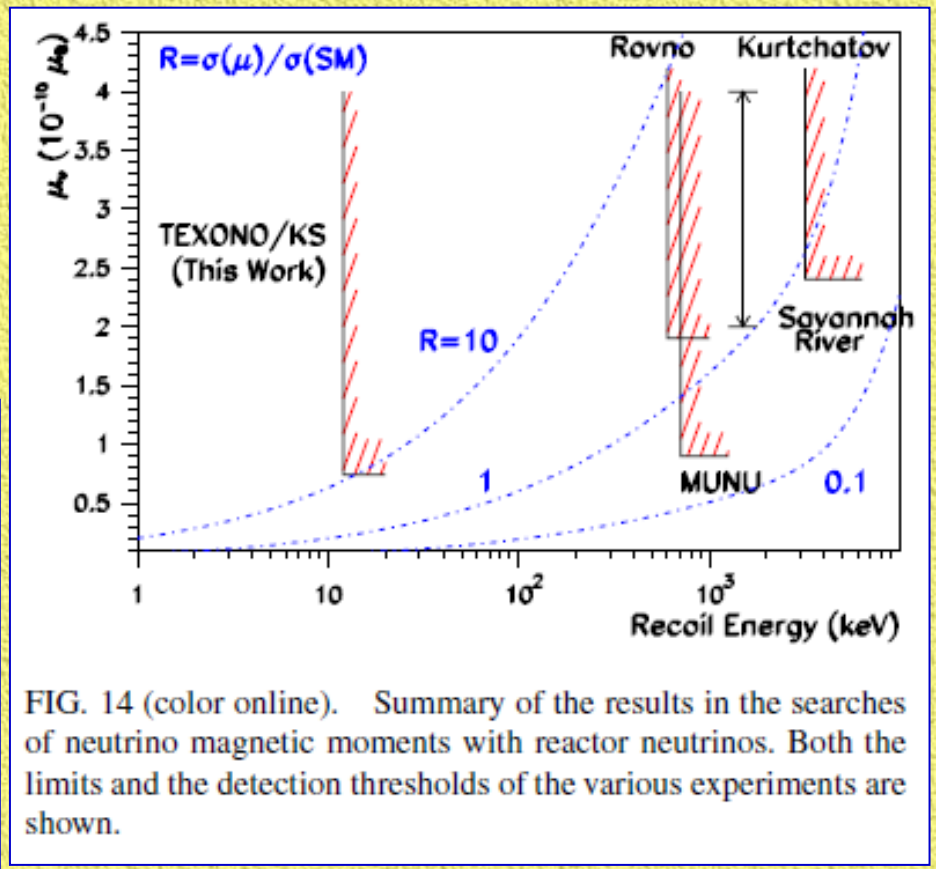


FIG. 14 (color online). Summary of the results in the searches of neutrino magnetic moments with reactor neutrinos. Both the limits and the detection thresholds of the various experiments are shown.

微中子與電子交互作用的研究

[2⊗ Phys. Rev. D 2010]

於新能區證明標準模型有效、限制新物理

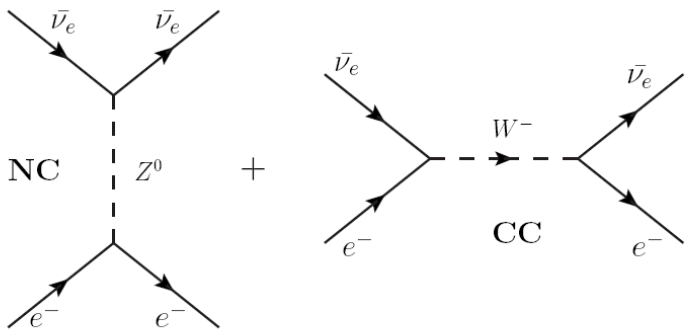


FIG. 1: Interactions of $\bar{\nu}_e$ with electron via the SM-allowed charged current (CC) and neutral current (NC) channels. There is in addition interference effect between them.

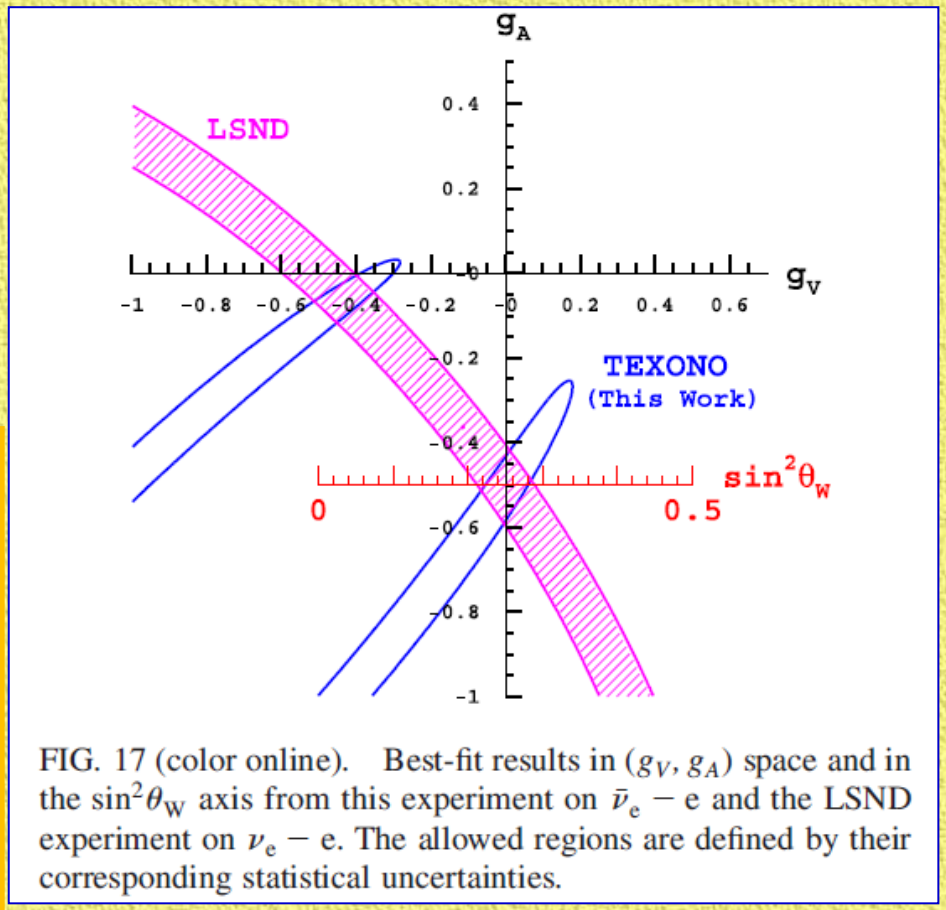
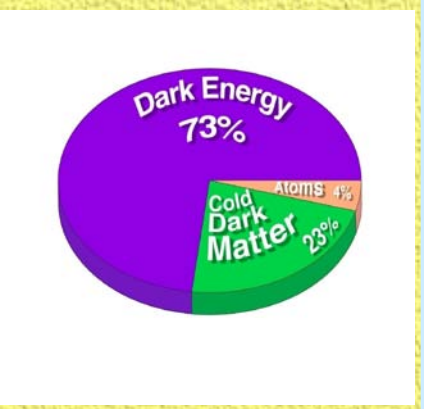
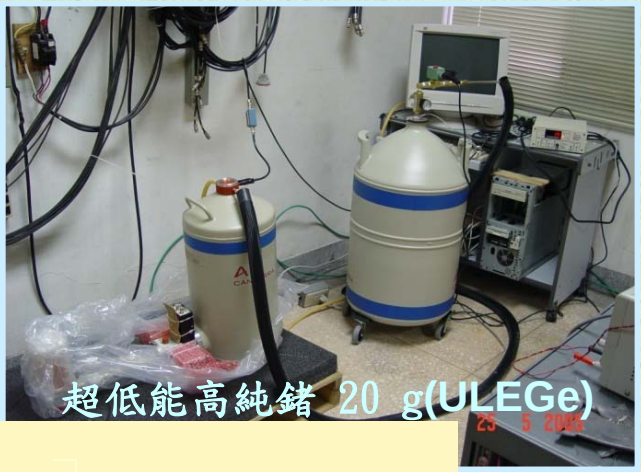


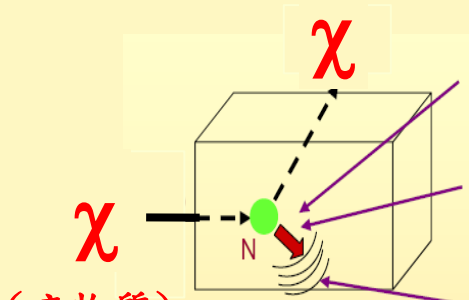
FIG. 17 (color online). Best-fit results in (g_V, g_A) space and in the $\sin^2\theta_W$ axis from this experiment on $\bar{\nu}_e - e$ and the LSND experiment on $\nu_e - e$. The allowed regions are defined by their corresponding statistical uncertainties.

找尋暗物質 *[Phys.Rev.D (RC) 2009]*

- 微中子探測器之開發
  - ⇨開啟低質量暗物質視窗
- 靈敏度世界前沿
- 迅速有效開展CJPL研究的重要基礎



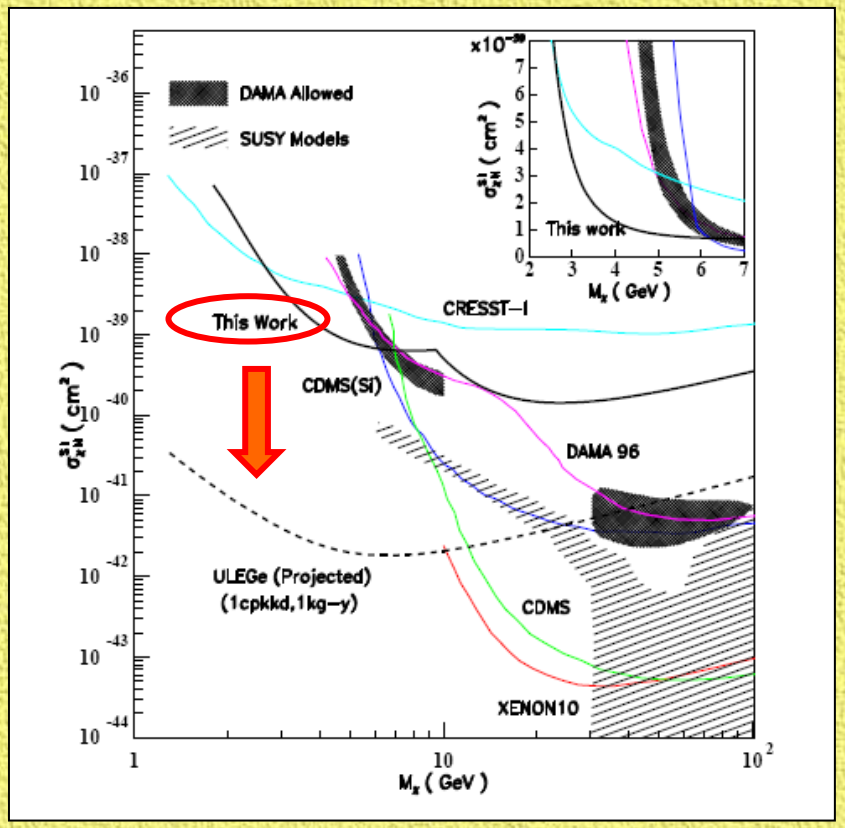




Ionization: 正負電荷
Ge, Si

Bolometer: 熱量
TeO_2, Ge, $CaWO_4$, …

Scintillation: 光
NaI(Tl),
LXe,CaF_2(Eu), …



Current Research Theme:

"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 magnetic moments**
  - **Implications on reactor operation monitoring**
  - **Open new detector window & detection channel available for surprises**

Neutrino-Nucleus Coherent Scattering :

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

Standard Model Cross-Sections:

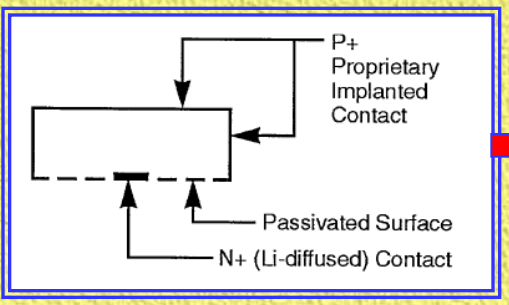
$$\left(\frac{d\sigma}{dT}\right)^{coh}_{SM} = \frac{G_F^2}{4\pi} m_N [Z(1 - 4\sin^2\theta_W) - N]^2 [1 - \frac{m_N T_N}{2E_\nu^2}]$$

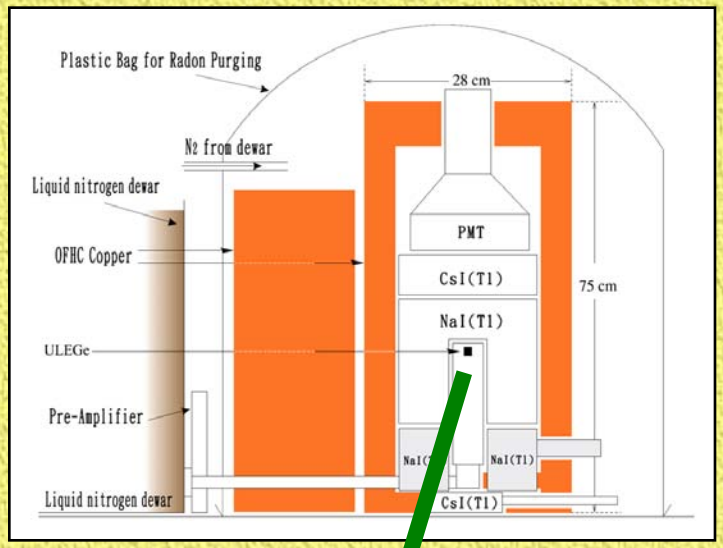
$$\sigma_{tot} = \frac{G_F^2 E_\nu^2}{4\pi} [Z(1 - 4\sin^2\theta_W) - N]^2$$

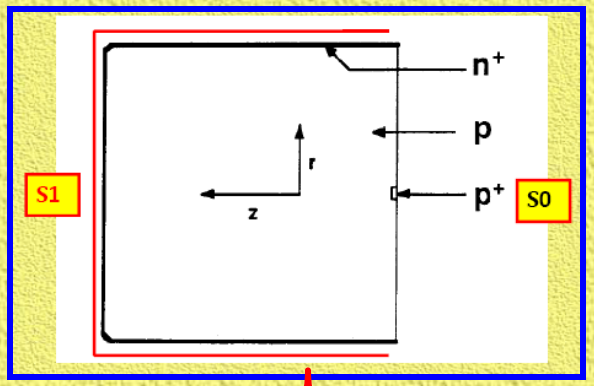
- a *fundamental neutrino interaction* never been experimentally-observed
- $s \propto \sim N^2$ applicable at $E_n < 50$ MeV where $q^2 r^2 < 1$
- a sensitive *test to Stardard Model*
- important interaction/energy loss channel in *astrophysics* media
- a promising new detection channel for neutrinos; relative compact detectors possible (implications to *reactor monitoring*); & *the* channel for *WIMP direct detection* !
- Typical Rates for Ge at KSNL :

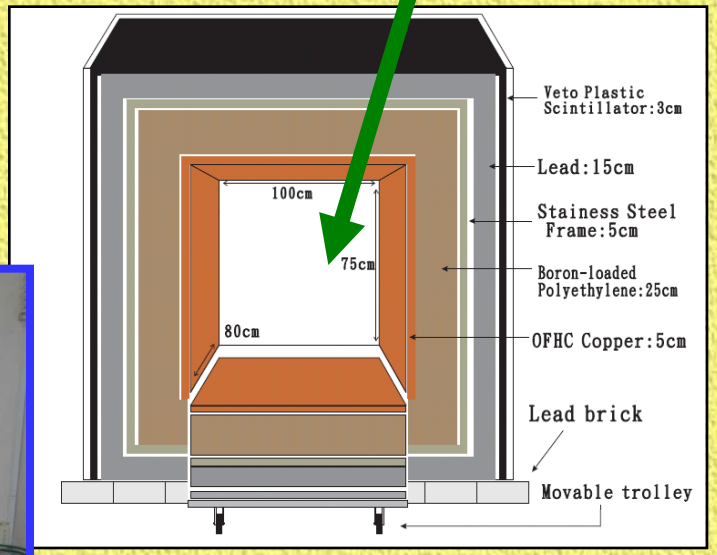
  ~10 kg^{-1} day^{-1} @ threshold~100 eV & QF~0.2

TEXONO-CDEX : ULEGe & PCGe @ KSNL & CJPL

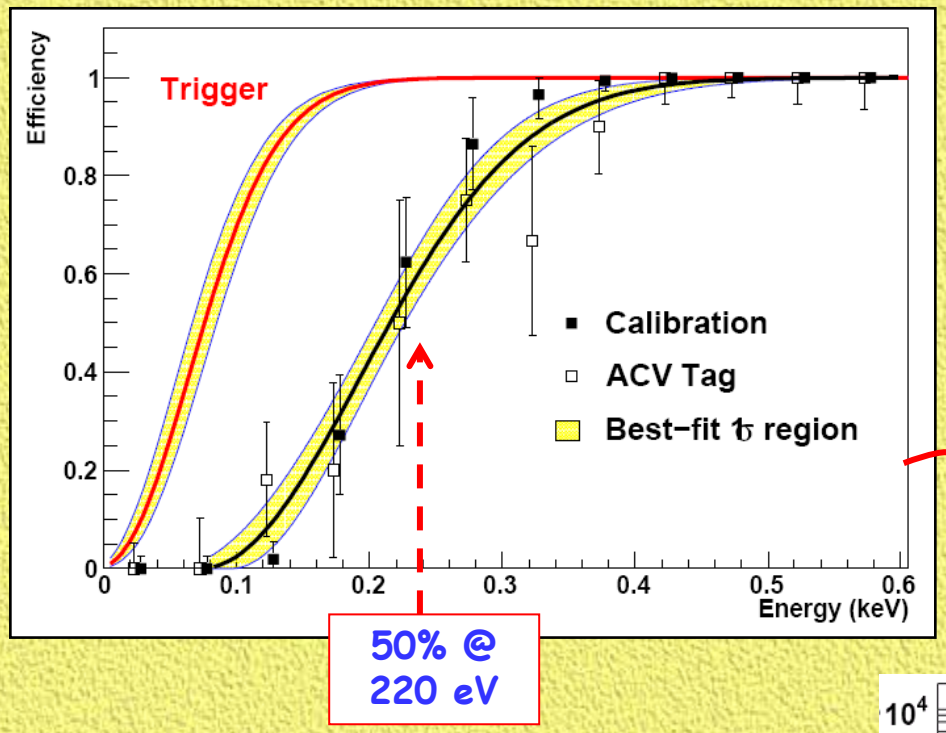




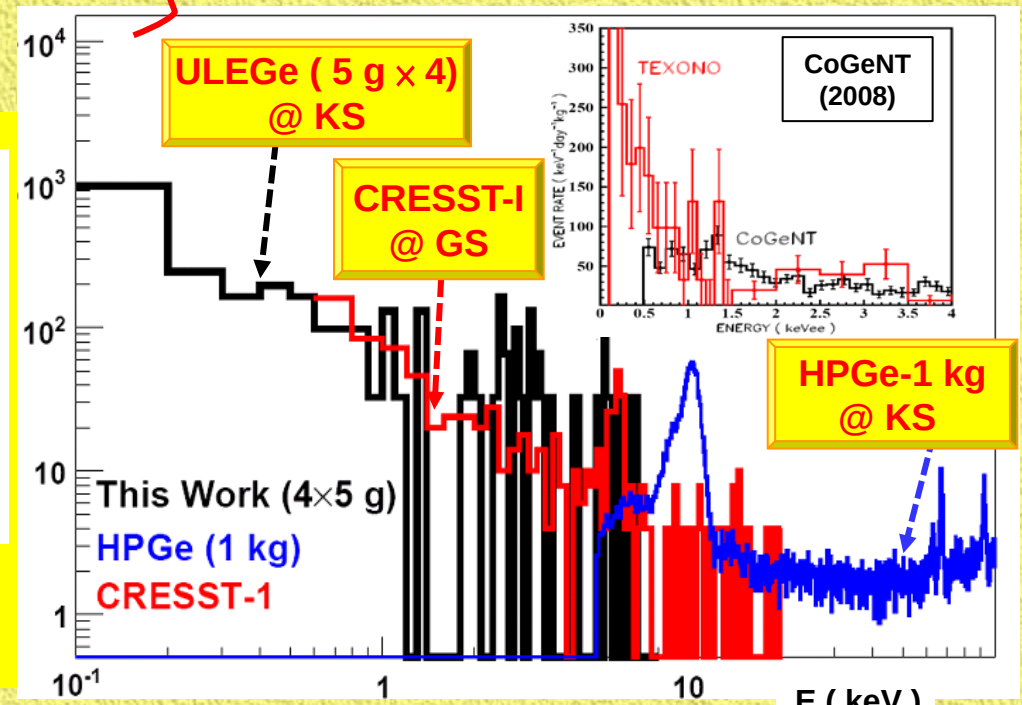




Threshold & Efficiencies & Background for 20g ULEGe (2007)



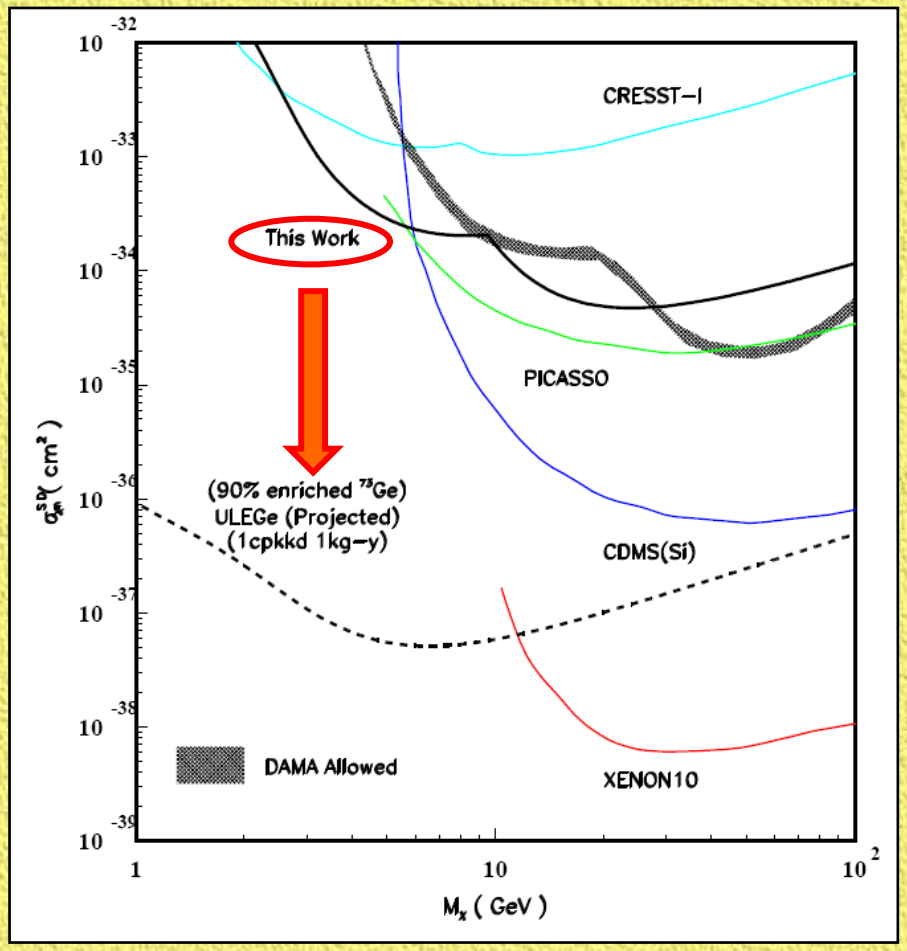
Dark Matter Searches Analysis

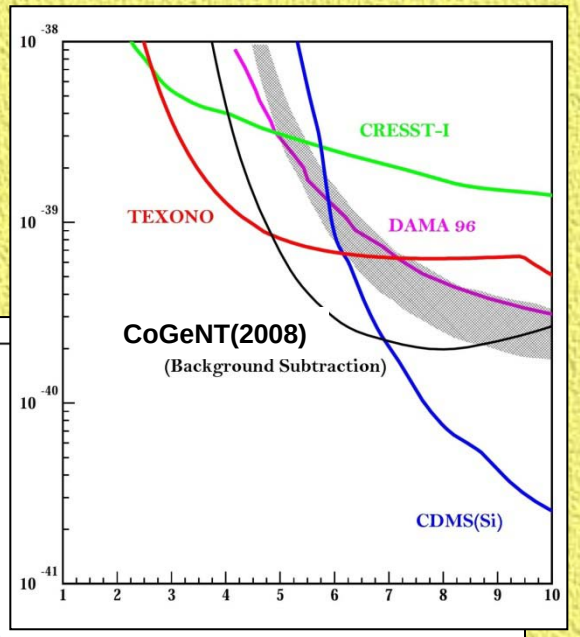


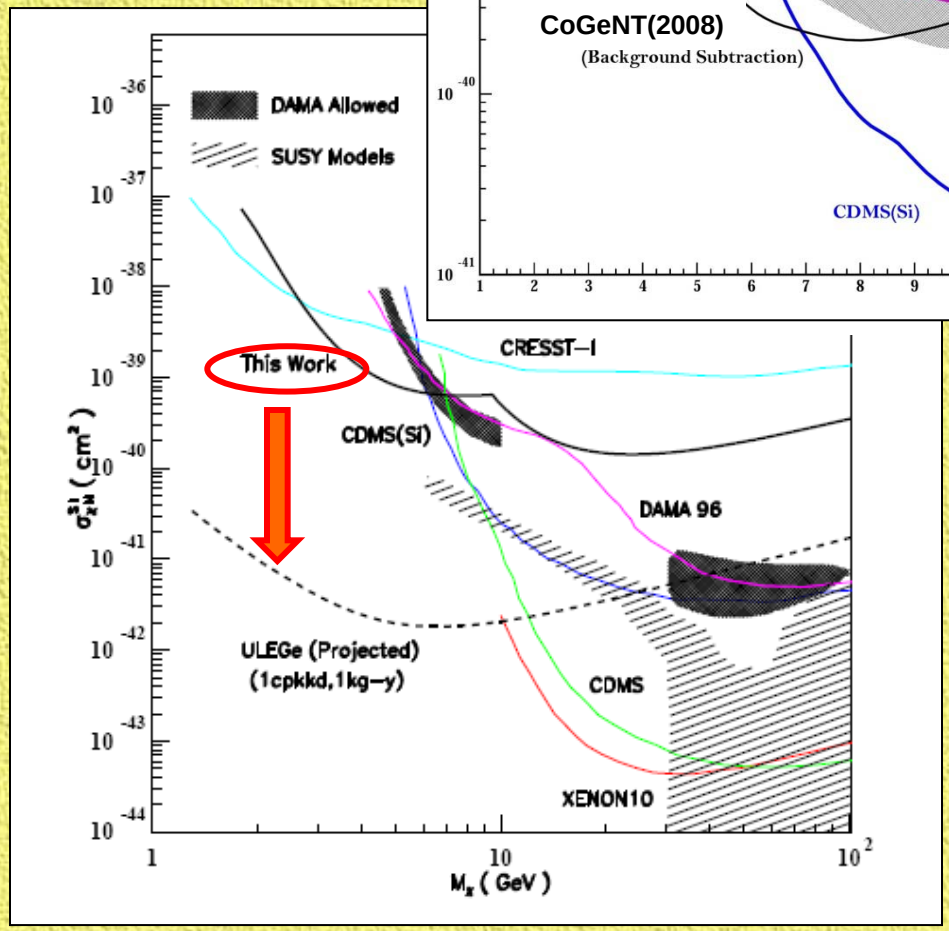
sub-keV Background :

- Not fully explained with conventional background modeling
- Intense work on hardware, software and data taking at new underground site

Limits on Low Mass WIMPs : Spin-Dependent & Independent Couplings (PRDRC09)



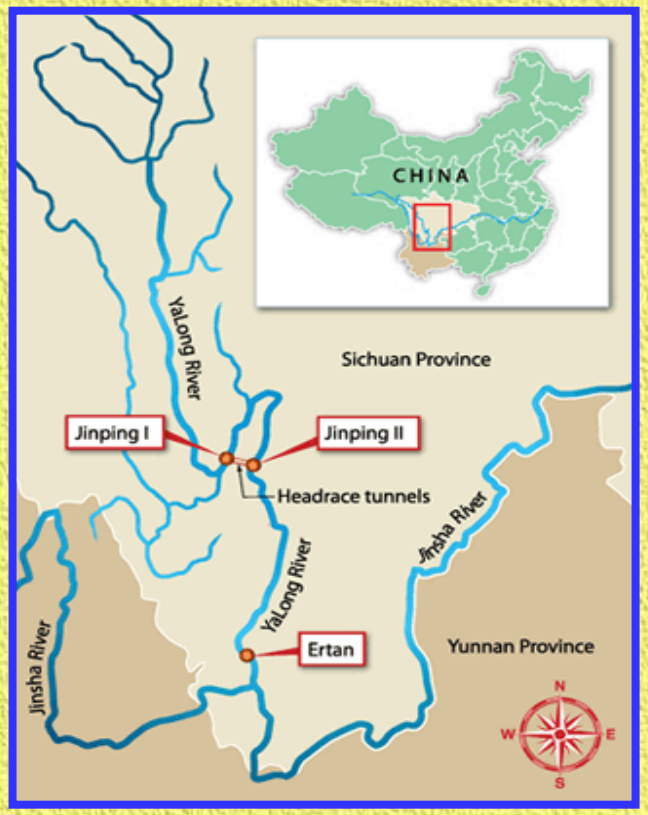


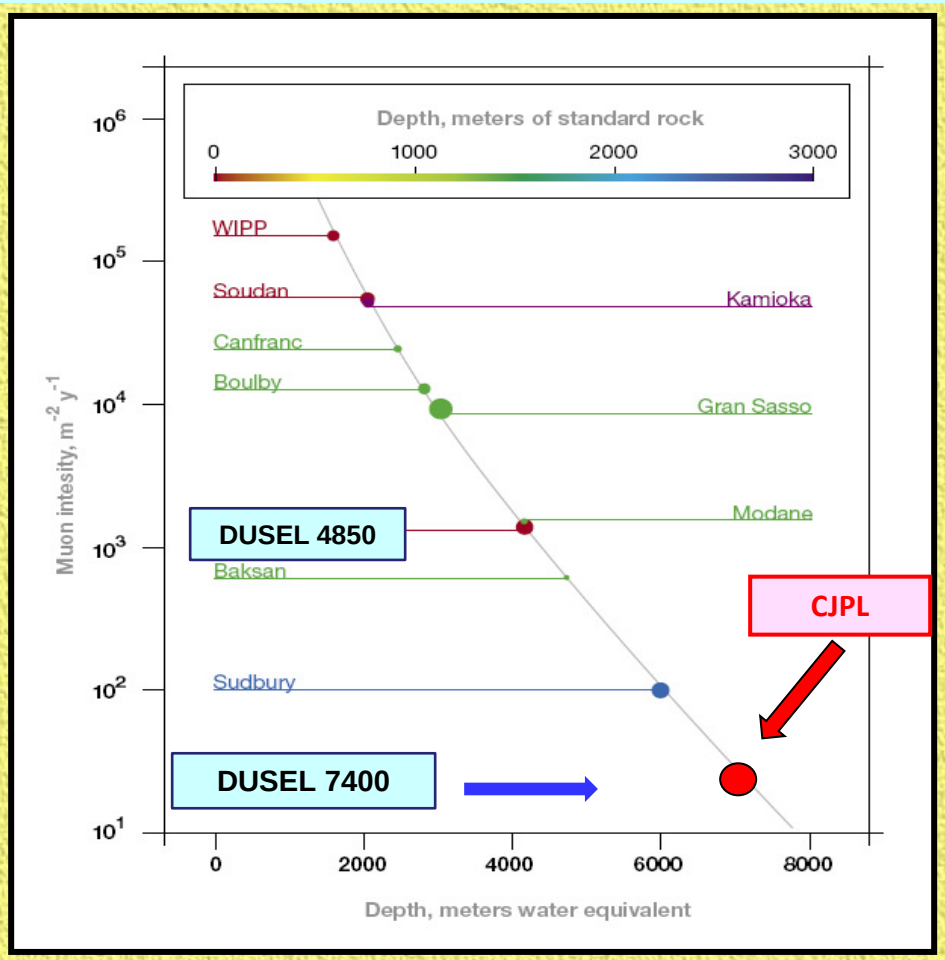


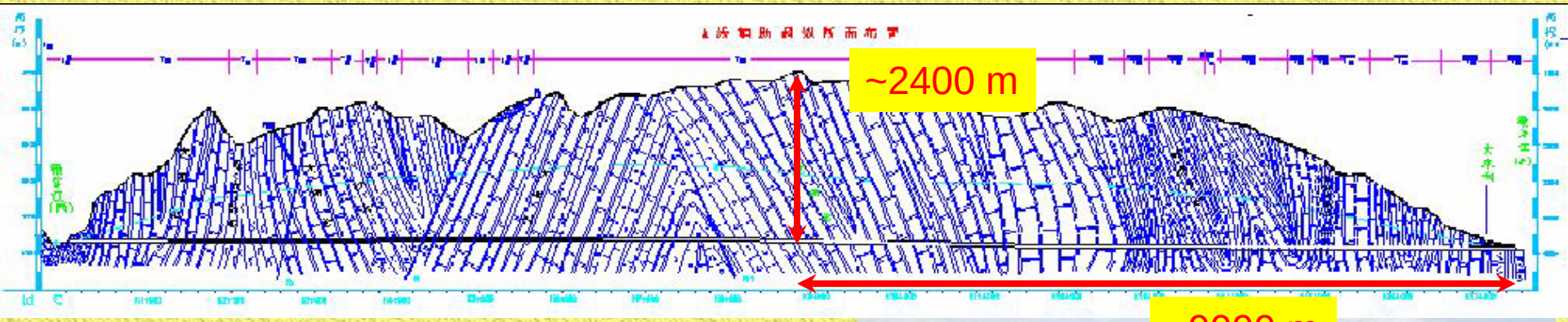
Latest : New CoGeNT 2010 Results (limits & allowed region) ; intense theoretical interest and speculations on low-mass WIMPS

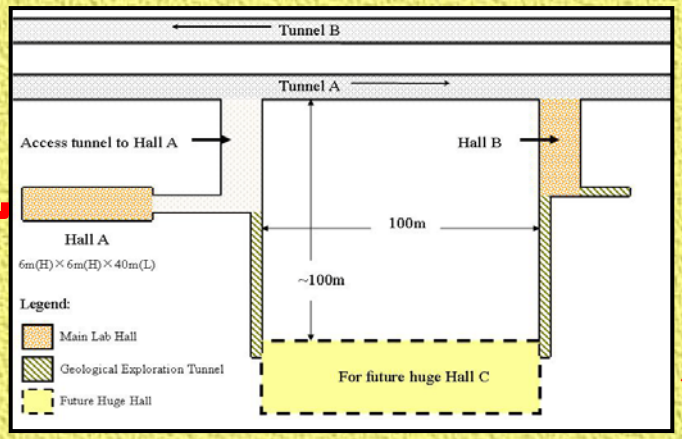
CJPL 中国锦屏地下实验室 China Jinping Underground Laboratory

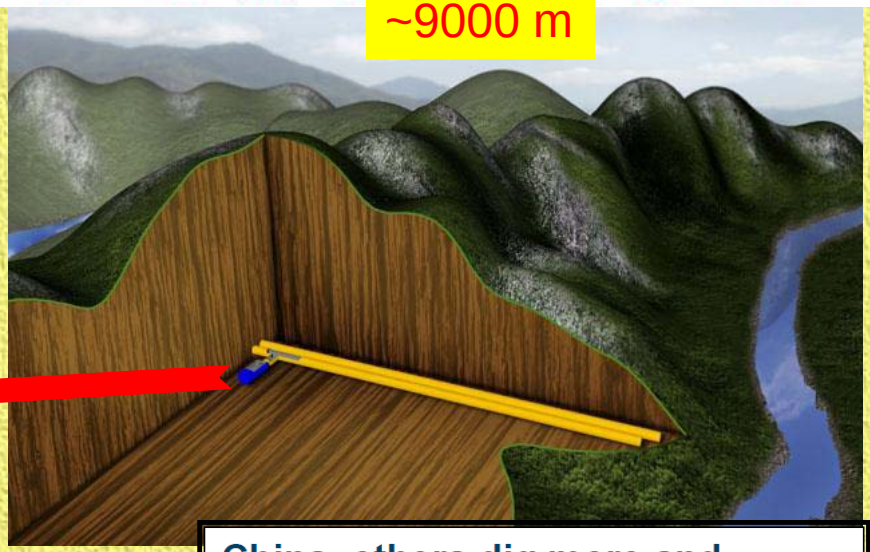
- **Merits:** 2500+ m rock overburden ; drive-in road tunnel access ; superb supporting infrastructures
- 6X6X40 m cavern construction completed *[THU & EHDC]*

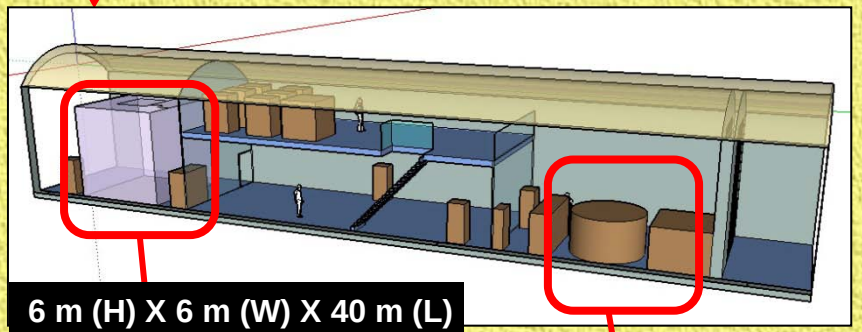












6 m (H) X 6 m (W) X 40 m (L)

CDEX-TEXONO

PandaX

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

Good Supporting Infrastructures

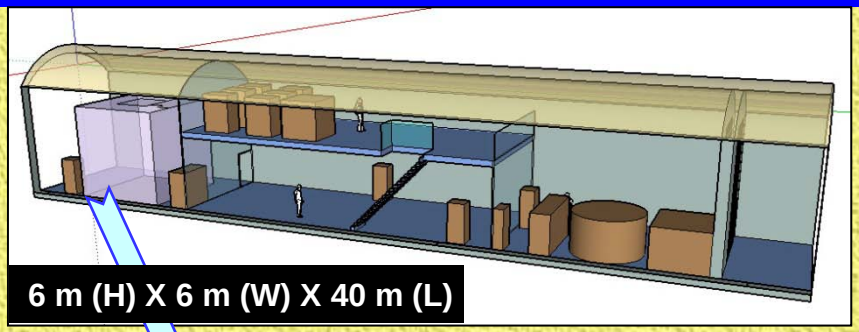
THU-EHDC MoU 2009/5/8

CJPL Excavation
2009/7— 2010/4

6月20日土建工程建成并通过验收

Inauguration Ceremony 2010/12/11

CJPL Hall A:
Basic Infrastructures Completed & Research Started Sept 27, 2010.



6 m (H) X 6 m (W) X 40 m (L)

Inside with shielding structure

Status and Plans

- Competitive limits at *WIMP-mass < 10 GeV* obtained with sub-keV Ge prototype at a shallow depth reactor laboratory KSNL, for both spin-independent and spin-dependent couplings
- Studies on background understanding at *sub-keV* range
- Data taking as KSNL with 500g/900g Point-Contact Ge
- Evolving to dedicated dark matter searches at new deep underground laboratory at Sichuan CJPL 2010.
- Prepare towards detectors at 10-kg range
- *Goals :* open new *detection channel* and *detector window* for neutrino and dark matter physics ; available for *surprises*

更上層樓：

- KSNL 與 CJPL 實驗計畫，繼續全速發展［繼往］
- 探討 CJPL 新研究方向［開來］

"The Rest will be History ...."