Future direct search for various types of dark matter

S. Moriyama, ICRR, University of Tokyo

October 29, 2015 @ Kashiwa, TeVPA 2015

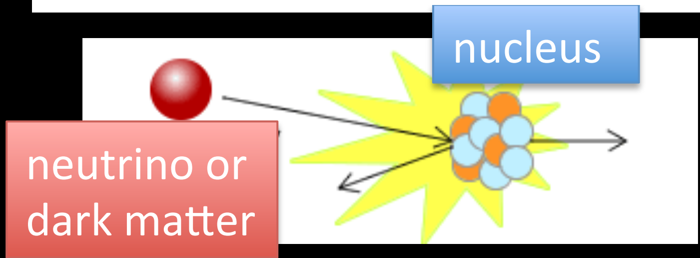
Birth of the WIMP detection exp.

The first experimental result

Volume 195, number 4 PHYSICS LETTERS B 17 September 1987

LIMITS ON COLD DARK MATTER CANDIDATES FROM AN ULTRALOW BACKGROUND GERMANIUM SPECTROMETER

S.P. AHLEN [a], F.T. AVIGNONE III [b], R.L. BRODZINSKI [c], A.K. DRUKIER [d,e], G. GELMINI [f,g,1] and D.N. SPERGEL [d,h]



- Expect nuclear recoils by DM.
- Leading candidate: SUSY WIMPs

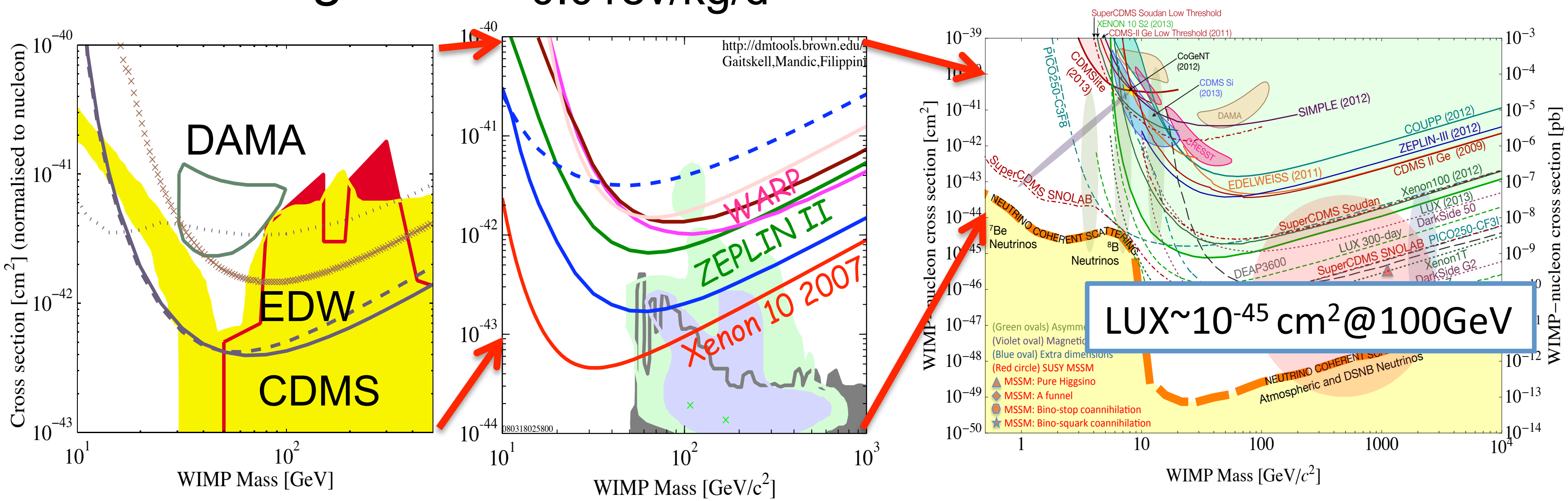
Experimental source	Event rate in $kg^{-1} day^{-1}$	Recoil energy range
Spallation source	10^2—10^3	10—100 keV
Reactor	10	50—500 eV
Solar neutrinos		
pp cycle	10^{-3}—10^{-2}	1—10 eV
^{7}Be	10^{-2}—5×10^{-2}	5—50 eV
^{8}B	10^{-3}—10^{-2}	100 eV—3 keV
Galactic halo		
coherent $m \sim 2$ GeV	50—1000	10—100 eV
$m \gtrsim 100$ GeV	up to 10^4	10—100 keV

20-30yrs later: unexpected (expected) difficulty

2004, CDMS
~0.1ev/kg/d

2008, B. Sadoulet
at neutrino conf.
~0.01ev/kg/d

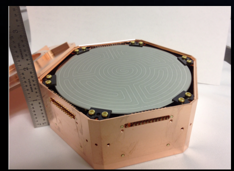
2013 snowmass
best limit ~0.1ev/ton/d
down to ~0.00001ev/ton/d

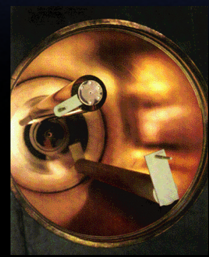


- 5 orders of mag. improvement from 1985 has not show any evidence yet. No signal from LHC either.
- Consider stories different from SUSY WIMP miracle

Multiple paths toward positive detection

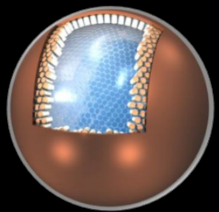
semiconductor/crystals
<10GeV WIMPs
and lighter mass





axion
cavity etc.

Weakly
Interacting
Slim Particles
(WISPs)



DM direct
detection

Liquid noble
>10GeV WIMPs

Electron recoils

yearly/monthly/daily modulation

directional, threshold type…

- Various types of dark matter candidates are being investigated and this must be more extended toward positive detection in future.
- Missing so far: high sensitive search for Electron Recoils

Example of theoretical models

- DAMA motivated
  - Leptophilic dark matter (electron scattering dark matter, by DAMA): J. Kopp et al., PRD, 083502 (2009)
  - Mirror dark matter: R. Foot, PRD 90, 121302(R) (2014).
  - Lumious dark matter: B. Feldstein et al., PRD 82, 075019 (2010).
  - …

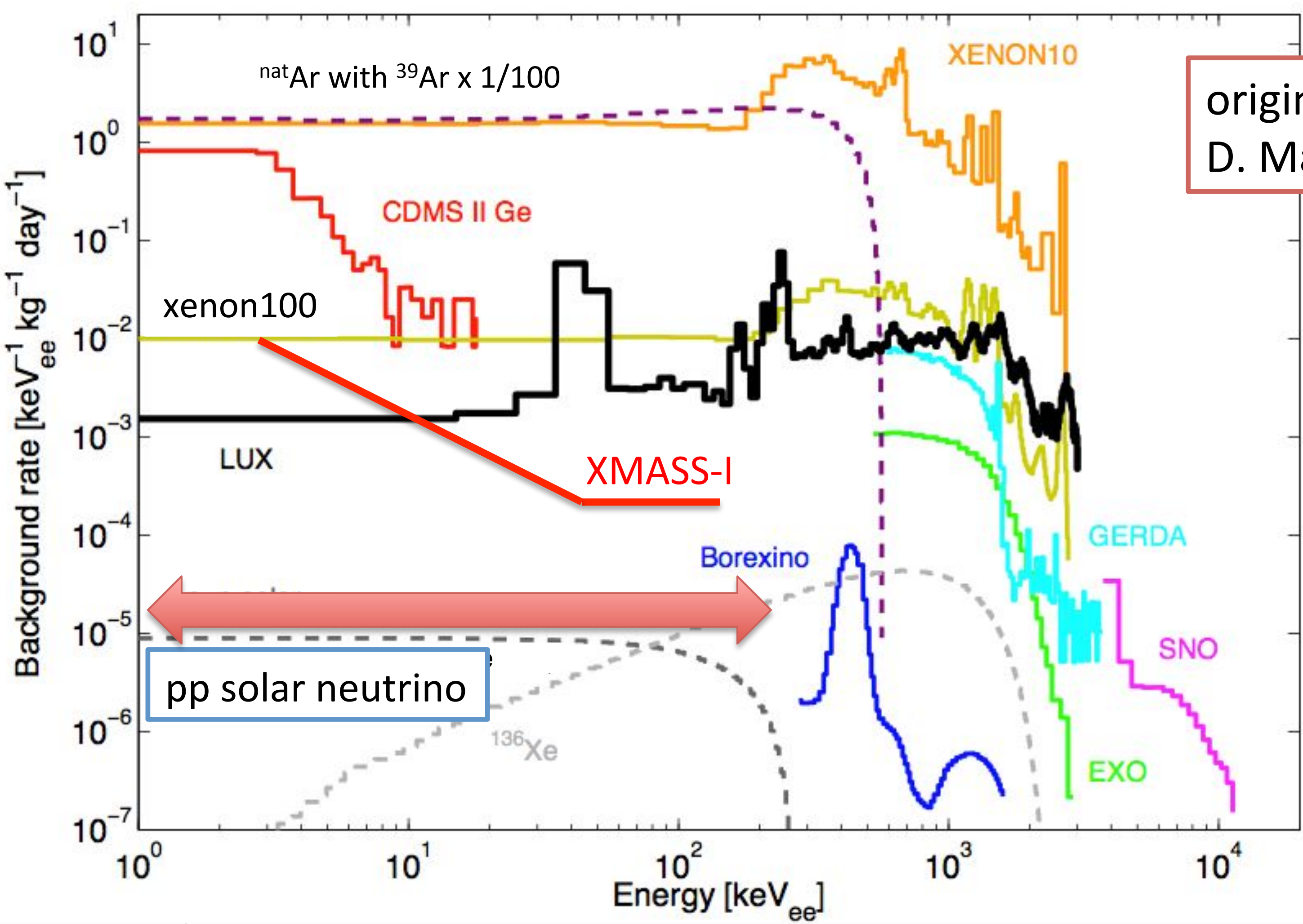
First experimental search
Fei Gao this afternoon

- Light dark matter, etc.
  - Bosonic super-WIMPs: M. Pospelov et al., PRD 78, 115012 (2008).
  - axion like particles, hidden photons
  - …

XMASS collaboration,
PRL 113, 121301 (2014)

- Sometimes called as "exotics." "Less motivated" than SUSY and axion models but now their importance must be getting increased.

Electron recoil background among experiments

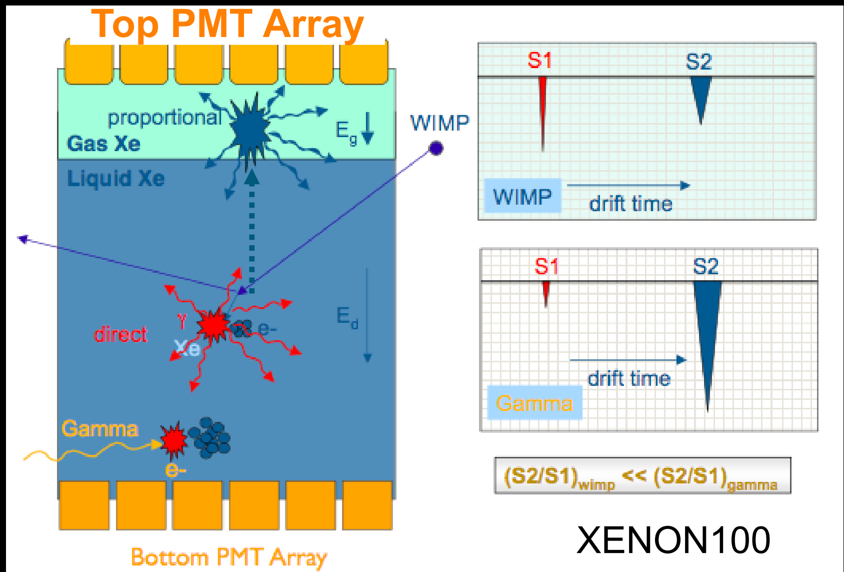


original figure
D. Malling

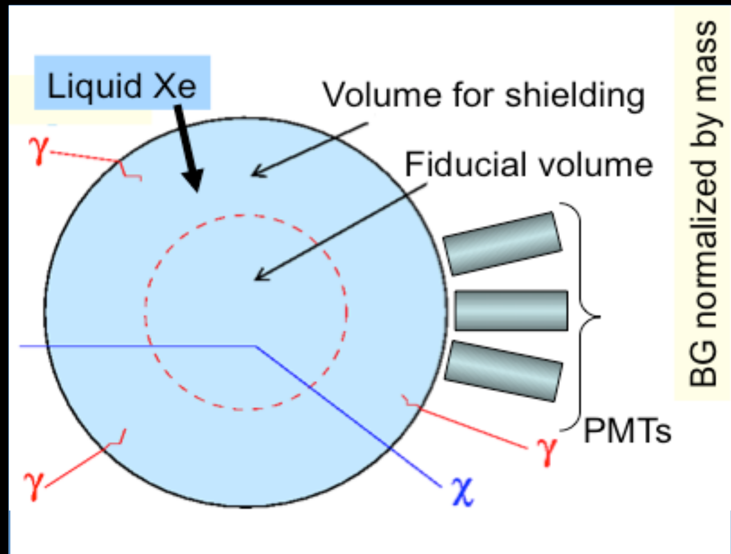
LUX-XMASS-Borexino/KamLAND-SK/SNO
<200keV (^{14}C) not explored down to pp-solar neutrino BG

Liquid noble detectors

- Advantage: scalability and purity of targets
  - LXe: no long life RI, Rn and Kr reduction possible.
  - LAr: pulse shape, RI ^{39}Ar (β) → e rejection necessary.
- Two types of detectors:



XENON*, LUX, LZ, DARWIN, Panda-X*, ArDM, DarkSide

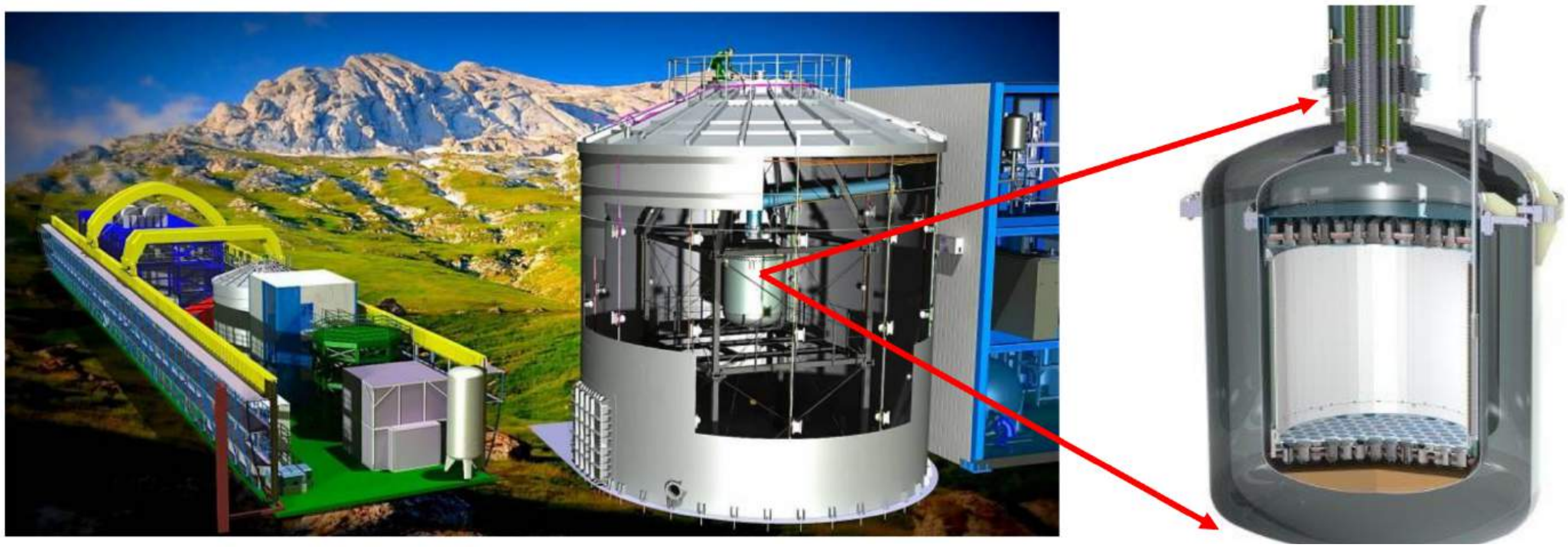


XMASS*, DEAP

* Talks by Coddere, Chen, Wada, and Ogawa this afternoon

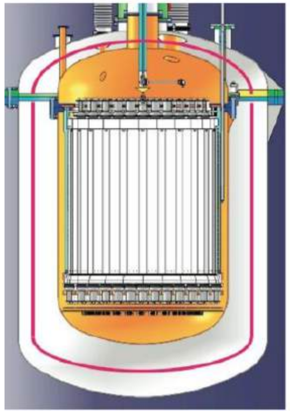
2 phase LXe: XENON1T@Gran Sasso

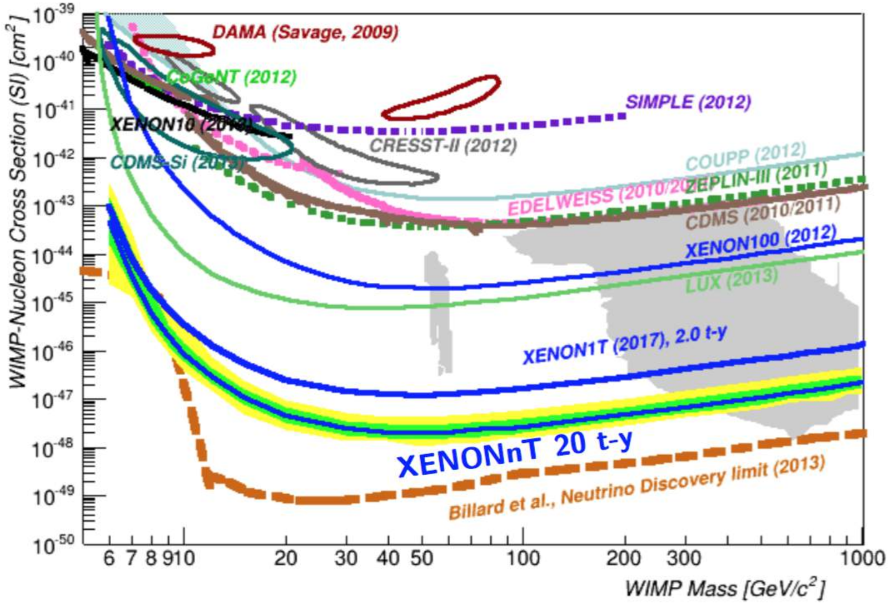
The Detector

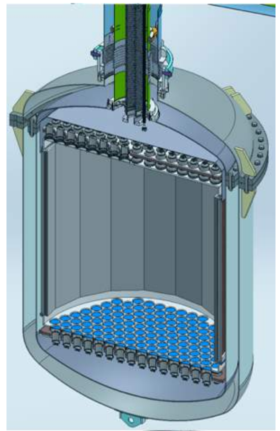


- Total Xe ~3.3t/inner ~2t/fiducial mass ~ 1t
- ~2×10^{-47}cm^2@100GeV in 2yrs
- <u>Electron BG: 5×10^{-5}/kg/keV/d (x6 pp solar ν)</u>
- Cryogenic system validated and works as designed.
- Detector assembly started last month
  The first data are expected by the end of the year.

2 phase LXe: XENONnT in future







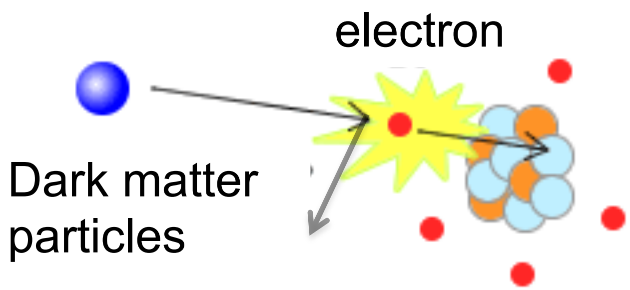
- Total Xe ~7ton
- ~2x10^{-48}cm^2@100GeV
- The system for XENON1T can be used
- Only the inner cryostat, PMTs, and TPC will be upgraded.
- Expected: 2018-2022

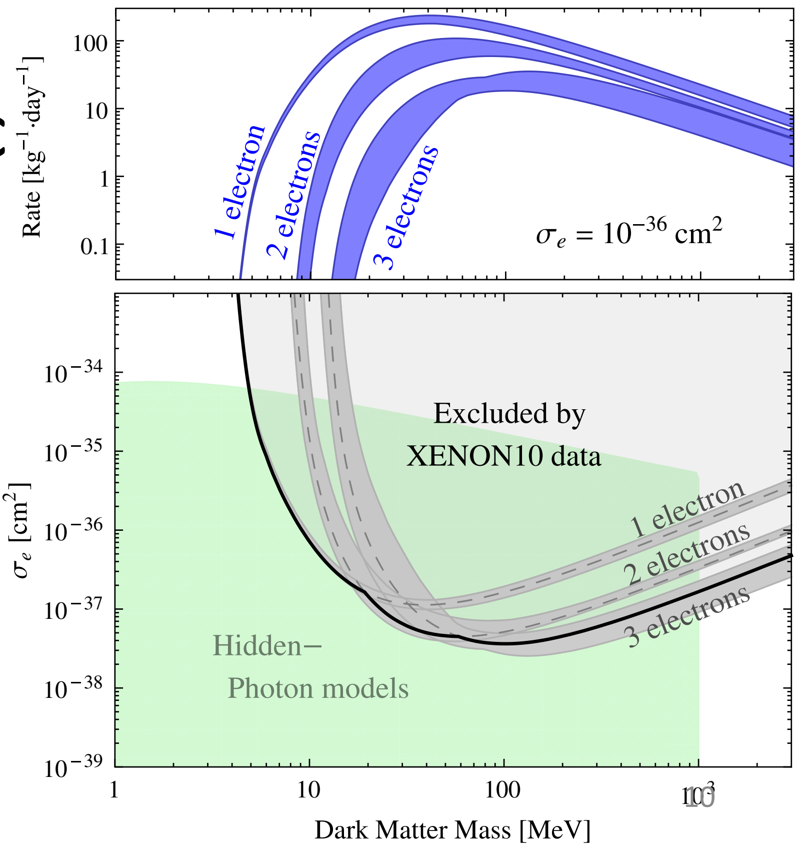
Further extension: the DARWIN project

Single electron detection for <GeV DM

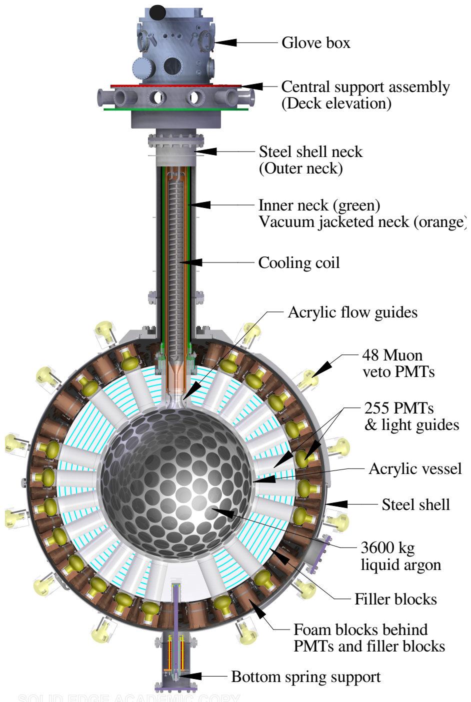
R. Essig et al., PRL 109, 021301 (2012)

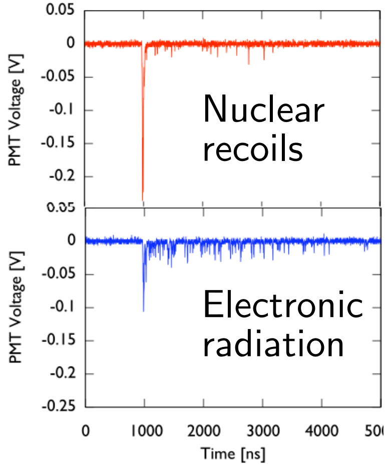
- DM-nucleus scattering << threshold of a DM detector
- DM-electron scattering: $\frac{1}{2}m_e\beta^2 \sim O(eV)$ may cause excitation of shallow atomic electrons.
- 2 phase LXe detector is able to see single electron (+ a few associated electrons).
- A good example to study a broader range of DM.

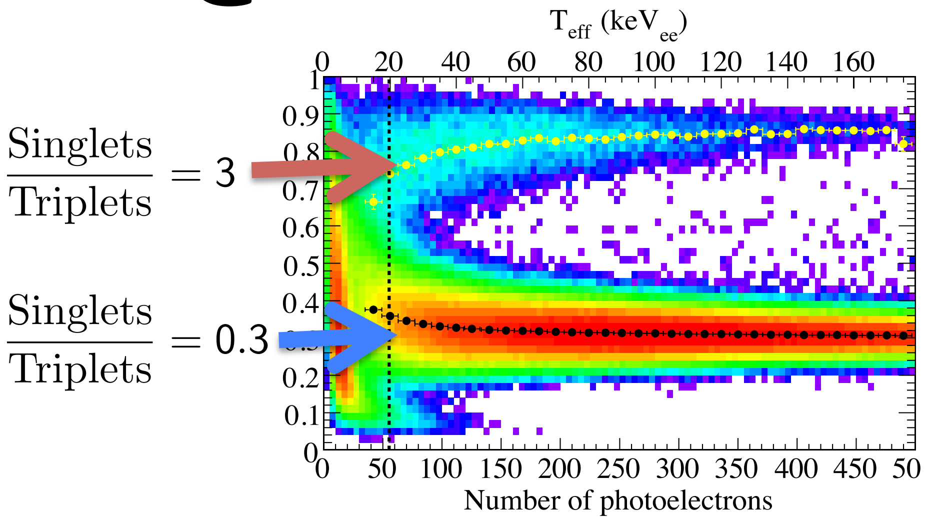




1 phase LAr: DEAP@SNOLAB

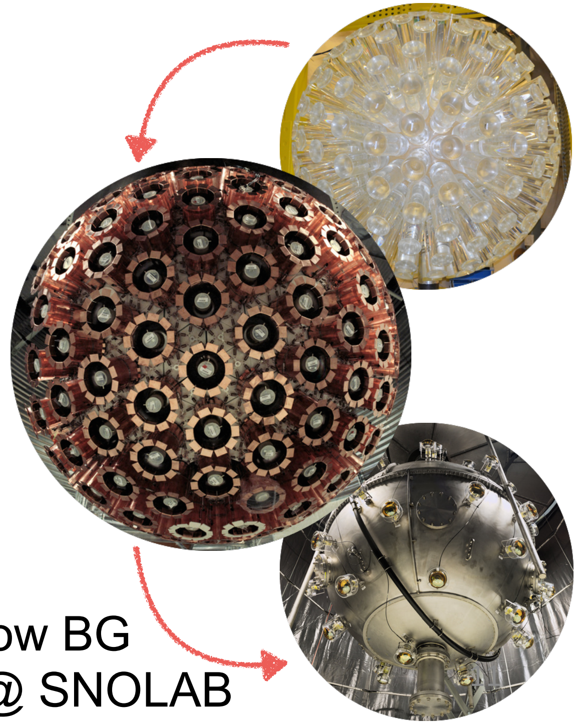






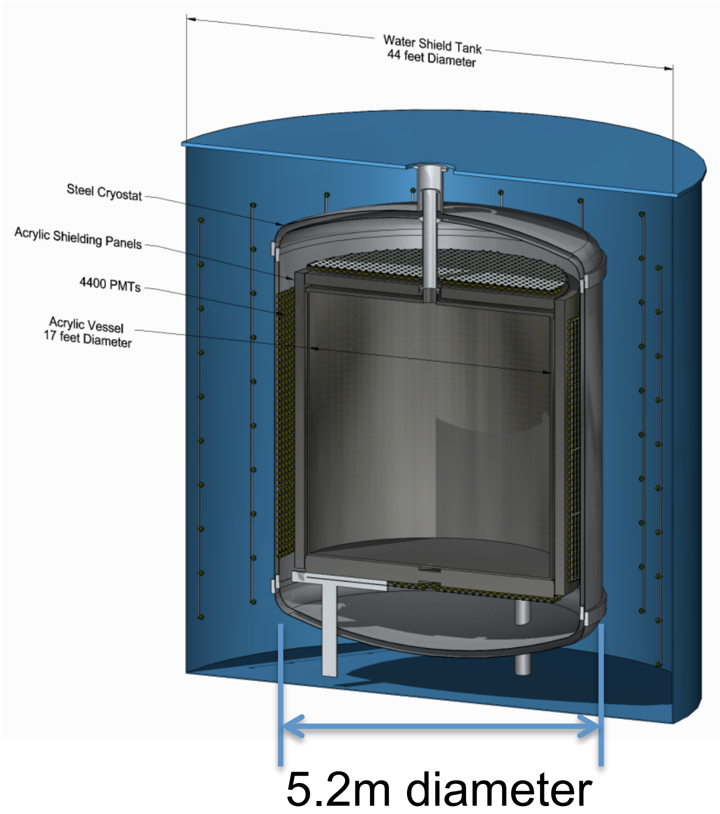
Beltran, Giampa, TAUP2013

- total 3.6t/fiducial mass 1t
- 1×10^{-46}cm^2 @100GeV in 3yrs
- Huge elec. BG ~200/keV/kg/d ^{39}Ar
- Cool down and Ar filling expected to start. First physics data is expected in 2015.

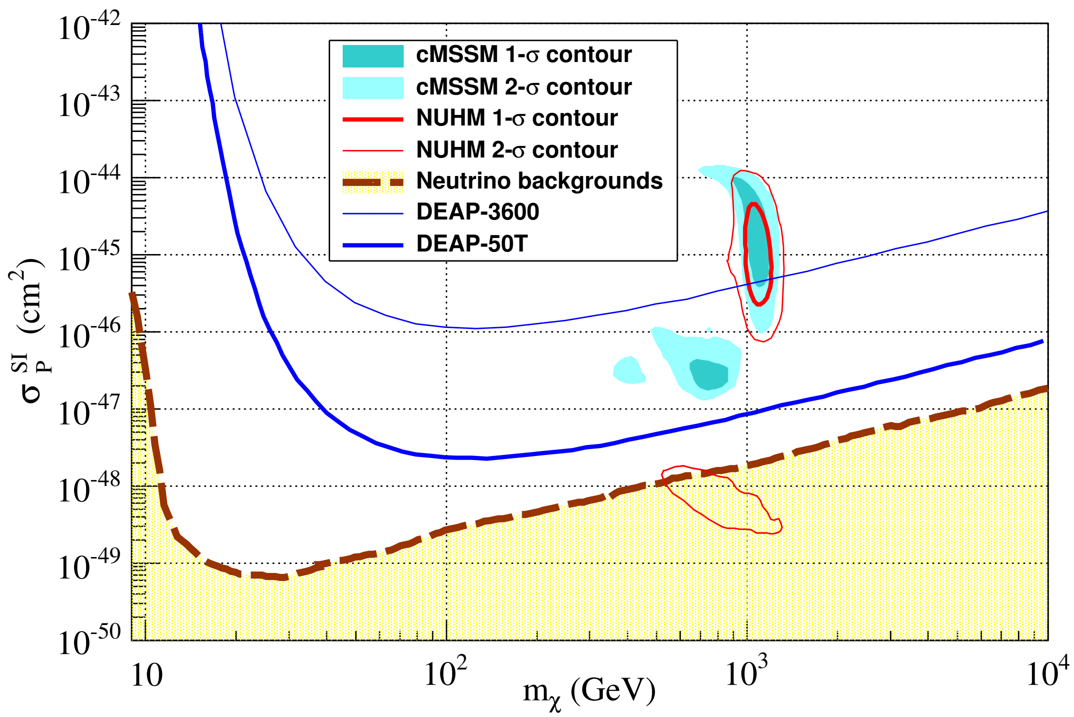


Large, low BG acrylic @ SNOLAB

1 phase Ar: DEAP-50T



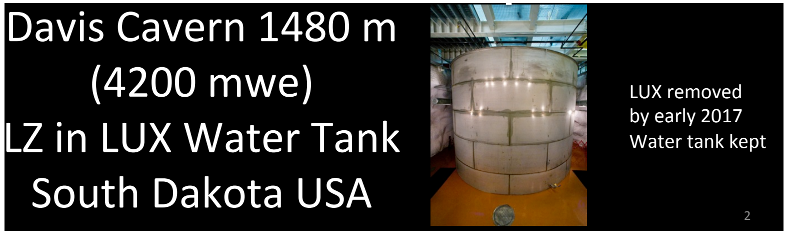
arXiv: 1410.7632

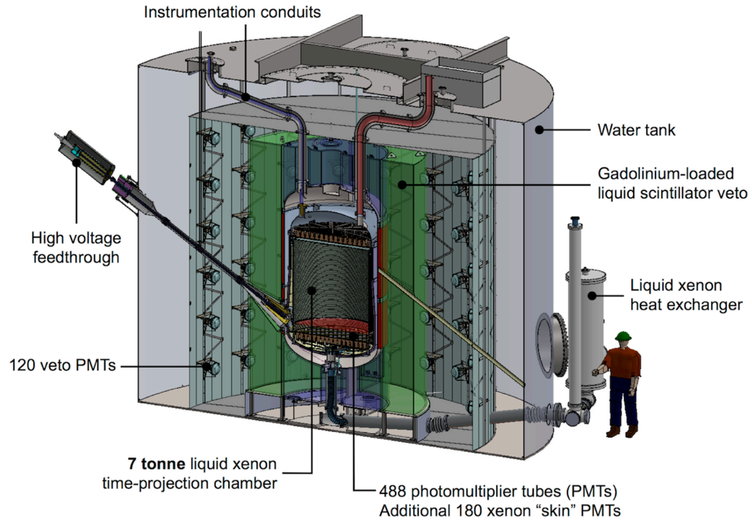


- total 150t/fiducial mass 50t
- low-background Ar (depleted ^{39}Ar) from underground to avoid pile up/suppress β events.
- 2×10^{-48}cm^2@100GeV

2 phase LXe: LZ@Sanford Lab, US

LZ = LUX + ZEPLIN

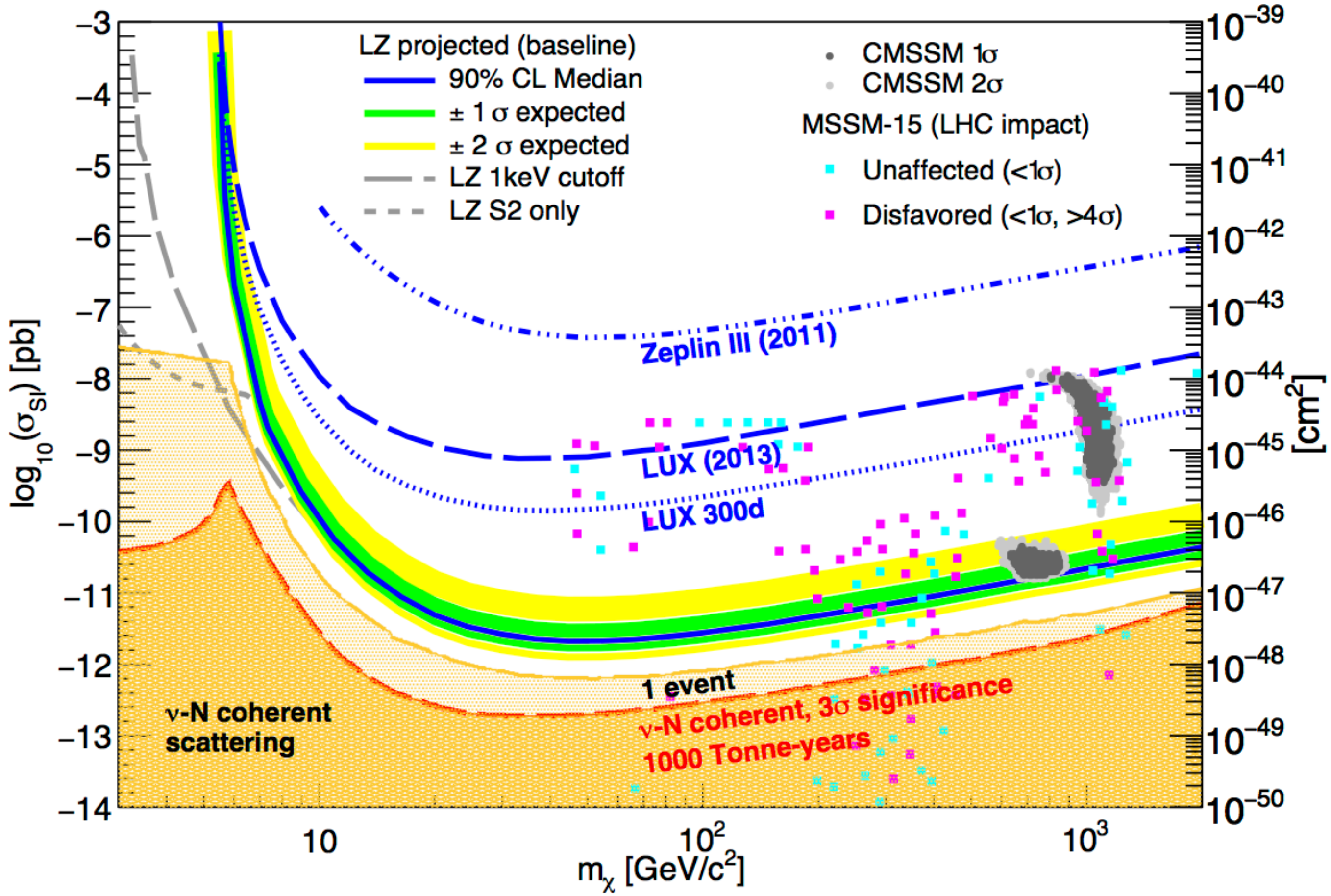




32 institutions currently
About 190 people

D. McKinsey, TAUP2015

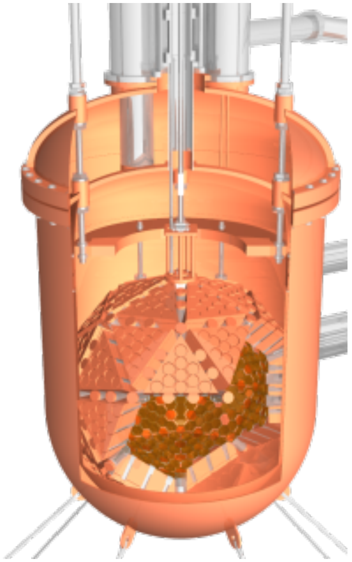
- Total ~10t/inner ~7t/fid.~5.6t
- ~2x10^{-48} cm^2@100GeV
- ~1.2x10^{-5}/keV/kg/d (~1.5 x pp solar ν)
- LUX removed by early 2017 with water tank kept.
- Expected to start commissioning in 2019.



2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK
		Begin long-lead procurements(Xe, PMT, cryostat)
2016	April	DOE CD-2/3b approval, baseline, all fab starts
2017	June	Begin preparations for surface assembly @ SURF
2018	July	Begin underground installation
2019	Feb	Begin commissioning

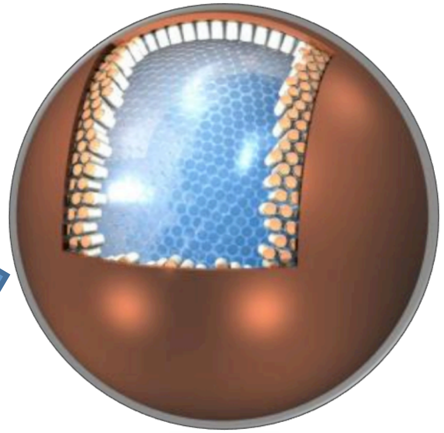
1 phase LXe: XMASS1.5/II @Kamioka

XMASS-I



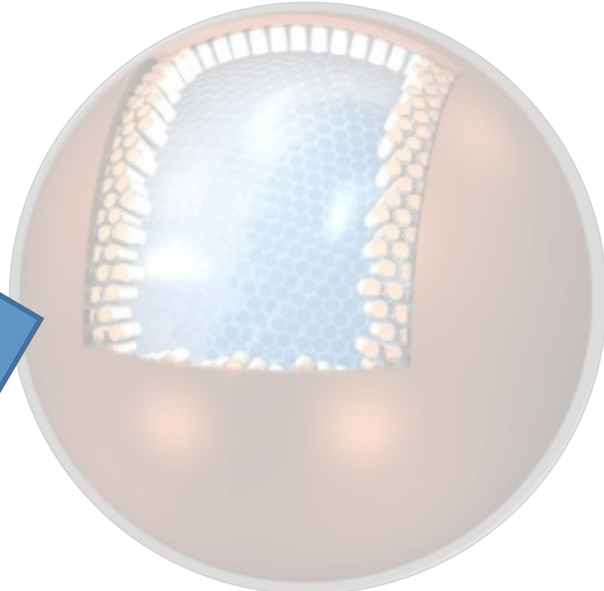
DM
100kg fid. (800kg)
0.8mϕ, 642 PMTs
2010-
DM search

XMASS-1.5



DM
1ton fid. (5ton)
1.5mϕ, ~1000 PMTs
pp solar ν limited
Ultimate BG for elec.
<10^{-46}cm^2
Annual/spectral info.

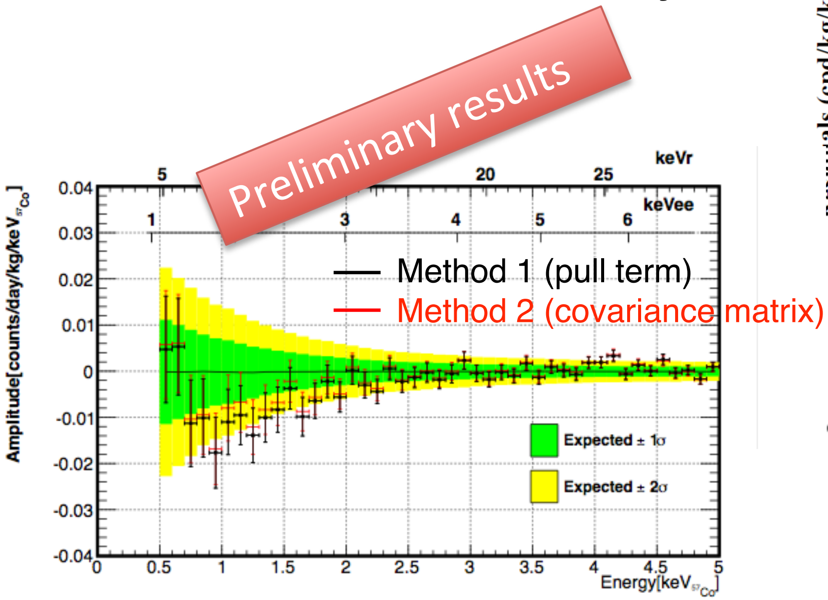
XMASS-II



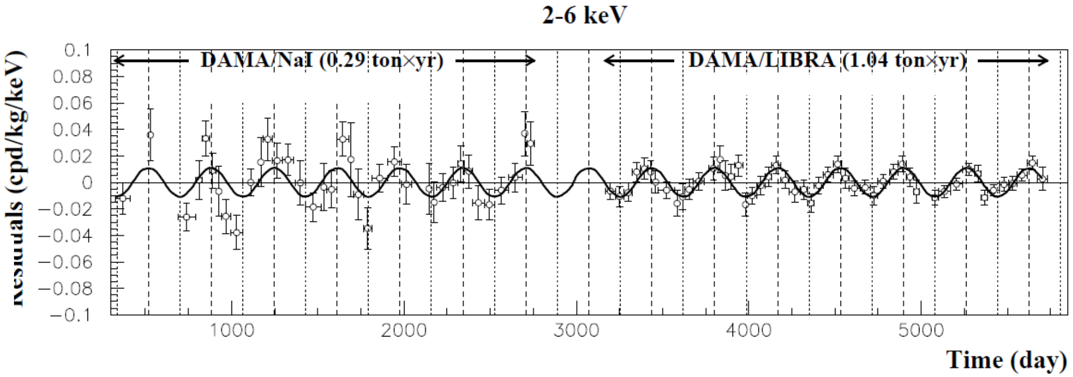
DM, solar, ββ
10ton fid. (25ton)
Detailed study of DM
including e channel
pp Solar nu
ββ ~30meV(IH)

Results from XMASS-I

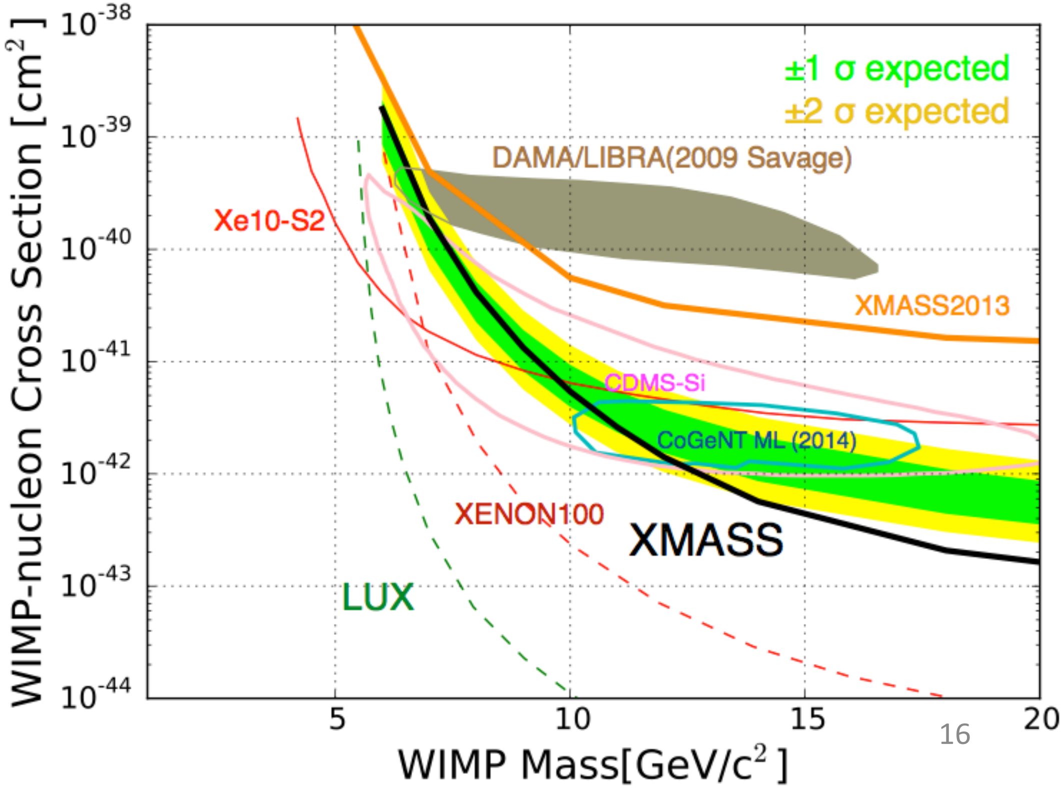
- Modulation analysis



DAMA 100-250kgx14yr



XMASS 832kg x ~1yr

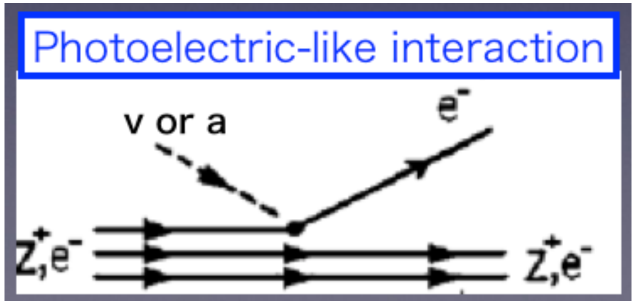


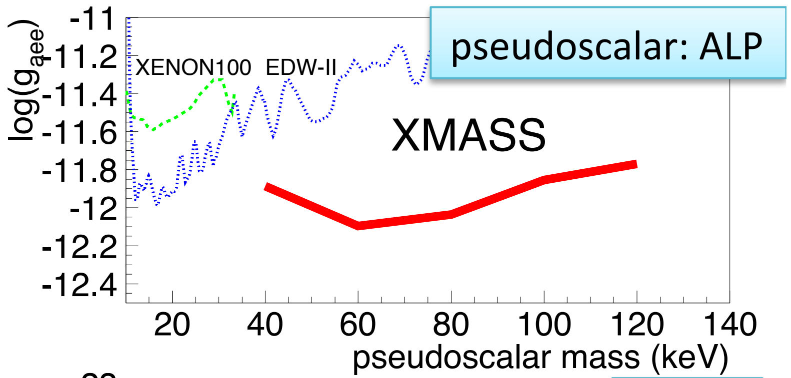
The first extensive search against the DAMA region, including electron recoils.

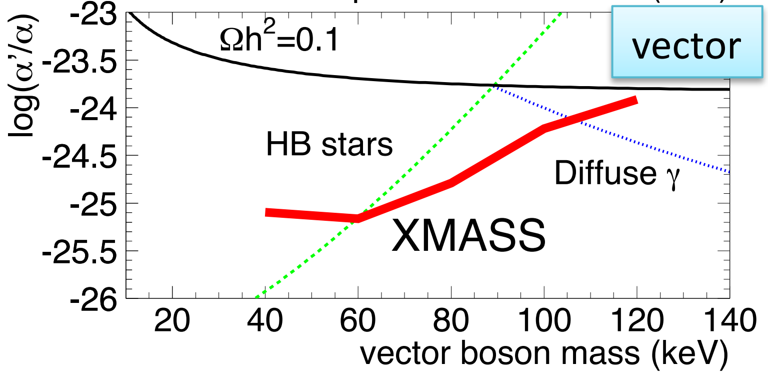
H. Ogawa this afternoon

Results from XMASS-I

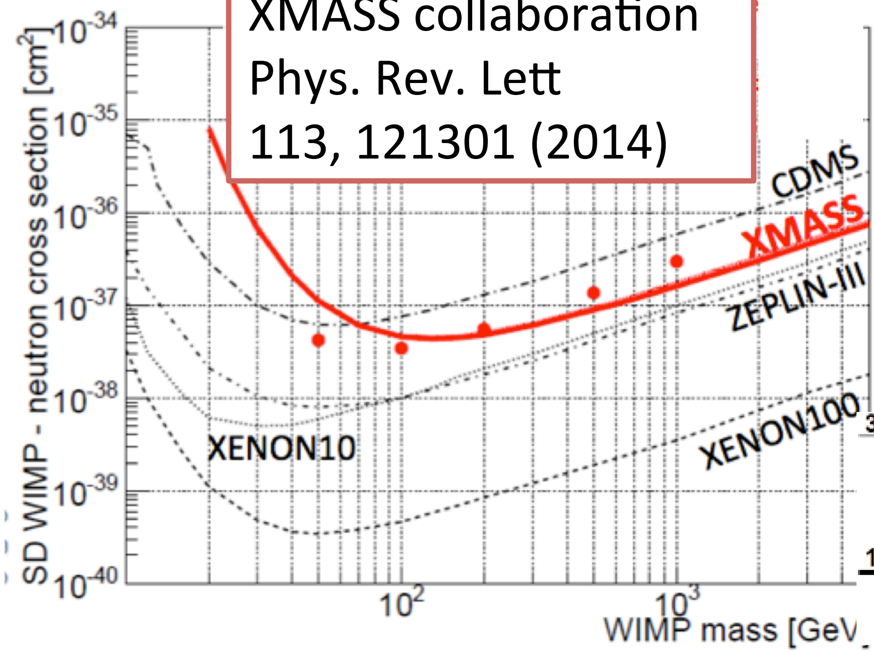
- First experimental search for bosonic Super-WIMPs as DM.
- Inelastic scattering on 129Xe.
- Large mass (835kg), low thre. (0.8keVee), <u>world best BG including electron events.</u>

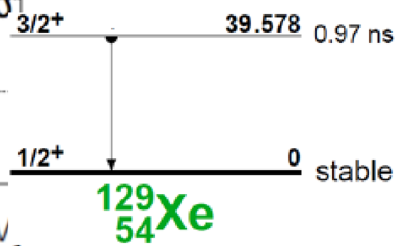






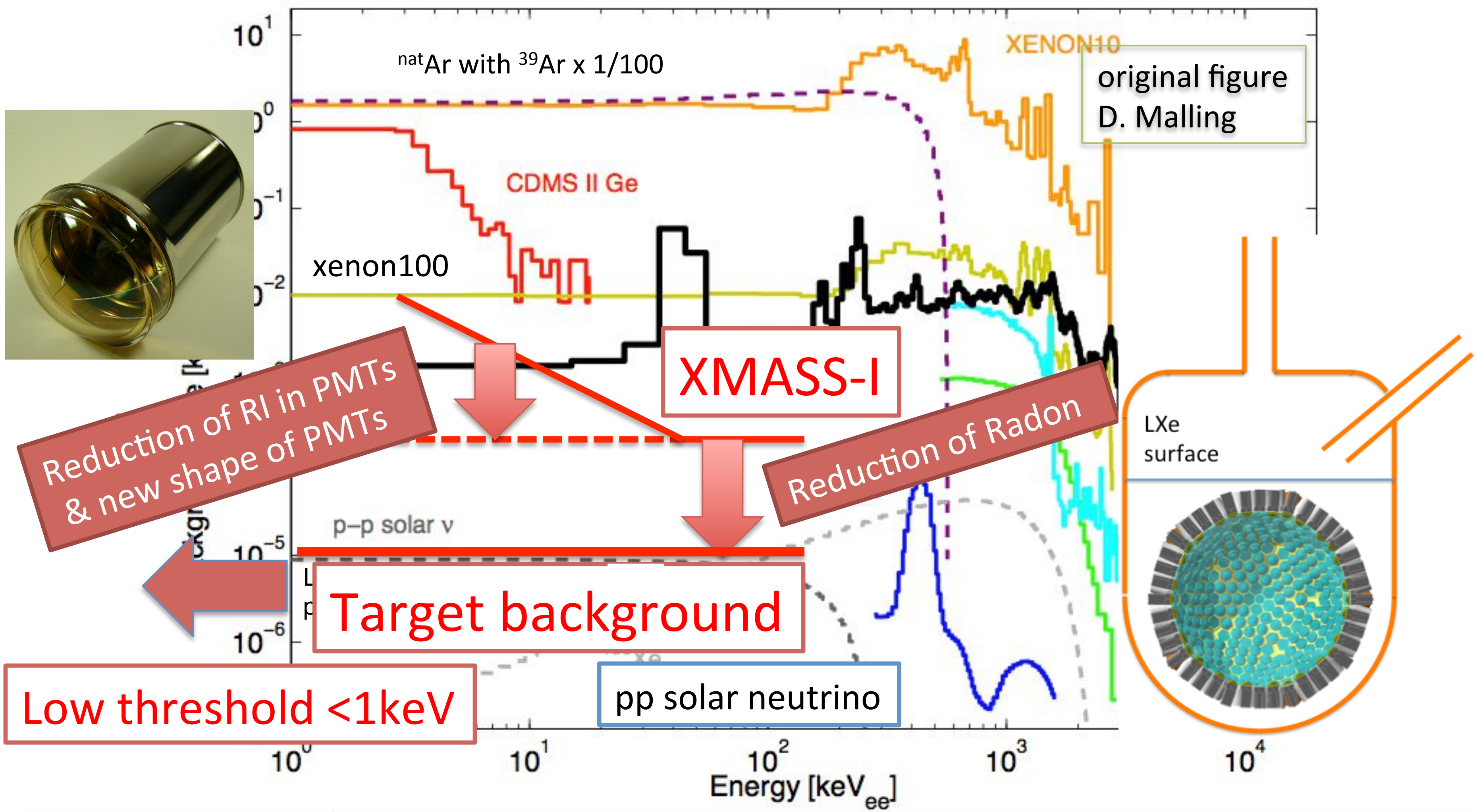
XMASS collaboration
Phys. Rev. Lett
113, 121301 (2014)





XMASS collaboration
Phys. Rev. Lett
113, 121301 (2014)

The world best background of electron recoils in fiducial volume and reduction for future XMASS

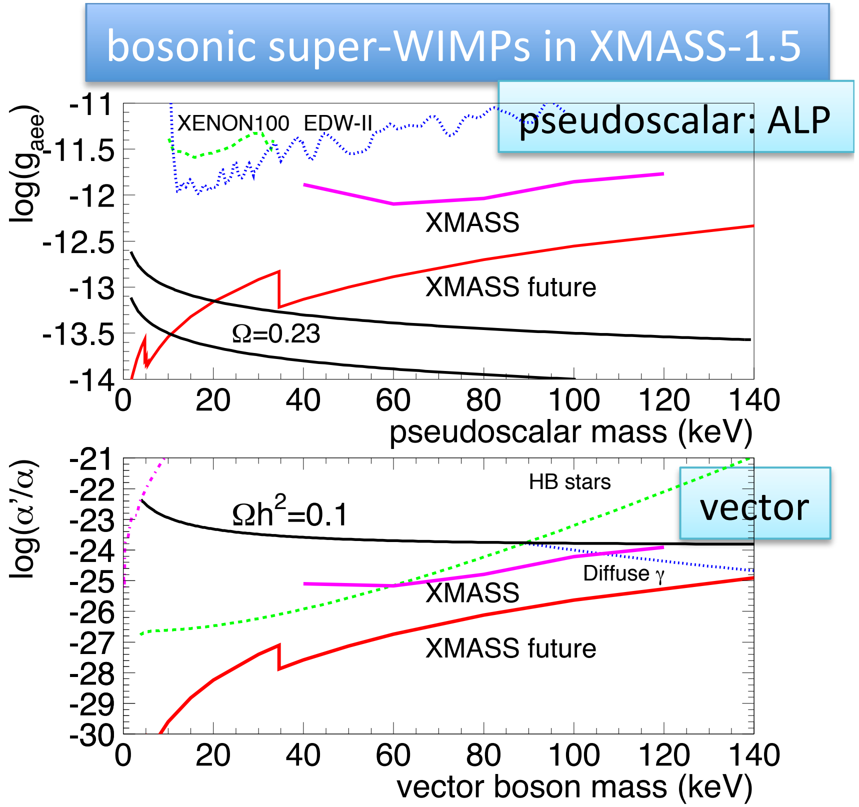


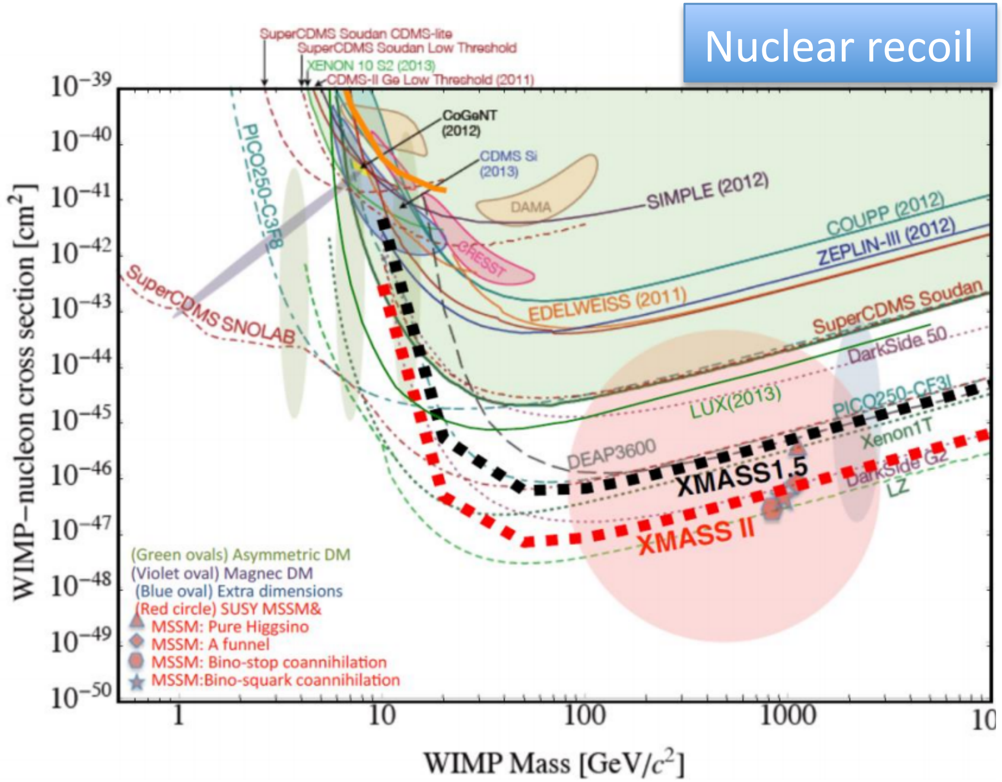
By achieving the ultimate BG caused by pp ν BG and utilizing the low threshold, an extensive search for DM signal must be done!

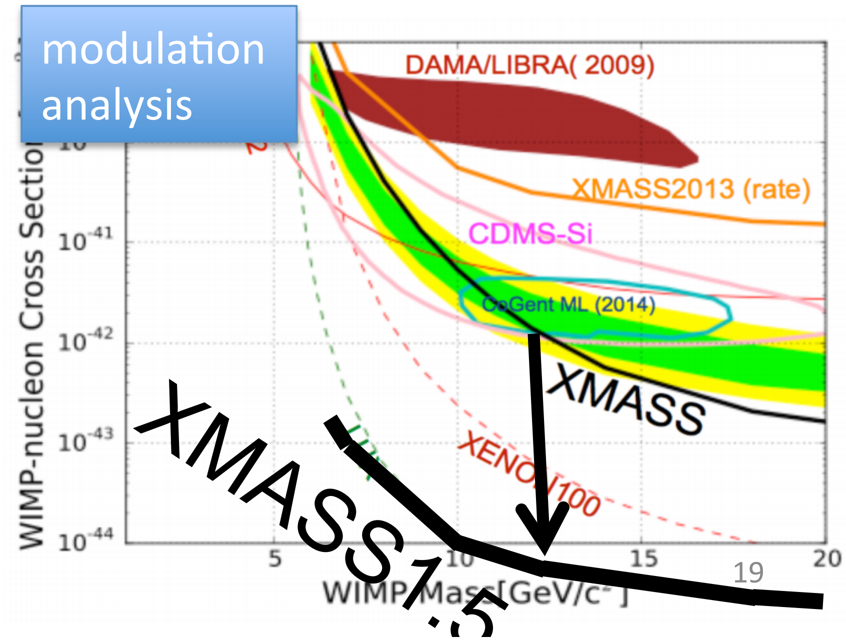
XMASS-1.5&II

- Total 5ton/fiducial 1ton
  Total 25ton/fiducial 10ton
- $9 \times 10^{-47} cm^2$ & $2 \times 10^{-47} cm^2$ @100GeV
- ~1×10^{-5}/keV/kg/d (~1 x pp solar ν)

Realize ultimate sensitivity for e recoil.

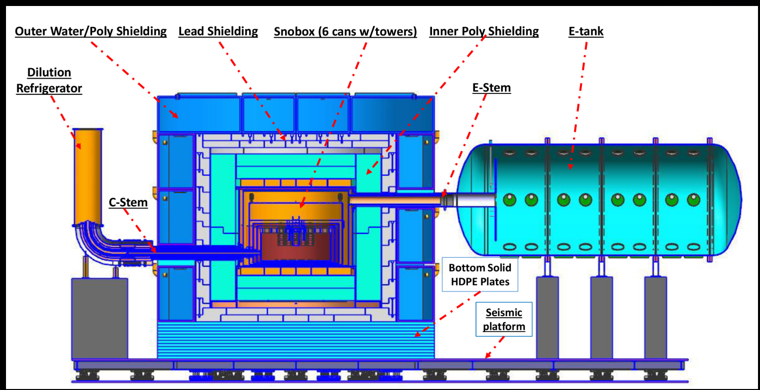


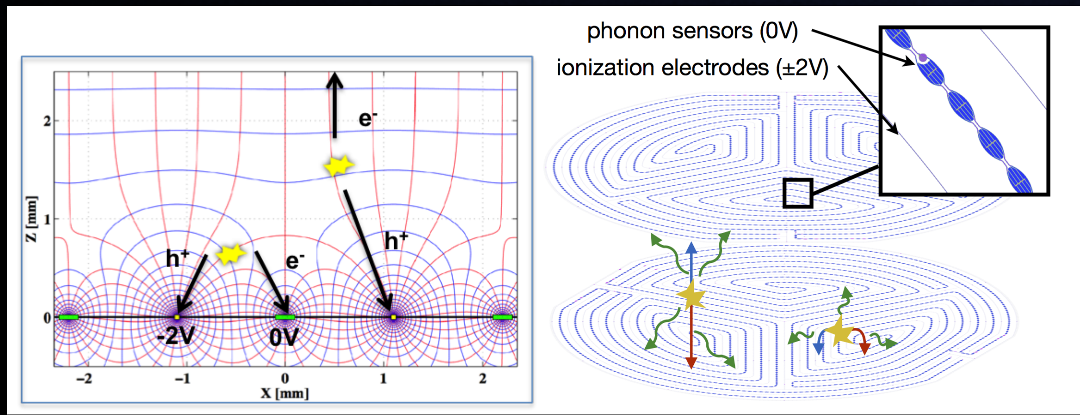




Semiconductors: SuperCDMS@SNOLAB

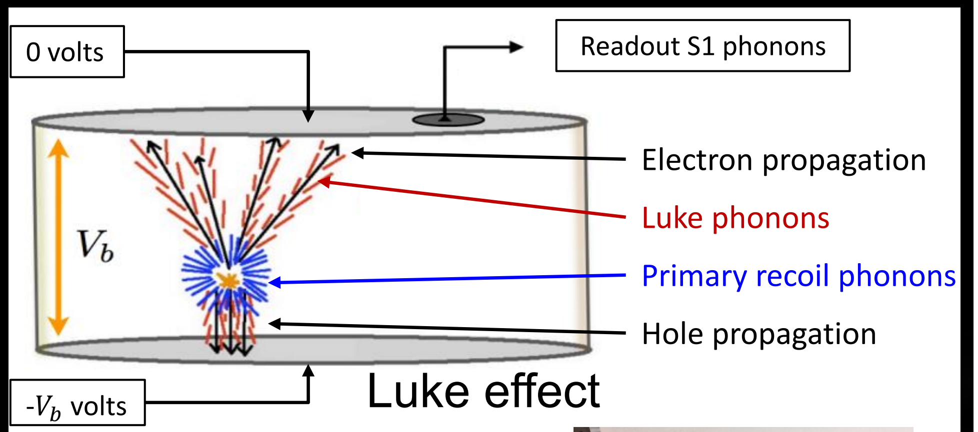
N.B. this is for Soudan

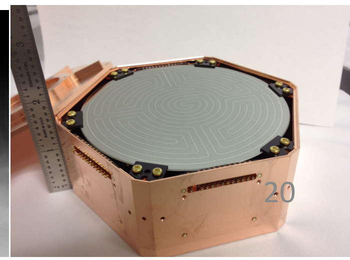




R. Calkins, M. Pepin, TAUP2015

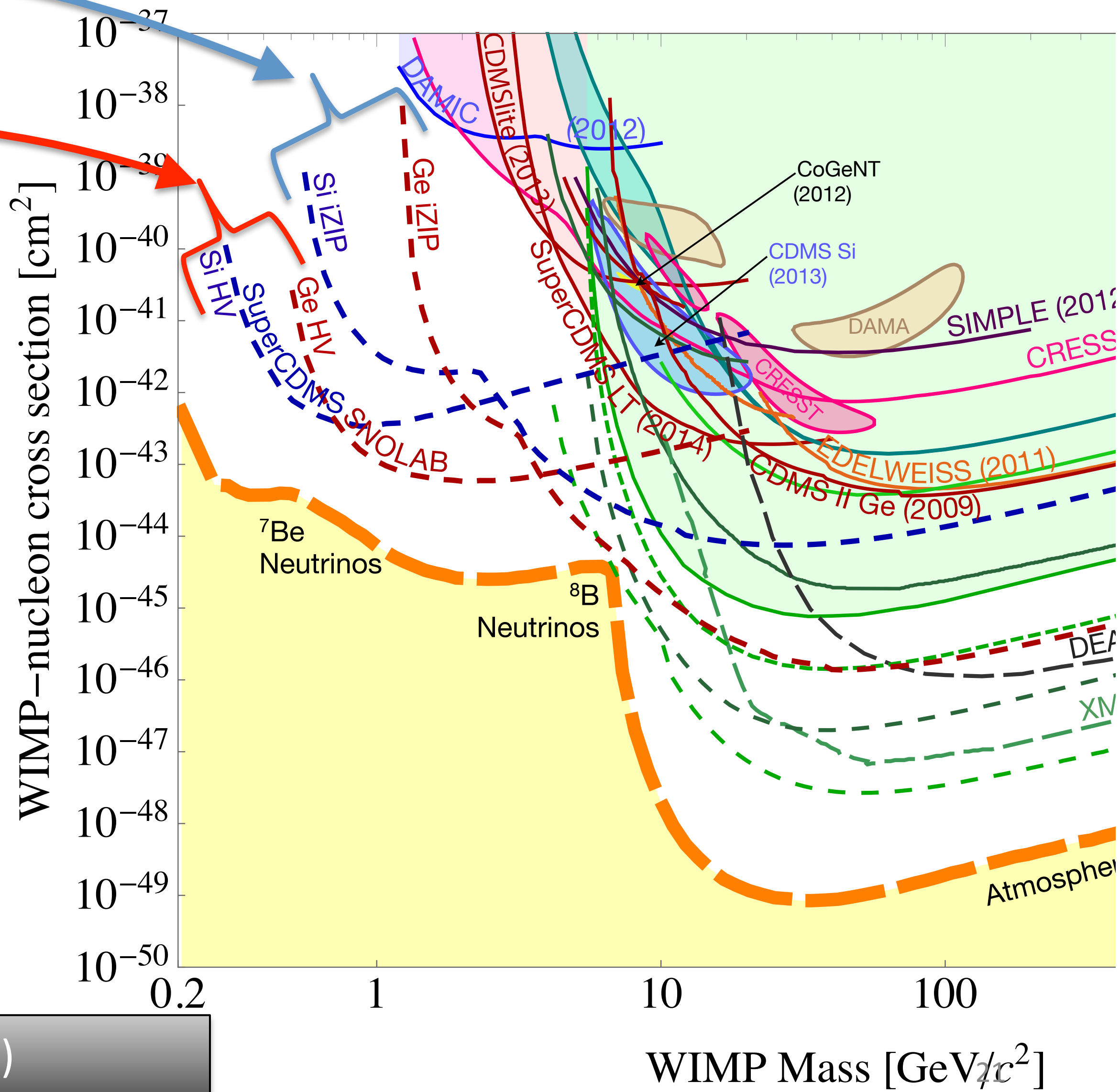
- ionization and phonon signal: e/n discri.
- By applying ~100V bias, amplification by electric field is expected. ➔ Low mass WIMPS





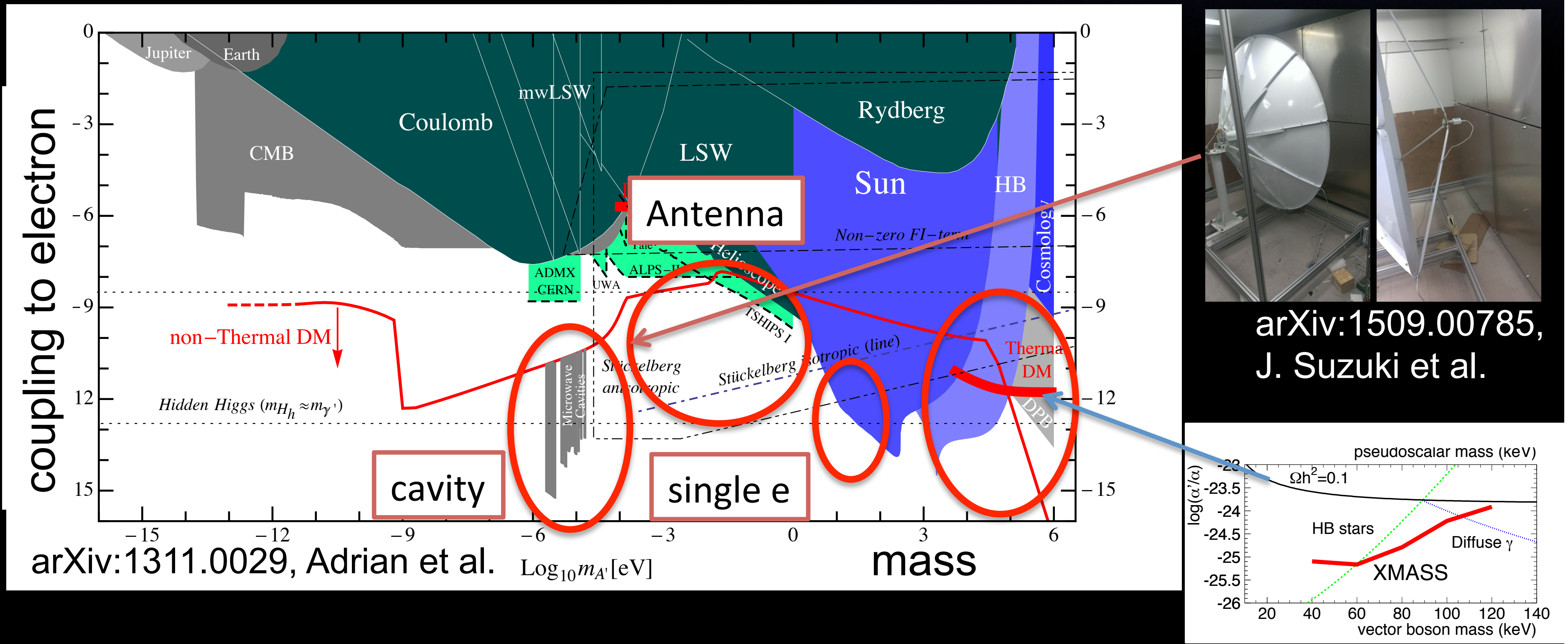
SuperCDMS@SNOLAB 5yrs

- iZIP
  - Ge 50kg
  - Si 4.1kg
- HV
  - Ge 5.6kg
  - Si 1.4kg
- <u>~0.05/keV/kg/d</u>
- axions/lightly ionizing particles
- ^{8}B solar neutrino coherent scattering



See EDELWEISS talk (Dr. Armengaud)
CRESST talk (Dr. Strauss) this afternoon

Hidden photon (<1MeV=$2m_e$)
(one of weakly interacting slim particles)



- Mix with usual photon and couple to electrons.
- Lighter version of vector super-WIMPs.
- Search for DM through electron coupling increasing!

Summary

- Stringent constraints by direct search and by collider search: various types of dark matter were started to be tested.
- Doubling the interaction channel to search for dark matter is important: "electron recoil"
  - Some direct experiments give ideal opportunity to search for any signal <200keV electron recoils.
- Careful understanding of background sometime reveals real nature of dark matter (like the discovery of the neutrino mass!).