Dark Matter Search with sub-keV Germanium Detectors

- Overview (Program; Facilities; Detectors)
- Highlights : Direct WIMP searches
- New Results *[arXiv: 1303.0925]*
- Status & Plans

Lin, Shin-Ted / 9 May 2013 @NCTS-NTHU Hsin-Chu

TEXONO + CDEX Collaboration

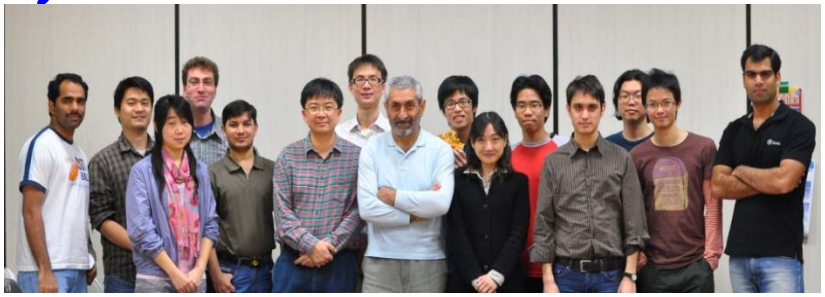
Research Program: Low Energy Neutrino and Dark Matter Physics

- **TEXONO :** *Taiwan EXperiment On NeutrinO* *[Since 1997]*

  Taiwan (AS, INER, KSNPS, NTHU)

  + Turkey (DEU, METU)

  + India (BHU)

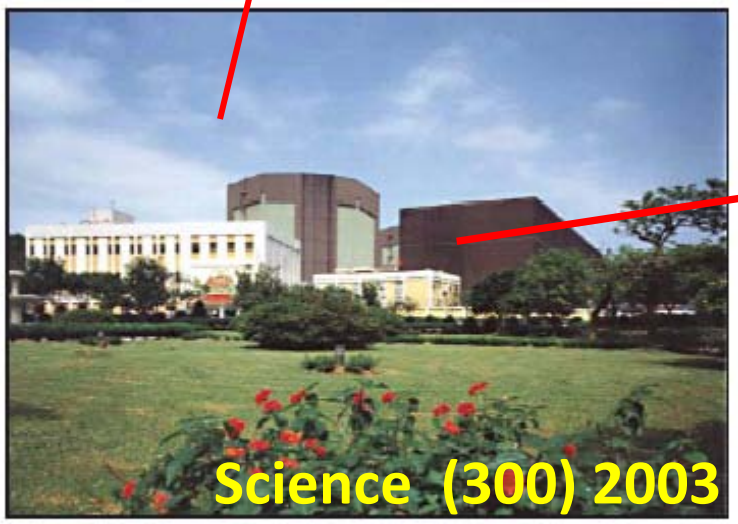


- **CDEX :** *China Dark Matter EXperiment* *[birth 2009]*

  China (THU, SUC, IHEP, CIAE, NKU,EDHC)

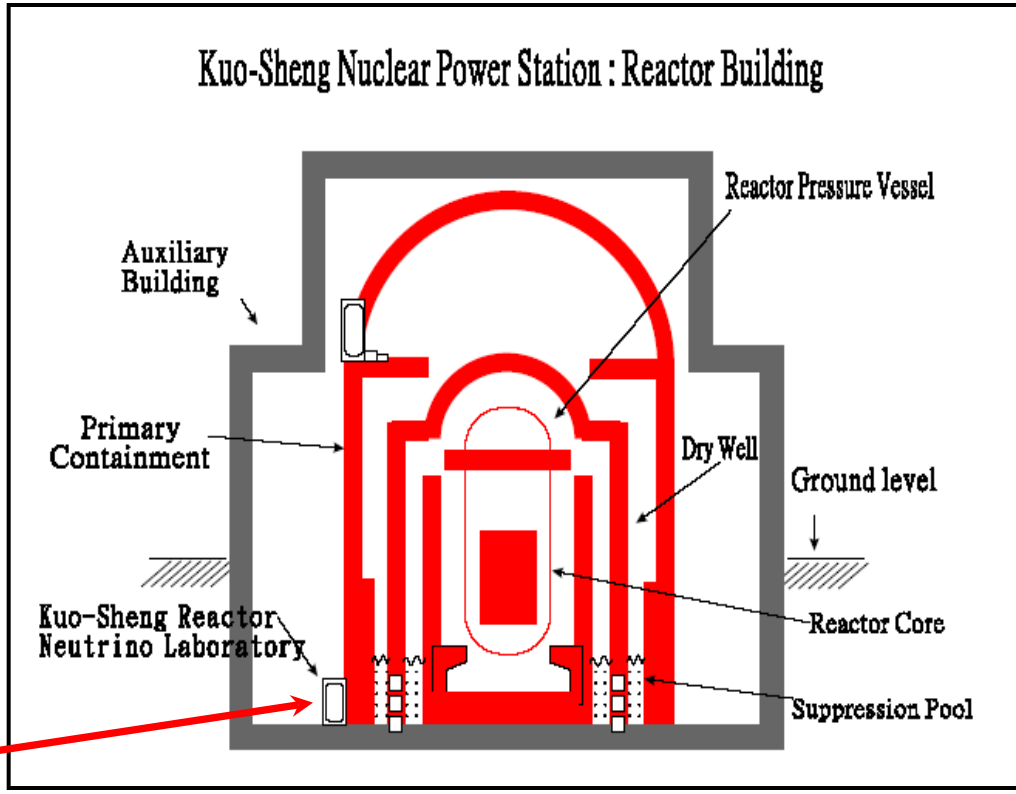
+ CJPL

Kuo Sheng Reactor Neutrino Laboratory



Science (300) 2003

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

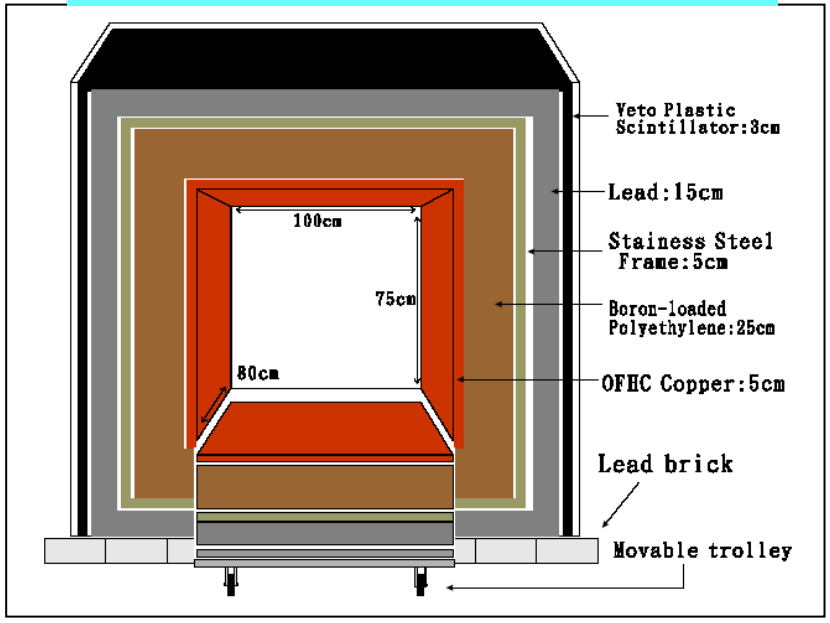


- **28 m from core#1 @ 2.9 GW**
- **Shallow site : ~30 *mwe* overburden**
- **~10 m below ground level**

Kuo Sheng Reactor Neutrino Laboratory

Inner Target Volume

Front View (cosmic vetos, shieldings, control room)



Configuration:

Modest yet Unique

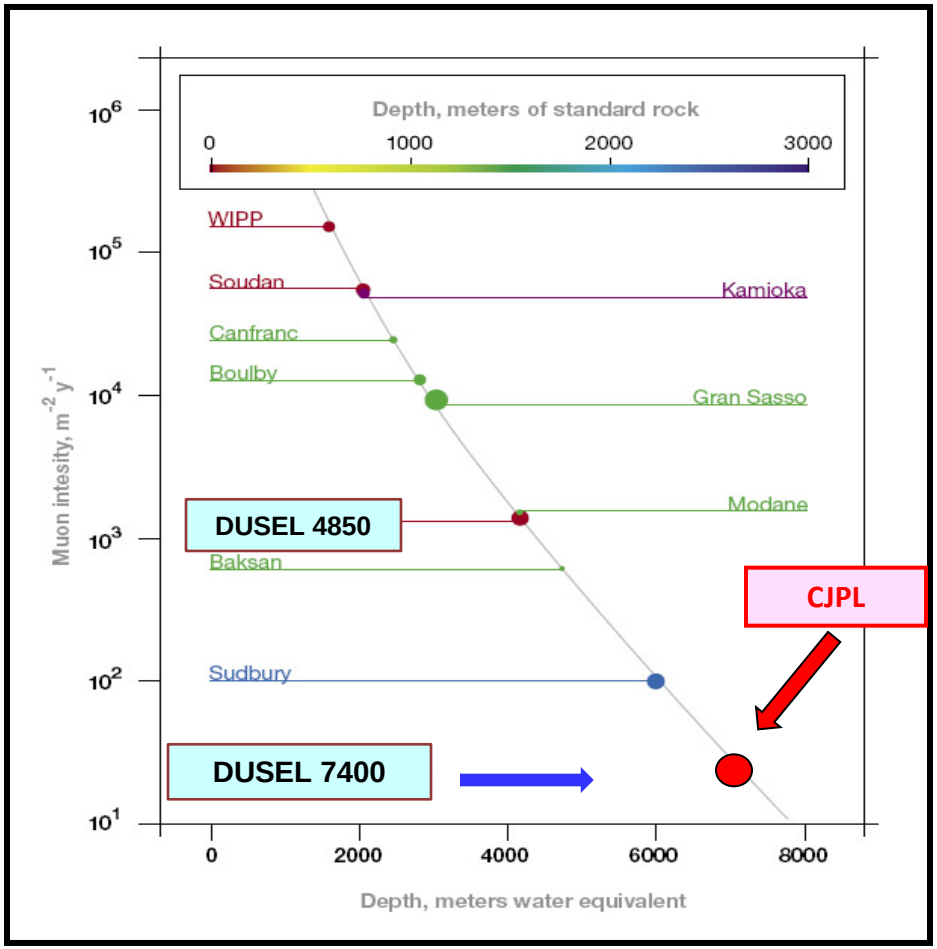
Flexible Design:

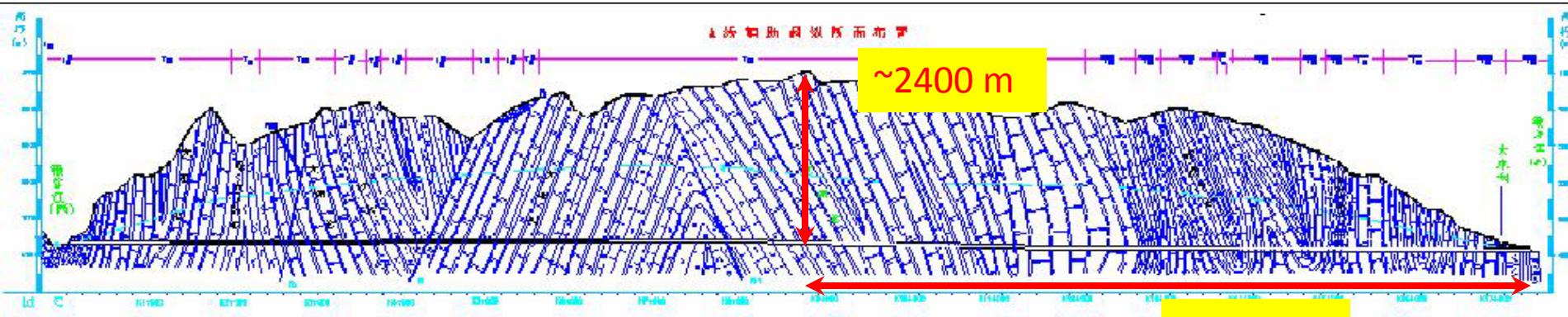
Allows different detectors conf. for different physics

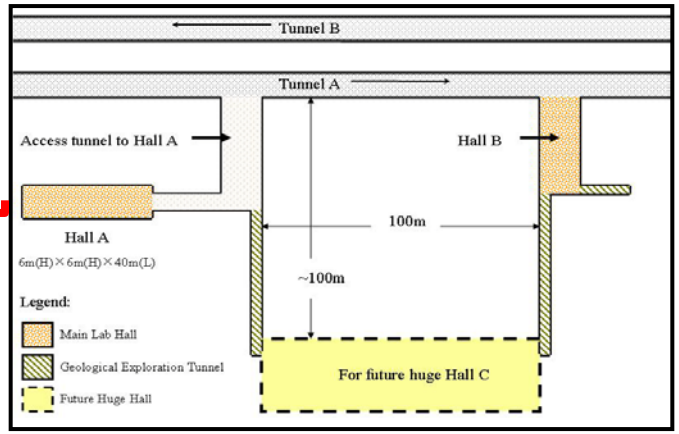
China Jin-Ping Underground Laboratory(CJPL)

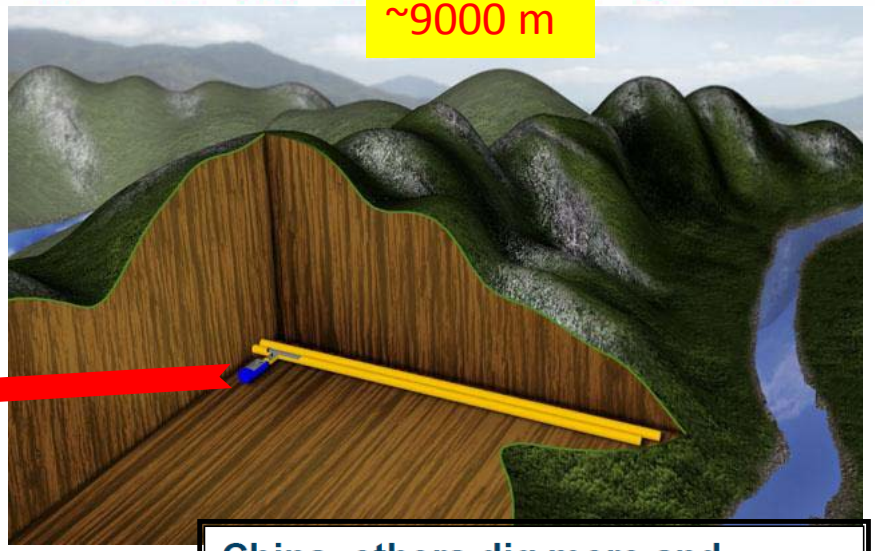
- 2500 m rock overburden, drive-in road tunnel access
- 6X6X40 m *[THU & EHDC]*
- DM-Search: 20 g ULEGe & 1 kg PCGe

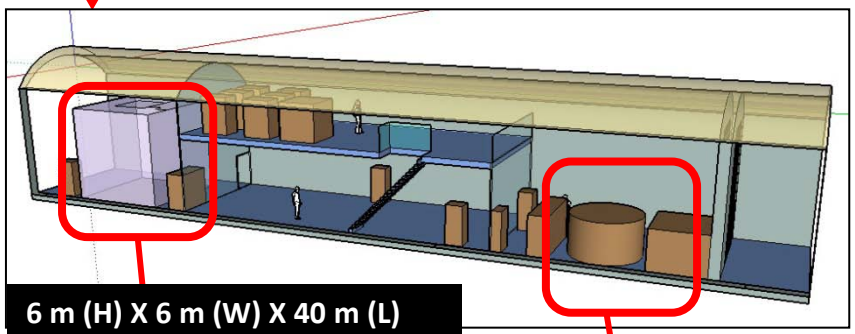
CJPL 中国锦屏地下实验室 China Jinping Underground Laboratory











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

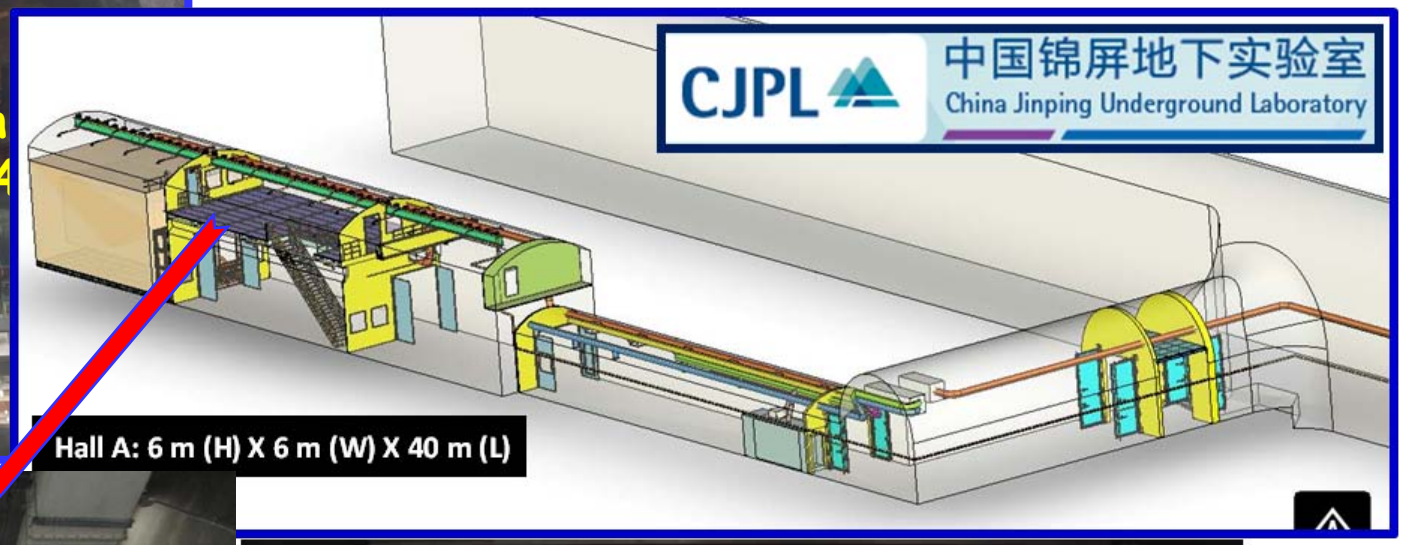
PARTICLE PHYSICS:

Chinese Scientists Hope to Make Deepest, Darkest Dreams Come True

Dennis Normile

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


CJPL Excavation
2009/7— 2010/4
2010/01/27
2010/04/24

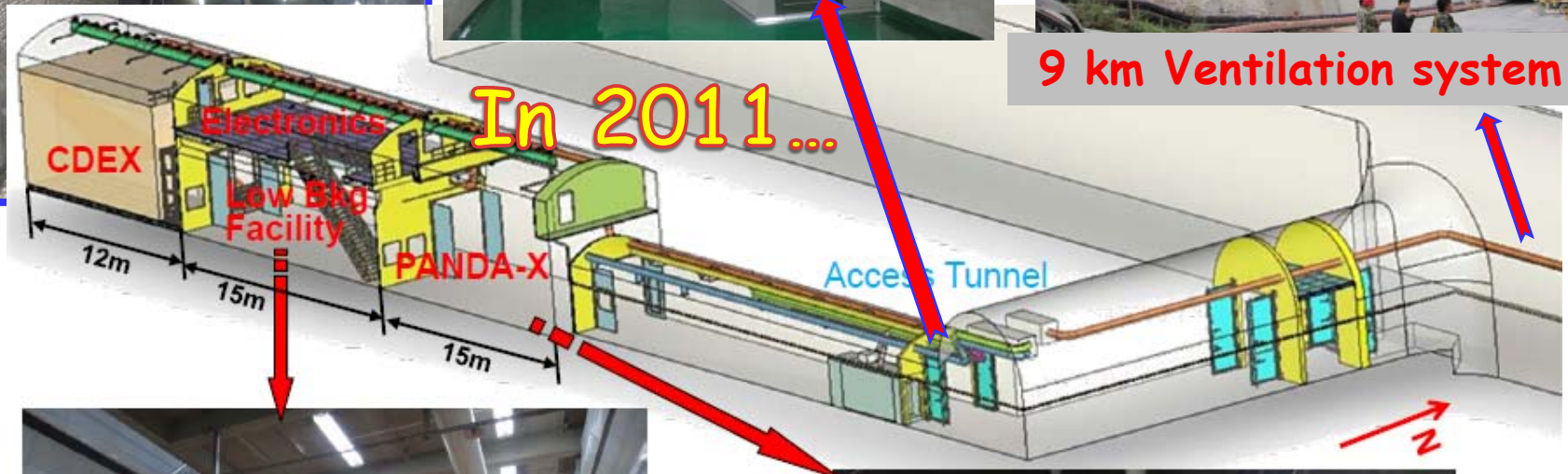


Basic Infrastructures Completed in 2010

Inside with shielding structure

9 km Ventilation system

In 2011…

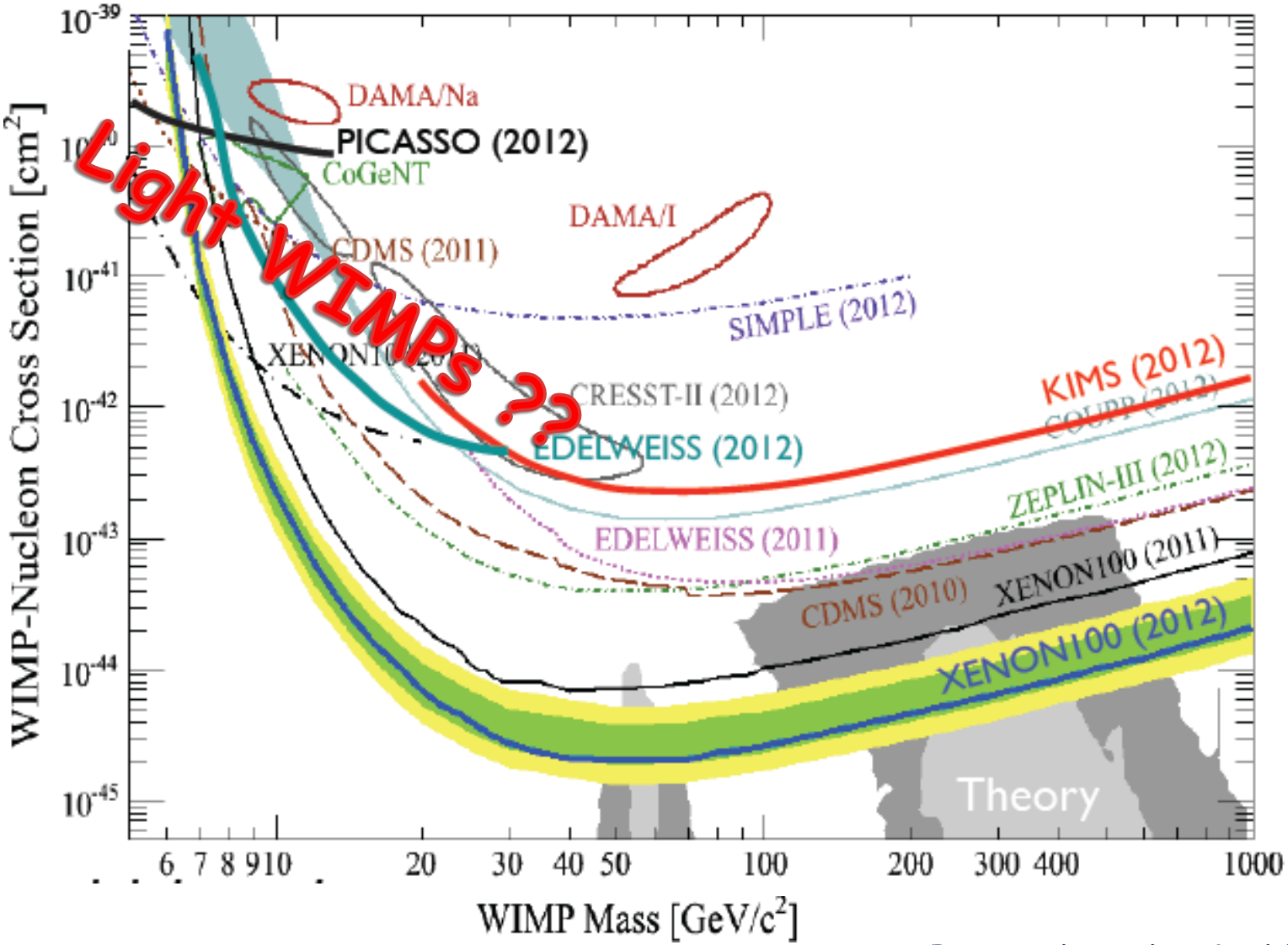


Current Research Theme:

"sub-keV" Ge Detectors

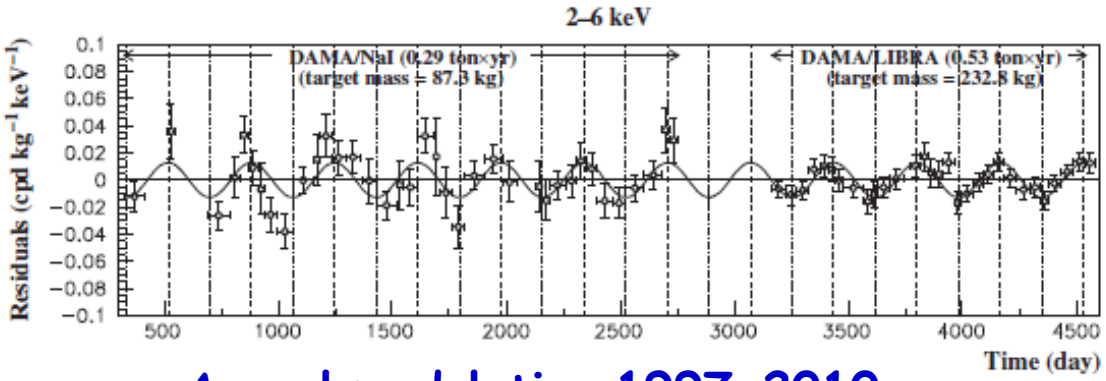
- **Physics Goals for** *O[100 eV threhold⊕1 kg mass⊕1 cpkkd] detector* **:**
  - νN coherent scattering
  - Low-mass WIMP searches
  - neutrino magnetic moments
  - *Open & Explore* new detector window & detection channel & physics parameter space

Spin-independent - update till March 2013

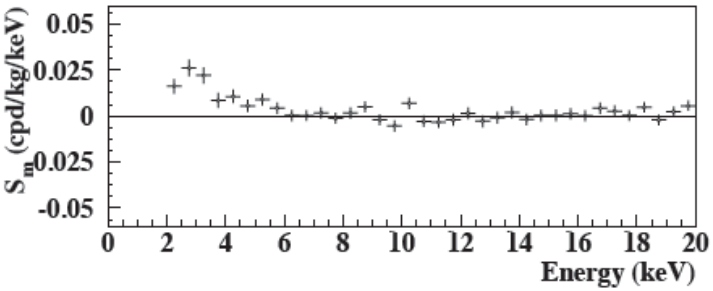


From Aprile et al.,+ Gondolo 2012

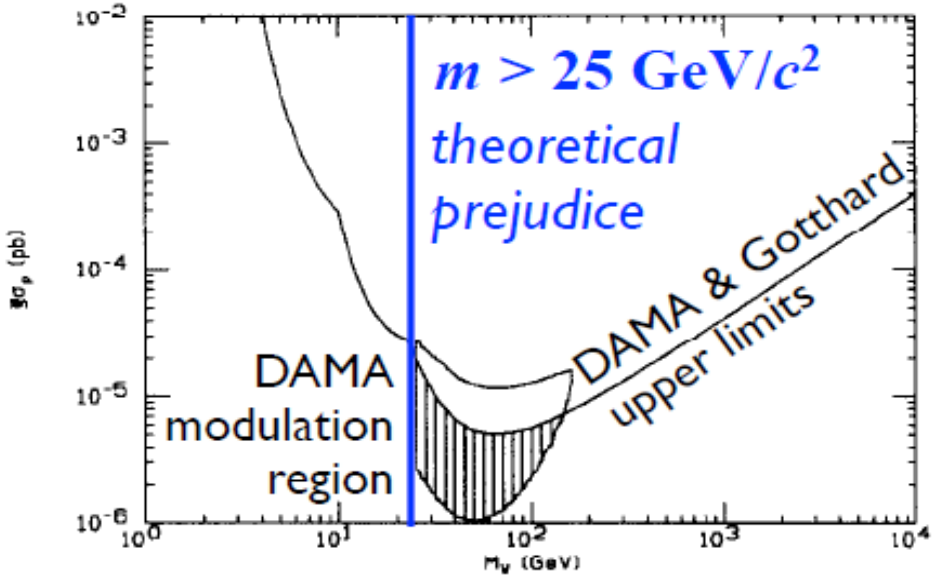
WIMP interpretation of DAMA data

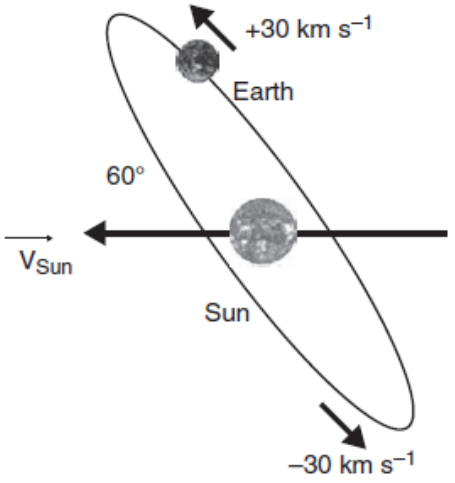


Annual modulation 1997-2010



The theoretical prejudice continued till 2003...





Bernabei et al., 1997

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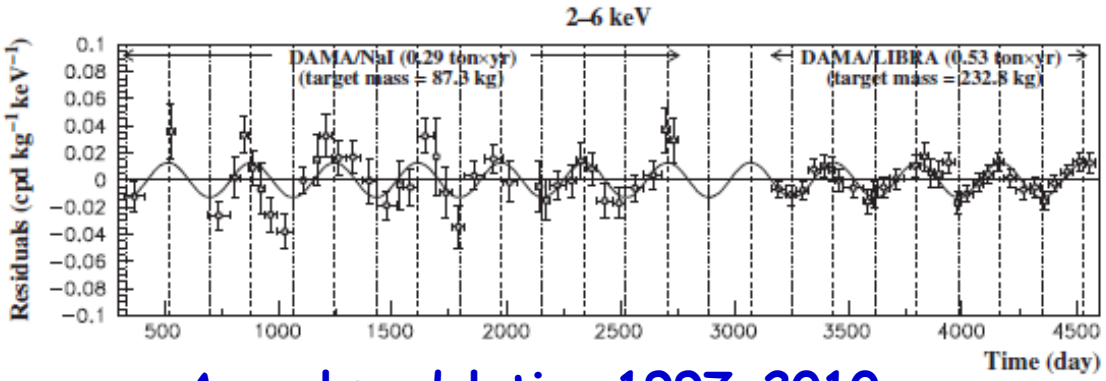

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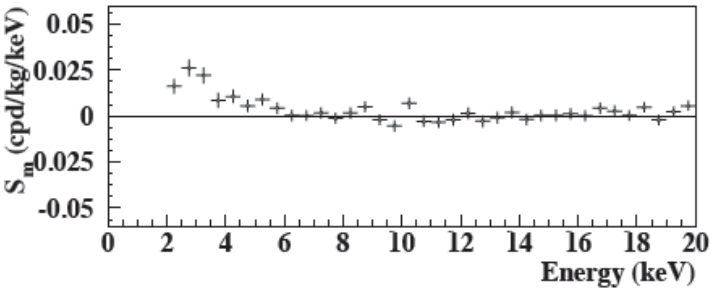

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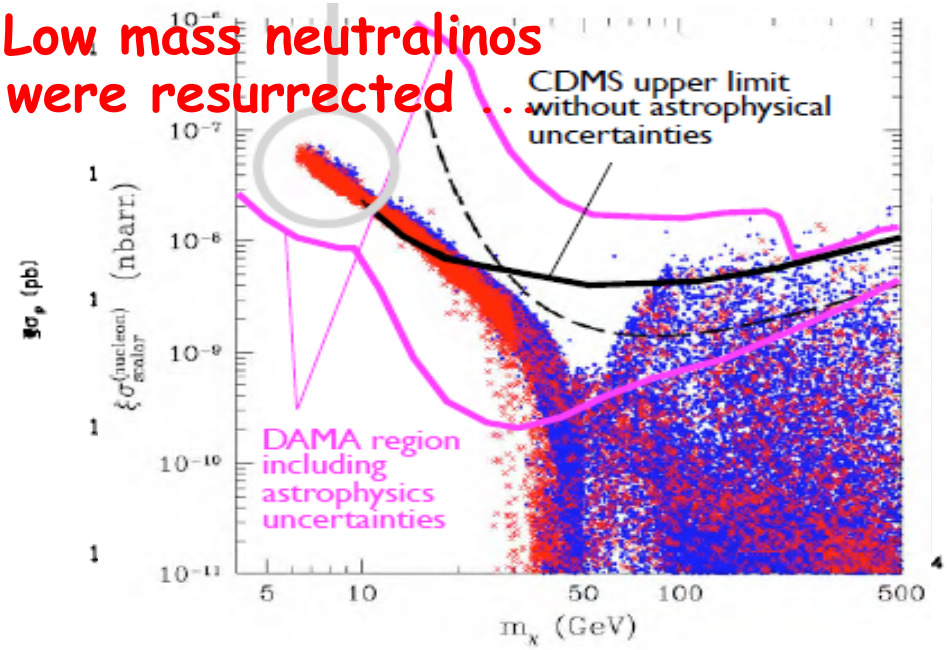

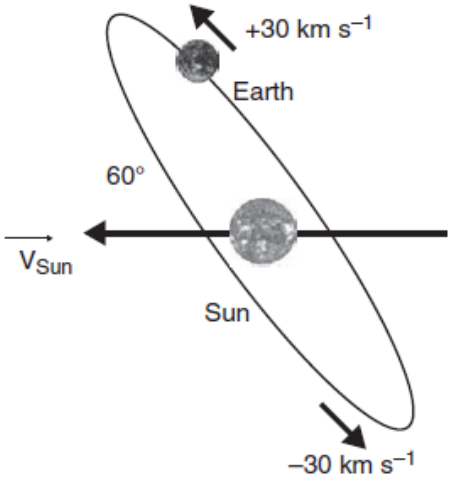

ST Lin et al,(TEXONO) PRD R(2009)

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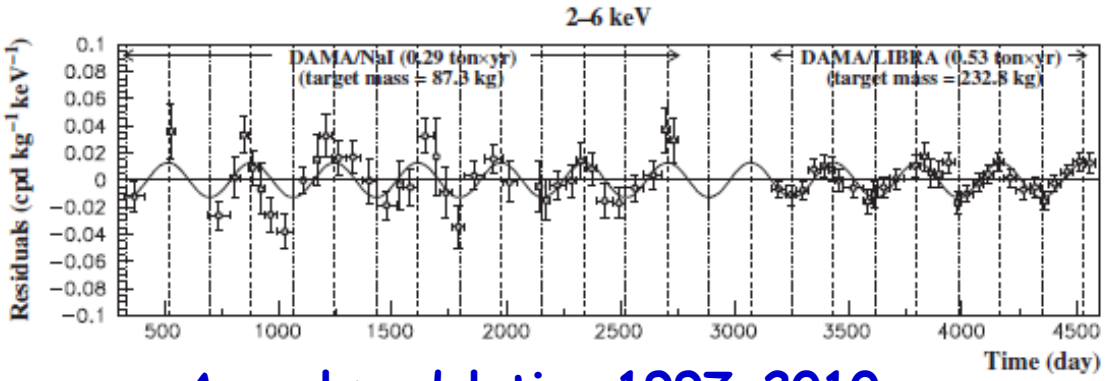

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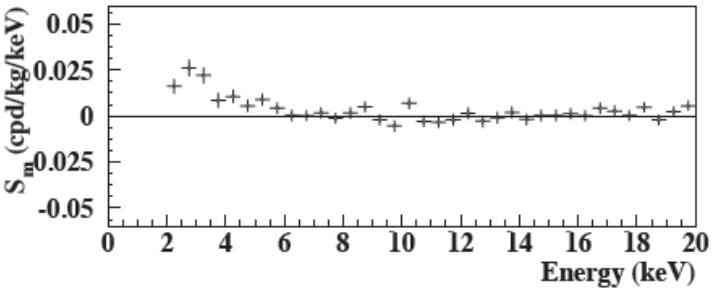

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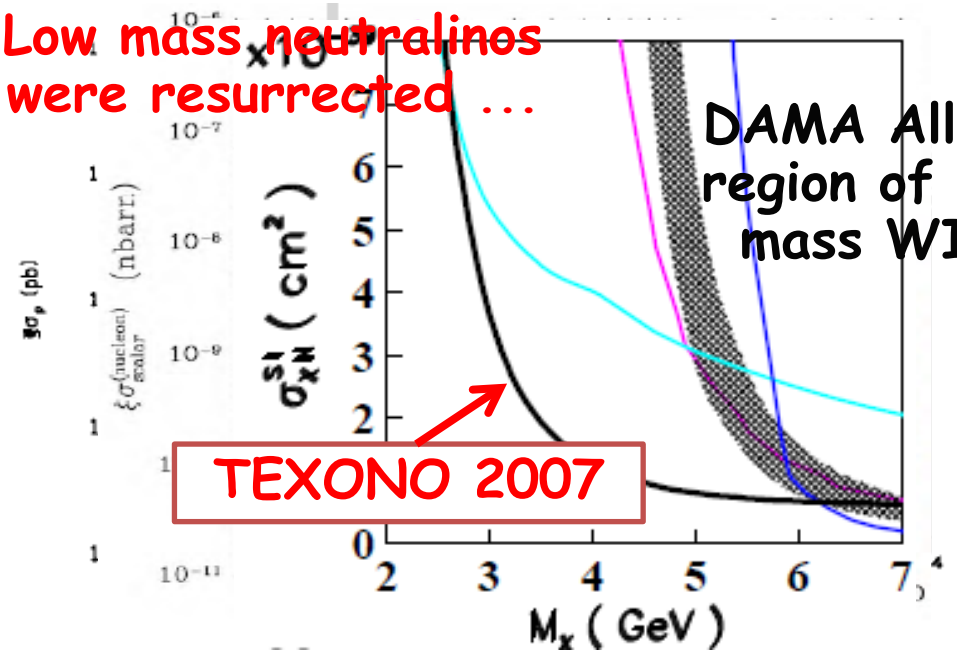

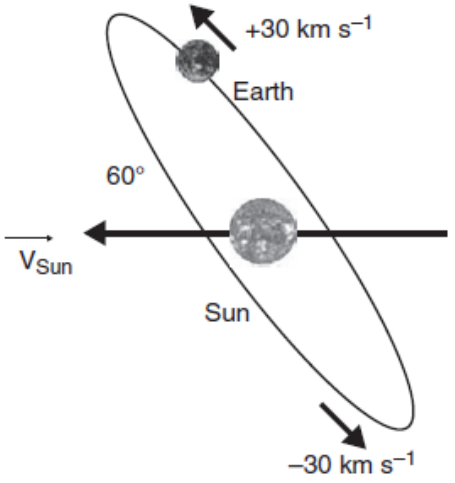

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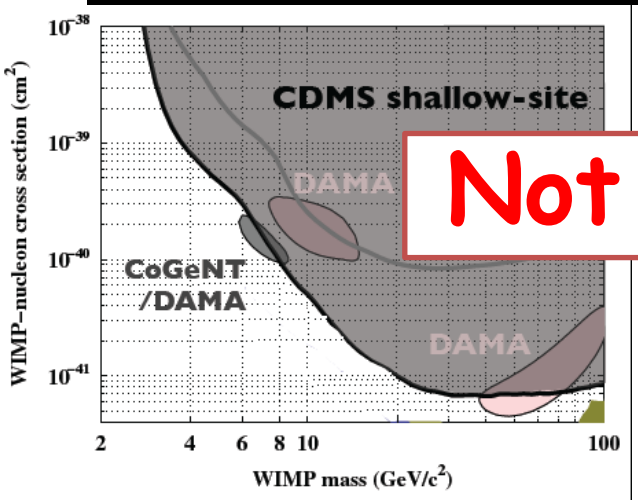
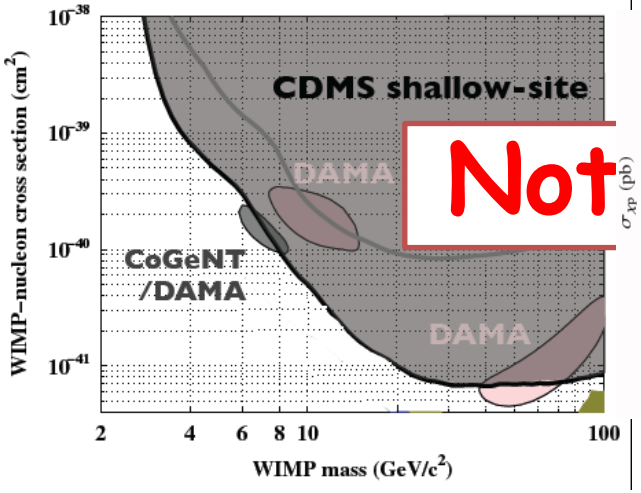
Tension between recent experiments



Not

Akerib (CDMS) PRD82, 122004, 2010

Tension between recent experiments



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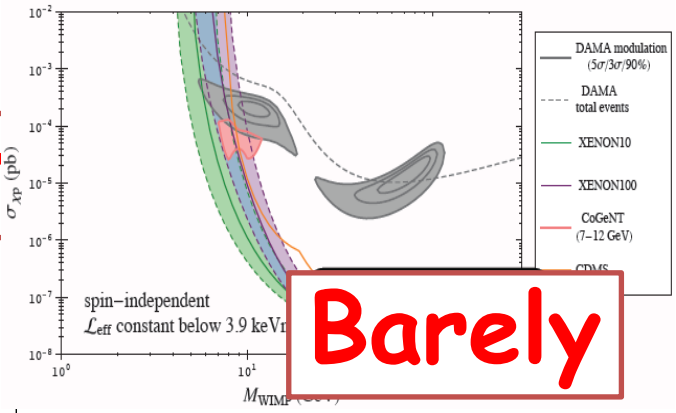

Barely

Savage,Gelmini,Gondolo,Freese 2010

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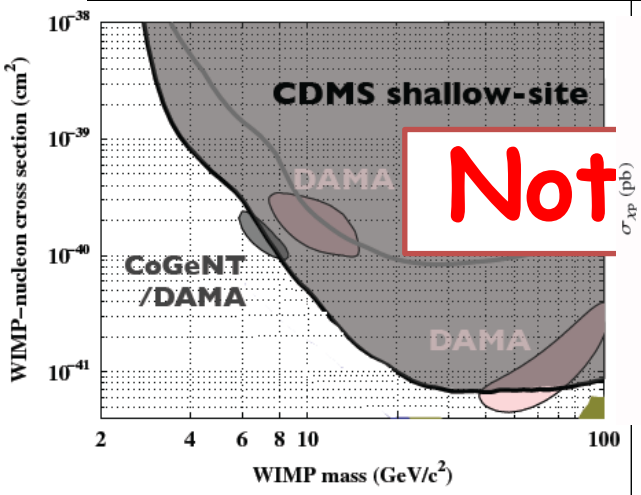

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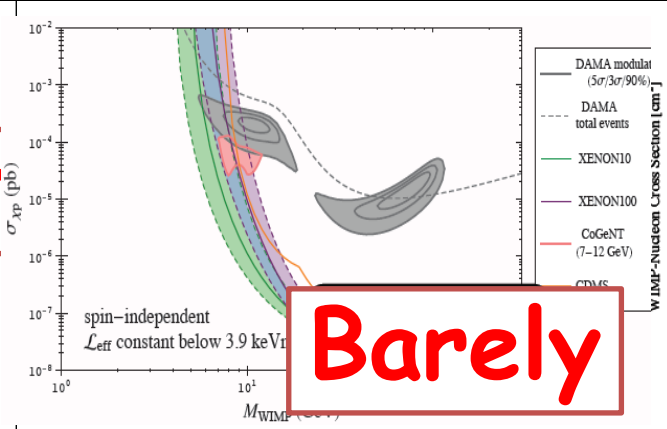

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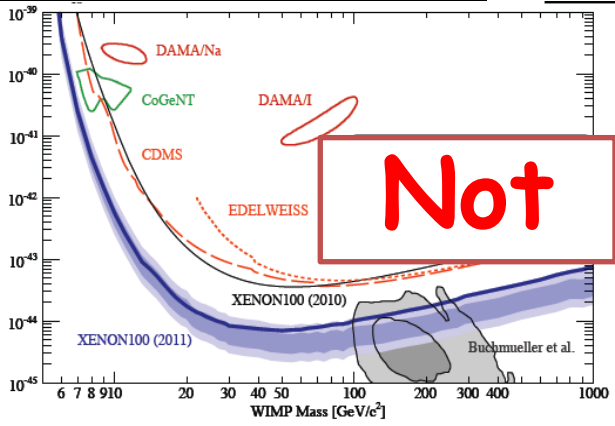

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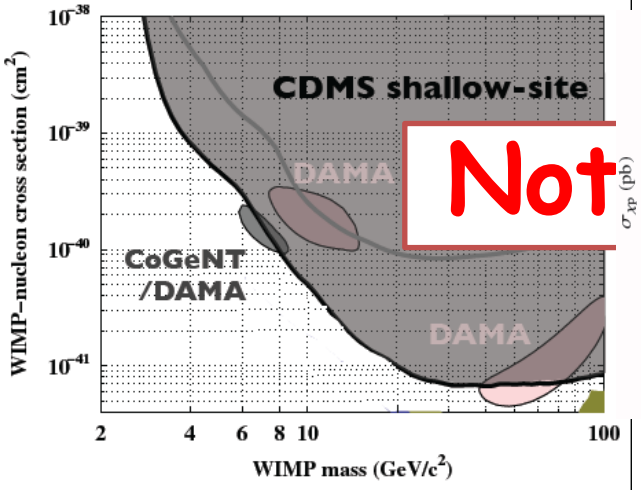
Aprile (XENON 100) 1104.2549

Compatible?

Tension between recent experiments



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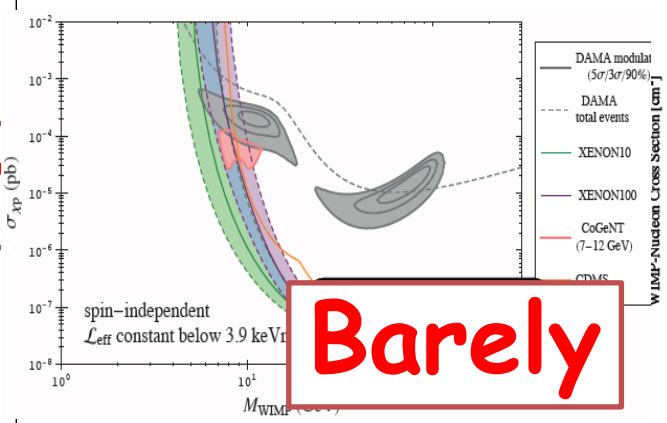
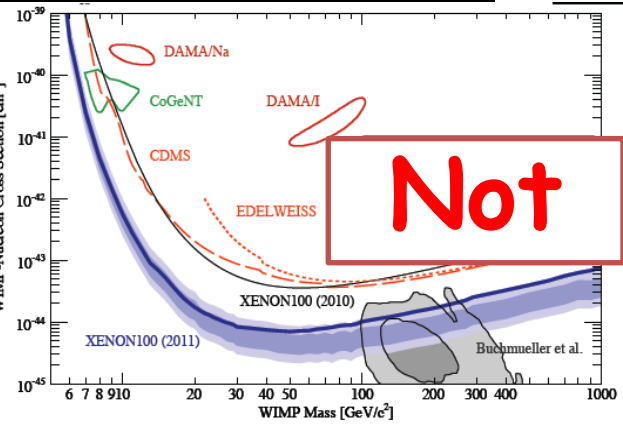


Barely

Savage, Gelmini, Gondolo, Fre



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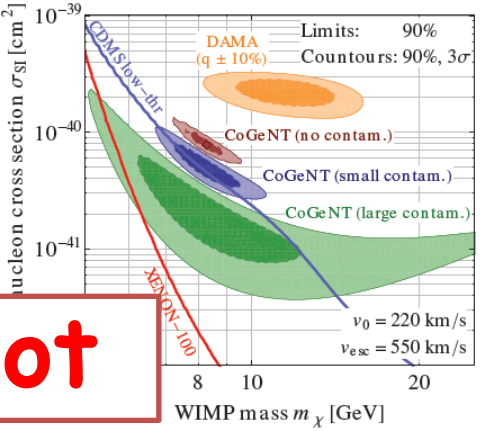

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Kopp, Schwetz, Zupan 2011

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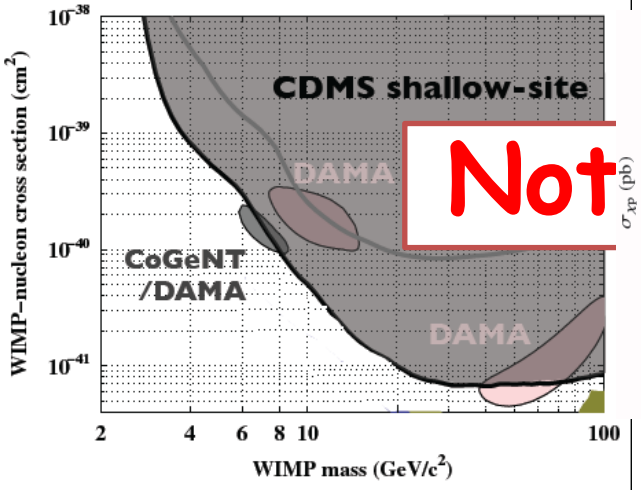

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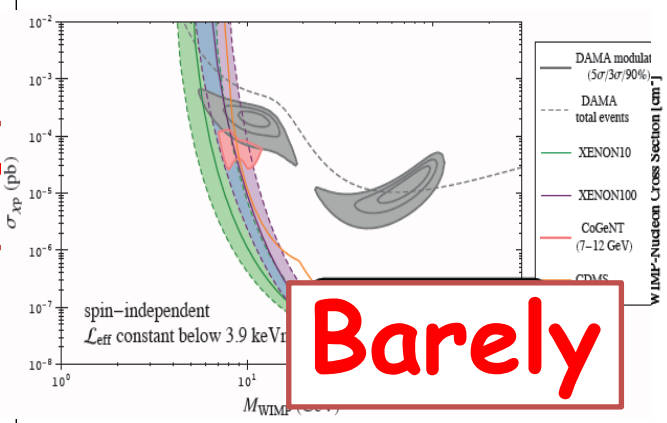

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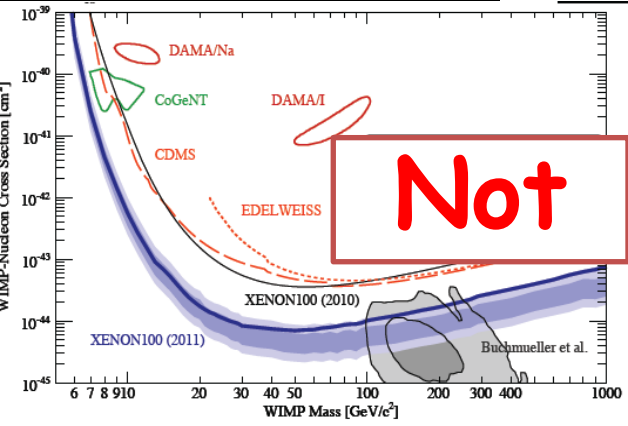

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Savage, Gelmini, Gondolo, Fre

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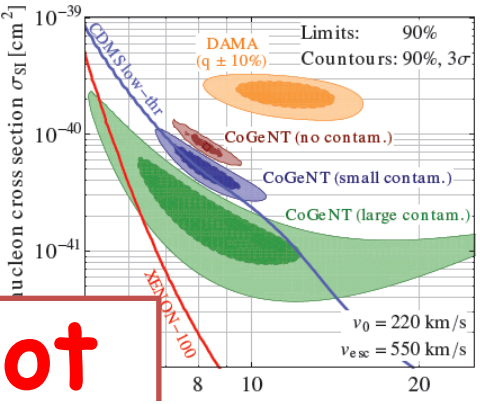
Compatible?



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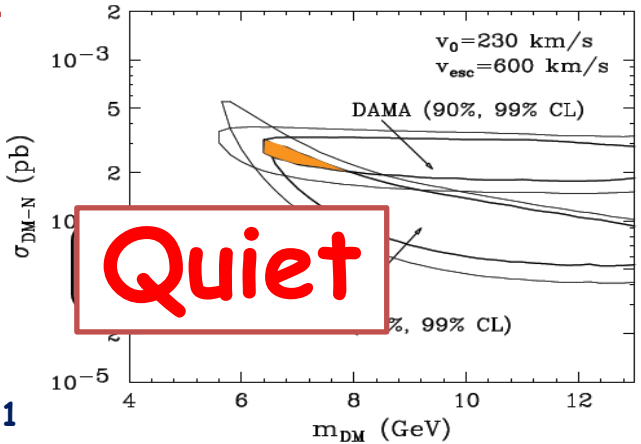
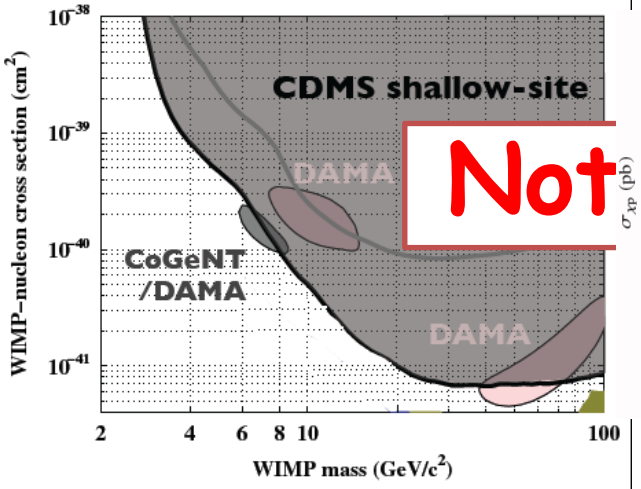


Quiet

Hooper, Collar, Mckinsey 2011

Tension between recent experiments



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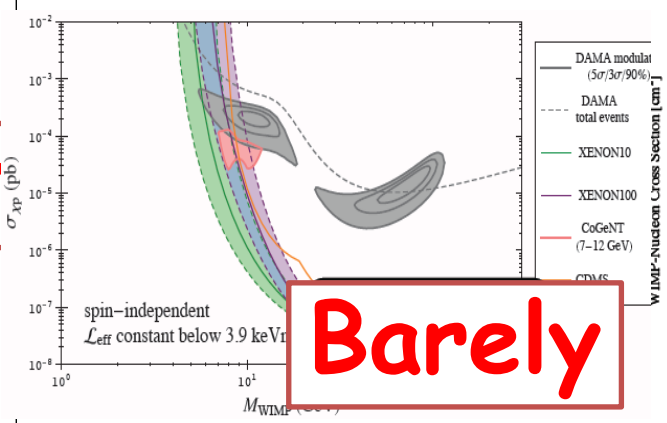

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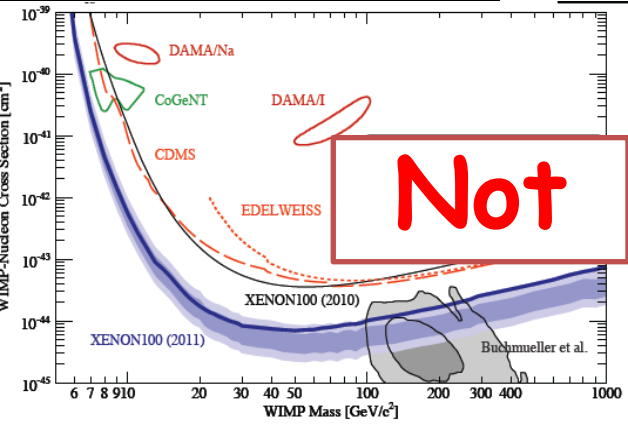

Not

Savage, Gelmini, Gondolo, Fre

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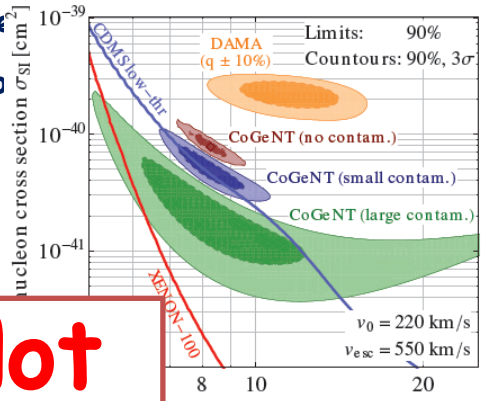
Compatible?



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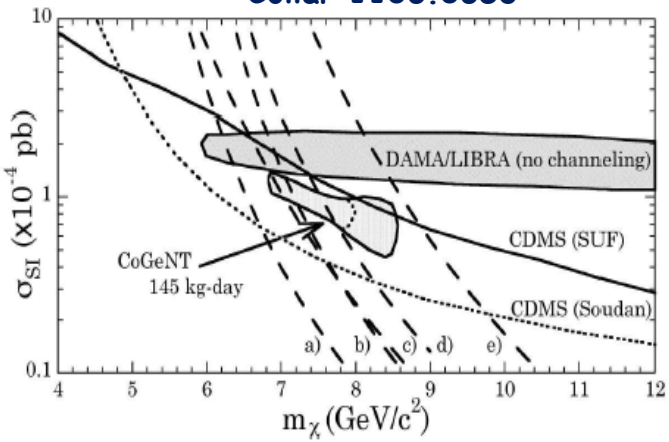
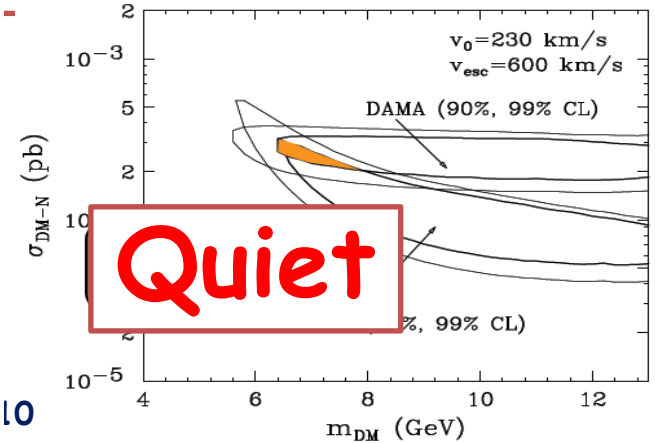
Collar 1106.0653

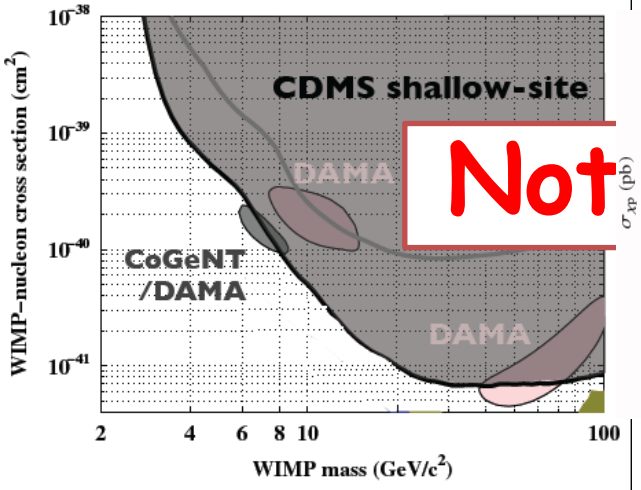




Quiet

10

Tension between recent experiments



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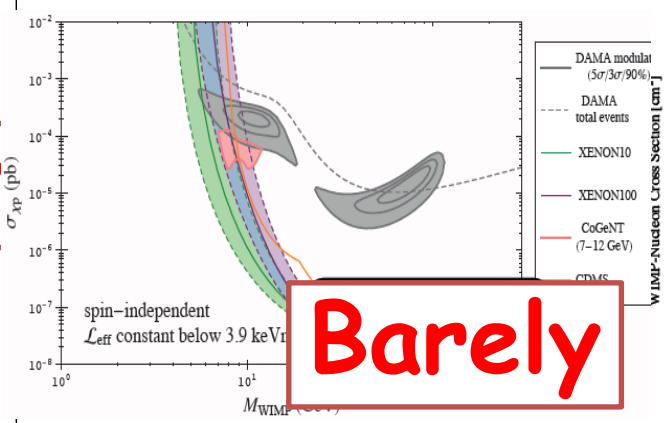

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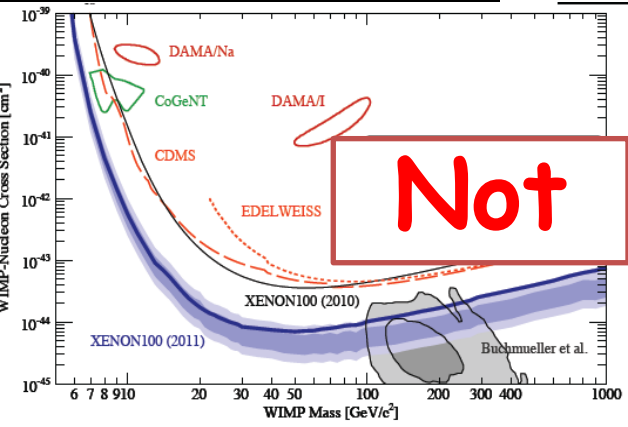

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Savage, Gelmini, Gondolo, Fre

Akerib (CDMS) PRD82, 122004, 2010

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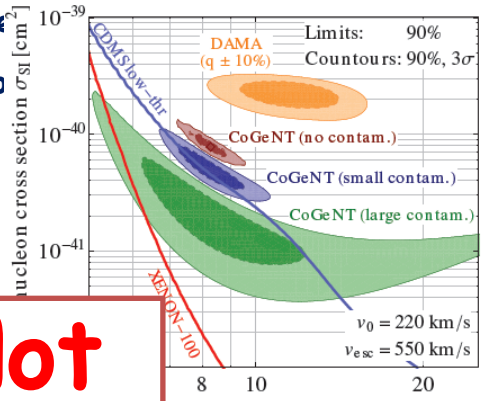

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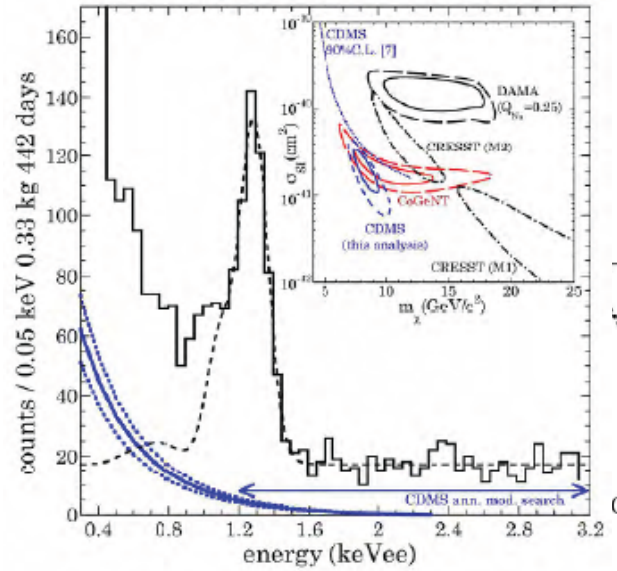
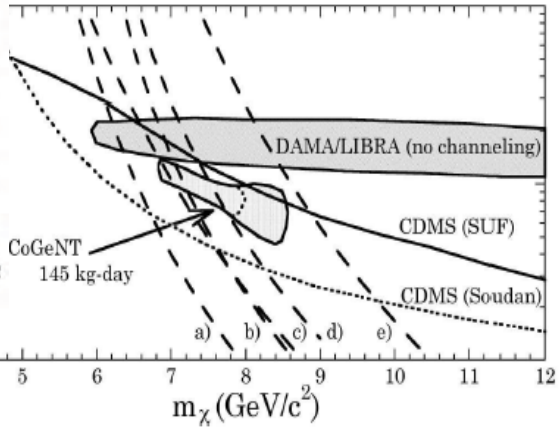
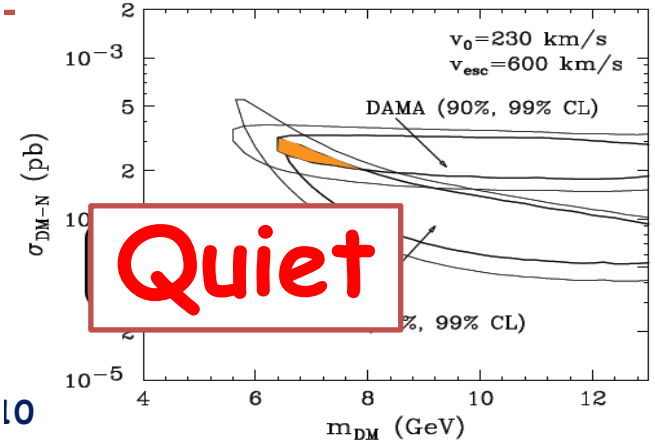


Collar & Fields 1204.3559(2012)

Collar 1106.0653(2011)





Quiet

10

Can it be compatible?

- **Do not couple to Xe?**

  "isospin-violating" Dark Matter (Kurylov,Kamionkowski 2003; Giuliani 2005; Cotta et al 2009; Chang et al 2010; Kang et al 2010; Feng et al 2011)

- **Strong Dependence on astrophysics model?**

  Xe is heavier and only sensitive to the tails of velocity (Fox, Lie, Weiner 1011.1915; Frandsen et al 1111.0292; Gondolo, Gelmini 1202.6359)

- **Calibration?**

  Efficiencies and energy resolution near threshold are essential (Collar 1106.0653v3) ;Quenching factor

- **Other models?**

  velocity-dependence form-factor; Inelastic Dark Matter, Axions, Leptophilic Dark Matter …

Can it be compatible?

- **Do not couple to Xe?**

  "isospin-violating" Dark Matter (Kurylov,Kamionkowski 2003; Giuliani 2005; Cotta et al 2009; Chang et al 2010; Kang et al 2010; Feng et al 2011)

- **Strong Dependence on astrophysics model?**

  Xe is heavier and only sensitive to the tails of velocity (Fox, Lie, Weiner 1011.1915; Frandsen et al 1111.0292; Gondolo, Gelmini 1202.6359)

- **Calibration?**

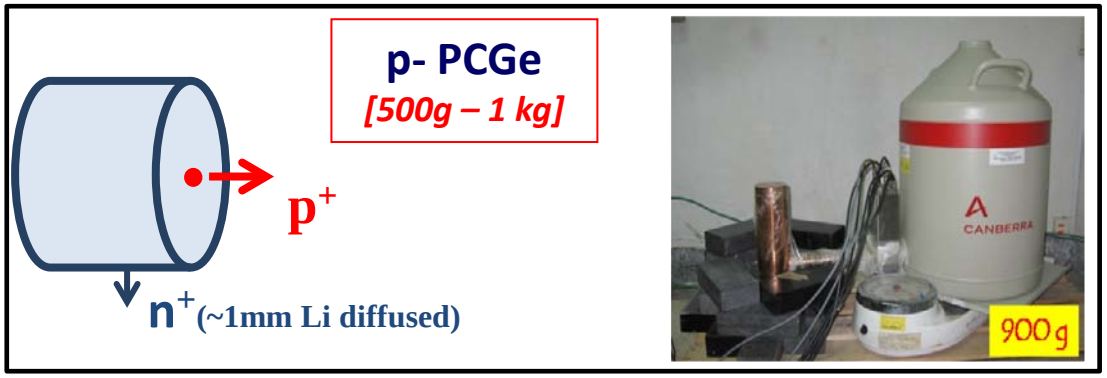
  Efficiencies and energy resolution near threshold are essential (Collar 1106.0653v3) Quenching factor

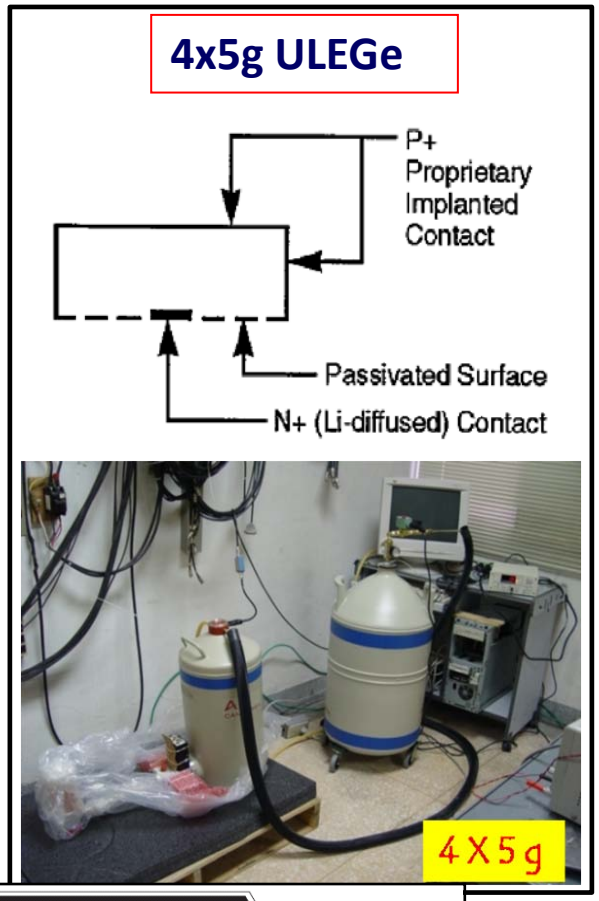
- **Other models?**

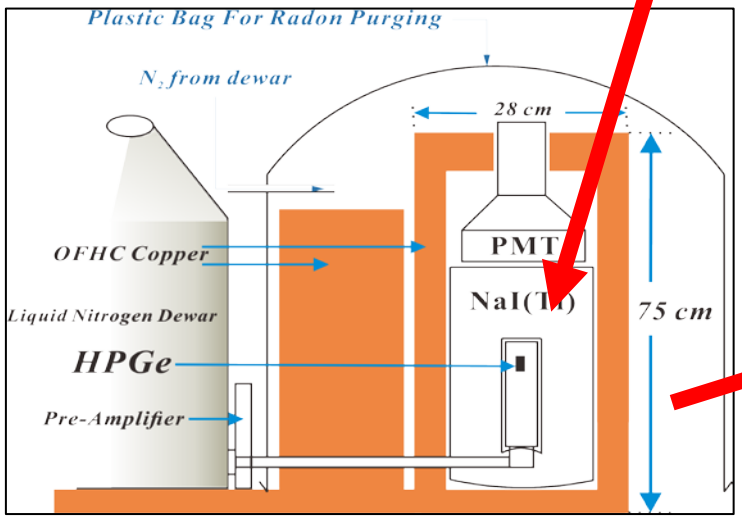
  velocity-dependence form-factor; Inelastic Dark Matter, Axions, Leptophilic Dark Matter …

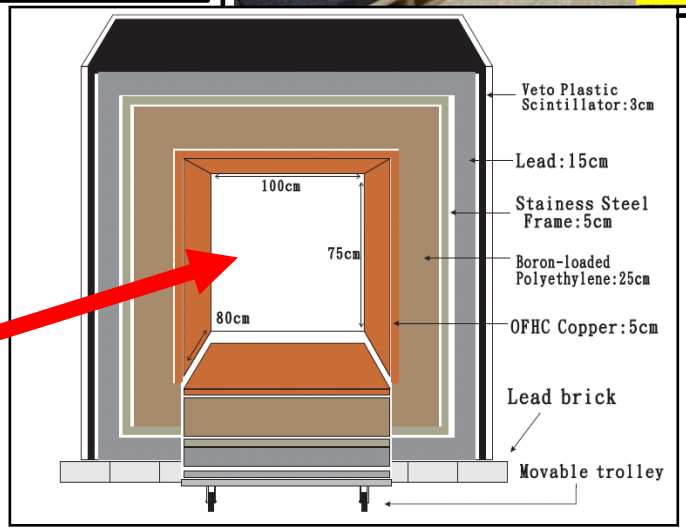
- **Conclusions : Confusion !**

Sub-keV Germanium Detector







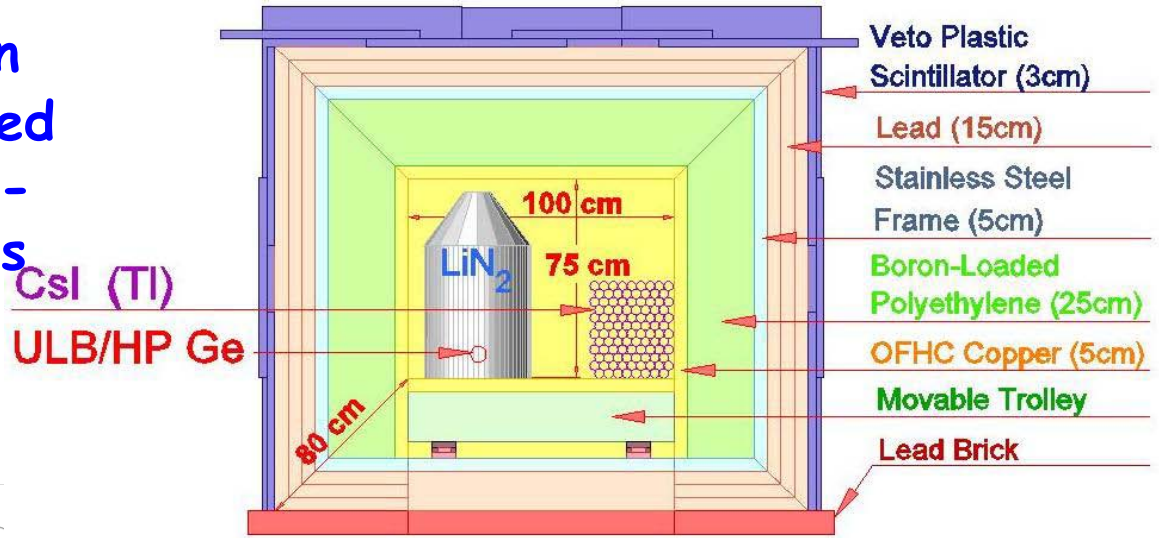


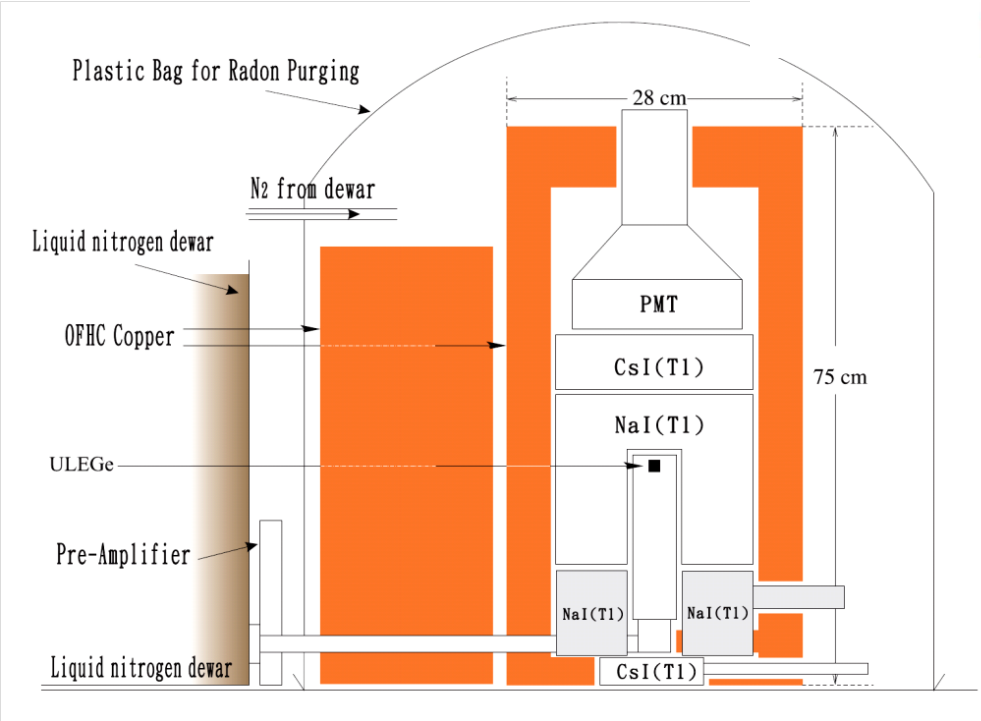
Special/Unique Features

- ☑ sub-keV sensitivities ⇨studies of low-mass WIMPs
- ☑ Anti-Compton detectors (+ cosmic-ray scintillators for KSNL) ⇨ *BOTH* vetos & tags ⇨ in situ (n,γ) calibration & diagnostics
- ☑ *BOTH* shallow & deep sites ⇨ diagnostic tools
- ☑ *BOTH* PPCGe & NPCGe ⇨ diagnostic tools
- ☑ Matured technology & compact solid detectors ⇨ stable operation ⇨ modulation studies (@ CJPL)
- ☑ Sensitive to gamma-absorption and electron recoils ⇨ studies of other interaction channels (e.g. axions)
- ☑ Good resolution ⇨ studies of structures (peaks, end-point .. etc) down to sub-keV range ⇨ background diagnostics, probe different DM-models and interaction channels.
- ☑ Quenching factor (conversion of nuclear recoil energy to ionization yields) in germanium is better known, down to sub-keVee

Analysis : Event Selection *CRV*、*ACV* Cut

- compact all-solid design : *sub-keV Ge* surrounded by active *NaI/CsI* anti-Compton detectors, plus passive shielding & cosmic veto

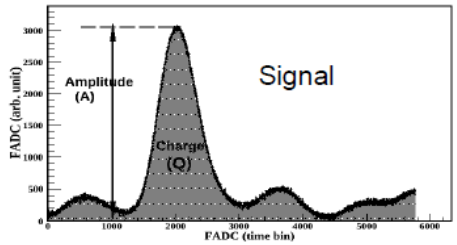


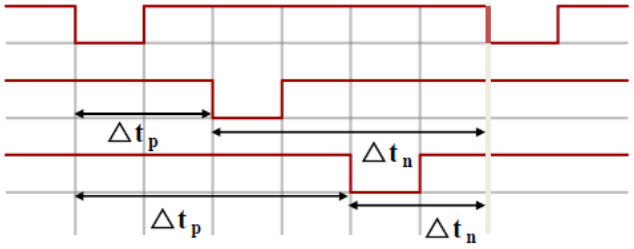


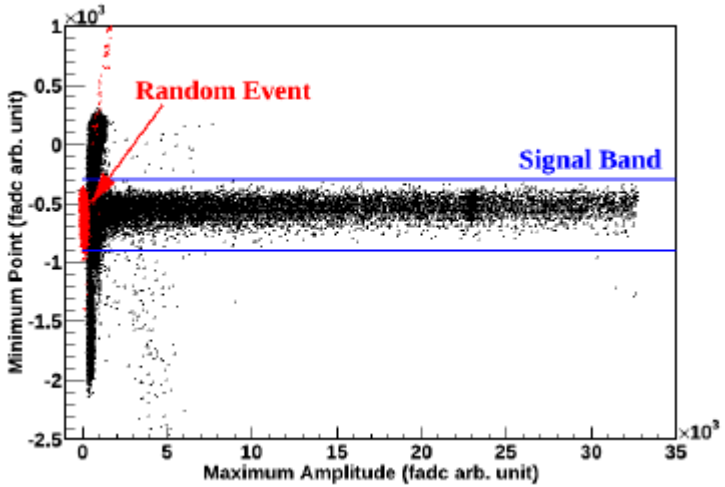
- Candidate events : survive Anti-Compton (*ACV*) and Cosmic-Ray (*CRV*) vetos

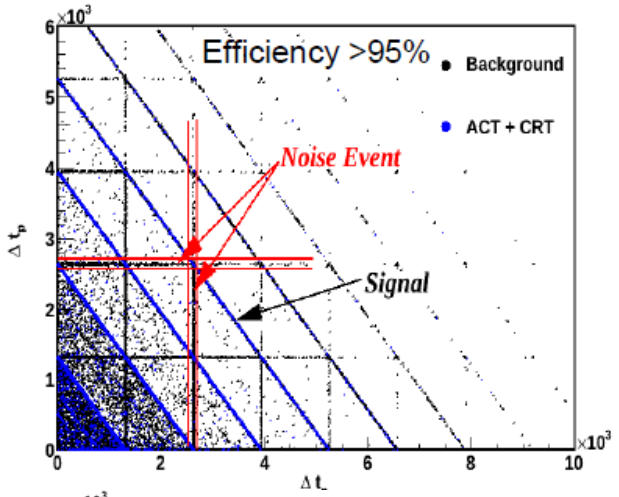
--- Efficiency evaluated by Random trigger events.

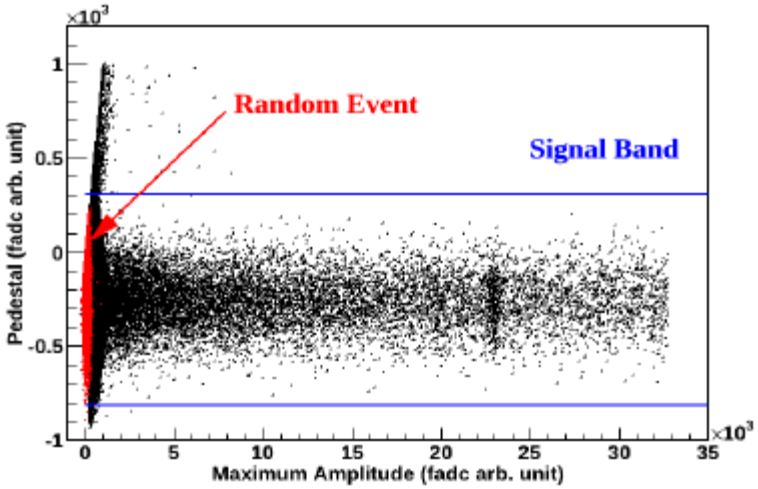
Suppress Electronic Noise

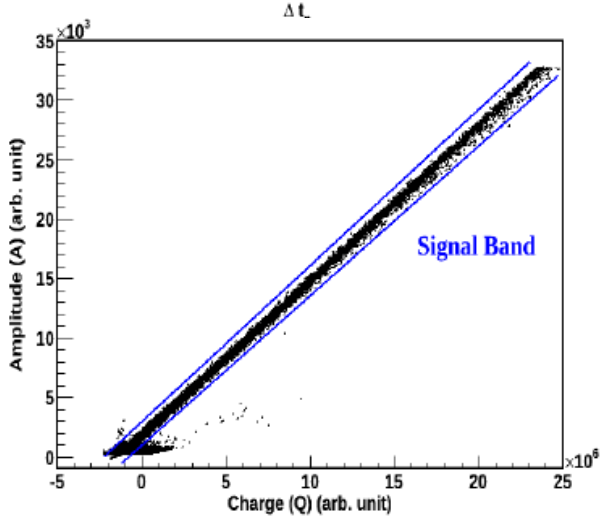






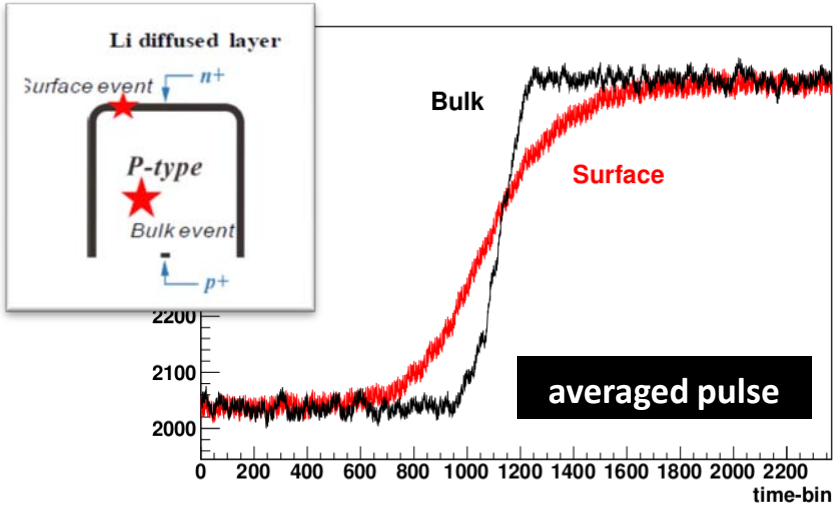


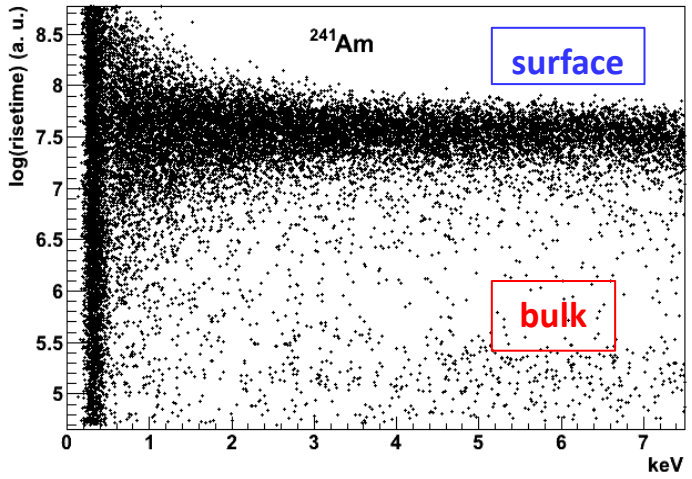


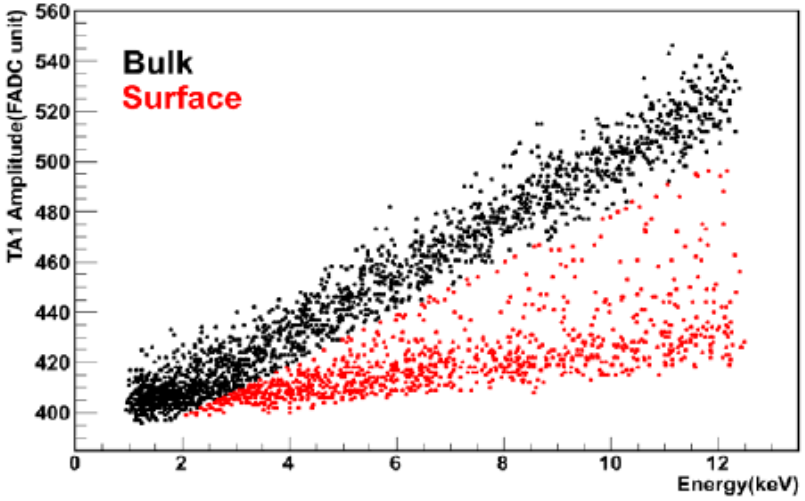


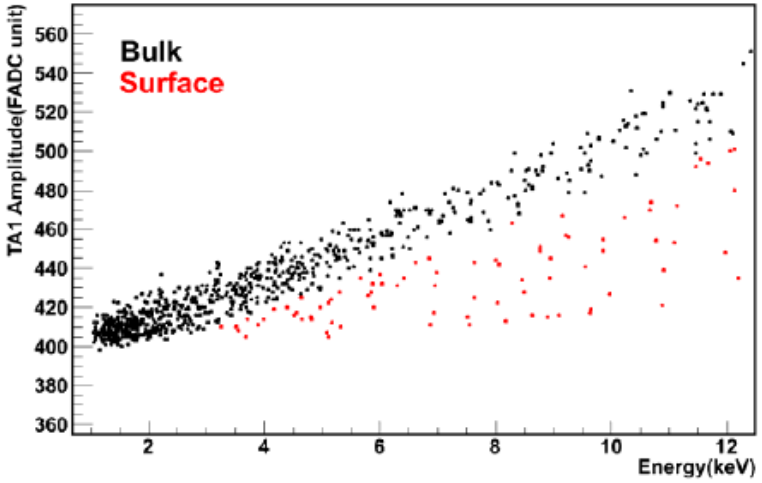
PSD for Surface Vs Bulk Events @ PCGe

- n+ "inactive layer" is not totally dead; signals finite but slower rise time
- ACV+CRT events (neutron rich) samples do not show surface band
- Understand/Measure Efficiencies and Suppression Factors









γ-rich background (CRV+ACT)

n-rich background (CRT+ACV)

New Results [arXiv:1303.0925]

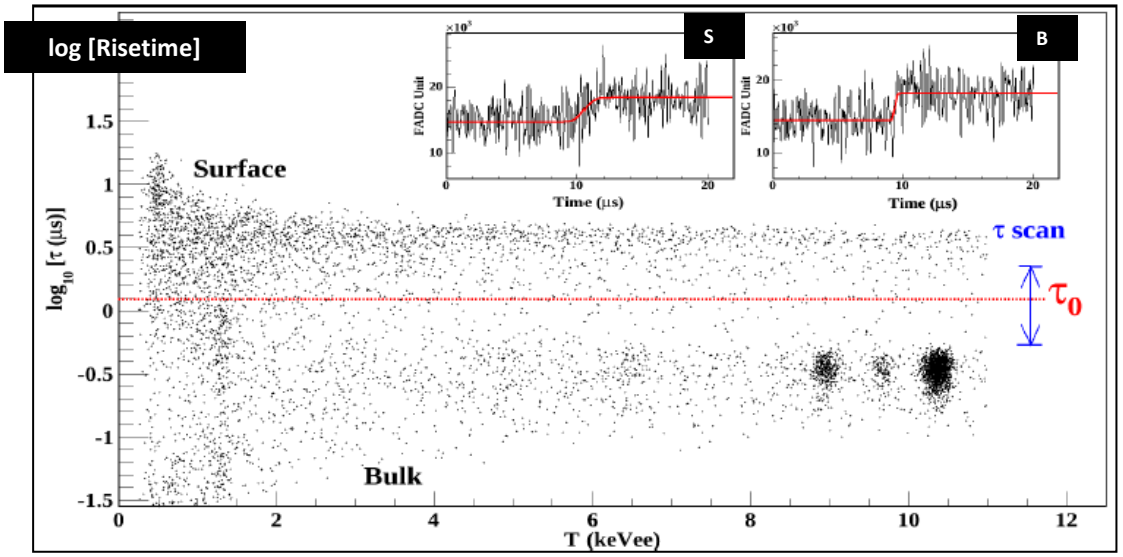
Configurations:

- 39.5 kg-days of data @ KSNL
- Baseline design with NaI(Tl) AC & active CR vetos
- PPCGe , 840 g fiducial mass
- Analysis above electronic noise edge of 500-eV

Basic (Previously Used) Selection Criteria:

- **Physics Vs Electronics Noise (PN) :**
  - pedestal tails, microphonics, preamp-reset induced ……
  - Via pulse shape analysis & timing
  - WIMP-eff ~ survival of doubly-tagged ACT+CRT events
- **Anti-Compton vetos (ACV) :** NaI(Tl) anti-coincidence
  - WIMP-eff ~ survival of random trigger (RT) events
- **Cosmic-Ray vetos (CRV) :**
  - WIMP-eff ~ survival of RT
  - CR-rejection eff : survival of reference samples with NaI(Tl)>20 MeV

Bulk Vs Surface (BS) Events Selection & Efficiencies



Valid scheme should produce physics rates insensitive to location

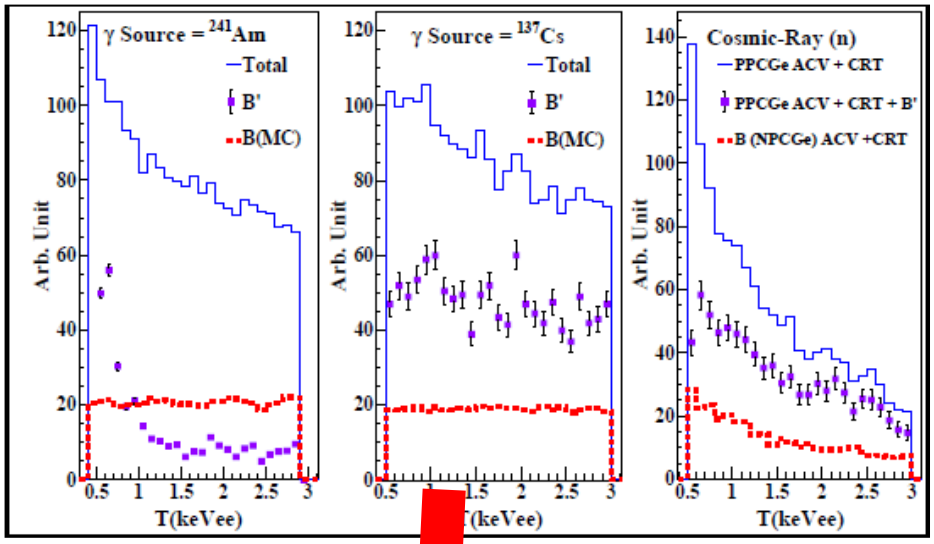
"Calibration" ≡ measure energy-dependent signal-retaining (ε_{BS}) & background-suppressing (λ_{BS}) efficiencies, such that [B,S=real ; B'S'=measured]

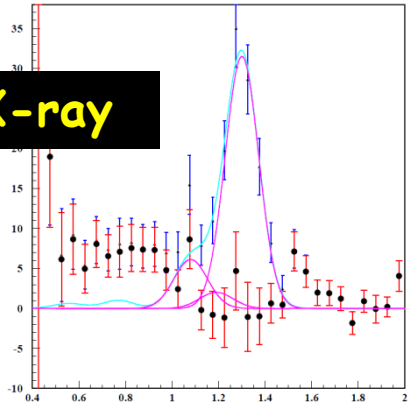
$$B' = \epsilon_{BS} \cdot B + (1 - \lambda_{BS}) \cdot S$$
$$S' = (1 - \epsilon_{BS}) \cdot B + \lambda_{BS} \cdot S$$

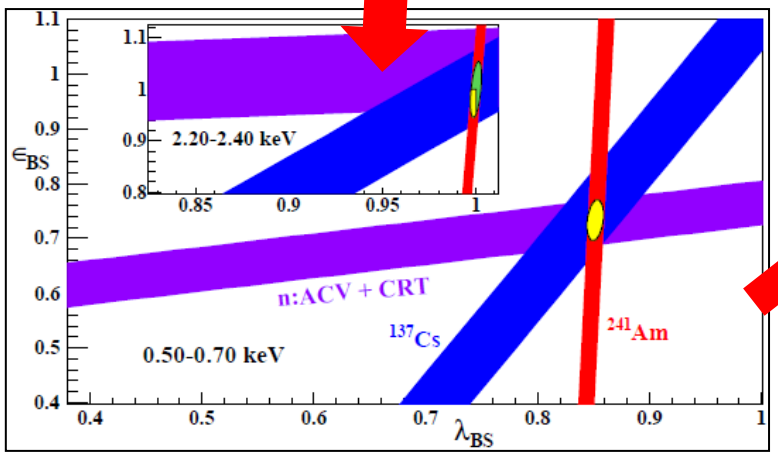
Approach: Identify *at least* two calibration data where (B,S) are known & (B',S') measured ⊕ solve coupled equation for (ε_{BS}, λ_{BS}) ⇨ correct physics (B'S') to get (B,S)

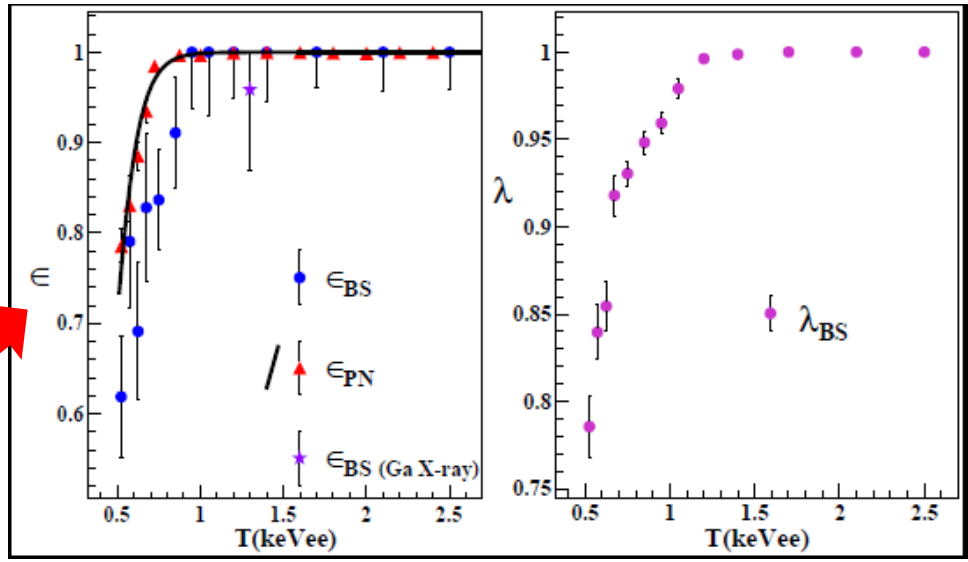
Three complementary *[different depth distributions]* calibration data:

- ☑ Very Surface-rich low-energy γ (^{241}Am, 60 keV) ; B=simulation
- ☑ Surface-rich high-energy γ (^{137}Cs, 660 keV) ; B=simulation
- ☑ Bulk-rich cosmic-induced high energy neutrons by ACV+CRT tagging ; B=same tag from NPCGe

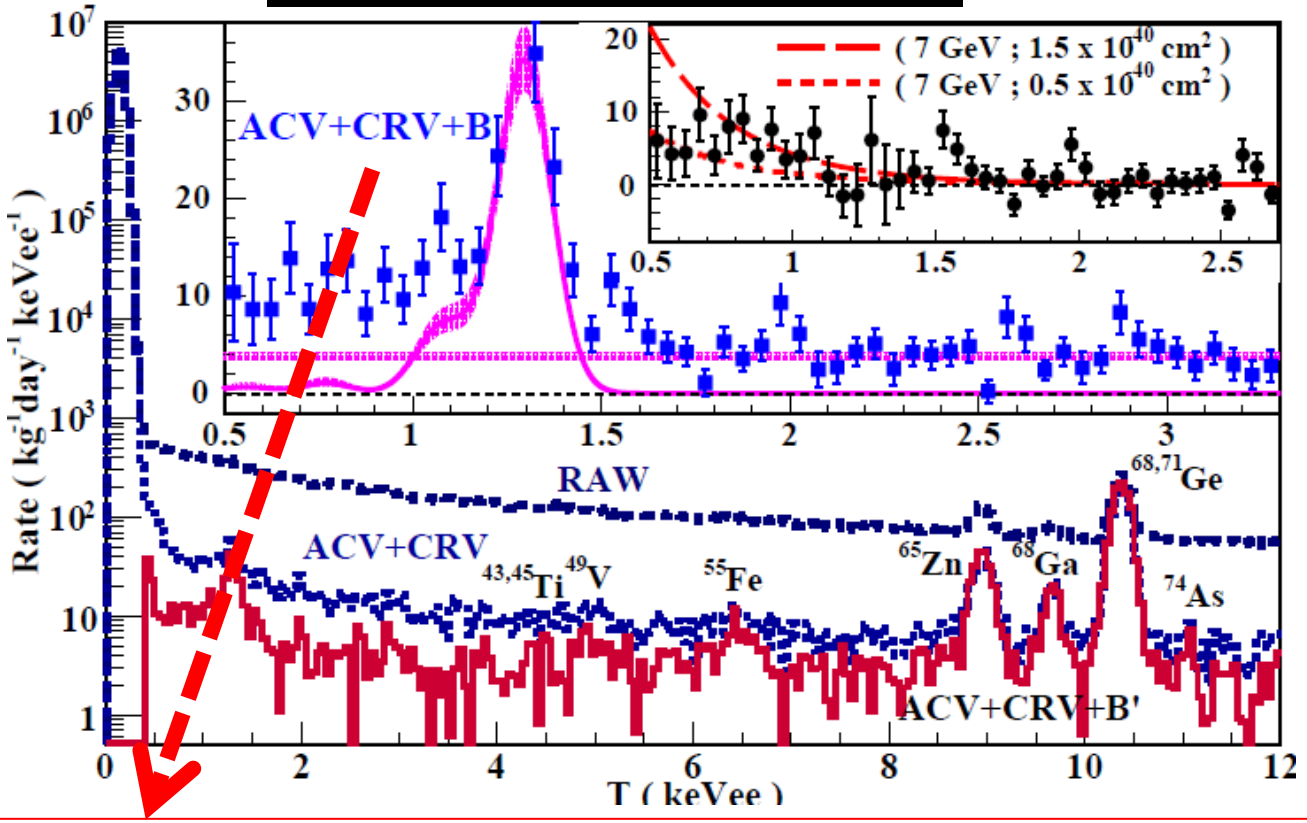








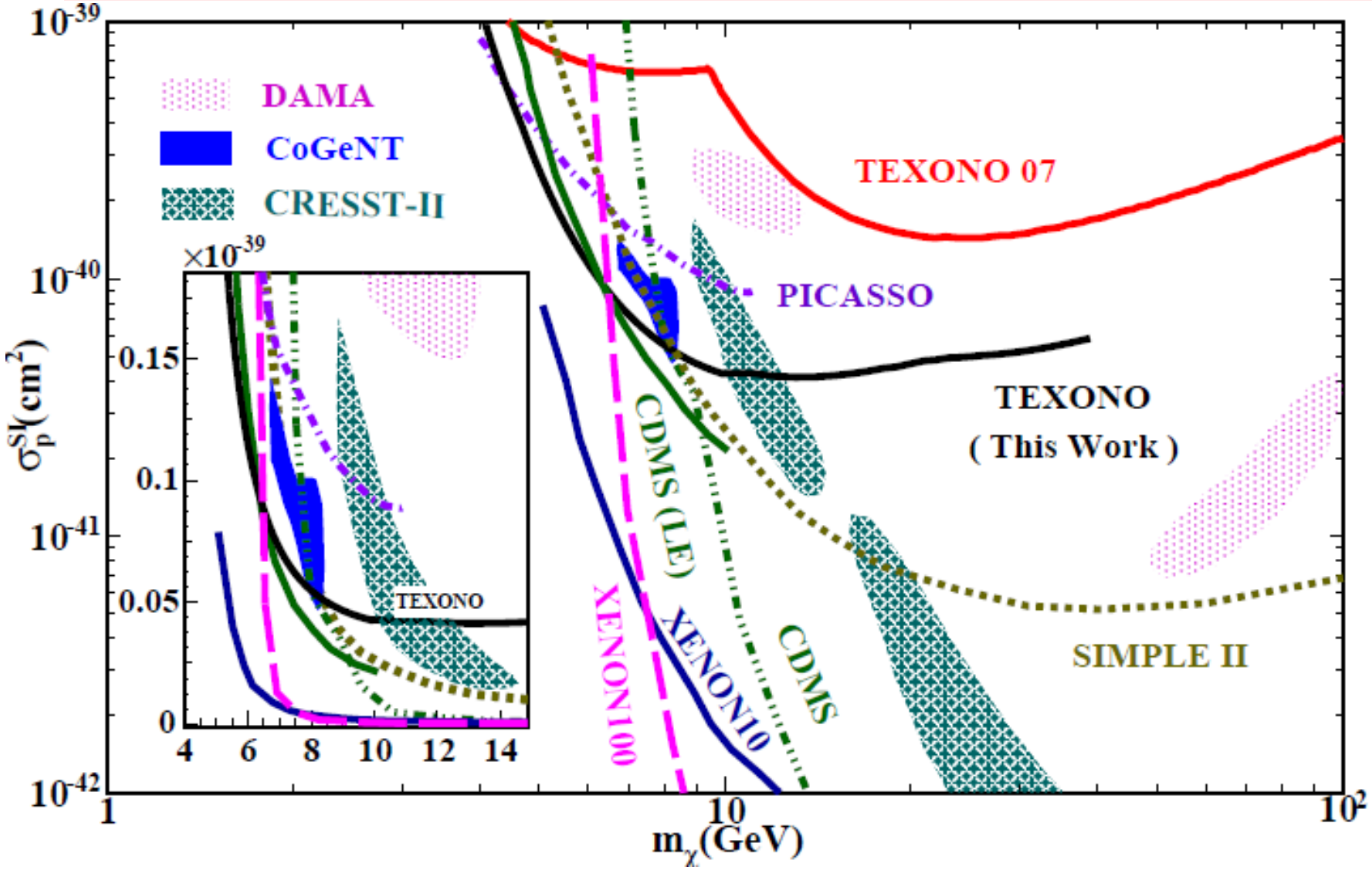
Recoil Spectrum



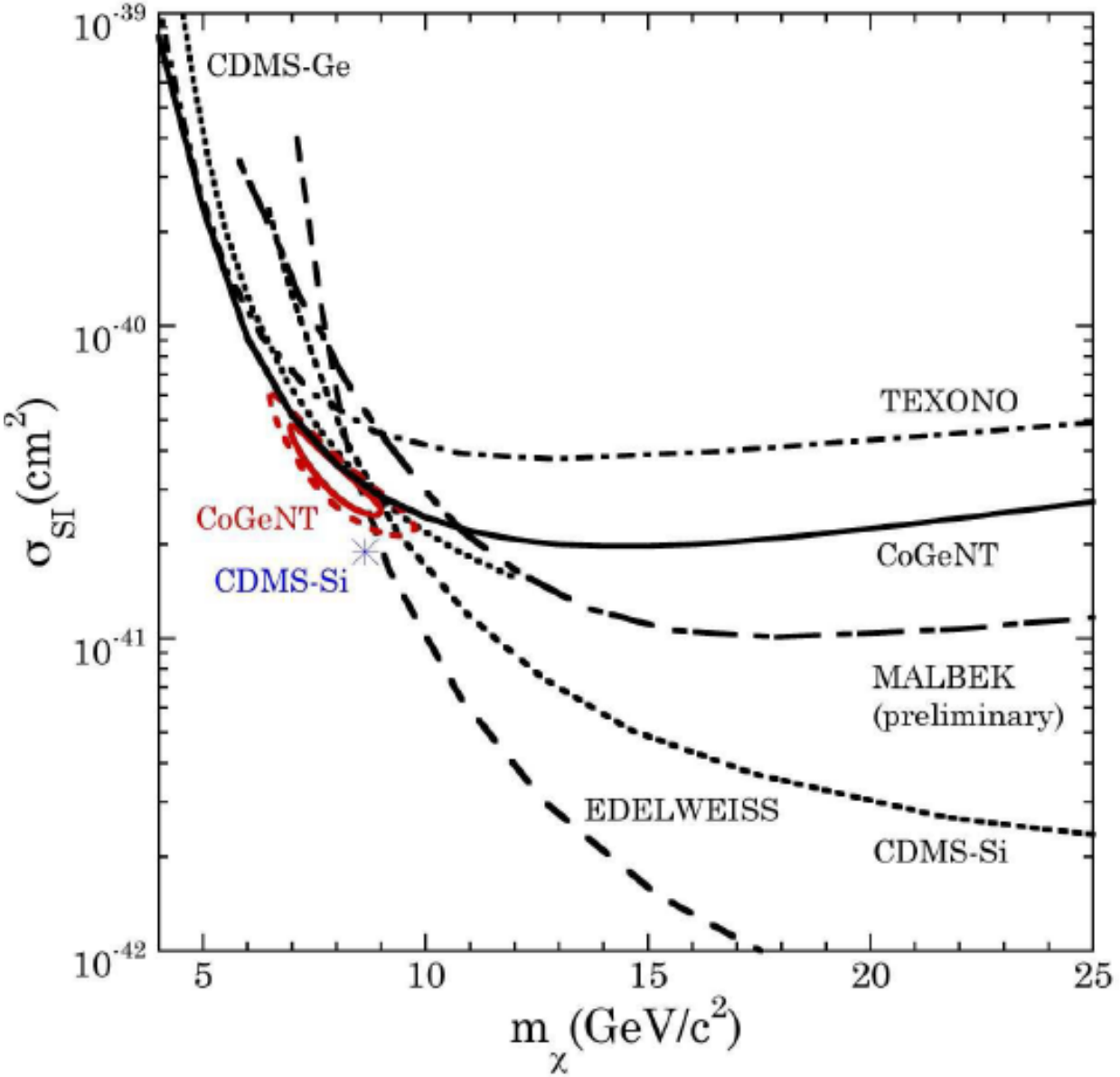
"Candidate Events" = ACV+CRV+B

- ACV+CRV+B' + (ε_{BS}, λ_{BS}) correction
- insensitive to exact BS-cut location
- Subtract flat γ background & L-X-ray
  - residual spectrum for placing WIMP constraints
  - $\exists$ not-yet-accounted-for sub-keV events

New limits probed and excluded some of the low-mass WIMP allowed regions implied by other experiments.



Updated…


CDMS-Ge
TEXONO
CoGeNT
CoGeNT
CDMS-Si
MALBEK
(preliminary)
EDELWEISS
CDMS-Si
10^{-39}
10^{-40}
10^{-41}
10^{-42}
$\sigma_{SI}(cm^2)$
5
10
15
20
25
$m_\chi (GeV/c^2)$

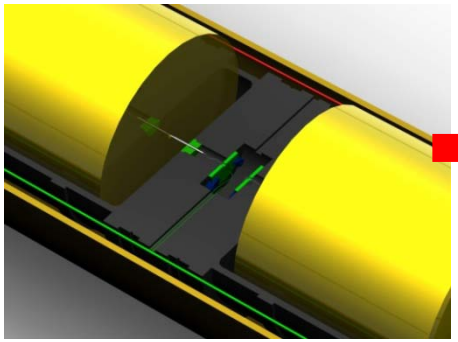
Status & Plans

- **2012+:** 1-kg class single module PPCGe & NPCGe @ KSNL & CJPL, with baseline design
- **2012-15:** 10-kg range PCGe array , with Liquid Argon Anti-Compton ; Acquisition of Ge and LAr detector technology ; Electronics Improvement R&D
- **2015 & Beyond:** explore 100 kg—1 ton scale experiment ; addition of Double Beta Decay ; CJPL Extensions (10+ space)
- **2010+:** characterize background at CJPL ; set up low background material screening facilities
- **When background & threshold adequately improved**

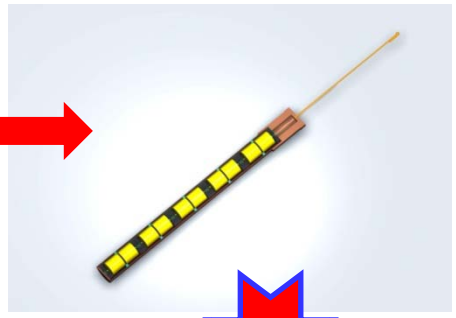
  ⇨ 🏆 νN coherent scattering @ KSNL

Design of CDEX-10 : with LAr Anti-Compton

Ge + JFET

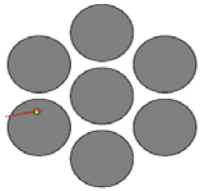


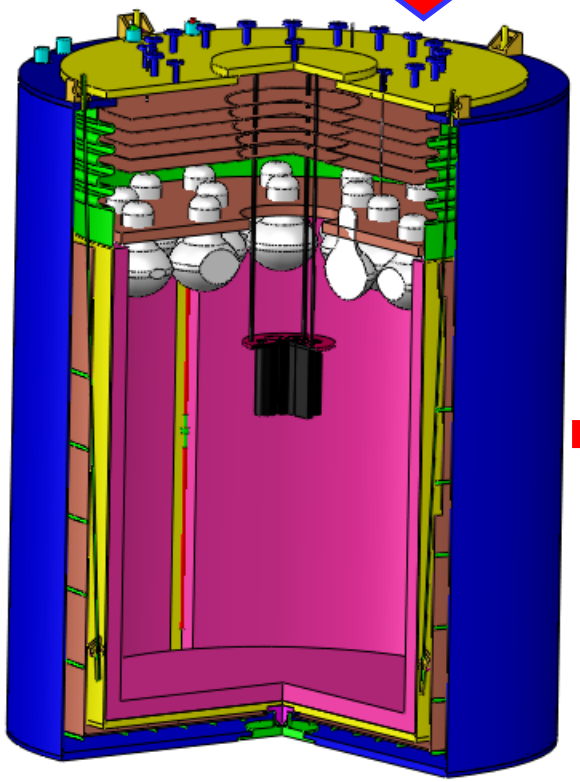
Ge Array in String

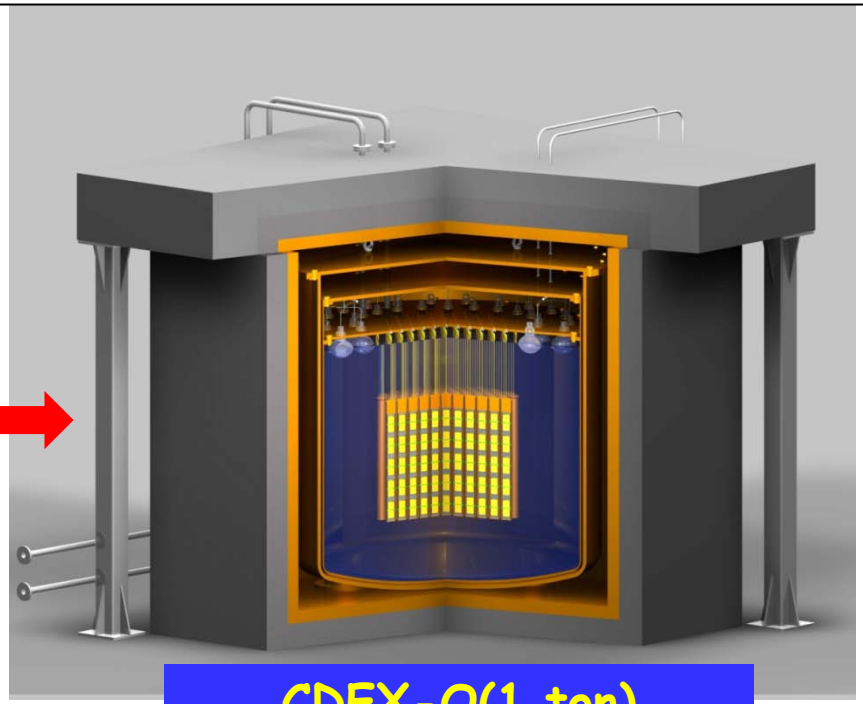


- PCGe in Arrays & Strings
- LiqAr as both cryogenics & active anti-Compton
- ~30-40 cm 4p shielding range
- Prototype 2013
- Baseline Design for Future O(1 ton) Experiment

CDEX-10 (2013+)



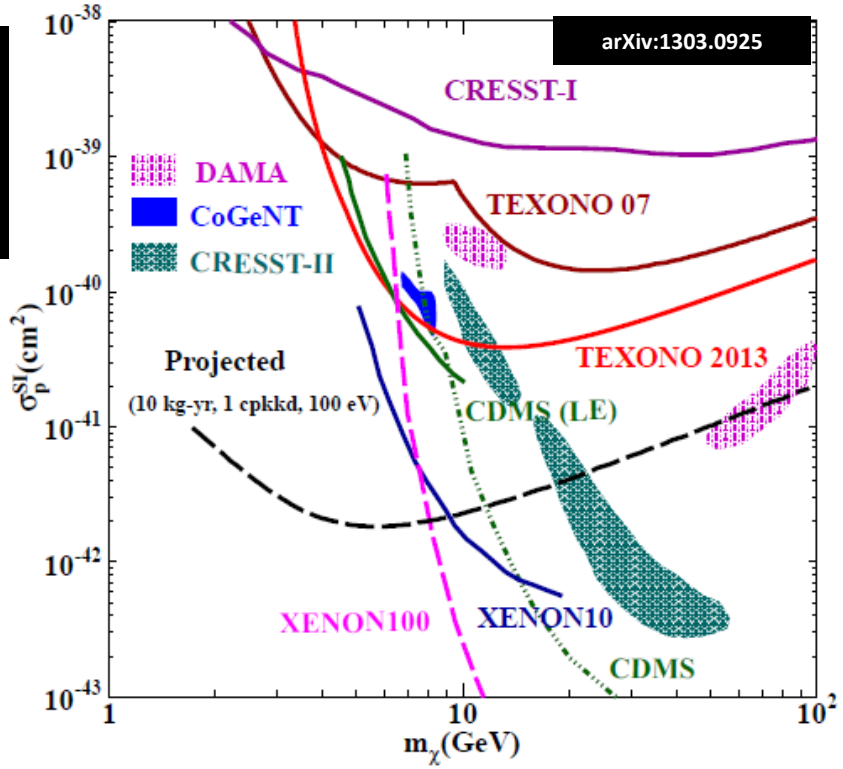




CDEX-O(1 ton) Artist's Conception

Prospects

[O(10 kg) detectors]



Reduce σ

- > keV : O(1 cpkkd) achieved
- Sub-keV Bkg goal : O(10 cpkkd)→O(1 cpkkd)
- How? Understand background and detector response

Lower m_χ

- 20 g target : 200-eV physics threshold achieved
- Kg-target Threshold goal : ~500 eV → 100 eV
- How? Sub noise-edge analysis ; electronics R&D