TEXONO Research Program Beside(Beyond) Reactor Neutrino and Dark Matter Physics

- Overview : *Program/Facilities/Highlights*
- Theory Program
- Ge R&D
- $0\nu\beta\beta$ @ CJPL
- Gravity Physics

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Academia Sinica / 中央研究院

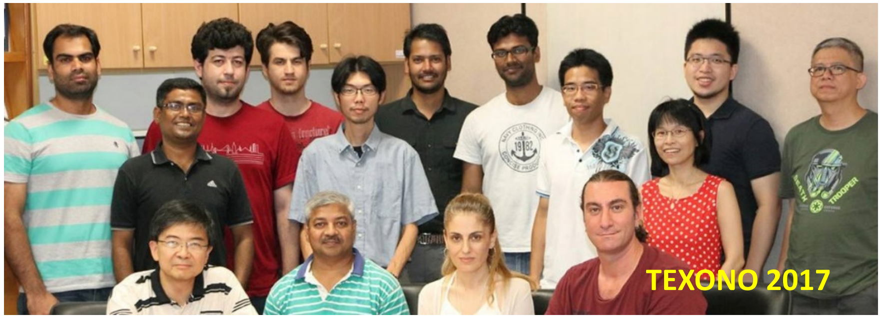
December 2018 @

TEXONO-CDEX Collaboration

TEXONO *Taiwan EXperiment On NeutrinO* *[since 1997]*:

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

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



CDEX *China Dark Matter EXperiment* *[birth 2009]*:

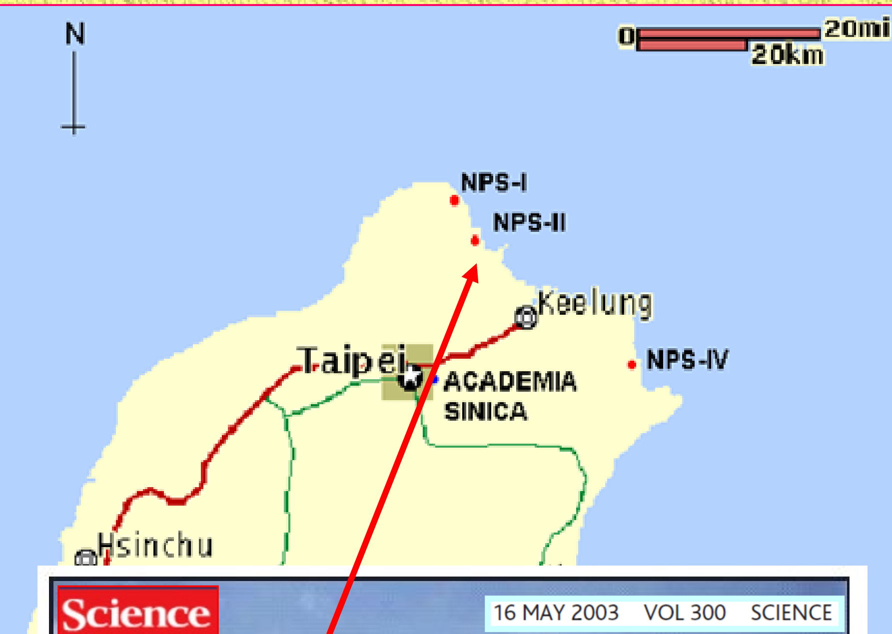
CJPL

⊙ **Dark Matter Searches at China Jin-Ping Underground Laboratory (CJPL)** *[L.T. Yang's talk]*

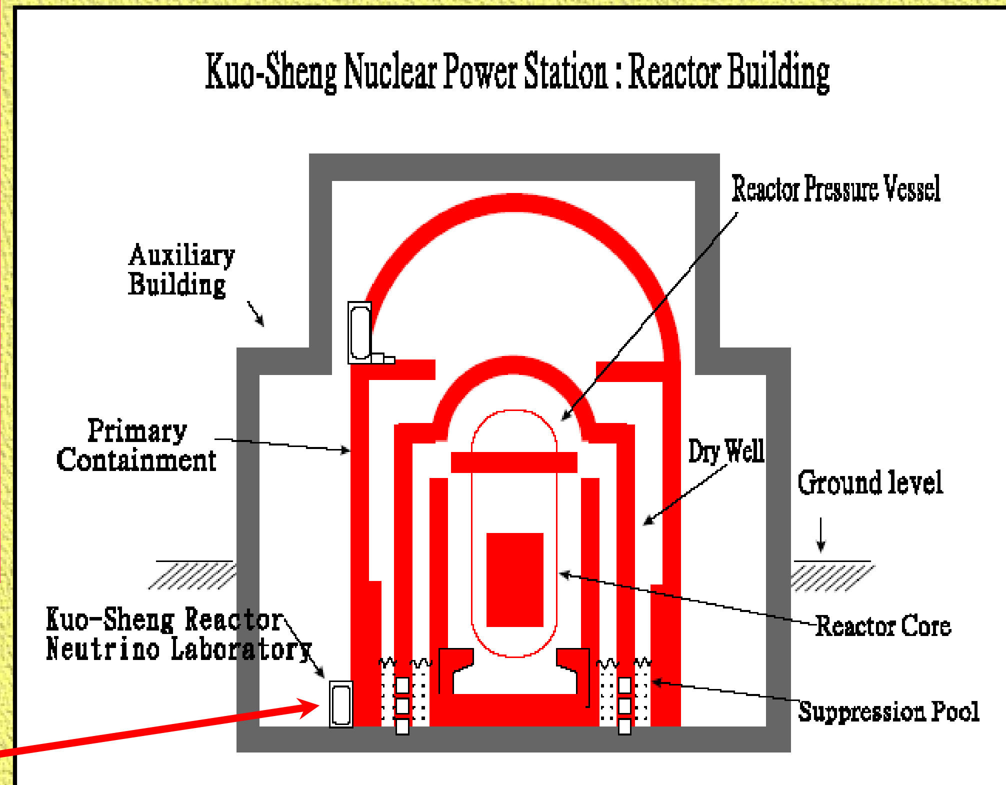
- **China** (THU, CIAE, NKU, SCU,YLJHD)

Research Program: Low Energy Neutrino and Dark Matter Physics

Kuo Sheng Reactor Neutrino Laboratory [KSNL]



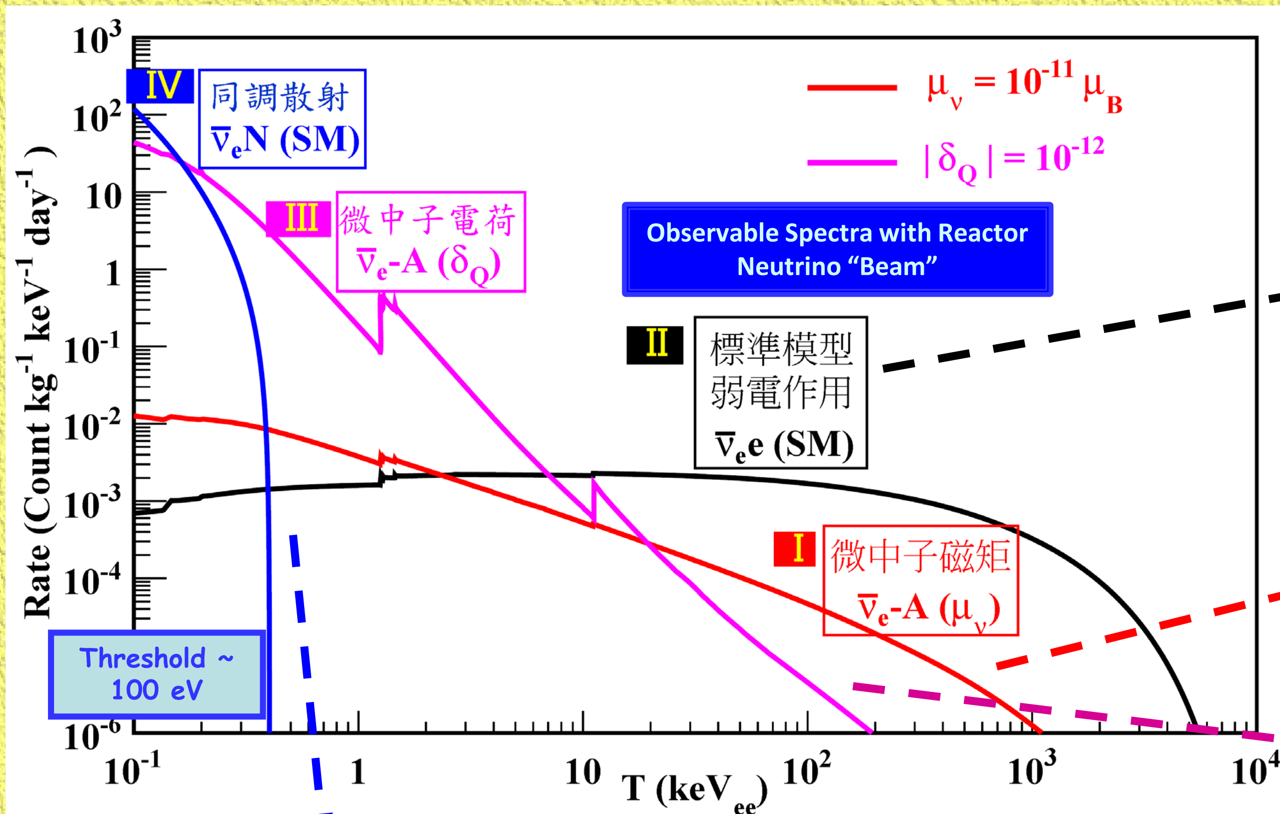

Science
AAAS
16 MAY 2003 VOL 300 SCIENCE
Taiwan-China Collaboration
A Bridge Over Troubled Waters
Researchers from Taiwan and the mainland have hit scientific pay dirt with the first—and so far the only—collaboration between two institutions across the Taiwan Strait

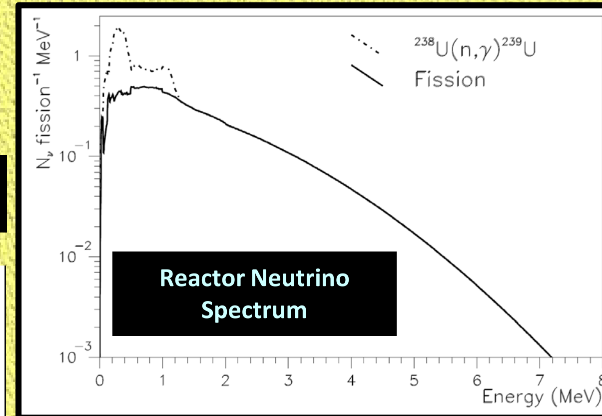


- **28 m from core#1 @ 2.9 GW**
- **Shallow site : ~30 *mwe* overburden**
- **~10 m below ground level**

Neutrino Properties & Interactions at Reactor

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





ν-e Scattering SM *[PRD10]*
& NSI/BSM
[PRD10,PRD12,PRD15,PRD17]
⇨ 200 kg CsI(Tl)

Magnetic Moments
[PRL03,PRD05,PRD07]
⇨ 1 kg HPGe

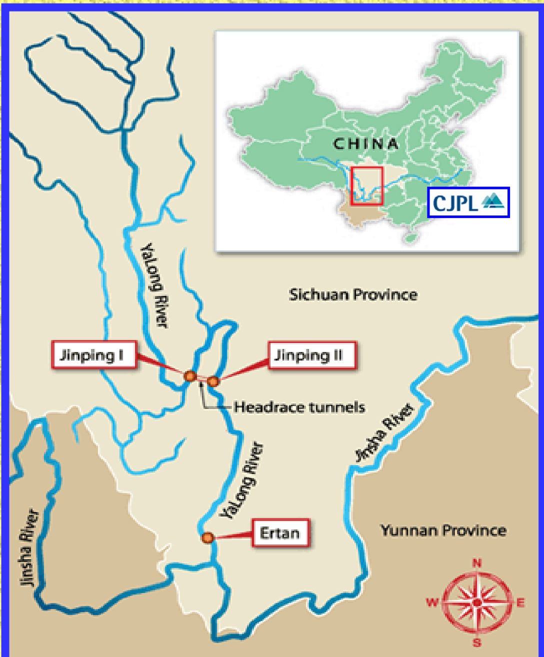
Neutrino Milli-charge
[PRD14]
⇨ sub-keV O(kg) PCGe

νN Coherent Scattering *[Current Theme;PRD16]*
- ⇨ sub-keV O(kg) ULEGe / PCGe
- ↳ Dark Matter Searches @ KSNL *[PRD09,PRL13,AP14]*
- ↳ CDEX Program@CJPL *[PRD13,2XPRD14,PRD16,PRD17,PC17,PRL18]*

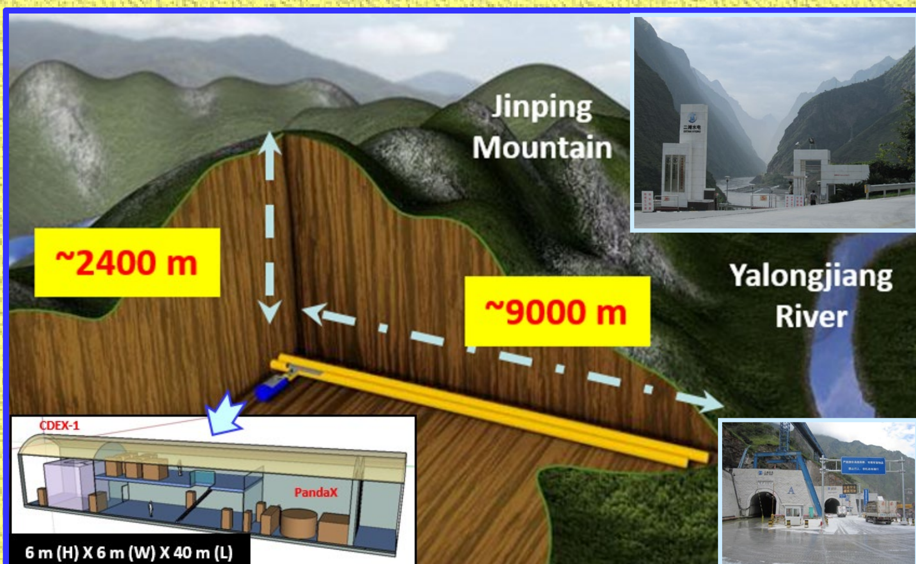
Independent, Thriving and Diverse Programs …

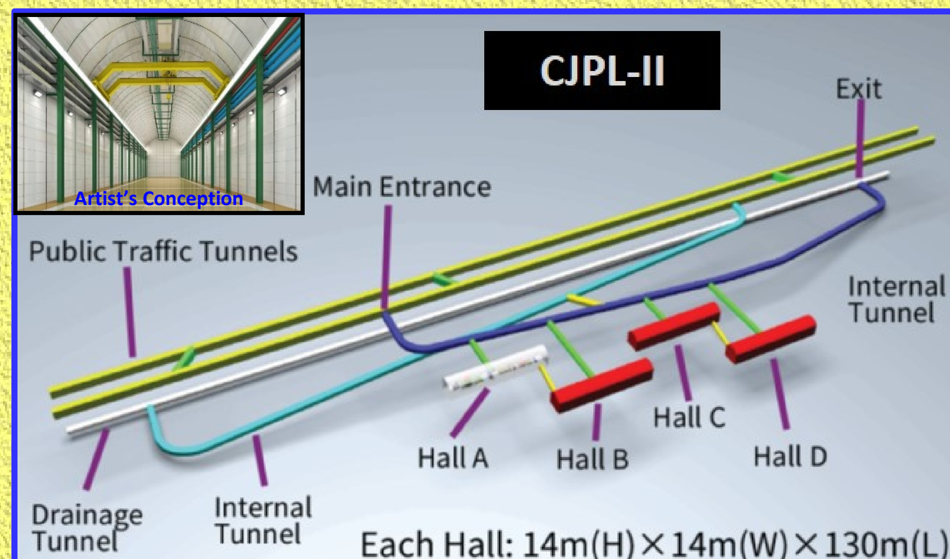
sub-keV PCGe

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



- **Discovered** by physicists via TV news on 2008/8/8 *(Construction Tunnel completed to commemorate Beijing Summer Olymics !)*
- **Merits:** 2400+ m rock overburden ; drive-in road tunnel access ; superb supporting infrastructures
- Operated & Managed by **THU** & **YLRHDC**
  CJPL-I (2010): 6X6X40 m cavern
  CJPL-II (2017+): [4X(14X14X130 m) Halls]+Pits
- The *Deepest* & *Largest* Underground Research Facility in the World
- National **Major S&T Infrastr.** Project in China.



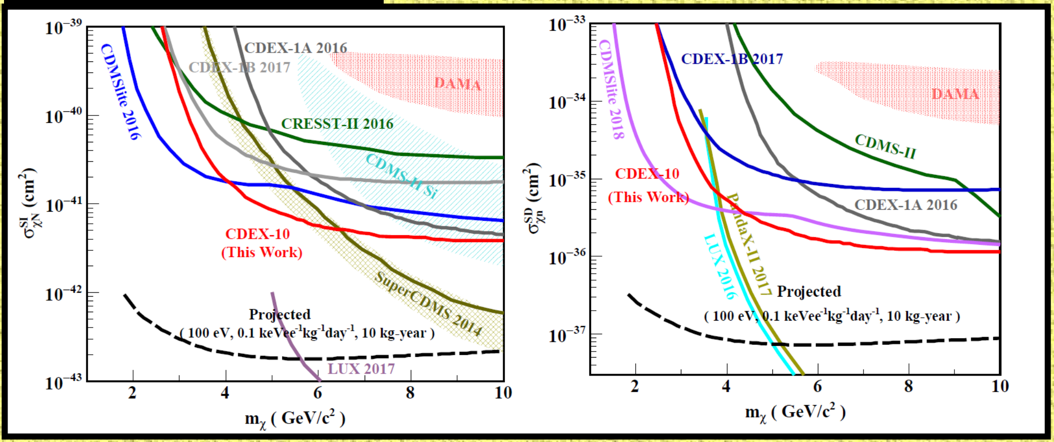


CDEX@CJPL1 *[L.T. Yang's talk]*

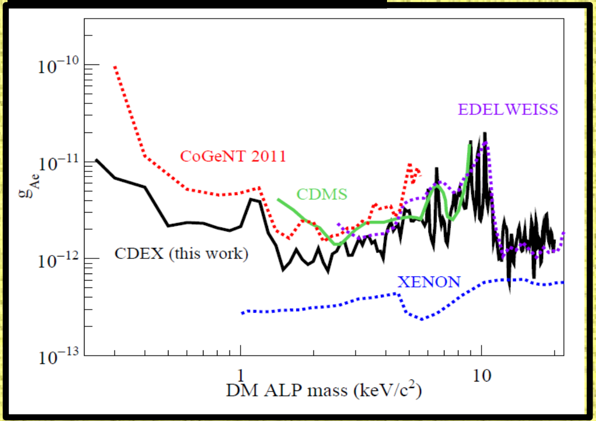
- **Adopt & Expand sub-keV Ge technologies from KSNL**
- **Competitive results on Dark Matter Light-WIMPs and Axions Searches**
- **Team & Expertise building for *FUTURE Projects***

Stages	Results
CDEX-1A	✓ PRD 88, 052004, 2013 ✓ PRD 90, 091701, 2014 ✓ PRD 93, 092003, 2016 ✓ PRD 95, 052006, 2017(Axion) ✓ Sci. China P.M.A. 60, 071011, 2017(0νββ)
CDEX-1B	✓ CPC 42, 023002, 2018
CDEX-10	✓ PRL120, 241301, 2018

Dark Matter WIMP Searches



Dark Matter Axions Searches

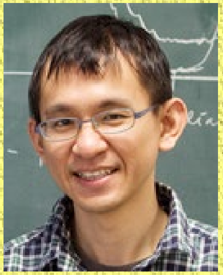


TEXONO Theory Program *[AS, NTU, NDHU, DEU(Turkey), SCU(China) ……]*

NCTS ECP (2015+)

C.P. Liu (NDHU)

J.W. Chen (NTU)



M.R. Wu (AS)

- ☑ **ν-NSI ; BSM ν-e & ν-N ;**
- ☑ **Atomic/nuclear effects in ν/χ interactions ;**
- ☑ **ν/χ – em effects** *(L. Singh's talk)* **;**
- ☑ **χ–Atom scatterings** *(M. Pandey's talk)***;**
- ☑ **Sterile-ν DM ;**
- ☑ **dark photons ;**
- ☑ **ν-N QM coherency effects ;**
- ☑ **……**

🛠 Connections: Studies of EW/BSM physics involves exquisite understanding of the detection physics mechanisms which require state-of-the-art command of atomic, nuclear & QCD physics.

Some Highlights …….

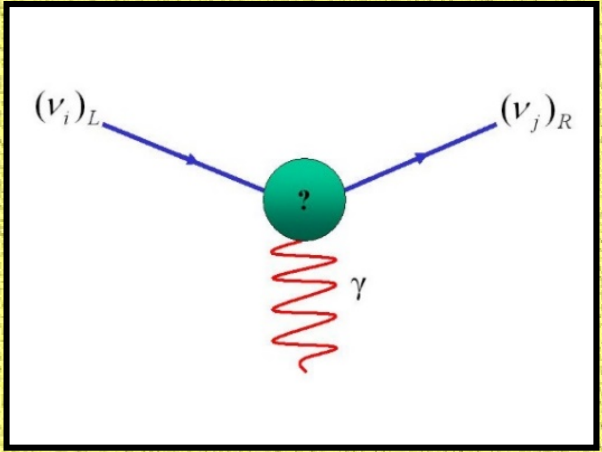
Neutrino Electromagnetic Interactions

Neutrino Electromagnetic Form Factors

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

$$F_1 = \delta_{\rm Q} \cdot e_0 + \frac{1}{6} \cdot q^2 \cdot \langle r_{\nu}^2 \rangle,$$

$$F_2 = (-i) \cdot \frac{\mu_{\nu}}{2 \cdot m_e},$$



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

Helicity Conserved : milli-charge

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

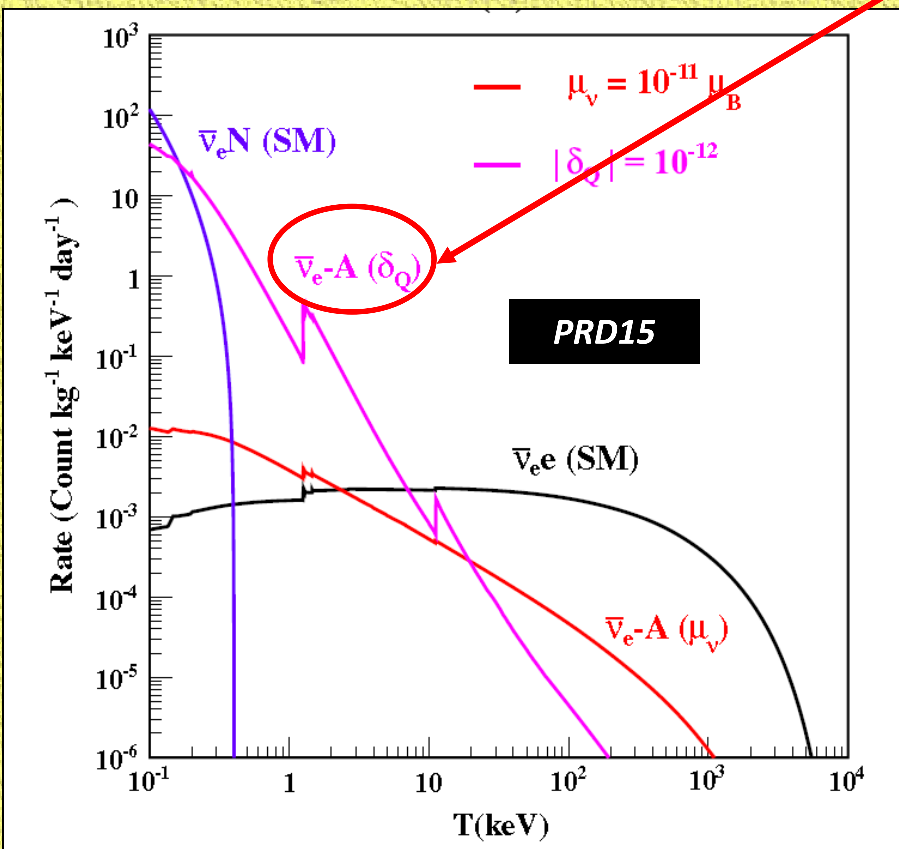
Helicity Flipped : Magnetic Moments

Neutrino "Milli-charge"

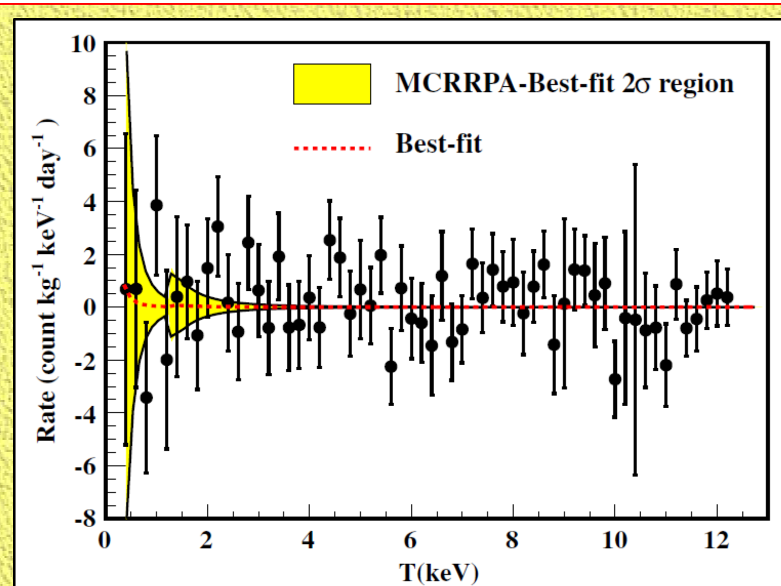
[PRD14]

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

Atomic Ionization Differential Cross-Section with full atomic physics many-body "MCRRPA" calculation [PL13]

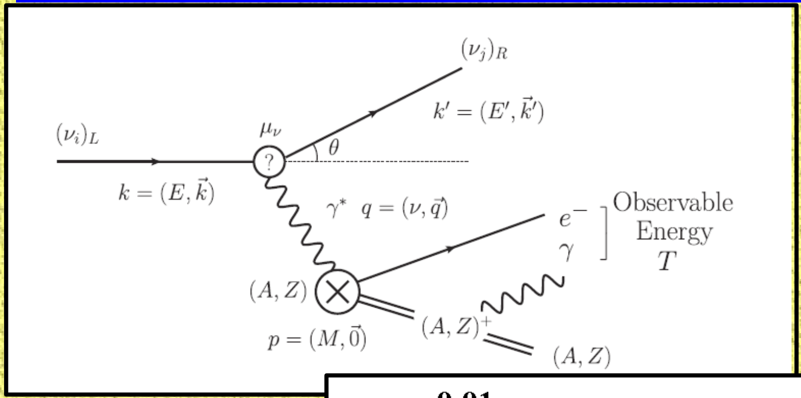


- ☑ **Identify New Twist - Cross-section enhanced at low energy transfer ("minimum ionizing")**
- ☑ **Smoking-gun signatures for positive signals: peaks at known K/L binding energy at known ratios *[different from cosmic-activation electron-capture background]***
- ☑ **Present Bound : $\delta_Q < 10^{-12}$**
- ☑ **Future Sensitivity Goal (100 eVee threshold): $\delta_Q \sim 10^{-14}$**

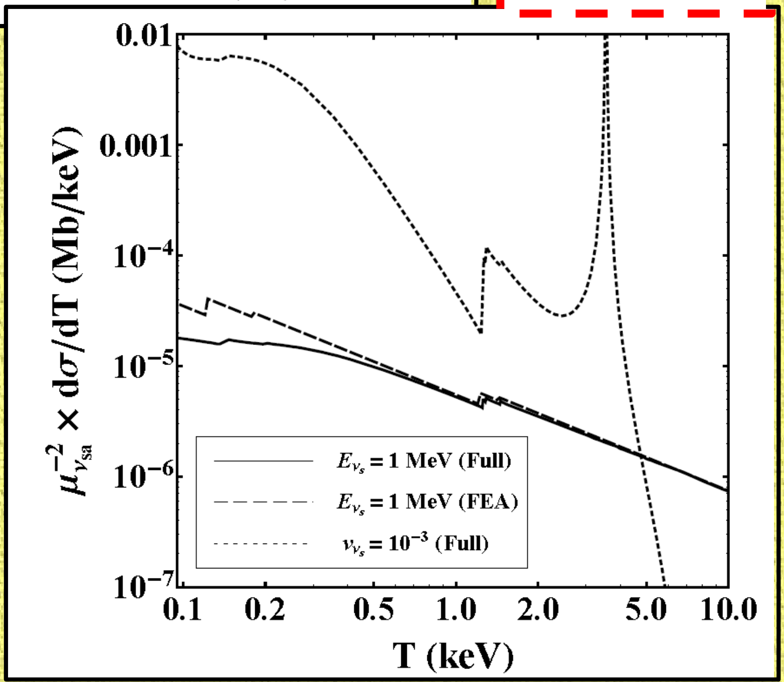


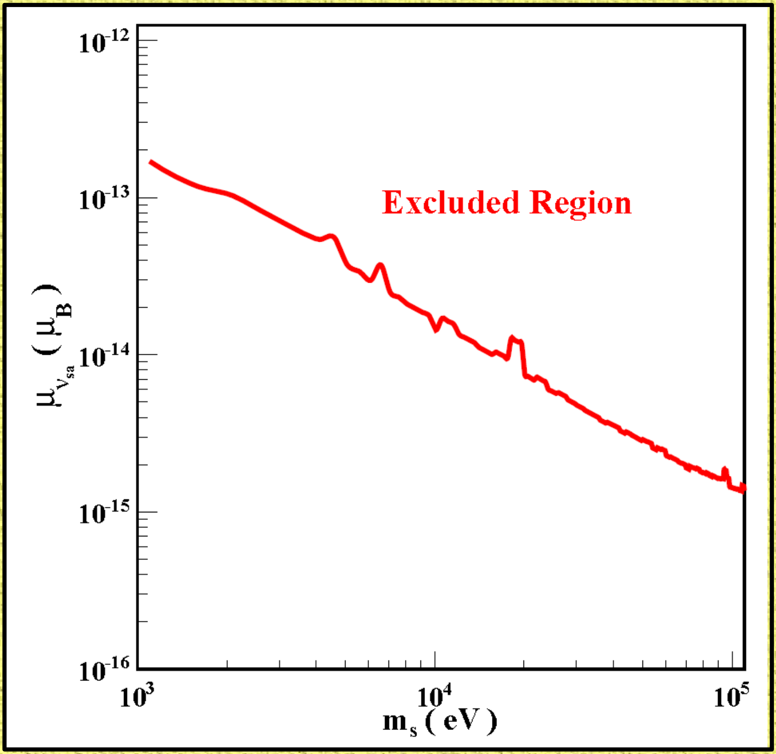
Non-Relativistic Massive Sterile Neutrino to Light SM Neutrinos Via Transition Magnetic Moment Atomic Ionization *[PRD16]*

- Pole structure at differential cross-section at $m_\nu/2$ ($q^2 \sim 0$)



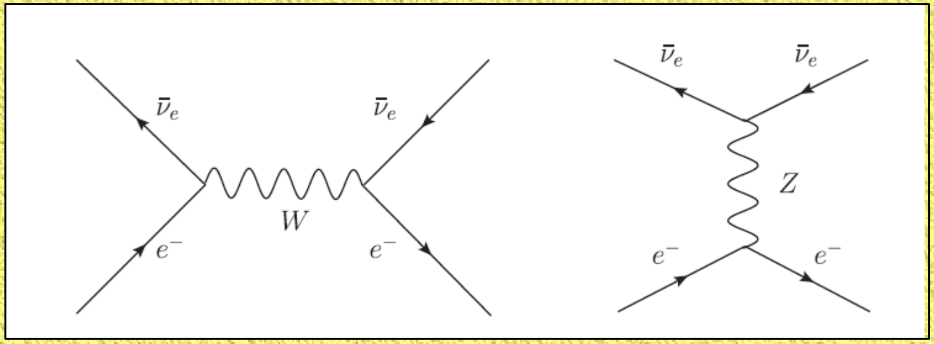
$m_s = 7.1$ keV





Direct Search of Sterile Neutrinos as Dark Matter

Constraints on Dark-Photon with n-electron Scattering *[PRD15]*



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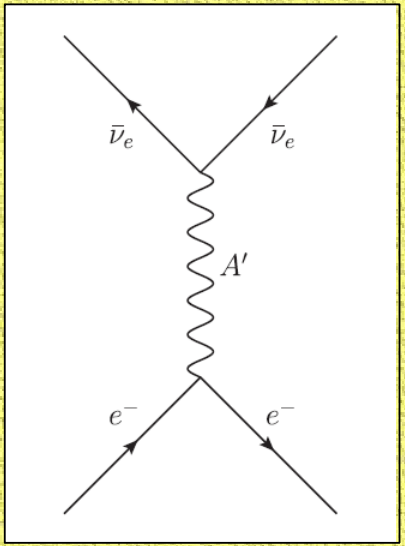
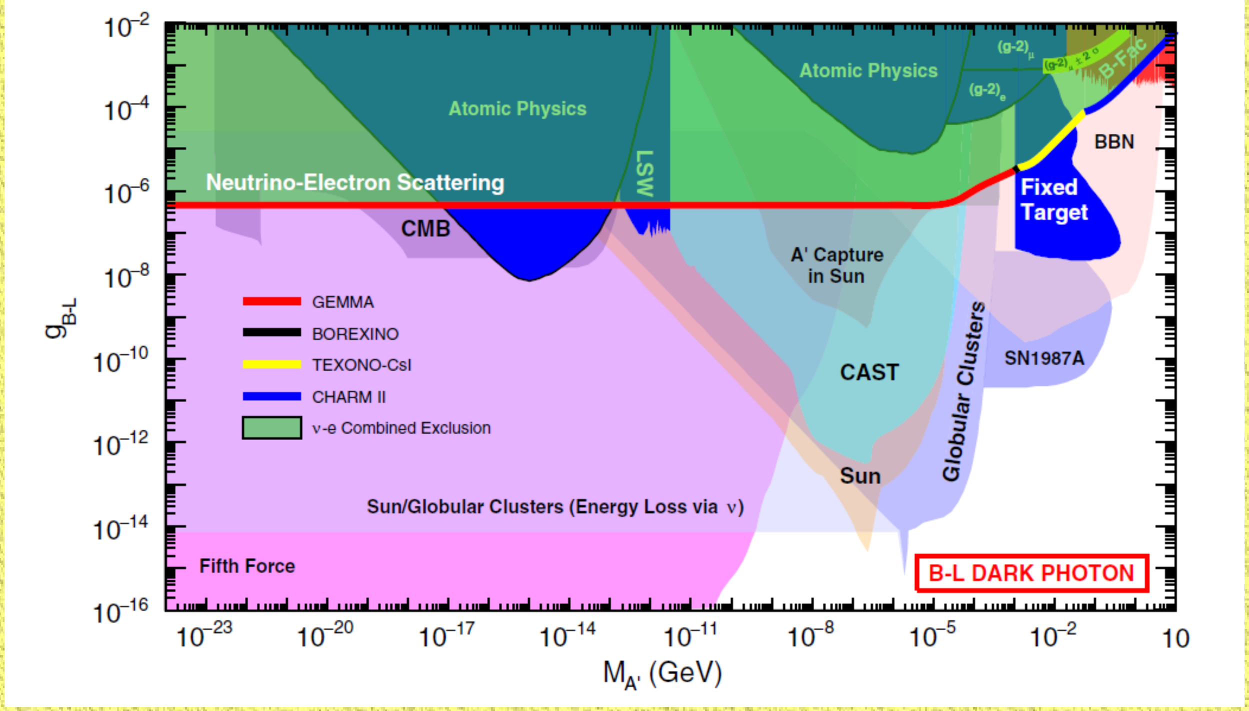
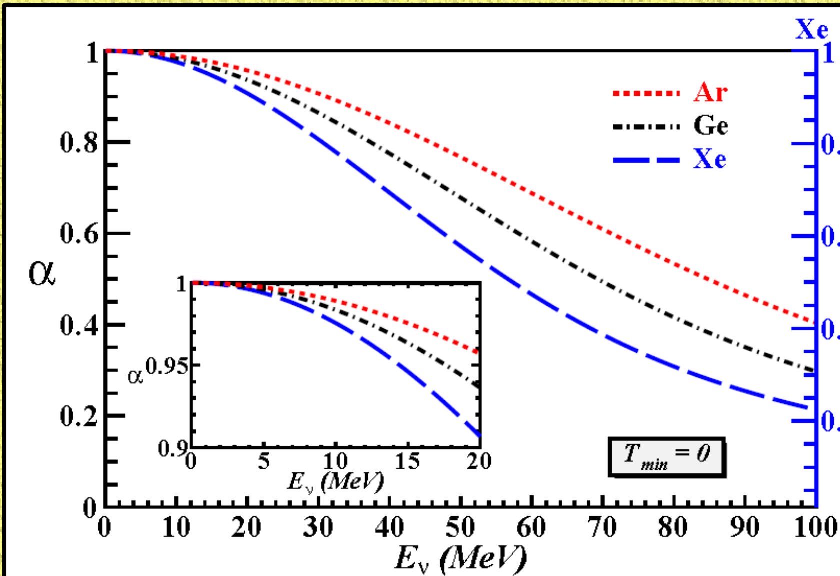
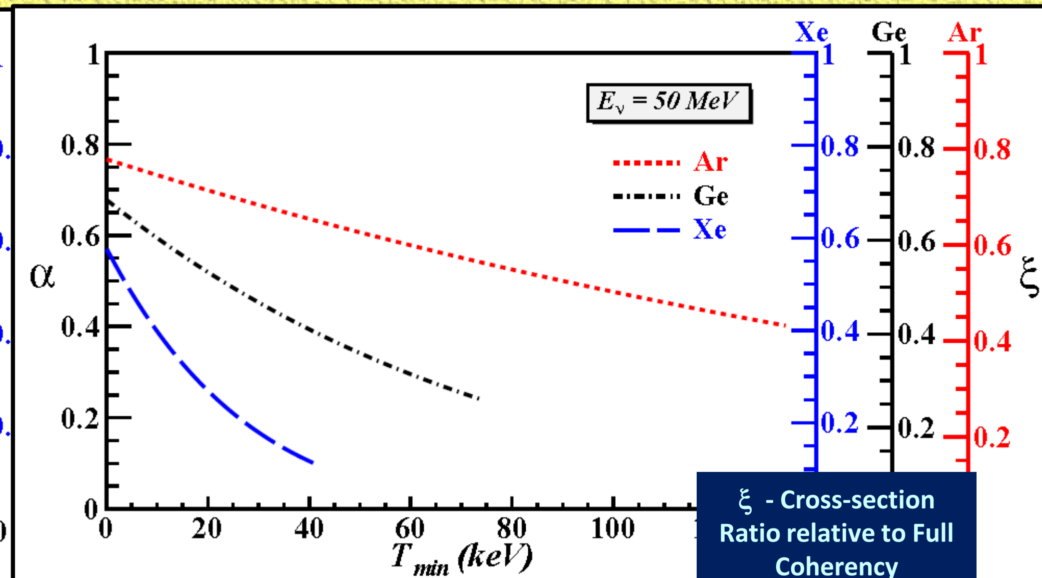




Coherency in Neutrino-Nucleus Elastic Scattering *[V.Sharma's talk]* [PRD16]

- Quantify transitions between Coherency & Decoherency
- Complementarity between different Sources & Target





ξ - Cross-section Ratio relative to Full Coherency

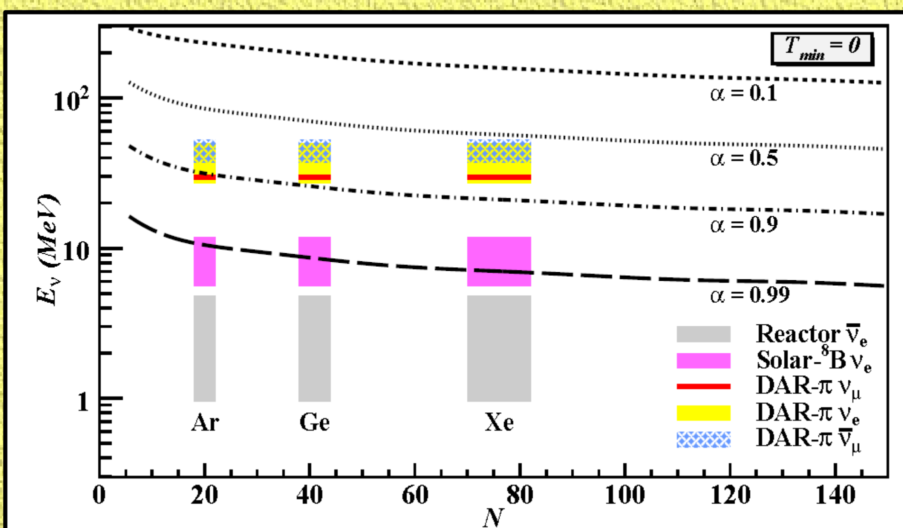


TABLE II: The half-maxima in the distributions of $[\Phi_\nu \cdot \sigma_{\nu A_{el}}]$ at T_{min}=0 for the different neutrino sources, and the values of $\langle\alpha\rangle$ probed by the selected target nuclei. The ν_μ from DAR-π is mono-energetic.

ν Source	Half-Maxima of $[\Phi_\nu \cdot \sigma_{\nu A_{el}}]$ in E_ν(MeV)	$\langle\alpha\rangle$ with Ar	Ge	Xe
Reactor $\bar{\nu}_e$	0.96−4.82	1.00	1.00	1.00
Solar-^{8}B ν_e	5.6−11.9	0.99	0.99	0.98
DAR-π ν_μ	29.8	0.91	0.86	0.80
DAR-π ν_e	27.3−49.8	0.89	0.83	0.76
DAR-π $\bar{\nu}_\mu$	37.5−52.6	0.85	0.79	0.71

$$\alpha \equiv \cos\langle\phi\rangle \in [0,1]$$

$\langle\phi\rangle$: averaged decoherence angle

PIRE

GEMADARC

since 2017

GEMADARC

Germanium Materials and Detectors
Advancement Research Consortium

NSF PIRE

NSF Partnerships for International Research
and Education Program

A global partnership funded by NSF PIRE to advance germanium technologies for the search of dark matter, neutrinoless double-beta decay and other rare physics processes with world-class education and training platforms and opportunities.

Collaboration

GEMADARC is a global partnership of 11 institutions across 5 countries. Meet the members and institutions from the U.S.A., Canada, China, Germany, and Taiwan on our collaboration page

Collaboration »

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Queen's University

Why Ge? *[Merits, Uniqueness, Competititve Edges …]*

☑ **Matured Technology ; Industry Support -**

- Less (entry level) investment

☑ **Excellent Resolution –**

- resolve structures (peaks, end-points ….) , smoking-gun signatures for certain BSM scenarios
- Good Continuum Background Rejection for Peak Signal *(e.g. $0\nu\beta\beta$)*

☑ **Fast (enough) timing –**

- slow detector response time *[thermalization (bolometers) / drift (TPCs)]* → problematic in vetoing anti-coincidences at surface (reactor,accelerator) locations.

Constraints/Limitations :

- **Target Mass** ***[or High Cost-per-unit-Mass]***

(i.e. suited for physics requiring "good detectors" rather "big detectors")

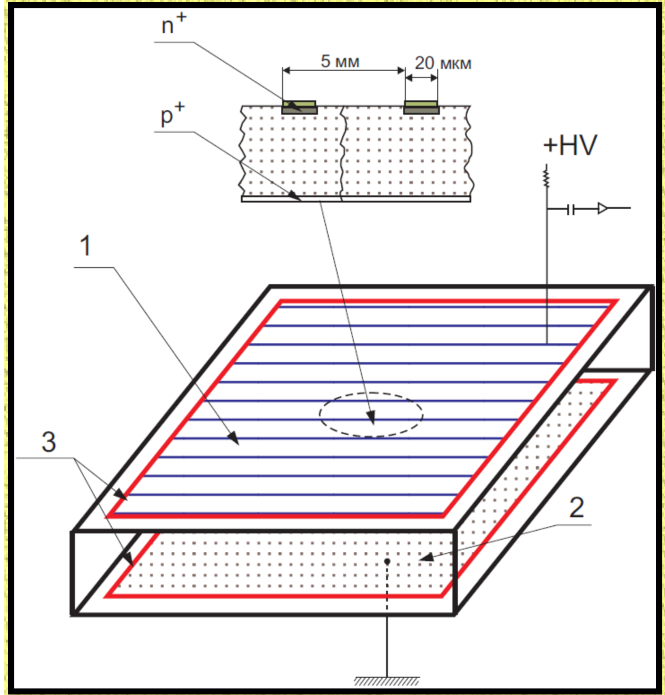
Operation & Characterization of Novel Electro-cooled Ge Detectors

Potenitial Merits:

- ☑ Customize Coldtip temperature for best frontend performance *(i.e. lower threshold)*
- ☑ Cooling with synchronized negative feedback pumping.
- ☑ Less microphonic noise.
- ☑ Compact (Portable) Design.
- ☑ New JFET and ASIC FE-electronics near point contact.

R&D on Ge-Ionization with Charge Amplification

- ☑ Partnership within NSF-PIRE-GEMADARC
- ☑ Ge-IA, following concept paper of *[Starostin & Beda 2000]* on Ge planar strip detectors, extend to point-contact design.
- ☑ Expect Charge multiplication @ 10^5 V/m E-field
- ☑ Potentials: O(10 eVee) threshold, with Ge-Ionization, LN2 operation, fast ~μs signals
- ☑ Applications: νA_{el} & other ν-physics at reactor, dark matter searches
- ☑ Groups: *USD (US), AS (Taiwan), THU (China), BHU (India) ….*
- ☑ Opportunity for Future CJPL-CDEX-DM

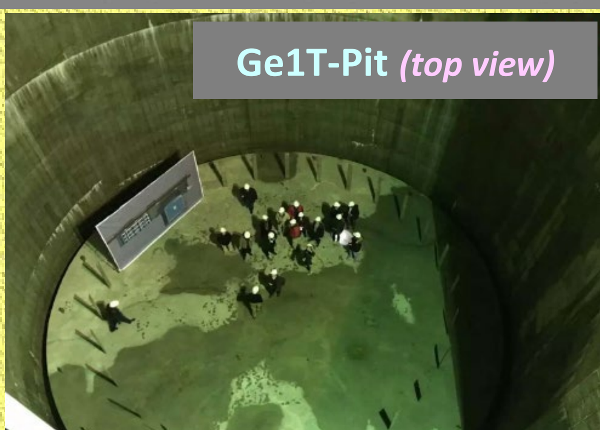


Starostin & Beda 2000

- Avalanche with V=4000 V ; E~105 V/m at O(10 mm)

Future Prospects @ CJPL-II: CDEX-Ge1T ($0\nu\beta\beta$+DM) Project

- **LEGEND-1T is a natural and excellent candidate for Ge1T@CJPL2**



LEGEND

Large Enriched Germanium Experiment for Neutrinoless ββ Decay

- ☑ **Towards Ton-scale enriched-Ge76 experiment for neutrinoless double beta decay experiment to *cover the "Inverted Hierarchy"***
- ☑ **Main Cast : mainly GERDA, Majorana, CDEX groups *[i.e. world's expertise teams in ultra-low-background Ge-detector experiments]***

LEGEND — Large Enriched Germanium Experiment for Neutrinoless ββ Decay

Mission: "The collaboration aims to develop a phased, Ge-76 based double-beta decay experimental program with discovery potential at a half-life significantly longer than 10^{27} years, using existing resources as appropriate to expedite physics results."

Select best technologies, based on what has been learned from GERDA and the MAJORANA DEMONSTRATOR, as well as contributions from other groups and experiments.

First phase:
- up to 200 kg
- modification of existing GERDA infrastructure at LNGS
- BG goal 0.6 c /(FWMH t y)
- start by 2021

Subsequent stages:
- staged 1000 kg
- timeline connected to U.S. DOE down select process
- BG: goal 0.1 c /(FWHM t y)
- Location: TBD
- Required depth (Ge-77m) under investigation

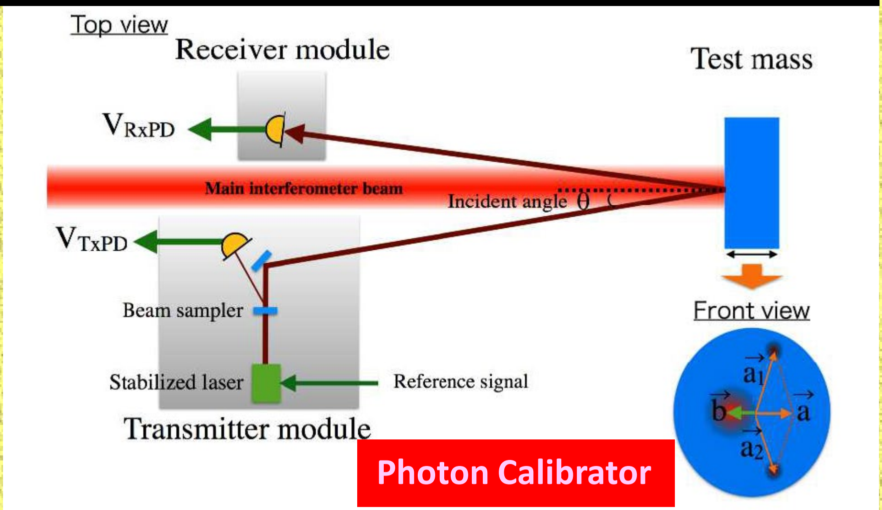
CDEX groups – building a case of hosting this experiment at CJPL-II

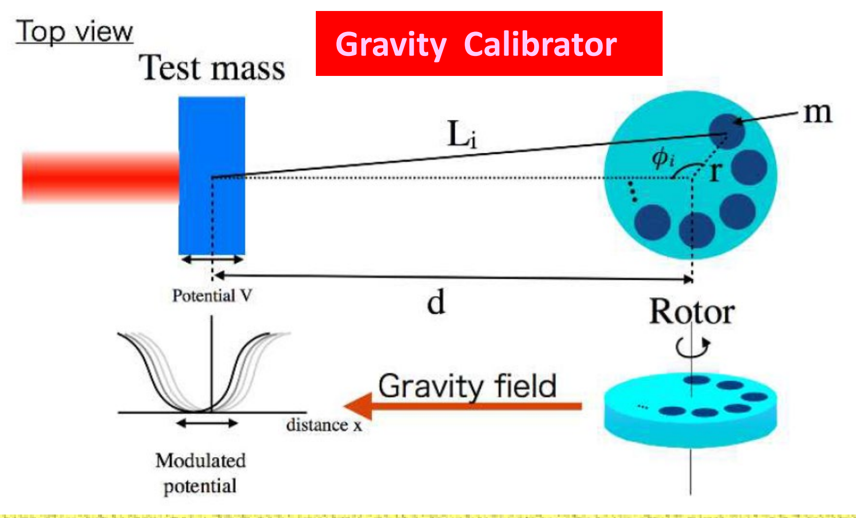
" Bring LEGEND to Jin-Ping !! "

Gravity Calibrator Project

(Join TW-KAGRA team, Y. Inoue & S. Haino)

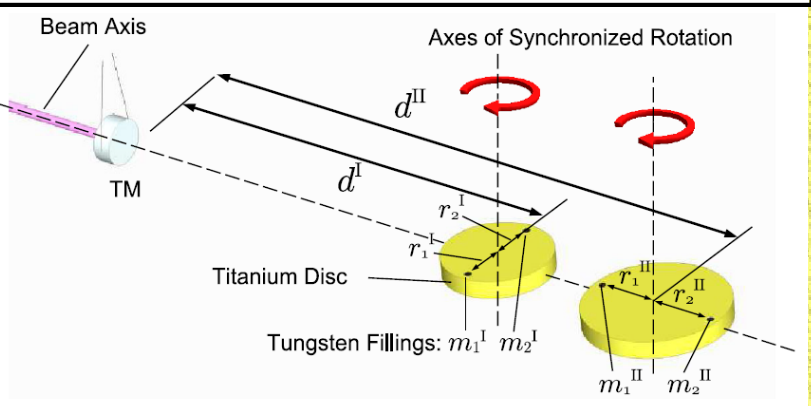
Next Generation of Calibration for GW Projects

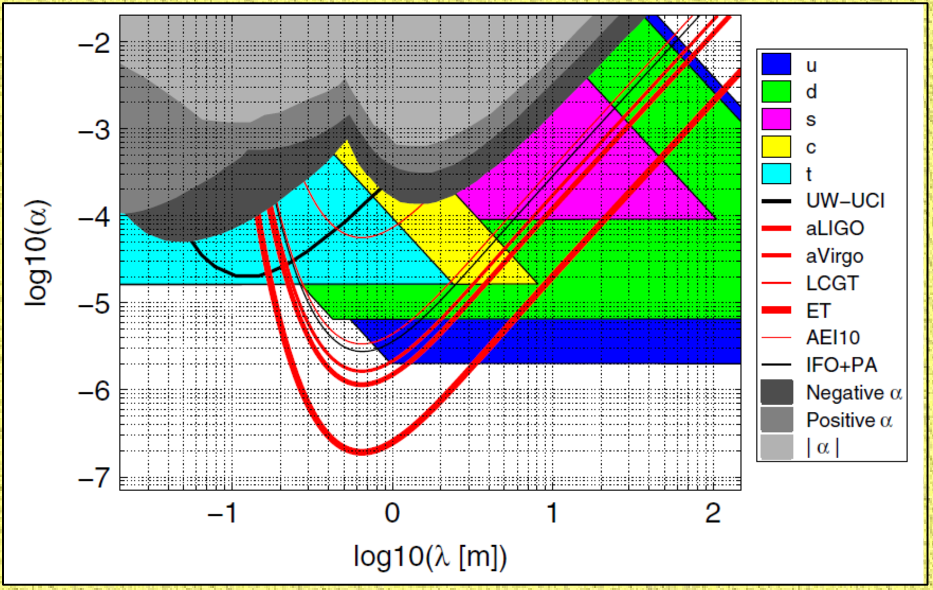




Probe Non-Newtonian Gravity *[e.g. Yukawa potential]*

$$V(r) = V^{\mathrm{N}}(r) + V^{\mathrm{Y}}(r) = -G\frac{mM}{r}[1 + \alpha e^{-r/\lambda}].$$





Summary & Outlook

- Mainstream TEXONO@KSNL & CDEX@CJPL contributed to neutrino electro-magnetic and electro-weak physics & light WIMP, axion searches etc.
- advances on theoretical tools & physics insights
- Frontline on sub-keV germanium detectors R&D
- Ge1T $0\nu\beta\beta$ @ CJPL-II can be a flagship research program for Asia
- Moving to Gravity Physics (intellectual diversity & fun ....)