Overview of Dark Matter Direct Detection Experiments

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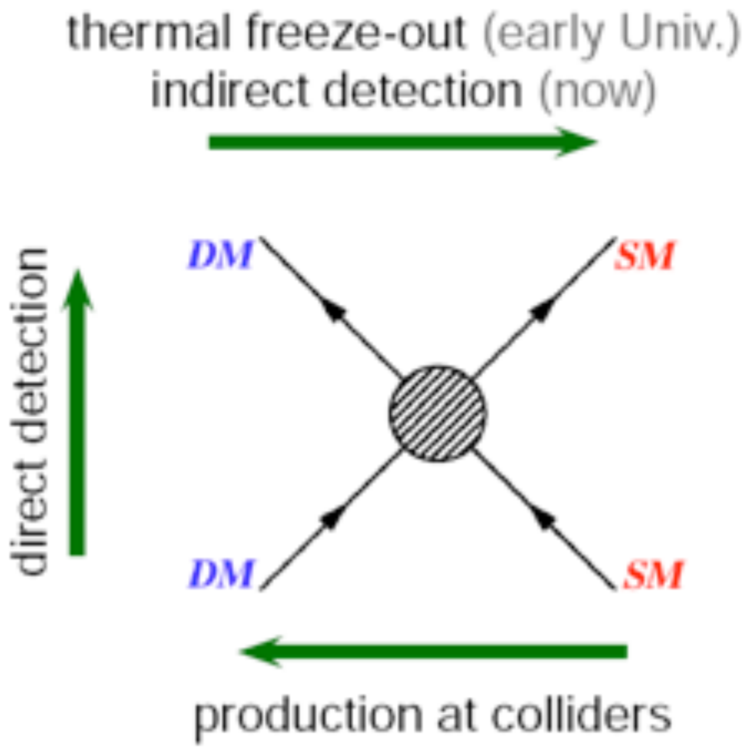
粒子物理前沿卓越创新中心第六次全体会议
2018-11-22

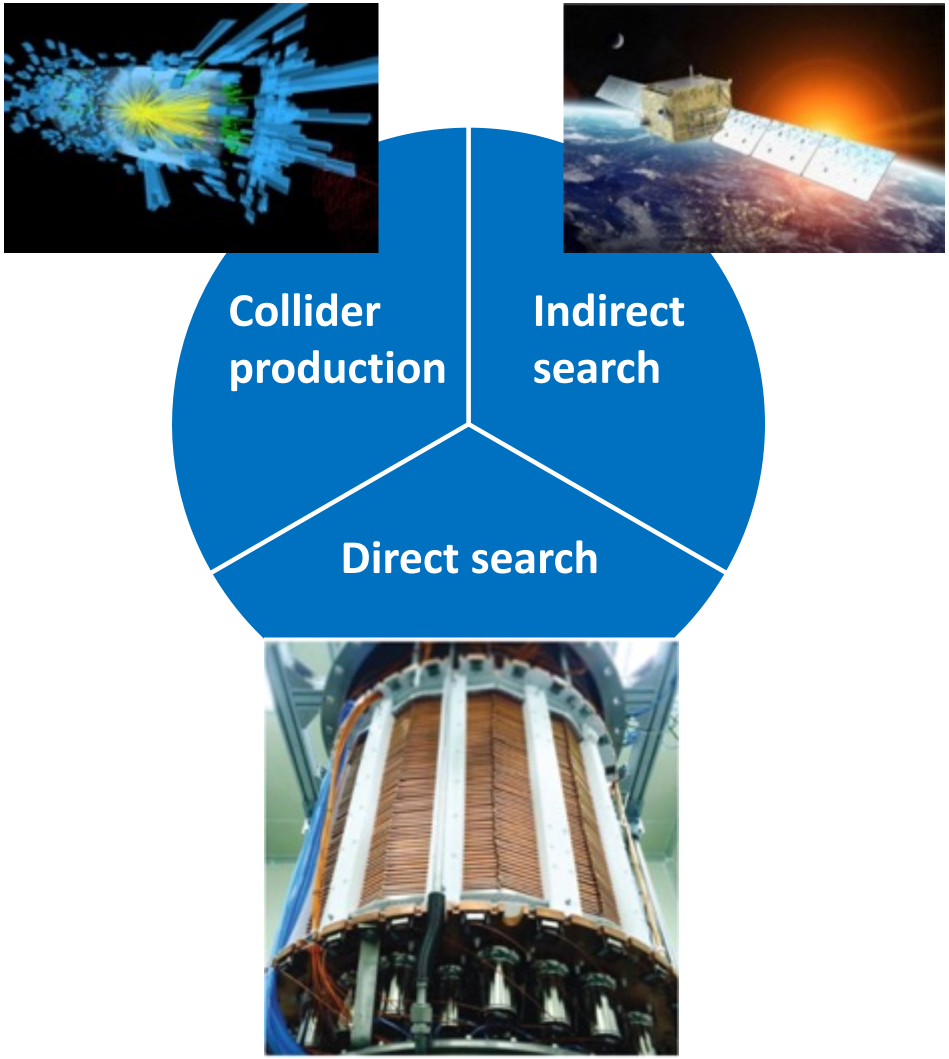
Outline

- Dark Matter Direct Searches
- **WIMP-Nucleon** SI Interaction
- **WIMP-Nucleon** SD Interaction
- **WIMP-Electron** Interaction
- DAMA/LIBRA Anomaly
- Directional Direct Search
- Summary

Dark Matter Searches

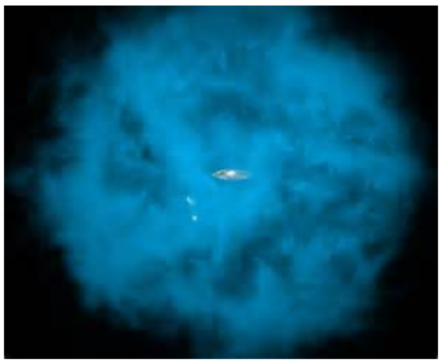
- **Direct detection**
- Indirection detection
- Collider search

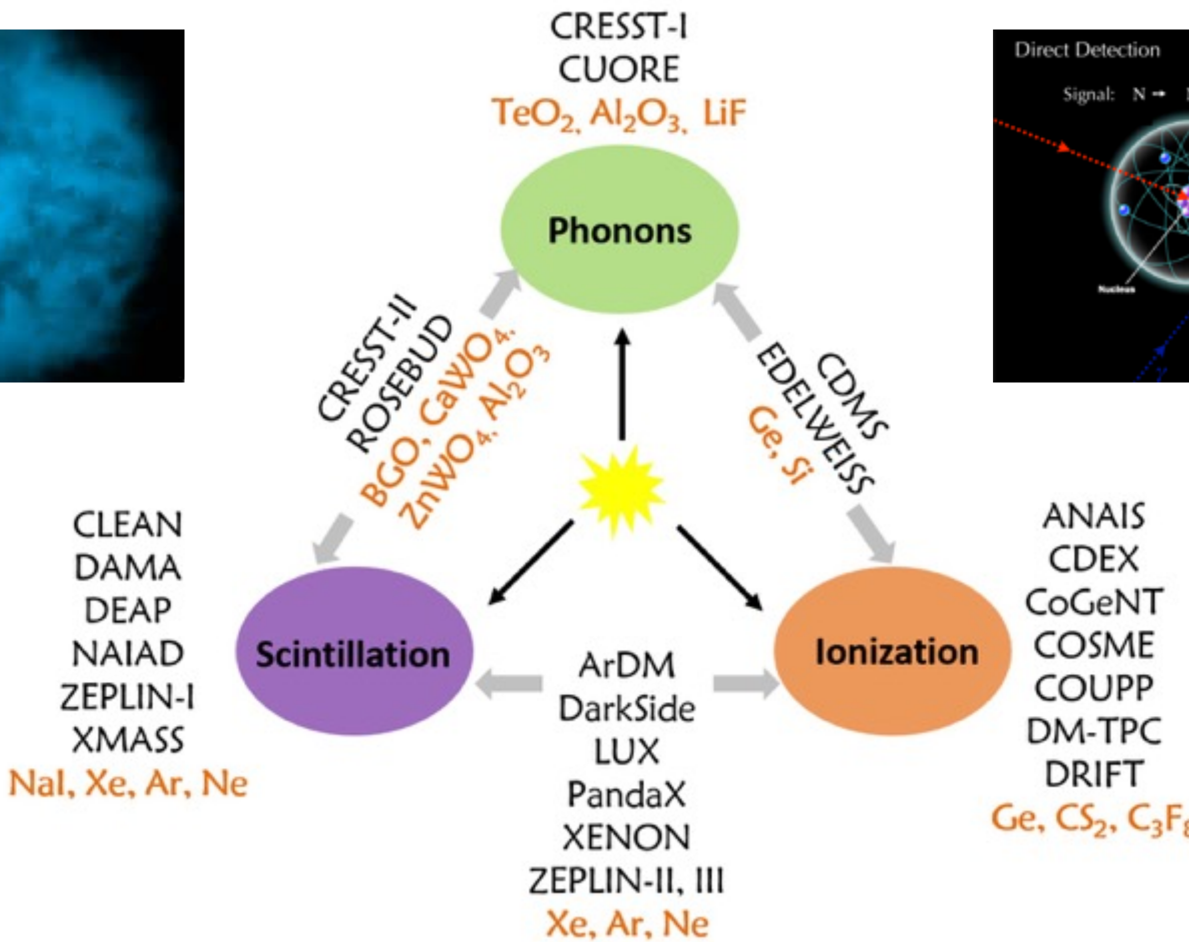


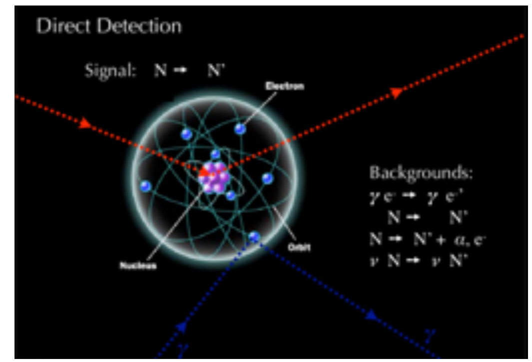


Dark Matter Direct Detection

- Nuclear recoil (**NR**) vs Electron recoil (**ER**)
- **Light** & **Charge** & **Heat**



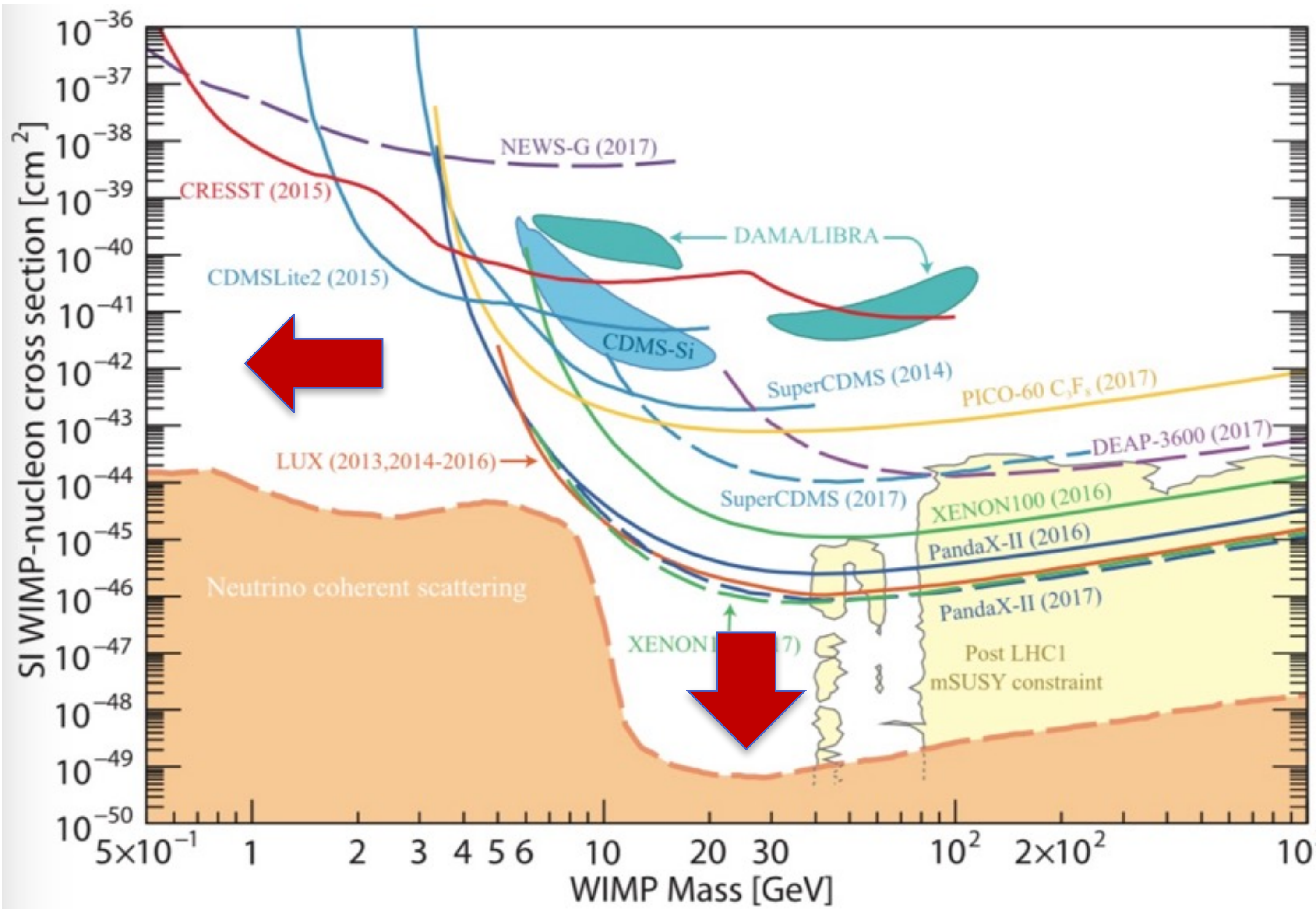




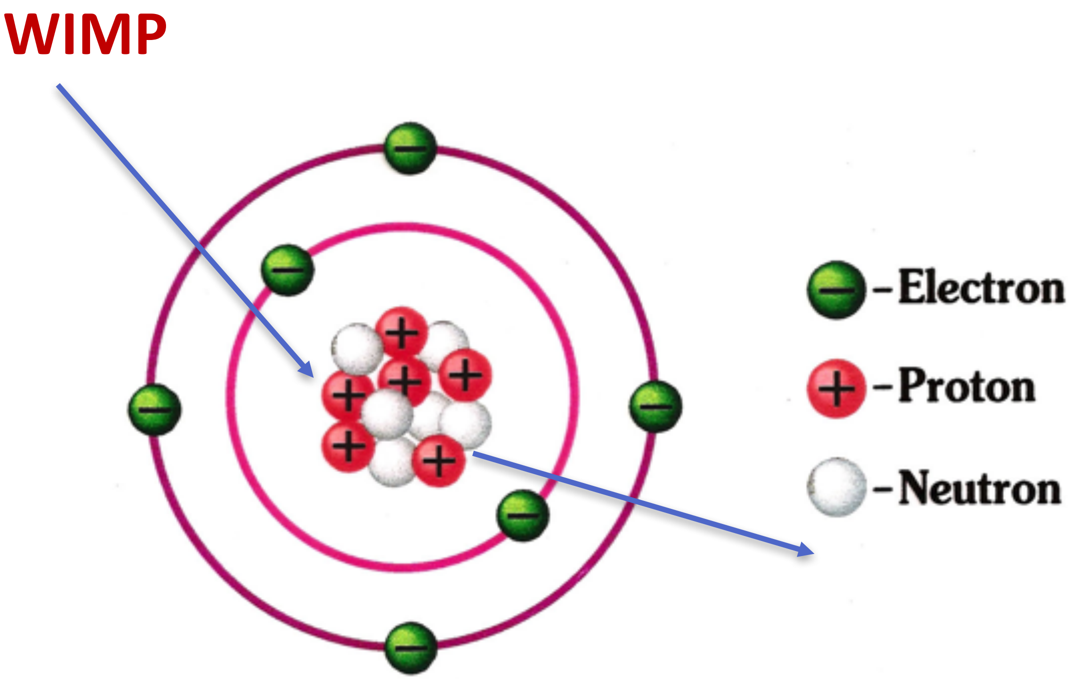
World-Wide Efforts

Current Constraints

- Towards lower **threshold** & lower **background**



- **Spin Independent WIMP-Nucleon Interaction**
- **High Mass**



Noble Liquid Experiment

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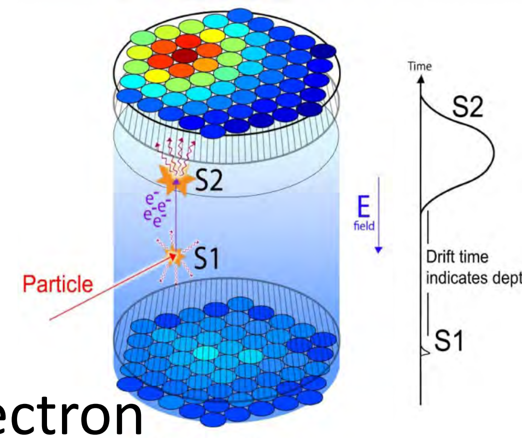
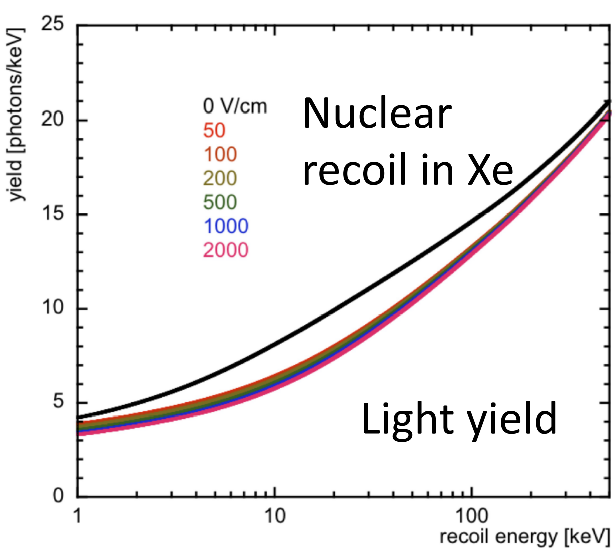
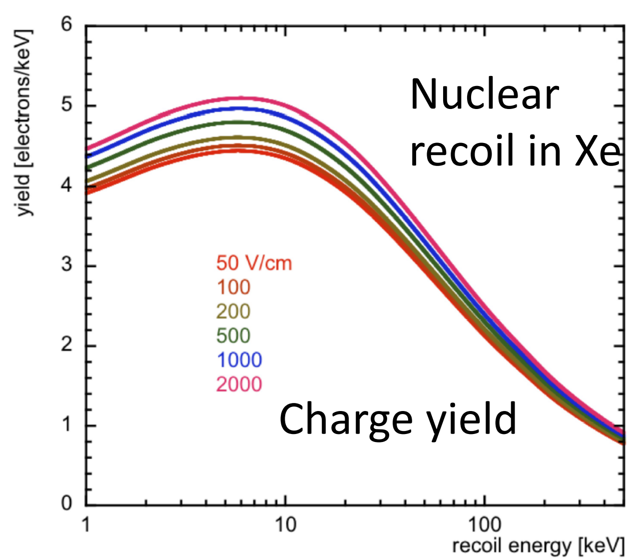
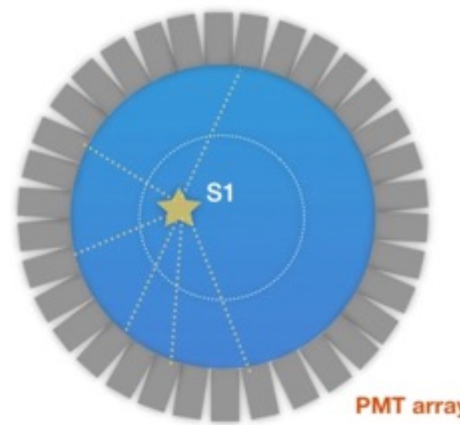
- Dense and homogenous target, self-shielding
- High light and charge yields
- **Dual-phase**: scintillation light and ionization electron
- **Single-phase**: scintillation light









Xenon Detectors

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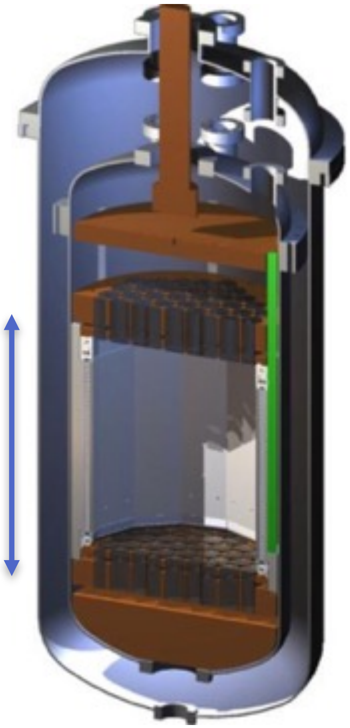
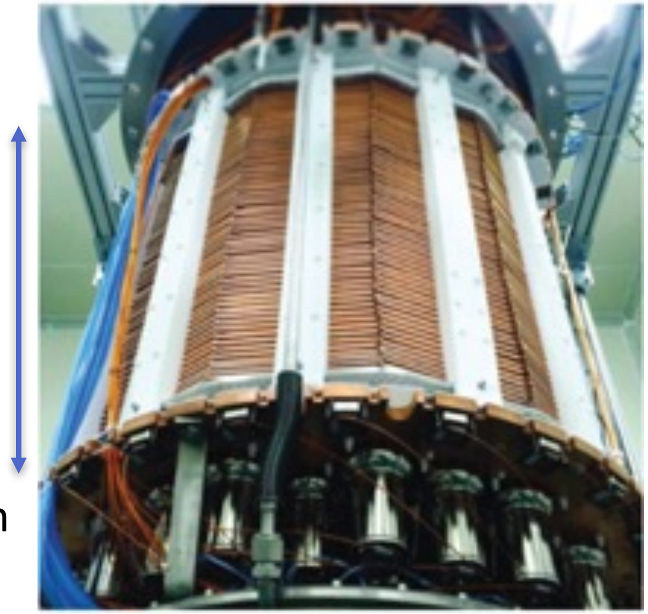
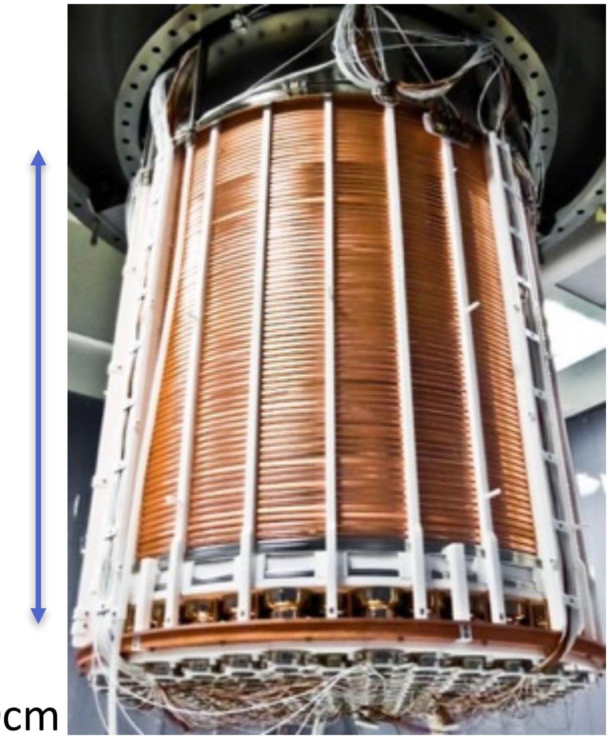


48cm



60cm



100cm

LUX

Sensitive volume 250 kg
Completed in 2016

PandaX-II

Sensitive volume 580 kg
54 ton-day, ongoing

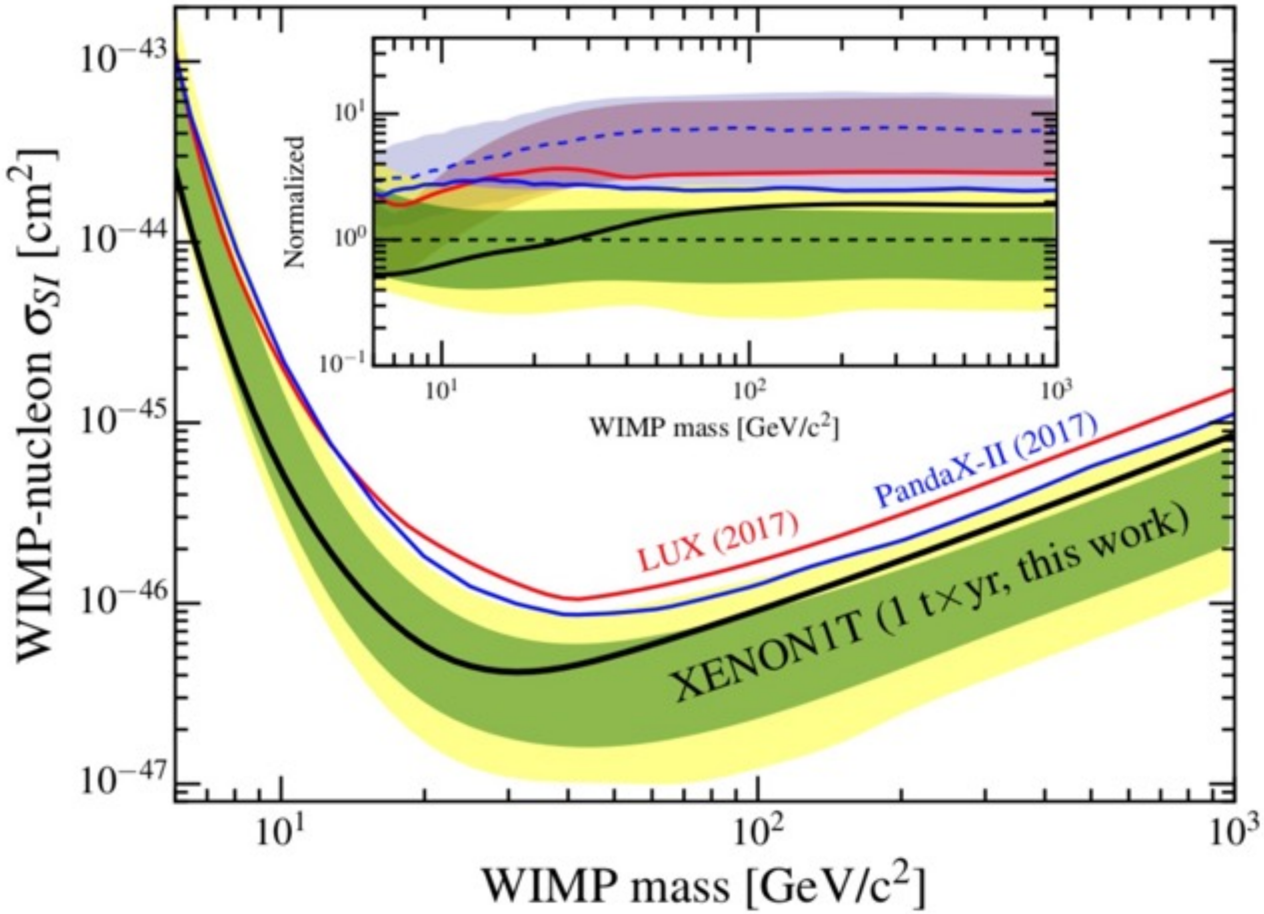
XENON1T

Sensitive volume 2000 kg
1 ton-year, ongoing

Xenon Detectors: LUX, PandaX-II, XENON1T

- Strongest constraints on the high mass WIMP
- XENON1T sets 4.1x10^{-47} cm^2 at 30 GeV WIMP

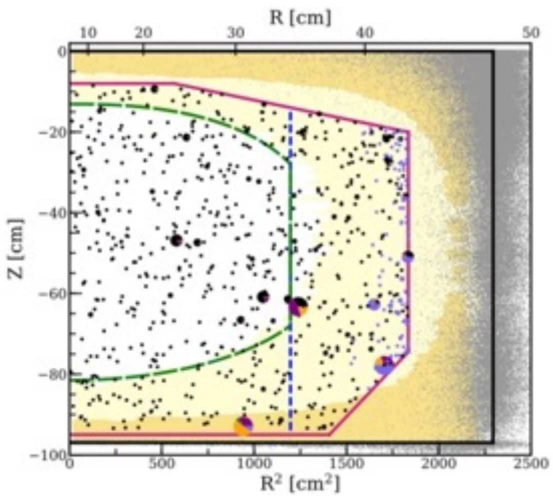
Phys. Rev. Lett. 121, 111302 (2018)

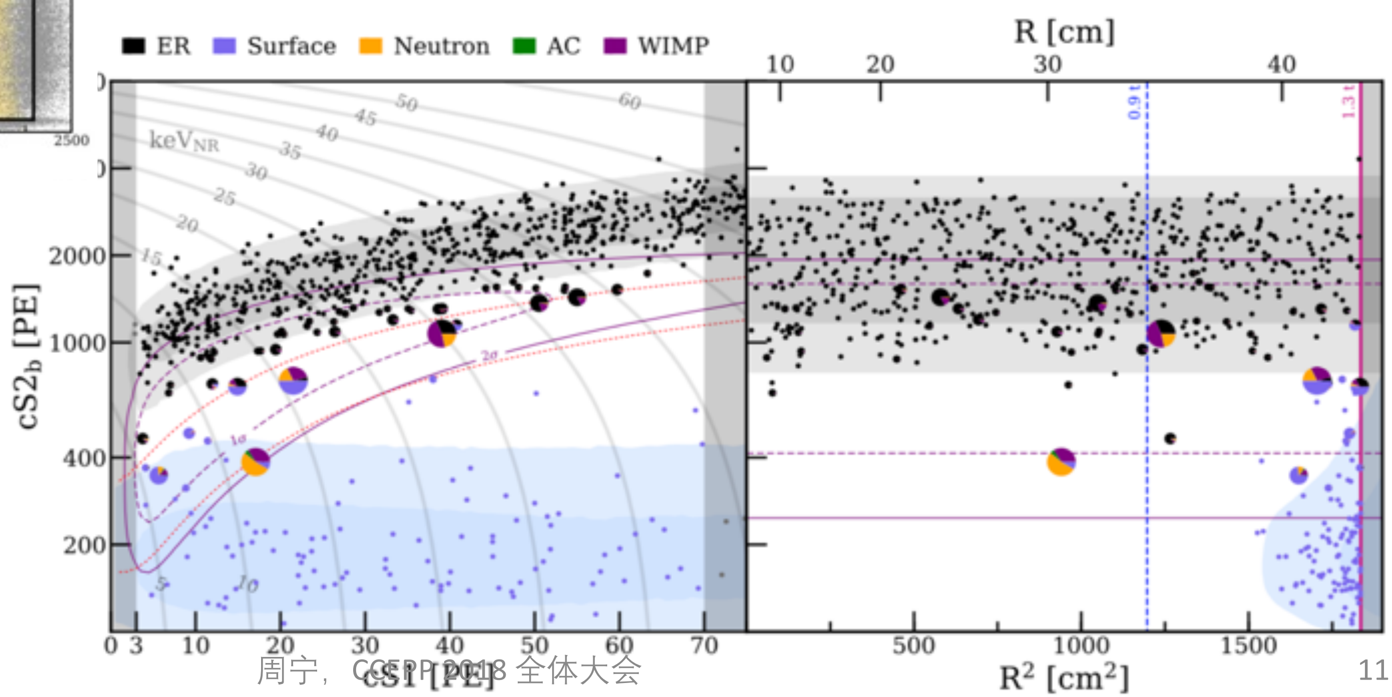


XENON1T Latest Results

- Exposure 1 ton-year
- Fiducial volume

Mass	1.3 t	1.3 t	0.9 t	0.65 t
$(cS1, cS2_b)$	Full	Reference	Reference	Reference
ER	627±18	1.62±0.30	1.12±0.21	0.60±0.13
neutron	1.43±0.66	0.77±0.35	0.41±0.19	0.14±0.07
CEνNS	0.05±0.01	0.03±0.01	0.02	0.01
AC	$0.47^{+0.27}_{-0.00}$	$0.10^{+0.06}_{-0.00}$	$0.06^{+0.03}_{-0.00}$	$0.04^{+0.02}_{-0.00}$
Surface	106±8	4.84±0.40	0.02	0.01
Total BG	735±20	7.36±0.61	1.62±0.28	0.80±0.14
$WIMP_{best\text{-}fit}$	3.56	1.70	1.16	0.83
Data	739	14	2	2



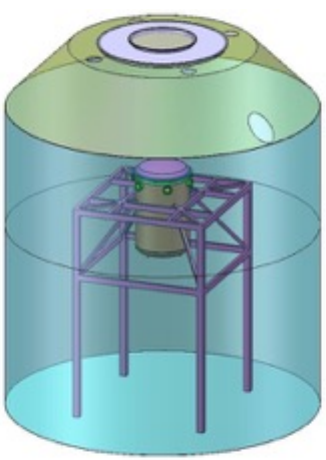


Phys. Rev. Lett. 121, 111302 (2018)

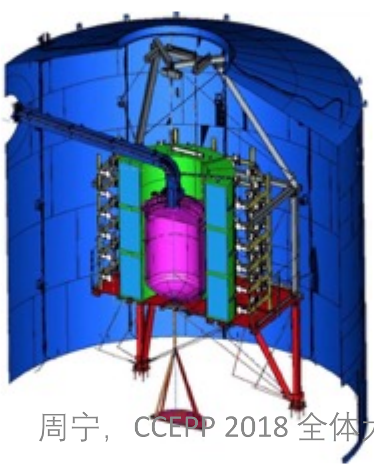
Future Xenon Detectors

Experiment	Sensitive Volume	Fiducial Volume	Expected exposure	Expected Sensitivity	Status
PandaX-4T	4 ton	2.8 ton	5 ton-year	10^{-47} cm^2	Commissioning 2020
XENONnT	6 ton	5 ton	20 ton-year	2×10^{-48} cm^2	Commissioning 2019
LZ	7 ton	5.6 ton	20 ton-year	2×10^{-48} cm^2	operations start April 2020
Darwin	40 ton	30 ton	200+ ton-year	Neutrino floor	CDR in 2-3 years

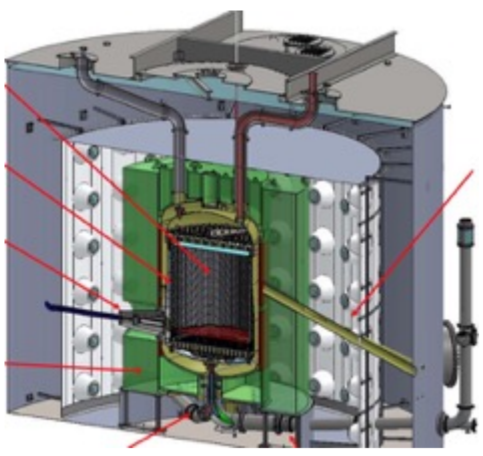
PandaX-4T



XENONnT

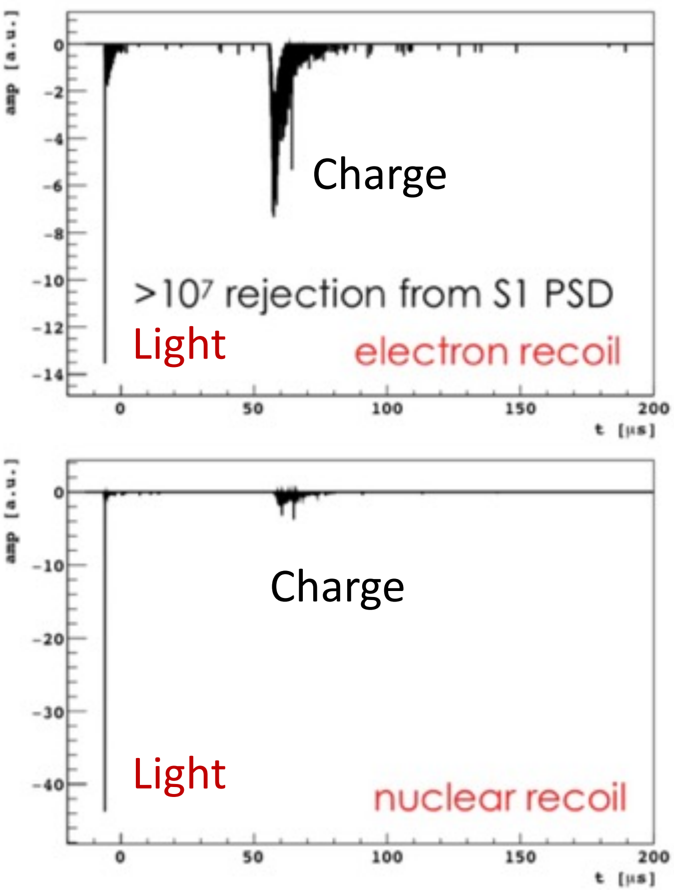


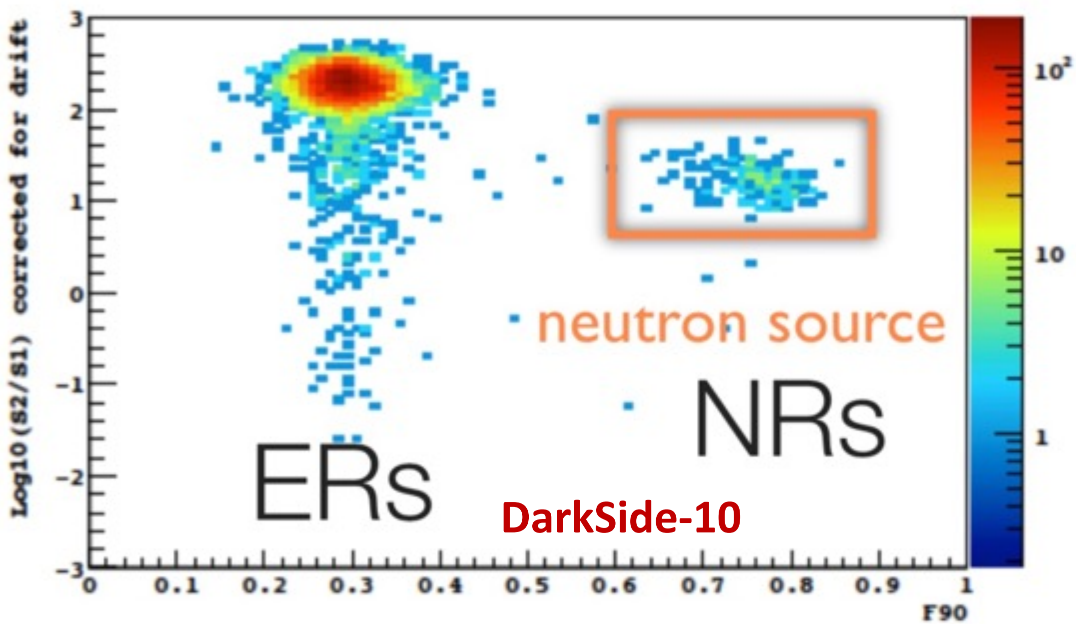
LZ



Argon Detectors

- **Pulse shape** of prompt scintillation signal
  - Singlet (6ns) and triplet (1.5μs)
- Dual-phase: Ionized electron vs prompt scintillation light



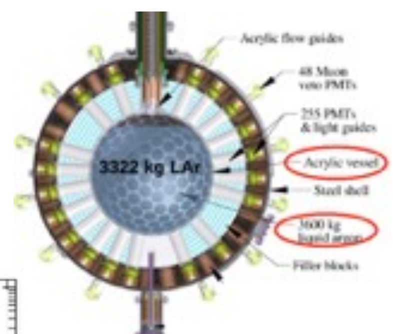


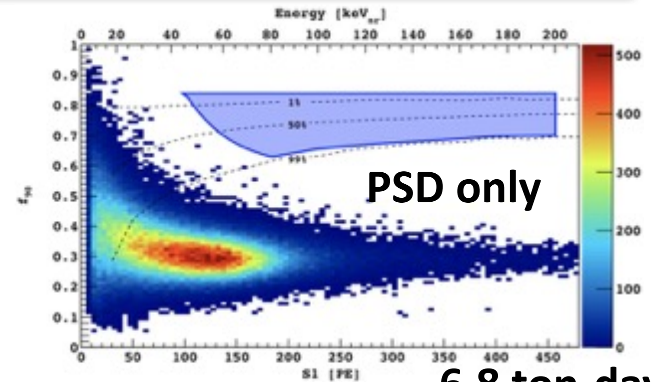
F90: the fraction of light collected within the first 90ns

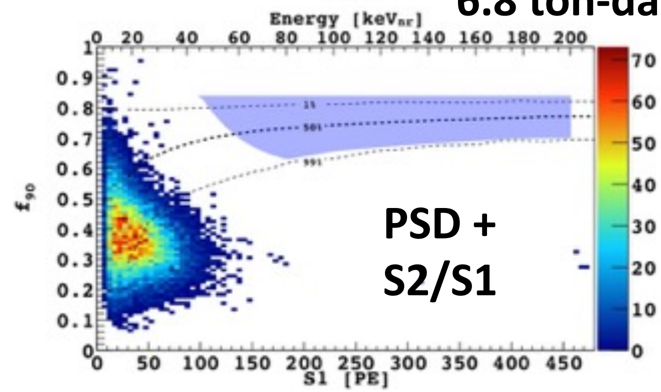
Current Running Argon Detectors

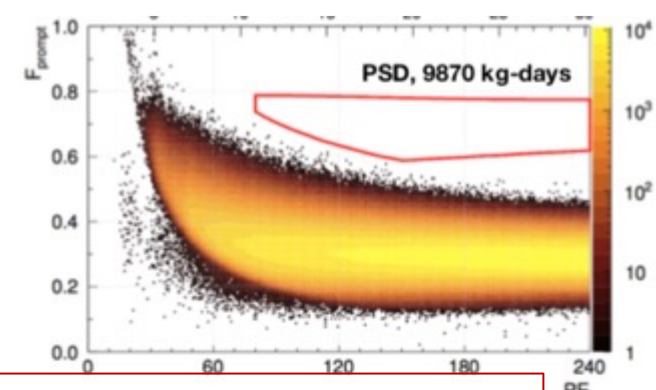
Phys. Rev. D 98, 102006 (2018)

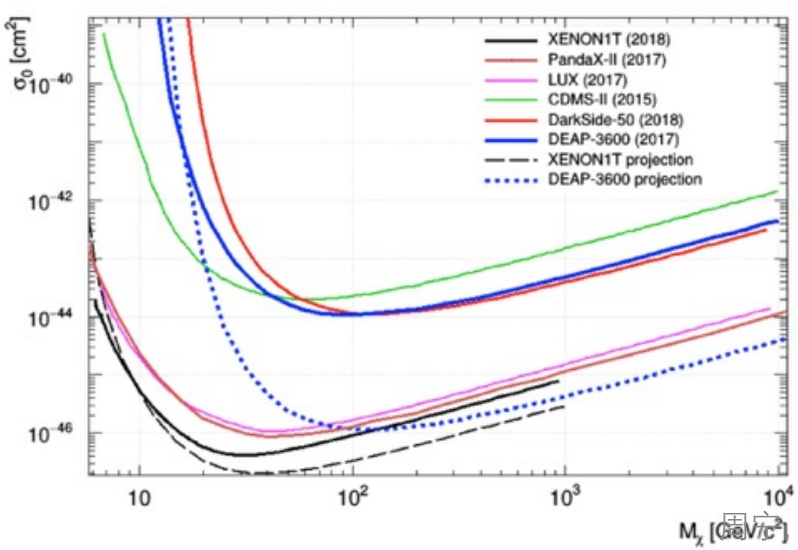
- **DarkSide-50** @LNGS
  - 46 kg underground Argon
  - Dual-phase
- **DEAP-3600** @SNOLAB
  - 3600 kg natural Argon
  - Containing ^{39}Ar (269 year)
  - Single-phase, R=85cm









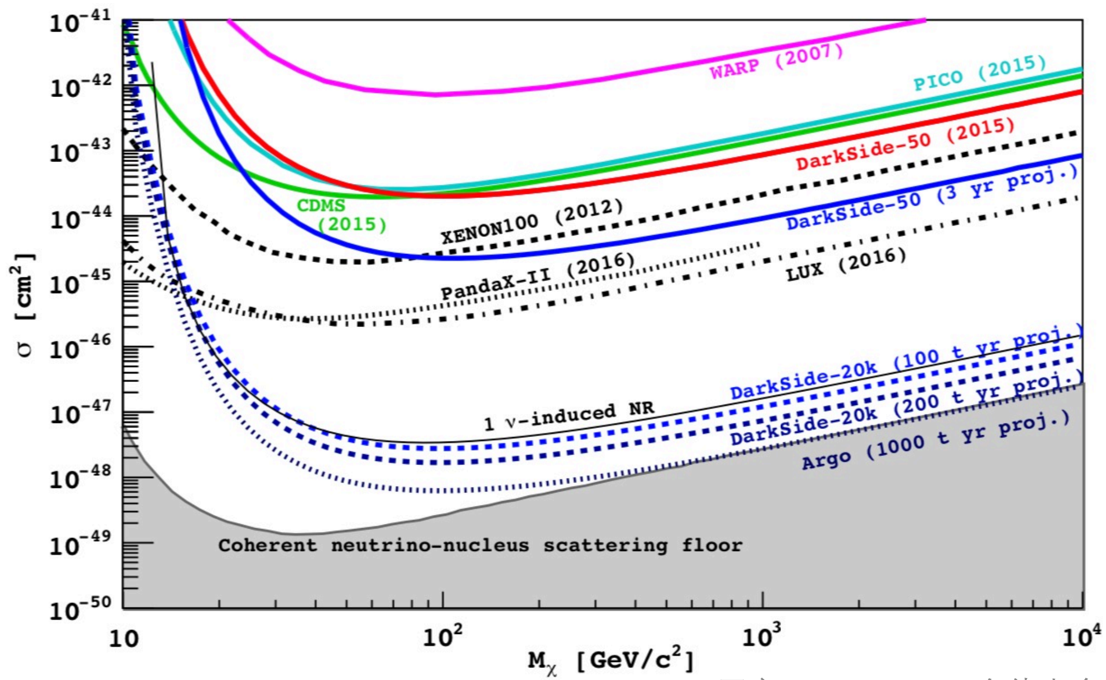


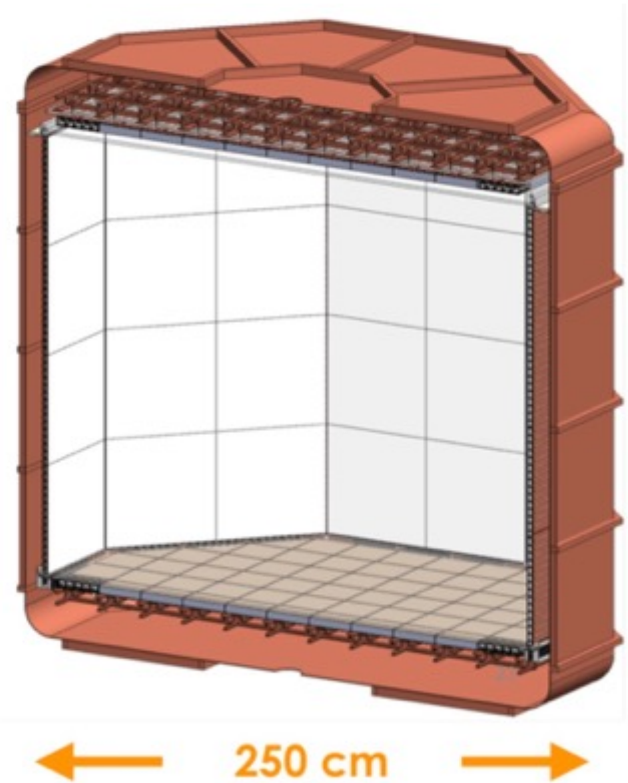
Phys. Rev. Lett. 121, 071801 (2018)

Future Argon Detector: GADMC

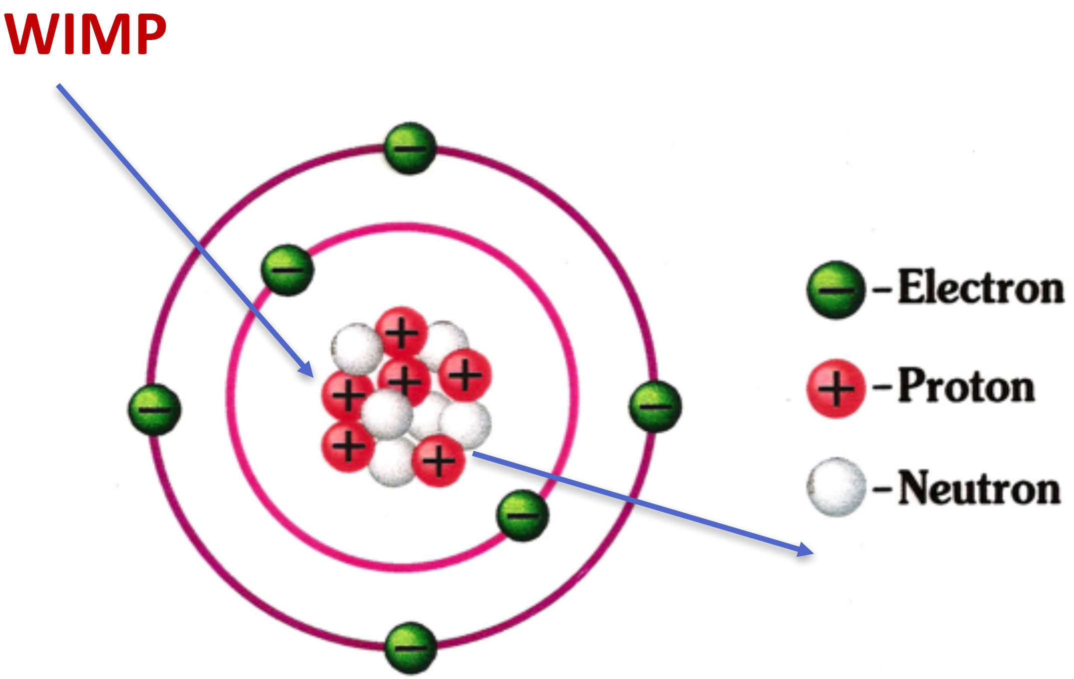
- **Global Argon Dark Matter Collaboration**
- **DarkSide-20k** (2021 -)
  - dual-phase, low radioactivity Ar
  - 50 tonne total mass, 30 tonnes fiducial mass
  - > 20 m^2 of SiPM coverage
- 300 tons fiducial mass detector (2026 -)

Eur. Phys. J. Plus (2018) 133: 131



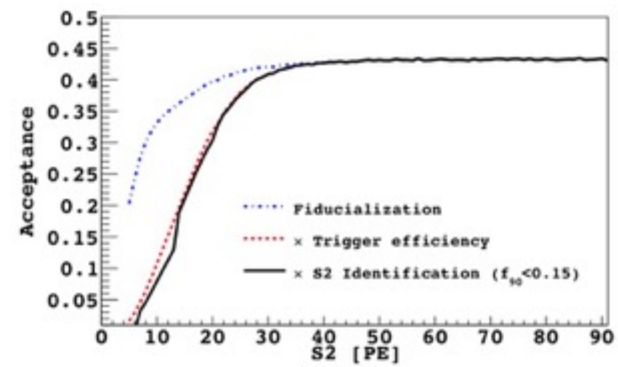


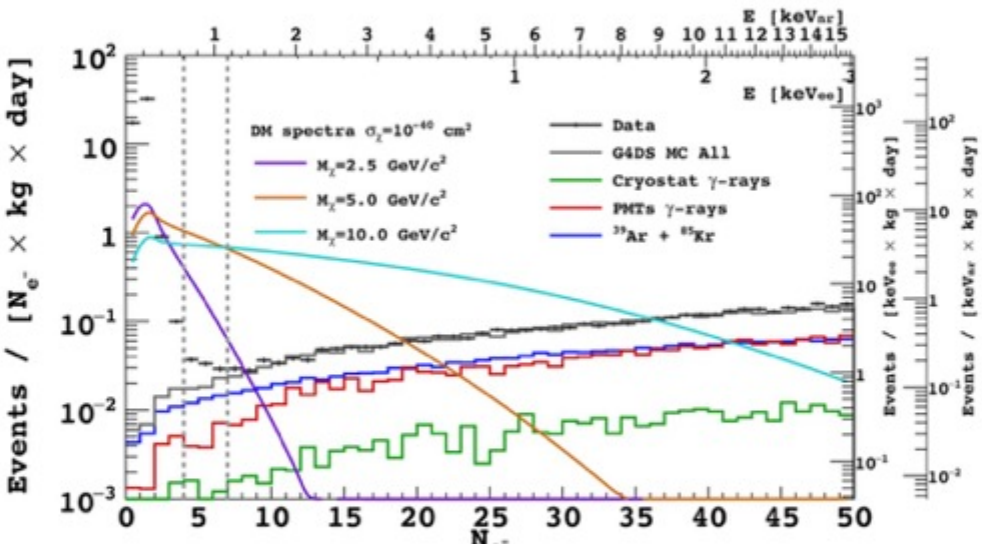
- **Spin-Independent WIMP-Nucleon Interaction**
- **Low Mass**

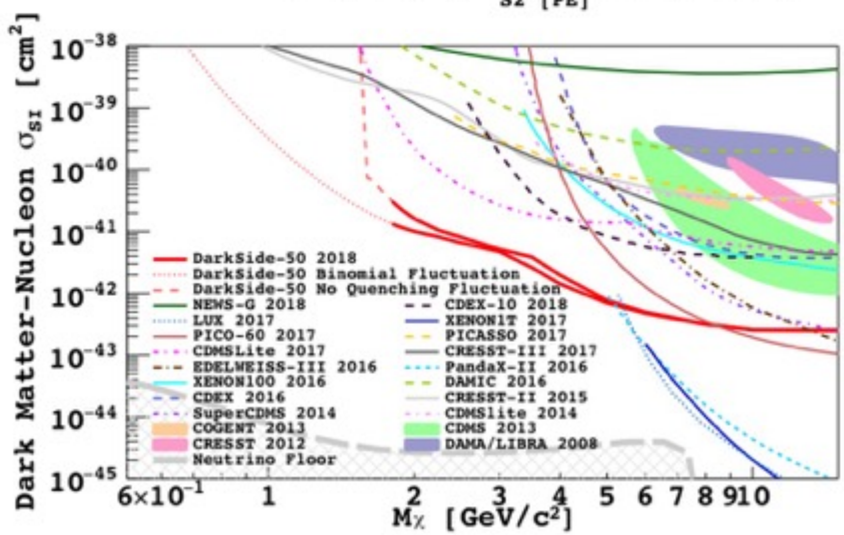


Noble Liquid: S2-only Signature

- Dual-phase noble liquid detector
- Usual signal region
  - PandaX: S1 [3PE, 45PE], S2 [100PE, 10000PE], Threshold ~ 1 keVee
- Low mass signal region @ **DarkSide-50**
  - S2-only, no ER/NR discrimination
  - Threshold N_{e-}=7 ~ **0.1 keVee**
  - ~10^{-41} cm^2 at **2 GeV**



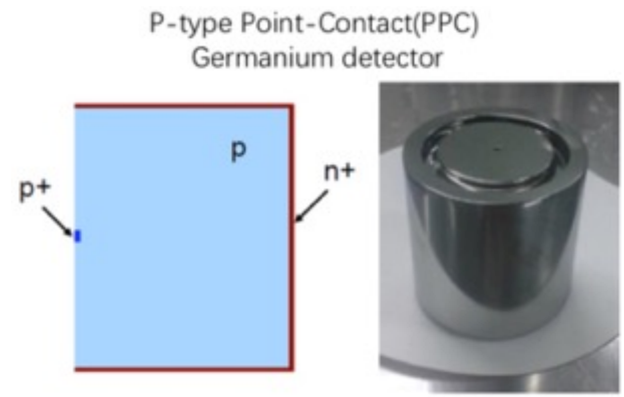


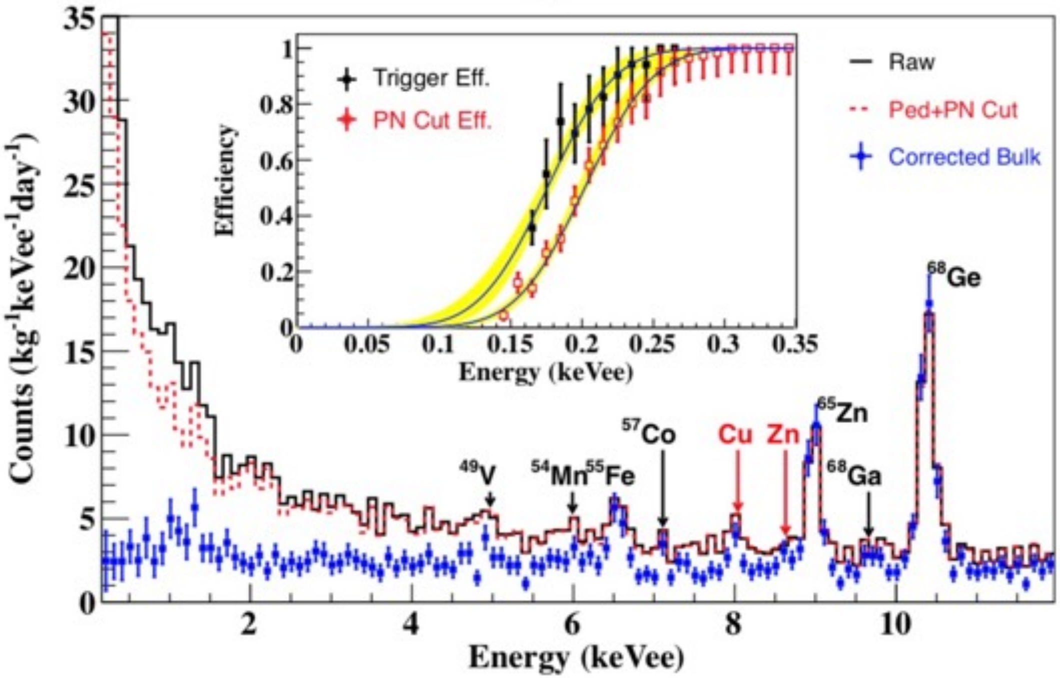


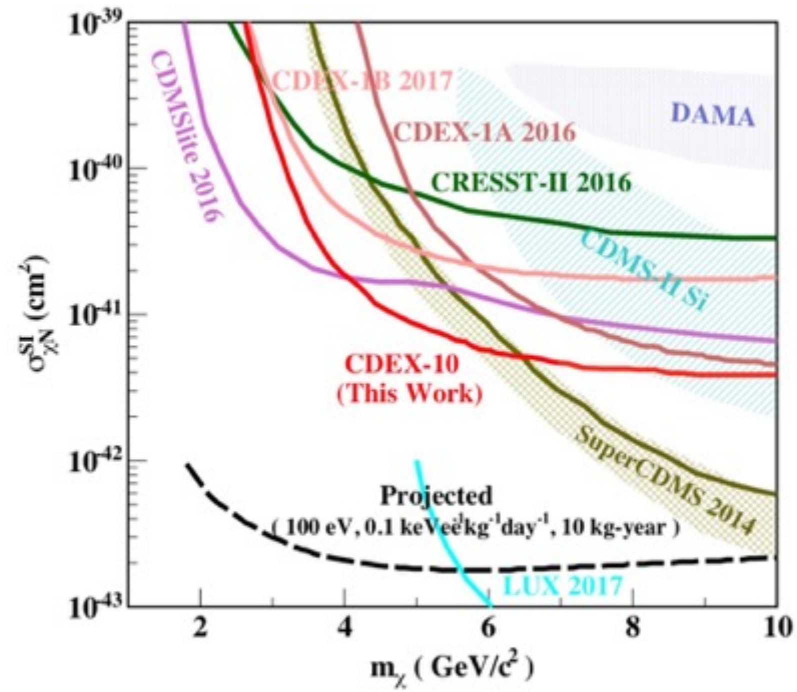
Phys. Rev. Lett. 121, 081307 (2018)

Germanium Detectors: CDEX

- **CDEX-10** @ CJPL
- 10 kg Ge in liquid N_2
- Analysis threshold **160 eVee**
- 102.8 kg-days exposure



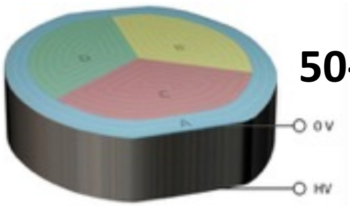




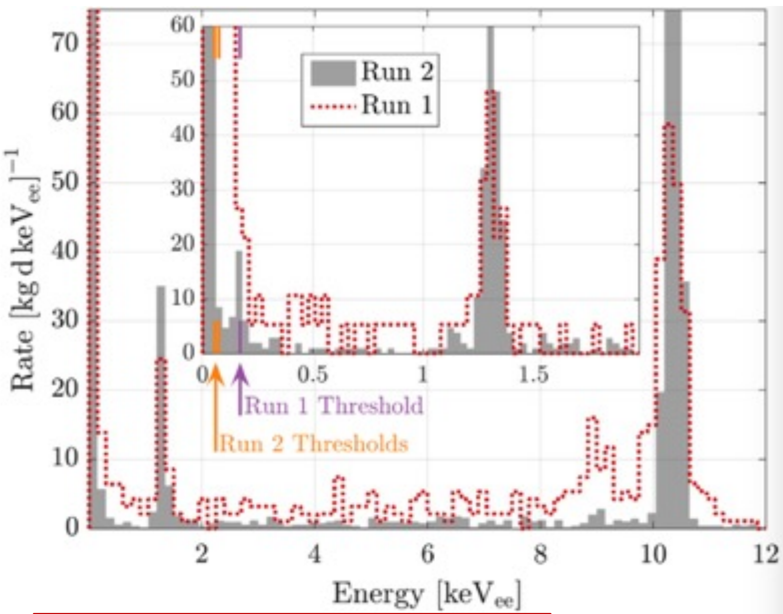
Phys. Rev. Lett. 120, 241301 (2018)

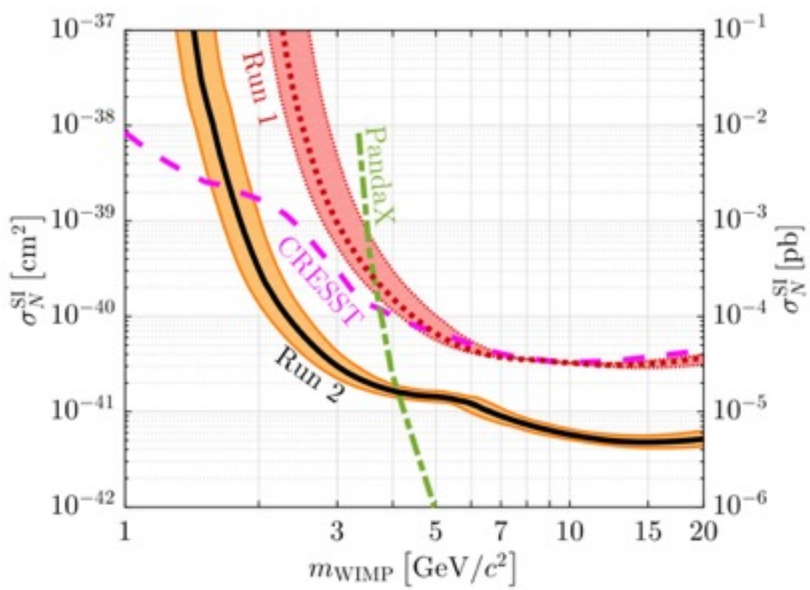
Germanium Detectors: SuperCDMS

- **SuperCDMS** @Soudan
- Standard iZIP mode: phonon and ionization, ER/NR discrimination
- **CDMSlite HV mode**: phonon only
  - Ionization electrons generate a large number of NTL phonons
  - => **Low threshold 56 eVee**



50-80V



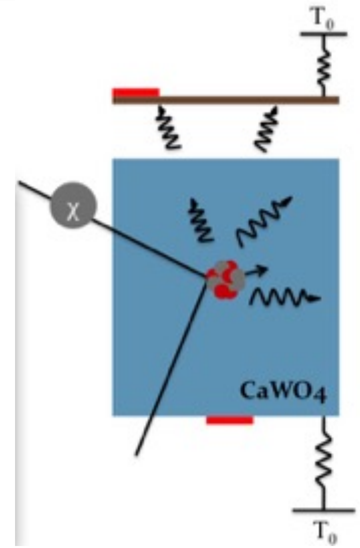


Phys. Rev. D 97, 022002 (2018)

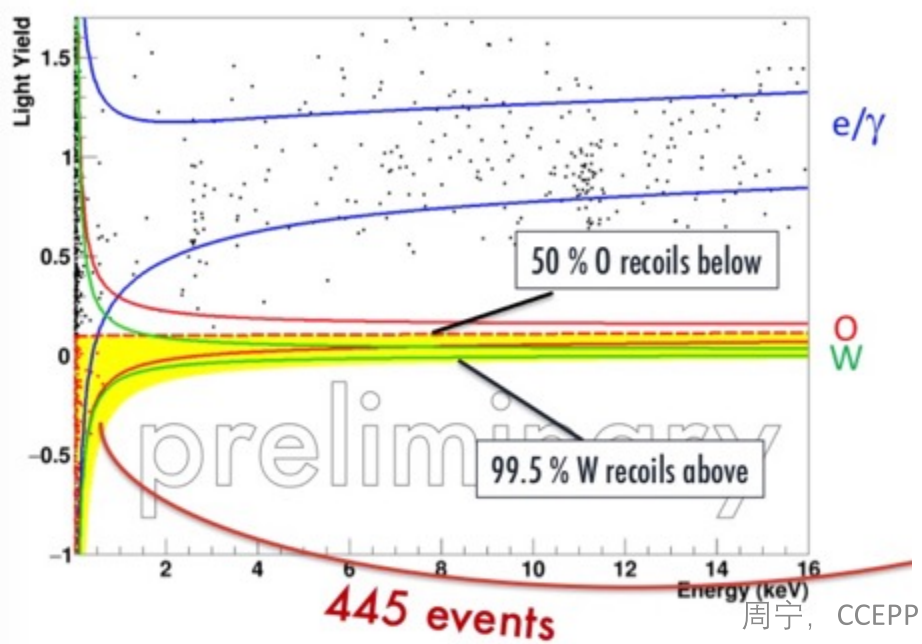
Crystal Detector: CRESST

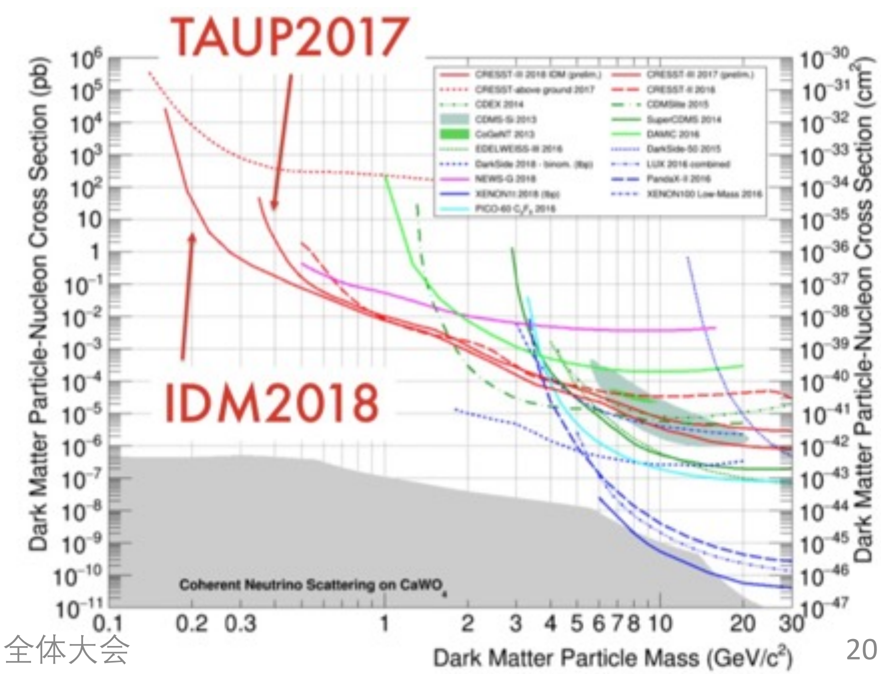
Nuc. Instr. Meth. A 845 (2017) 414-417

- **CRESST-III** experiment
- $CaWO_4$ crystal, 24g, @ ~15mK
  - Phonon signal: precise measurement of deposited energy
  - Scintillation light: particle-type dependent
- Nuclear recoil threshold **30.1 eV** => **subGeV** WIMP

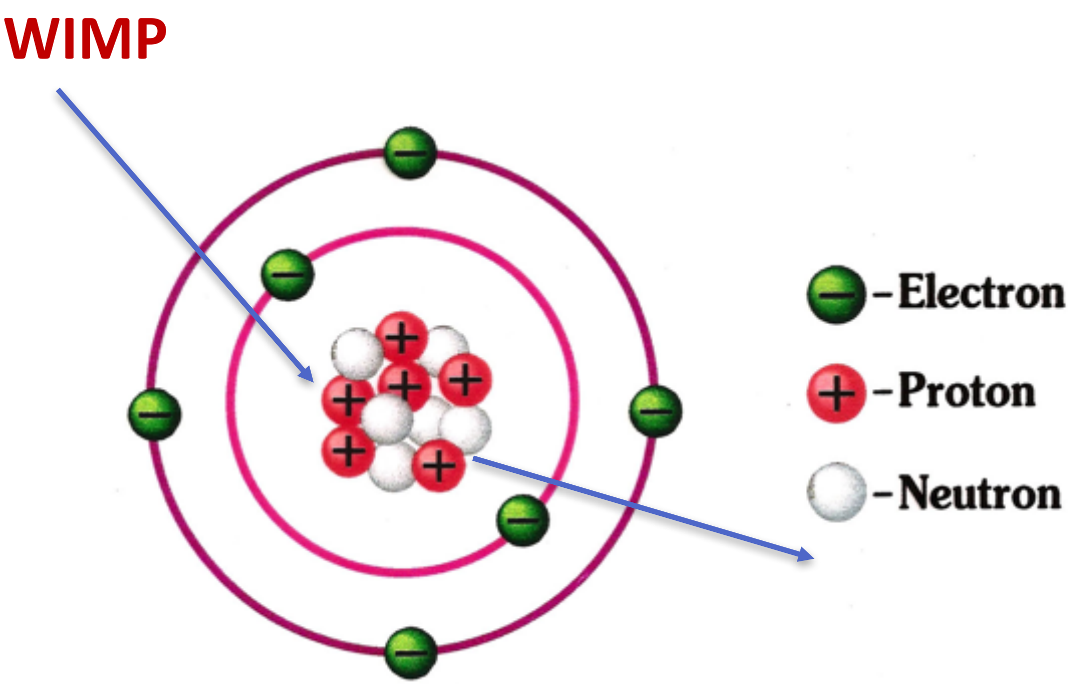


F. Reindl, IDM2018



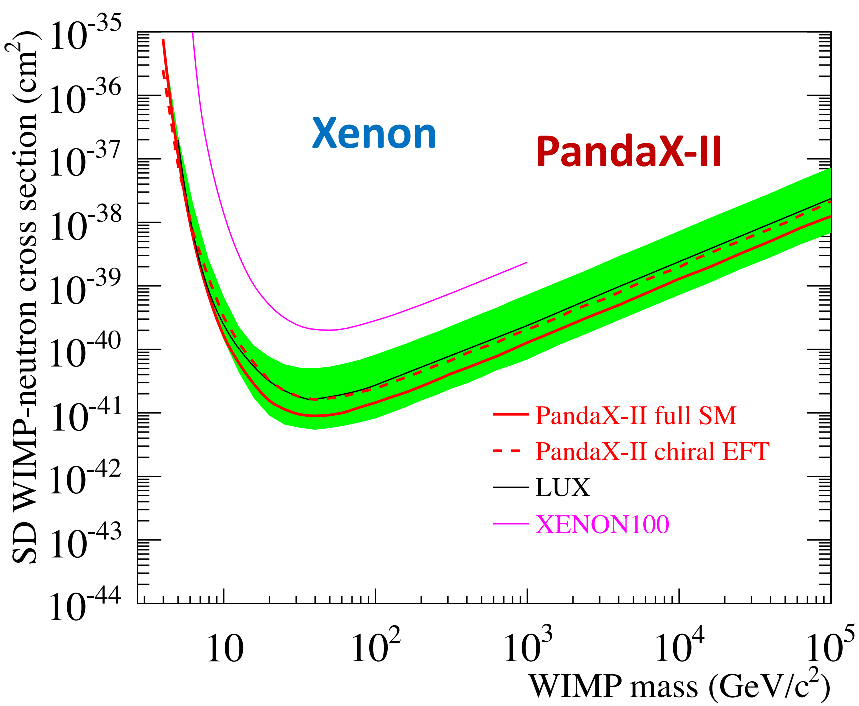


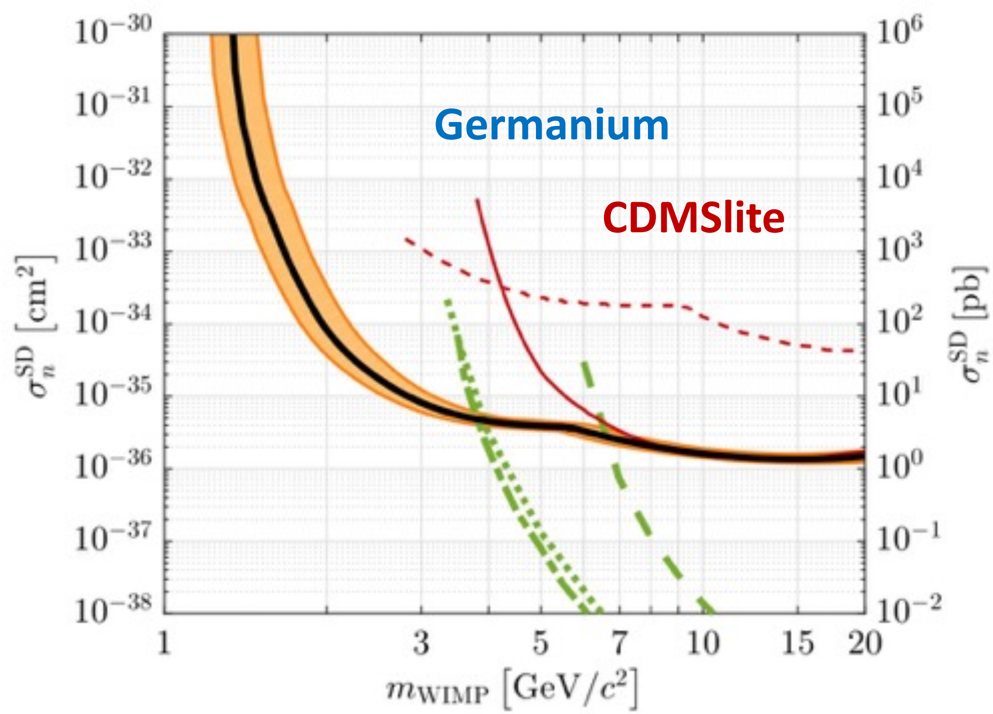
- **Spin-Dependent WIMP-Nucleon Interaction**



Spin-Dependent WIMP-Neutron Interaction

- **Xenon** odd-A isotope with unpaired **neutron** **=> High Mass**
  - Xe129 (26.4%) Spin 1/2
  - Xe131 (21.2%) Spin 3/2
- **Germanium** odd-A with unpaired **neutron** **=> Low Mass**
  - Ge73 (7.73%) Spin 9/2



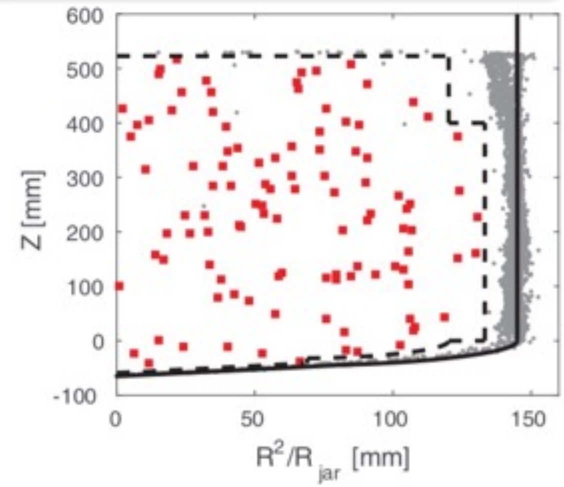


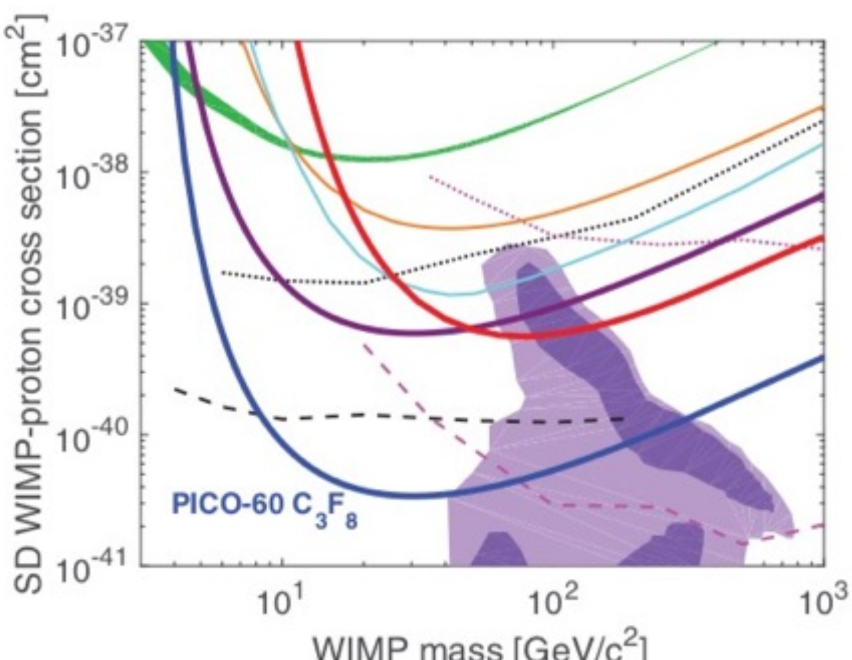
arXiv:1807.01936

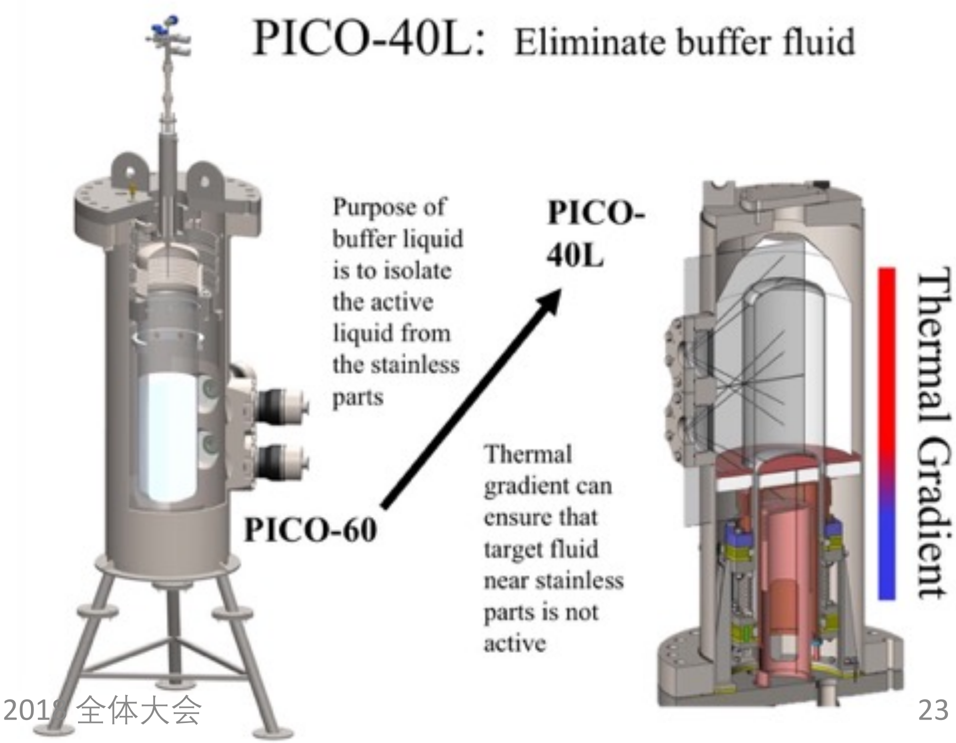
Phys. Rev. D 97, 022002 (2018)

Spin-Dependent WIMP-Proton Interaction

- **PICO-60** experiment with C_3F_8 as the target
  - F19, unpaired **proton**, spin 1/2
  - Bubble chamber with superheated liquid
  - 3.4 x10^{-41} cm^2 at **30 GeV/c²**
- **PICO 40L**, starting ~ December 2018

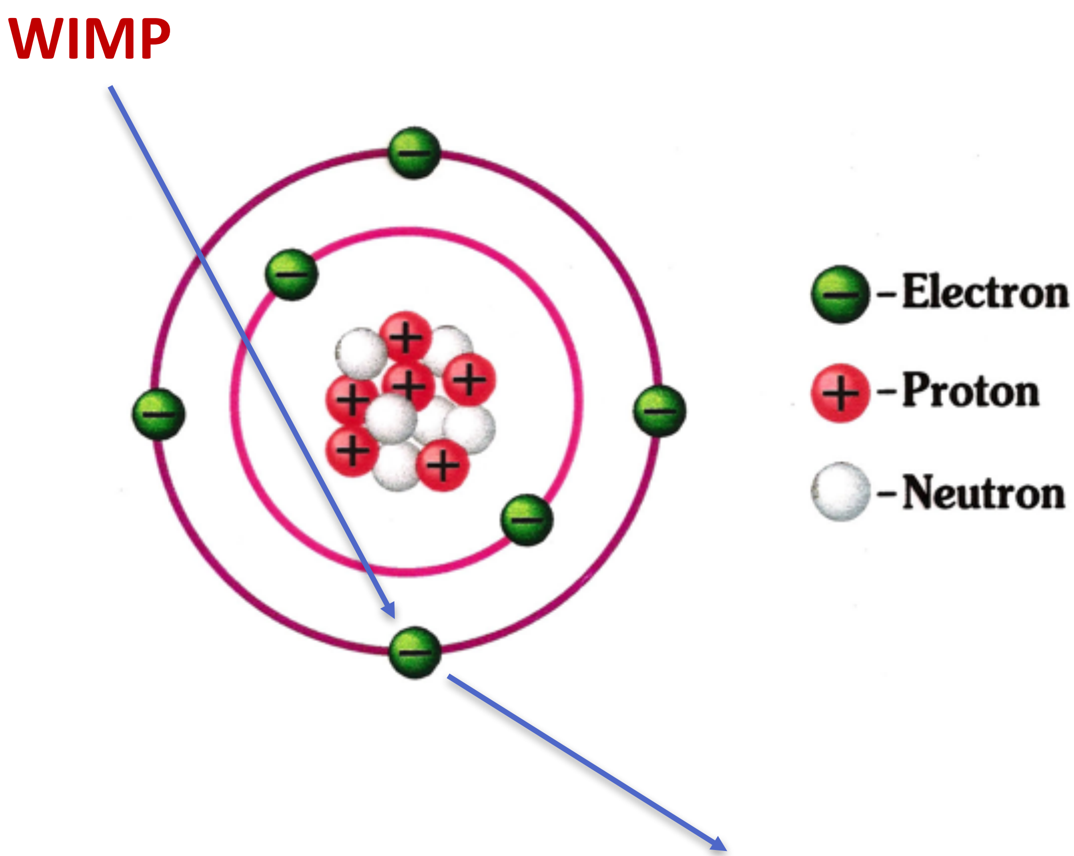






PRL 118 (2017) no.25, 251301

- **WIMP-Electron Interaction**

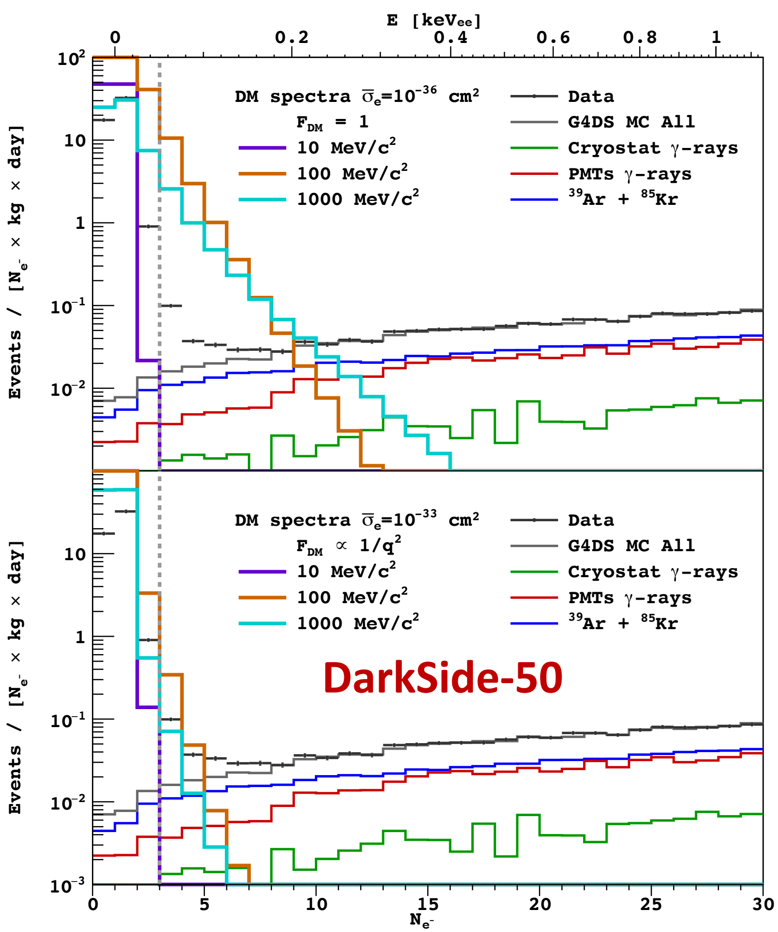


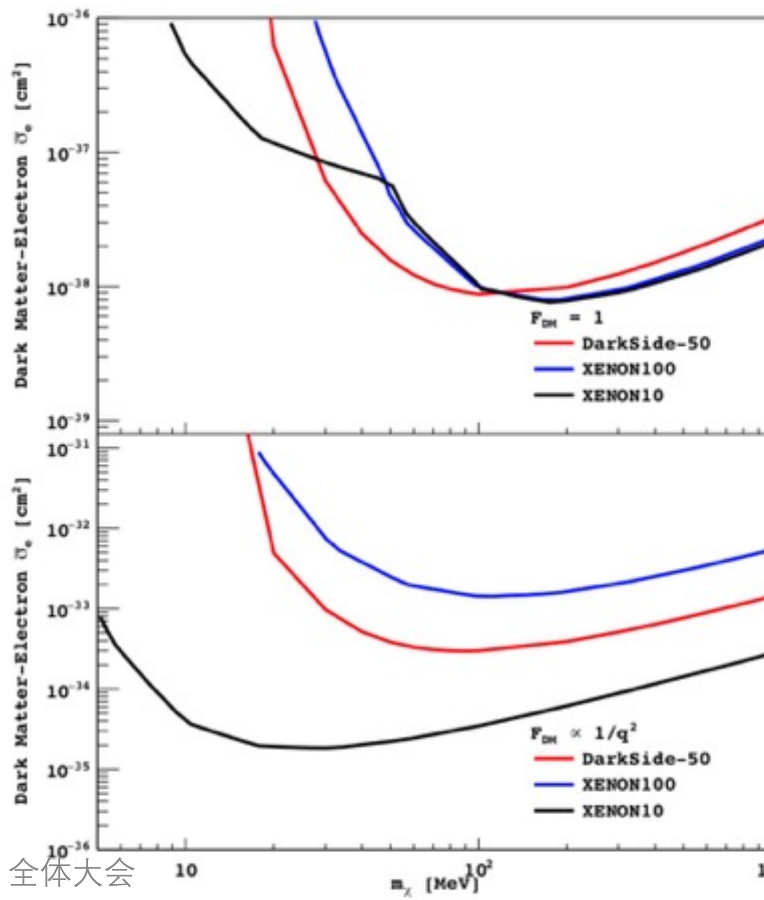
Argon Detector: DarkSide-50

- **S2-only** signal region
  - no ER/NR discrimination
- Threshold N_{e-}=3 ~ **0.05 keVee**

$$F_{\mathrm{DM}}(q) = \frac{{m_{A'}}^2 + \alpha^2 {m_e}^2}{{m_{A'}}^2 + q^2} \simeq \begin{cases} 1, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 {m_e}^2}{q^2}, & m_{A'} \ll \alpha m_e \,, \end{cases}$$

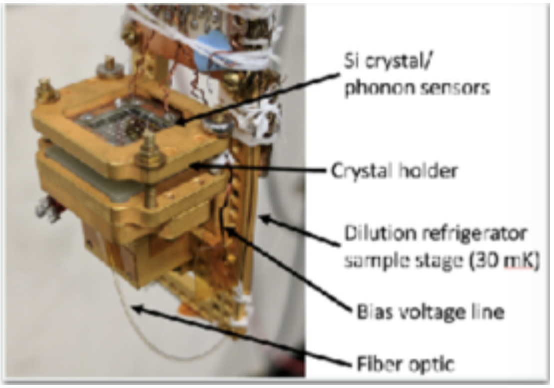
Phys. Rev. Lett. 121, 111303 (2018)

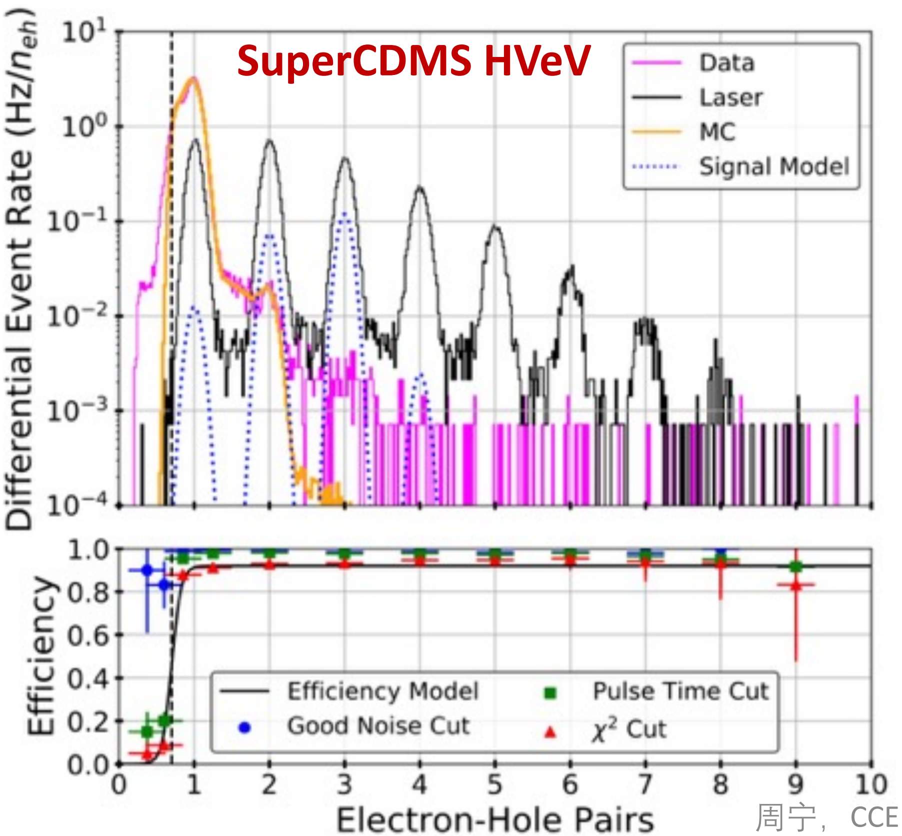


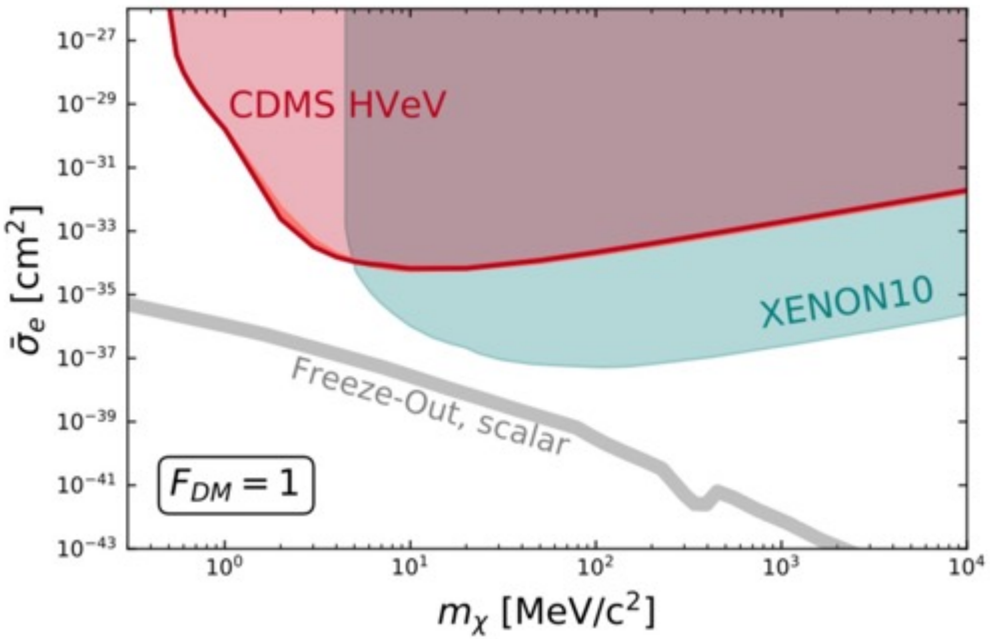


Silicon Detector: SuperCDMS HVeV

- Single-charge sensitive detector
  - Charge resolution: 0.1 electron-hole pairs
- 0.93 g Si crystal (1 x 1 x 0.4 cm3) @ 33-36mK
- 0.49 gram-days





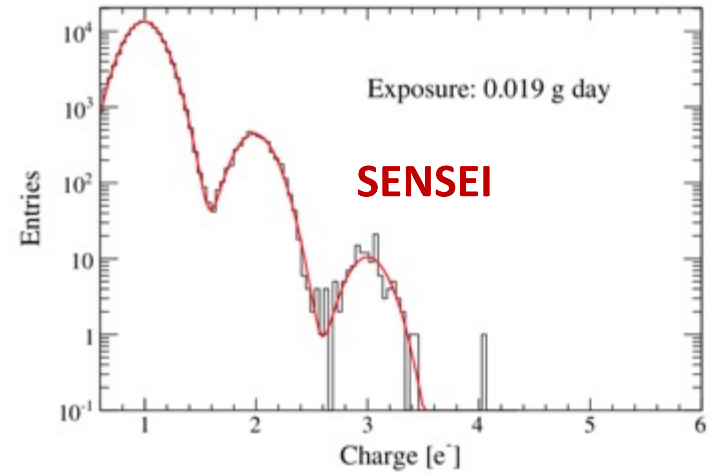


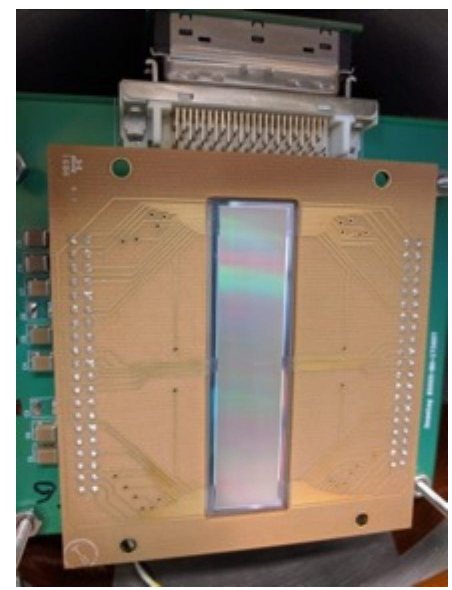
WIMP-electron interaction, heavy mediator

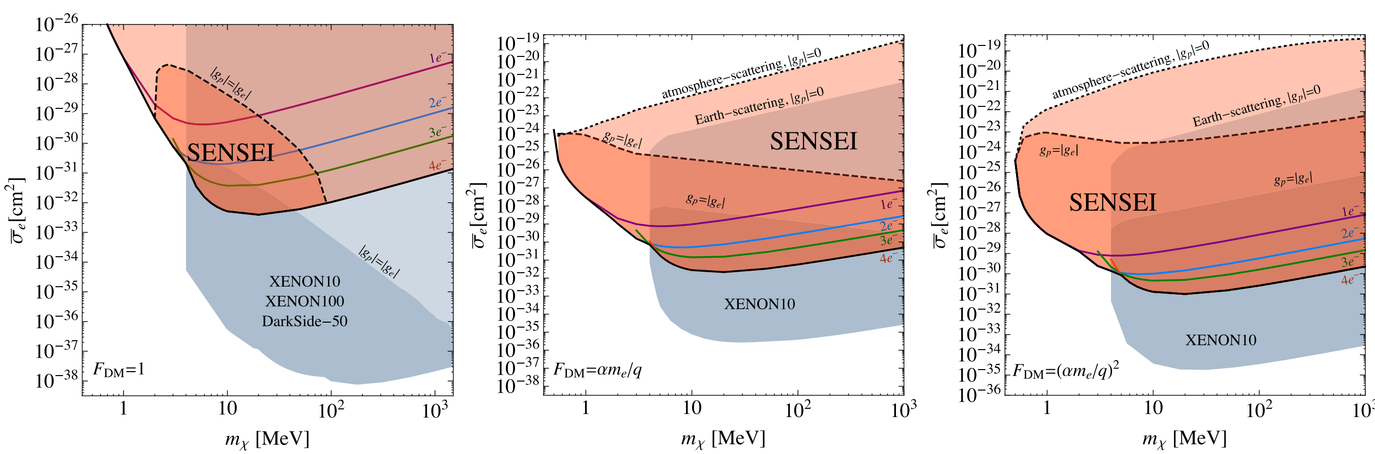
PRL 121, 051301 (2018)

CCD Detector: SENSEI

- A single Skipper-CCD @130K
  - 1.086cmx1.872cm, 0.0947g Si
  - Charge is sampled multiple times
  - Resolution 1e-
- **Above ground**: sensitive to DM that strongly interacts with SM
- 0.019 g day commissioning data
- Probe DM mass down to **500keV**

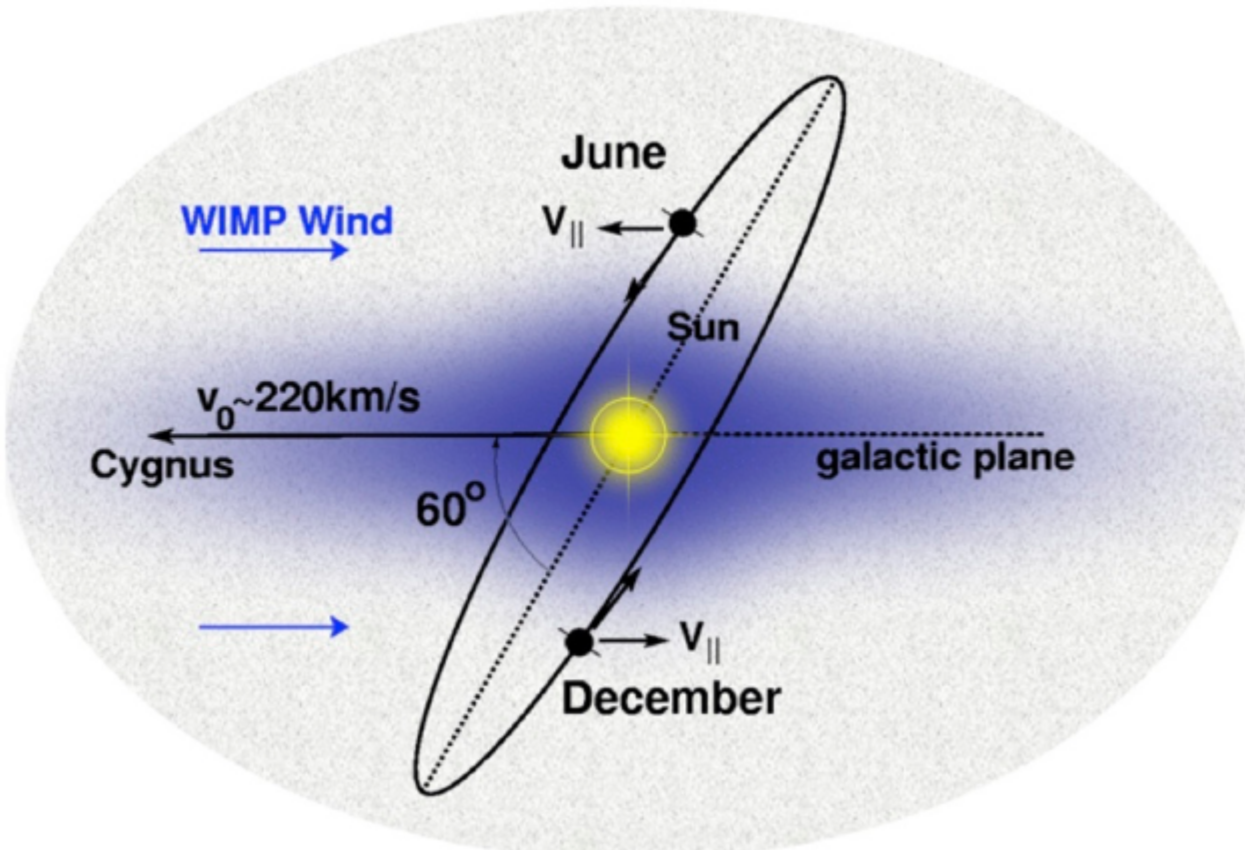






PRL 121, 061803 (2018)

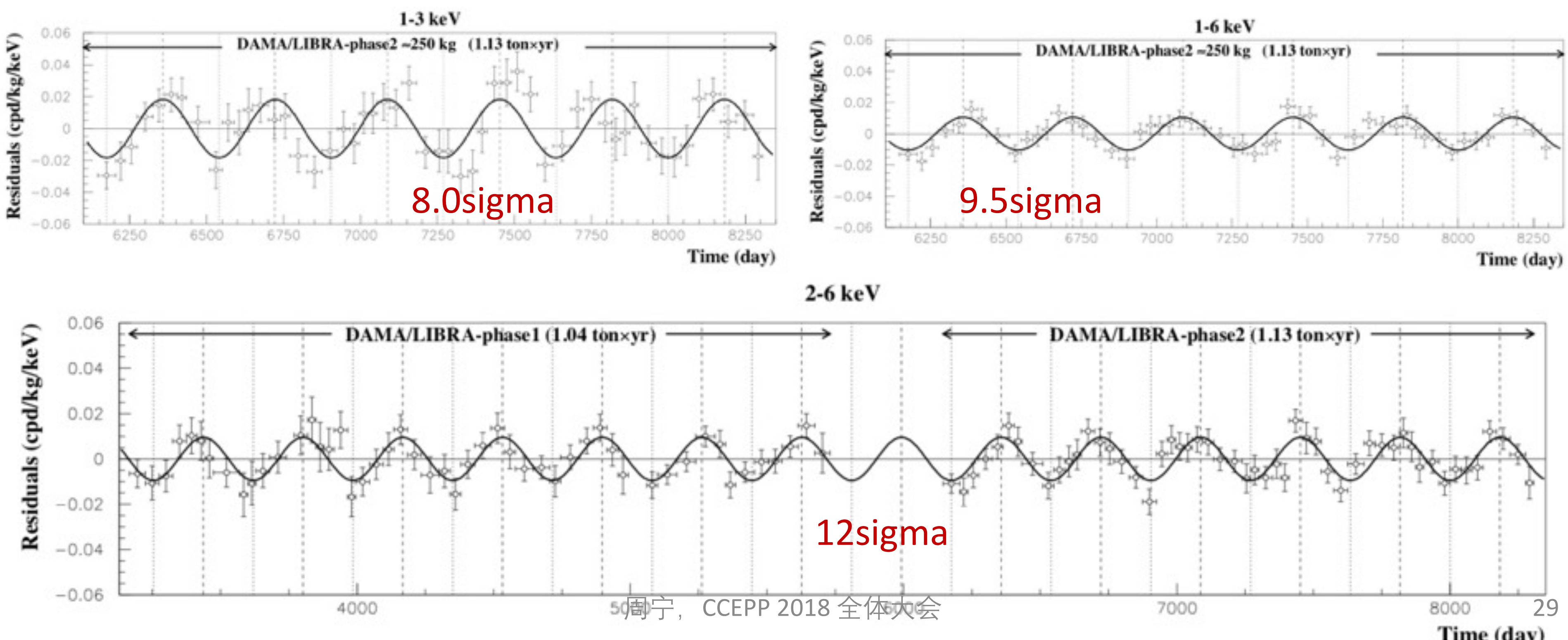
- **DAMA/LIBRA Anomaly**



DAMA/LIBRA

arXiv:1805.10486

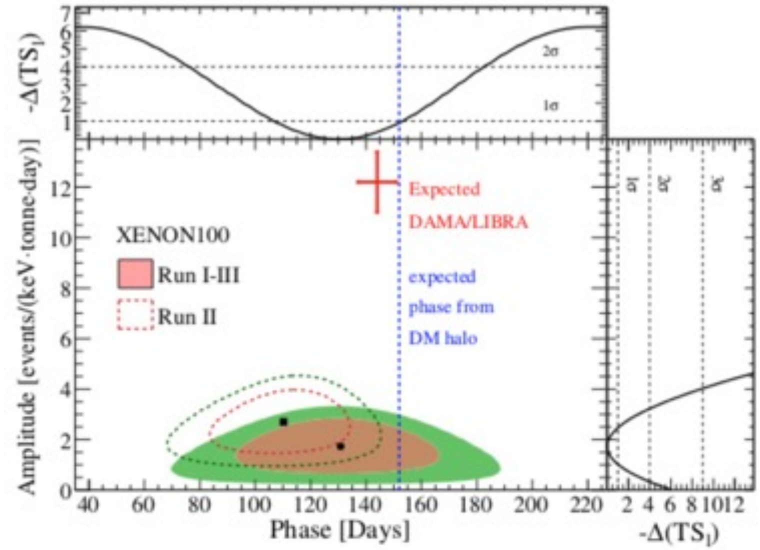
- **DAMA/LIBRA-phase2**
  - NaI (Tl) 250 kg, 6 annual cycles, 1.13 ton-year, light collection
- The only experiment claiming signal with > 5 sigma
  - 50 GeV with 7×10^{-6} pb or 6-16 GeV with 2×10^{-4} pb
- Not confirmed by experiments with other targets

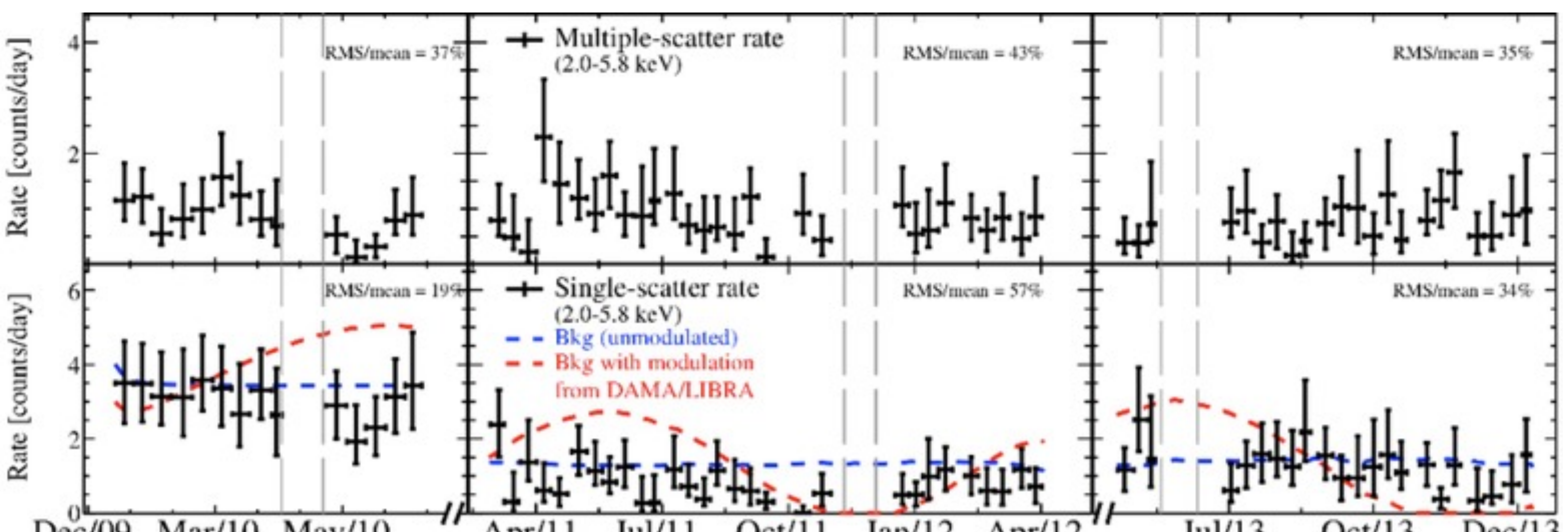


WIMP-Electron Annual Modulation

- 4-year exposure in **XENON100**
- Weak modulation signature at a period of 431 days in low energy SS events
- Not compatible with DAMA modulation

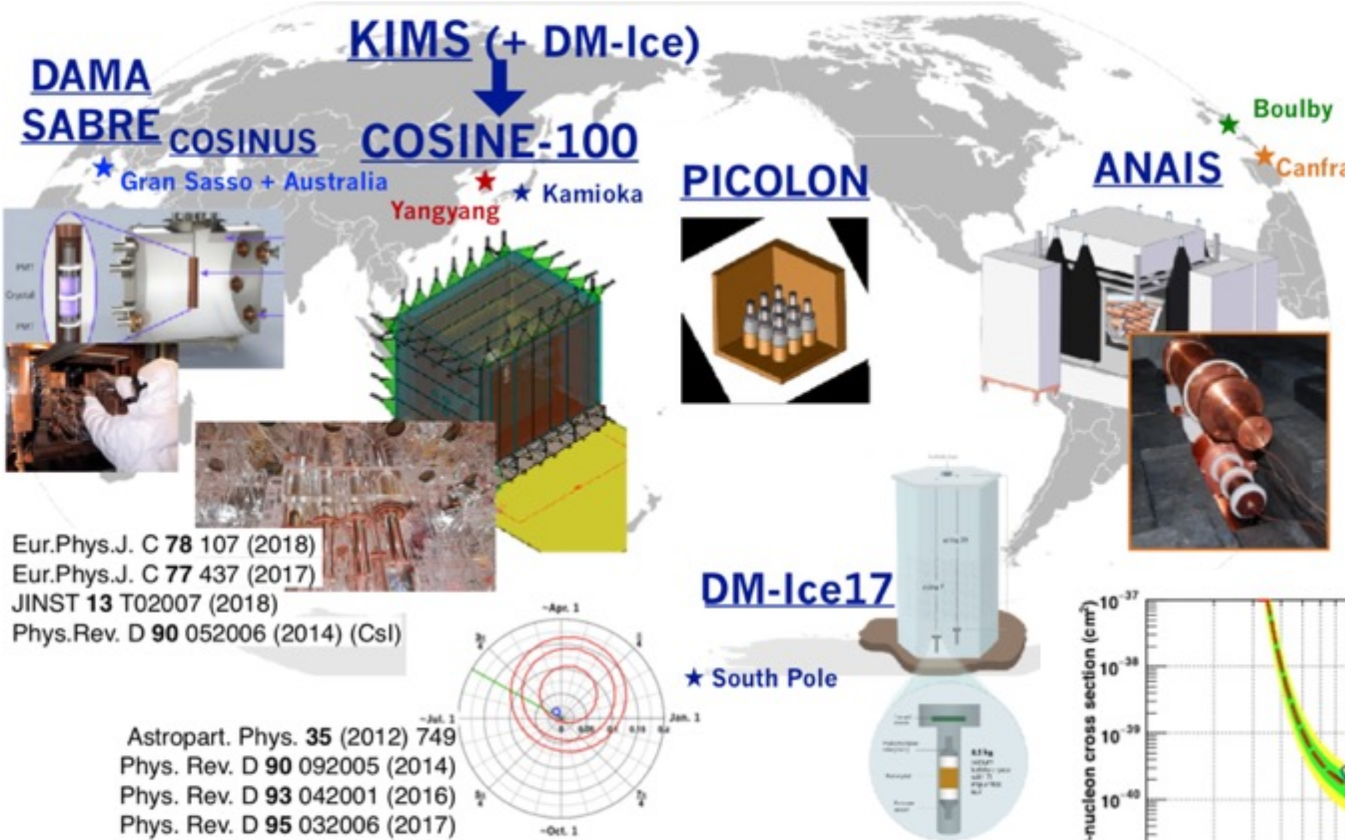
PRL 118, 101101 (2017)



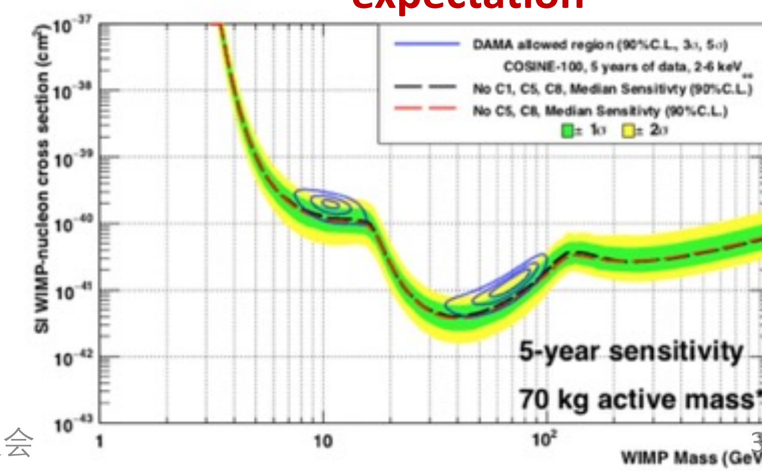


Other NaI Experiments

- SABRE, COSINE, DM-ICE, KIMS and ANAIS, etc
- Stay tuned!

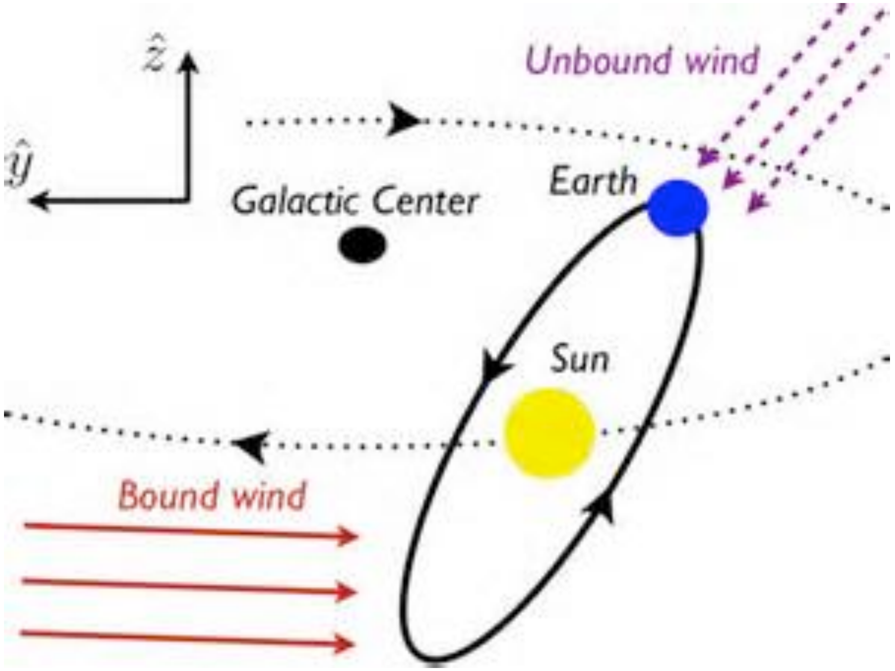


COSINE-100 5-year expectation

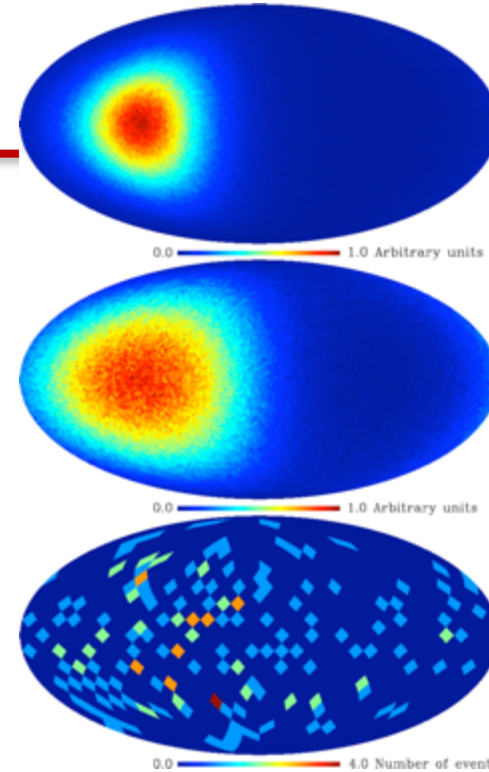


From Reina Maruyama's talk at CIPANP 2018

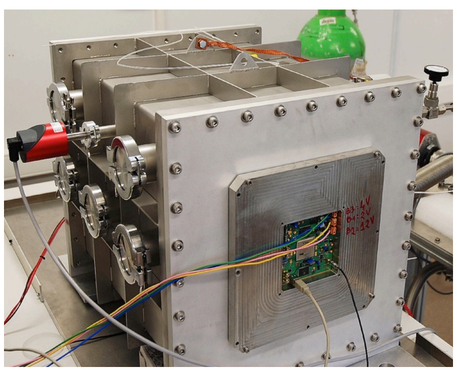
- **Directional Direct Search**



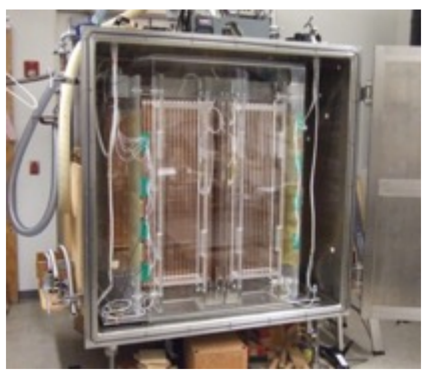
Directional Direct Search



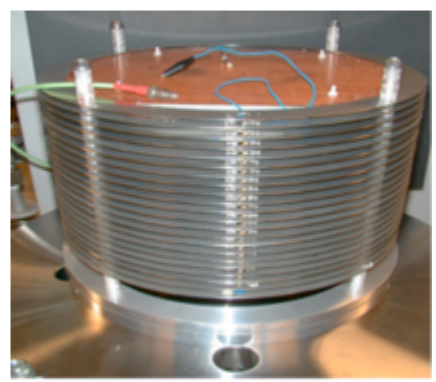
- Directionality:
  - Cygnus direction
  - Can help with neutrino floor!
  - 30deg angular resolution necessary to distinguish Cygnus from Sun
- To reconstruct the recoil track
- R&D work in progress



MIMAC
Micromegas



DRIFT
Negative ion MWPC



DMTPC
CCD

NEWAGE
Micro pixel

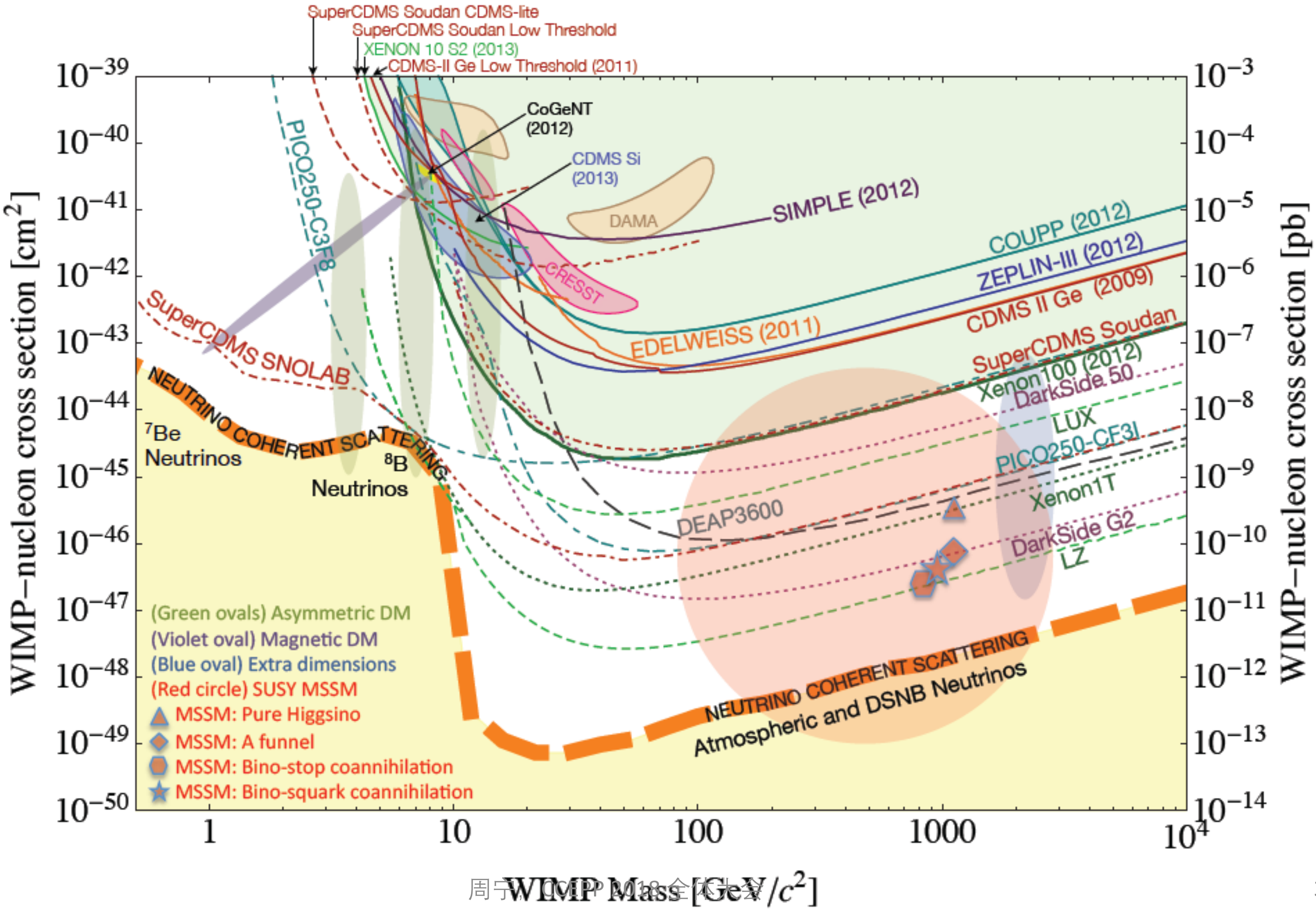
Summary

- World-wide efforts in the dark matter direct detection
- A large variety of techniques and targets
- No compelling positive results are obtained yet. DAMA’s anomaly is under further cross-check
- Within ~10 years, we may be able to reach the neutrino floor
- Stay tuned!

THANK YOU!

Backup

-



SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
CRESST
PICO250-C3F8
SuperCDMS SNOLAB
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
DEAP3600
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c2]