# Direct Detection of Dark Matter

**Hyun Su Lee**

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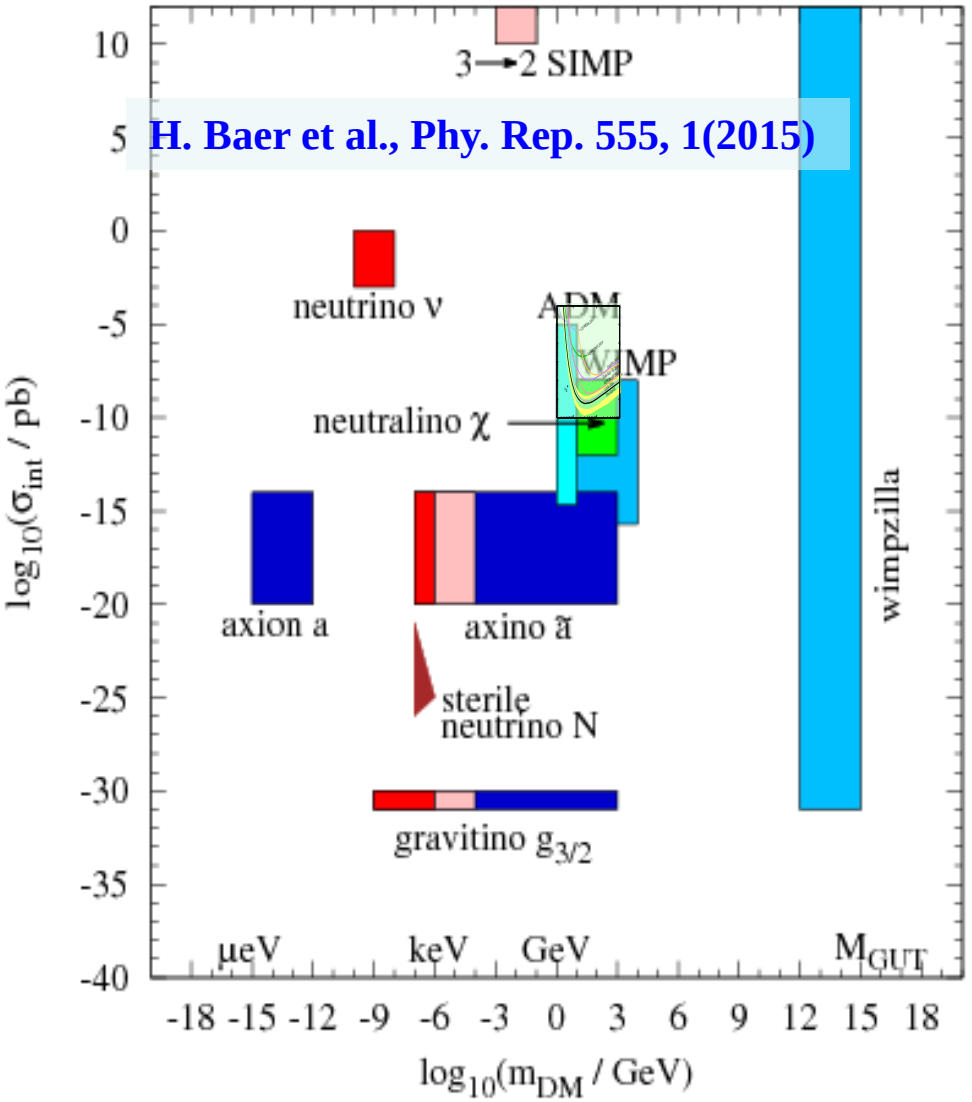
Institute for Basic Science (IBS)

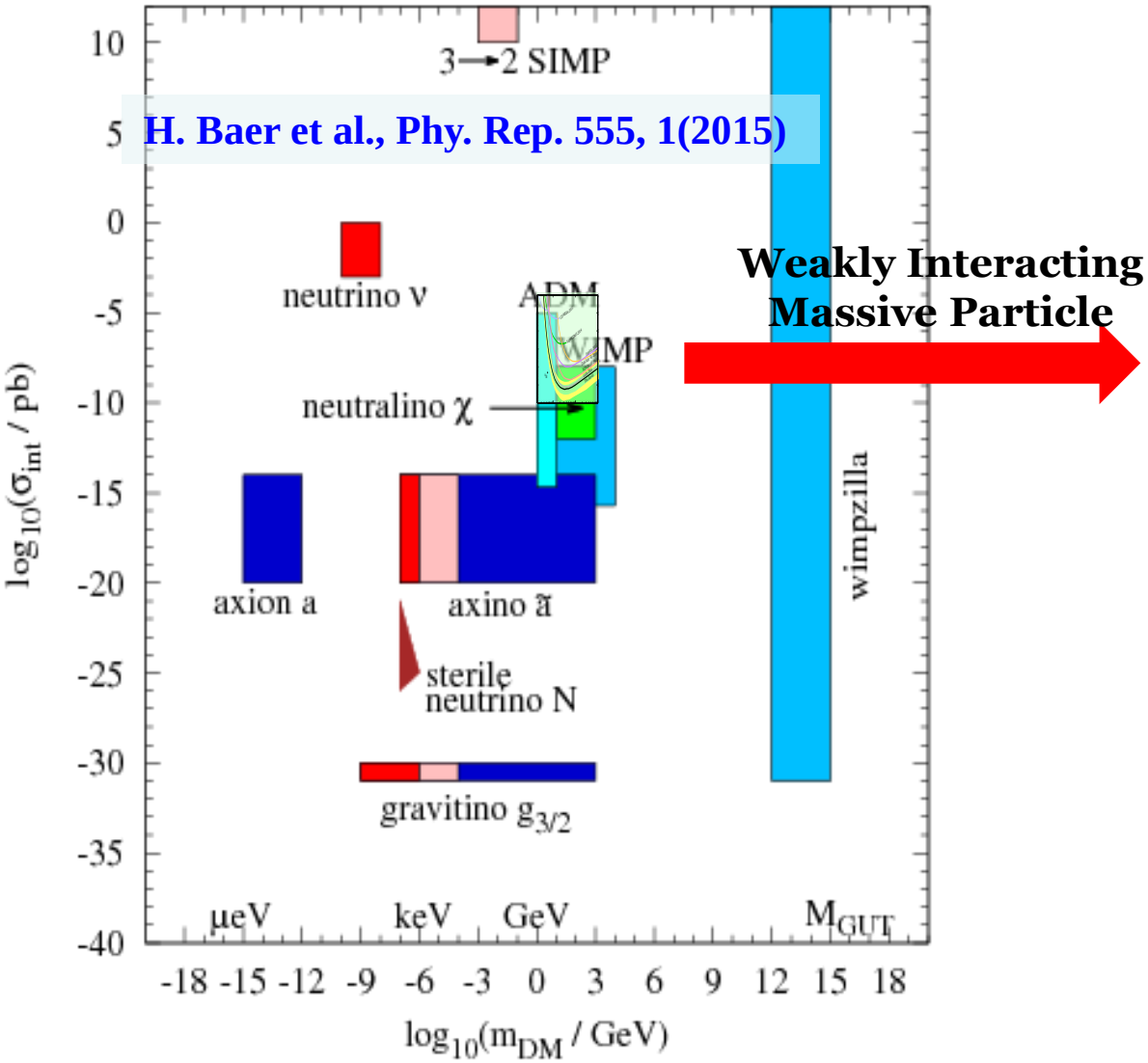
ICHEP2018 @ Seoul

# Scope

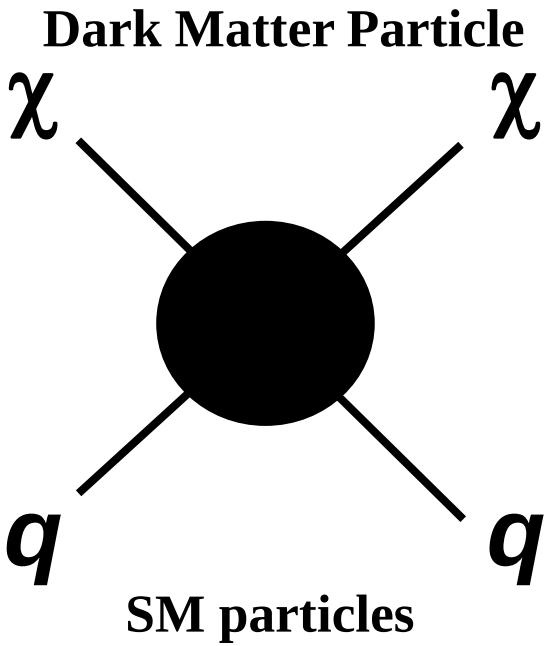



**Many candidates in many orders of magnitude of mass.**

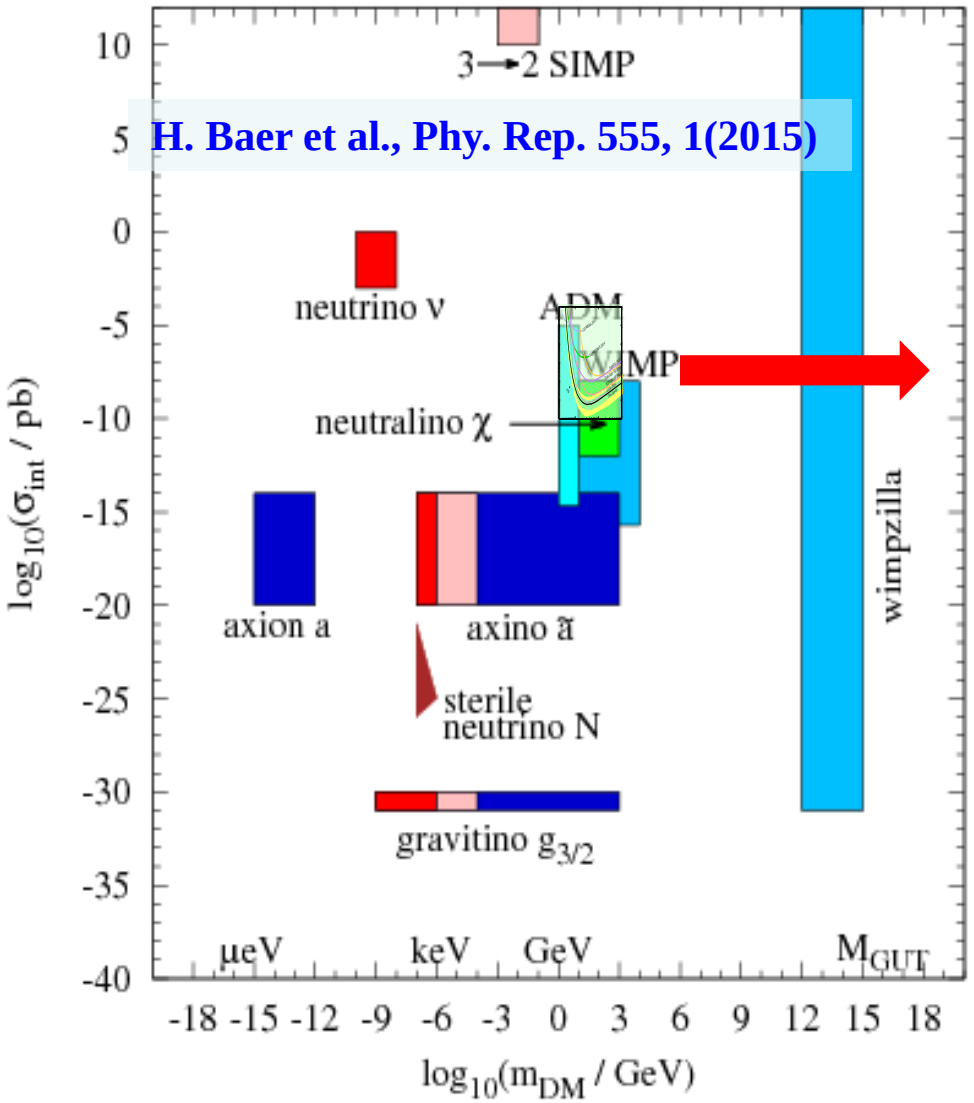
# Scope : WIMP

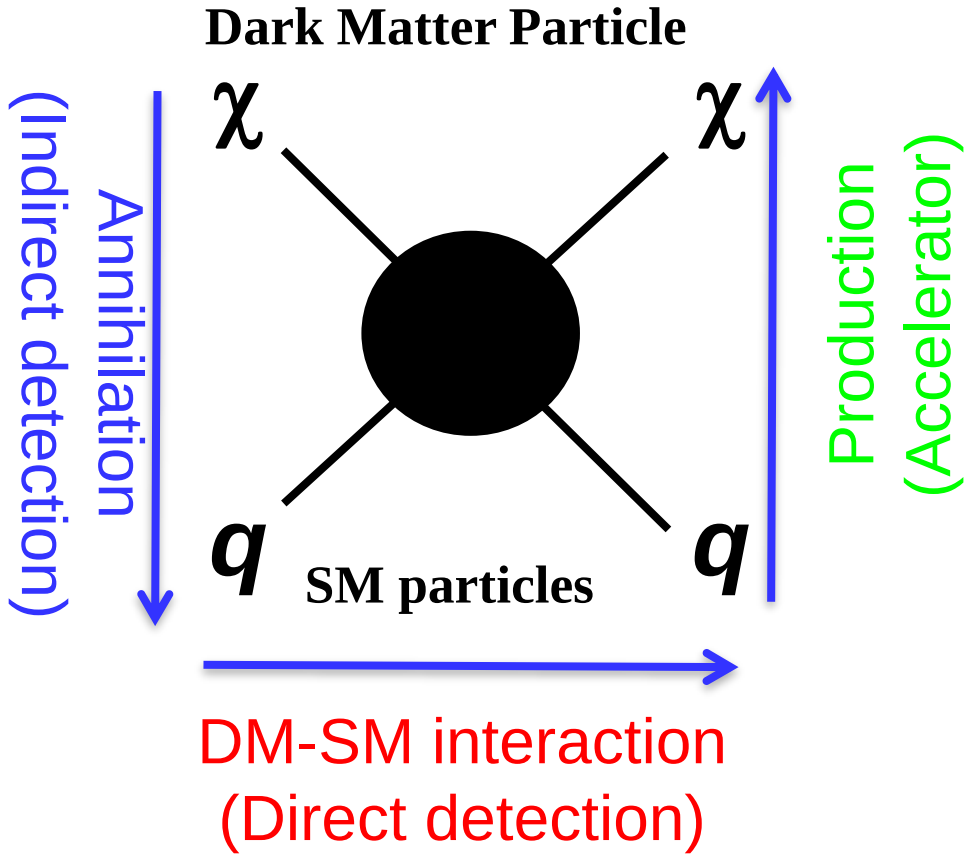



**Weakly Interacting Massive Particle**

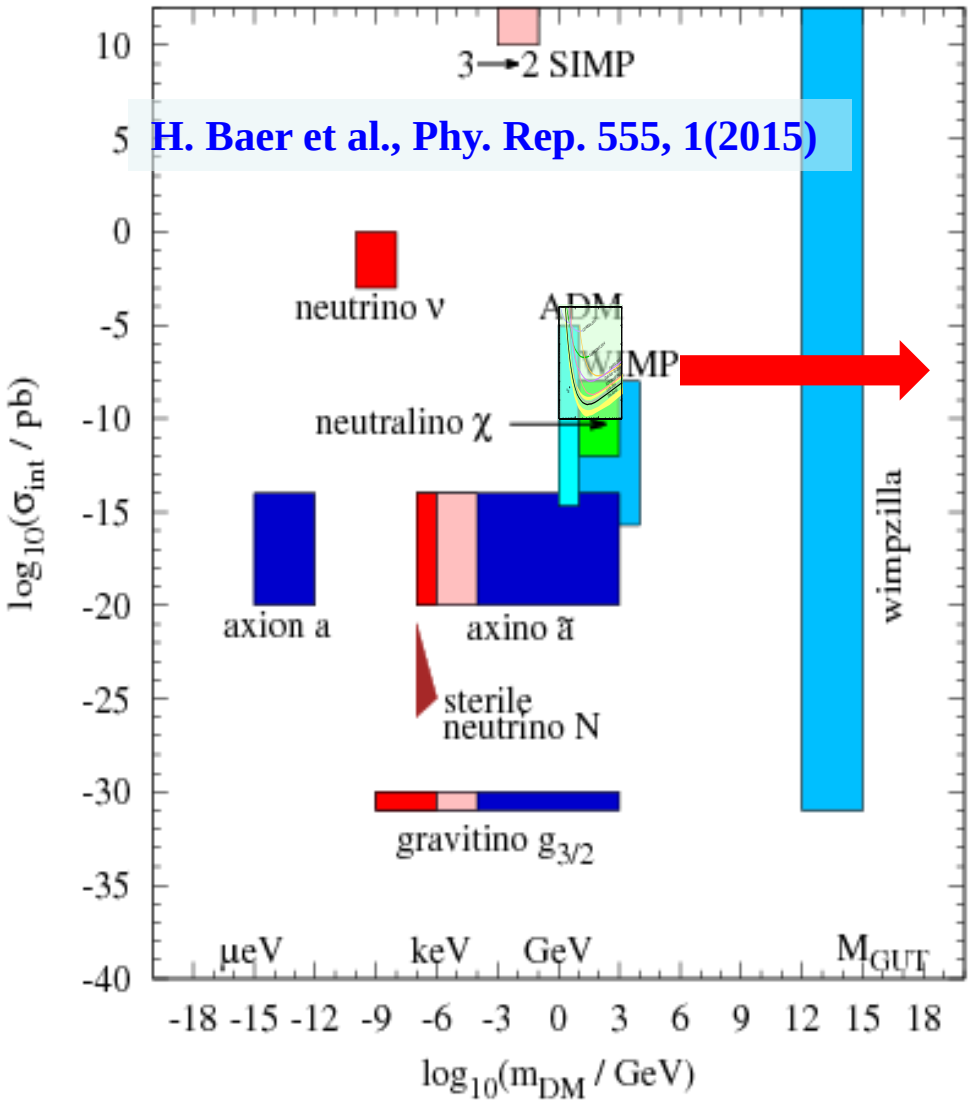


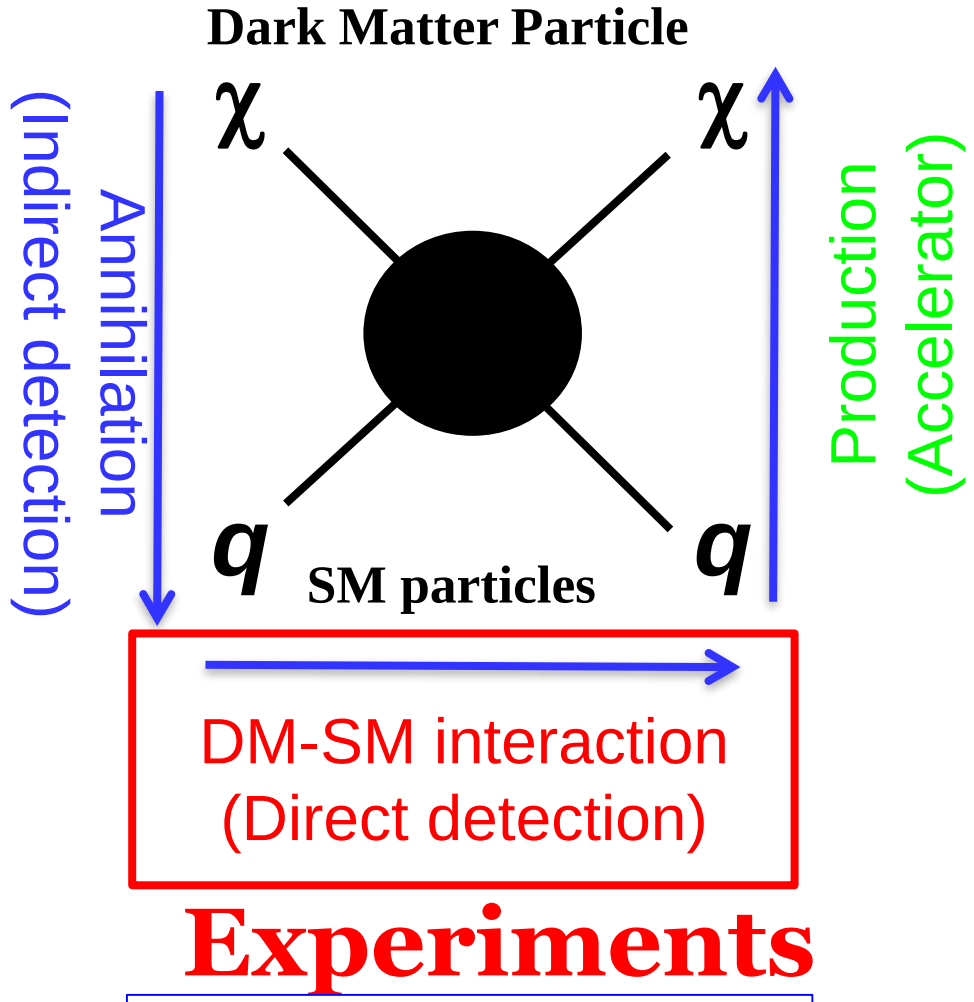
# Scope : WIMP Direct detection



# Scope : WIMP Direct detection experiments



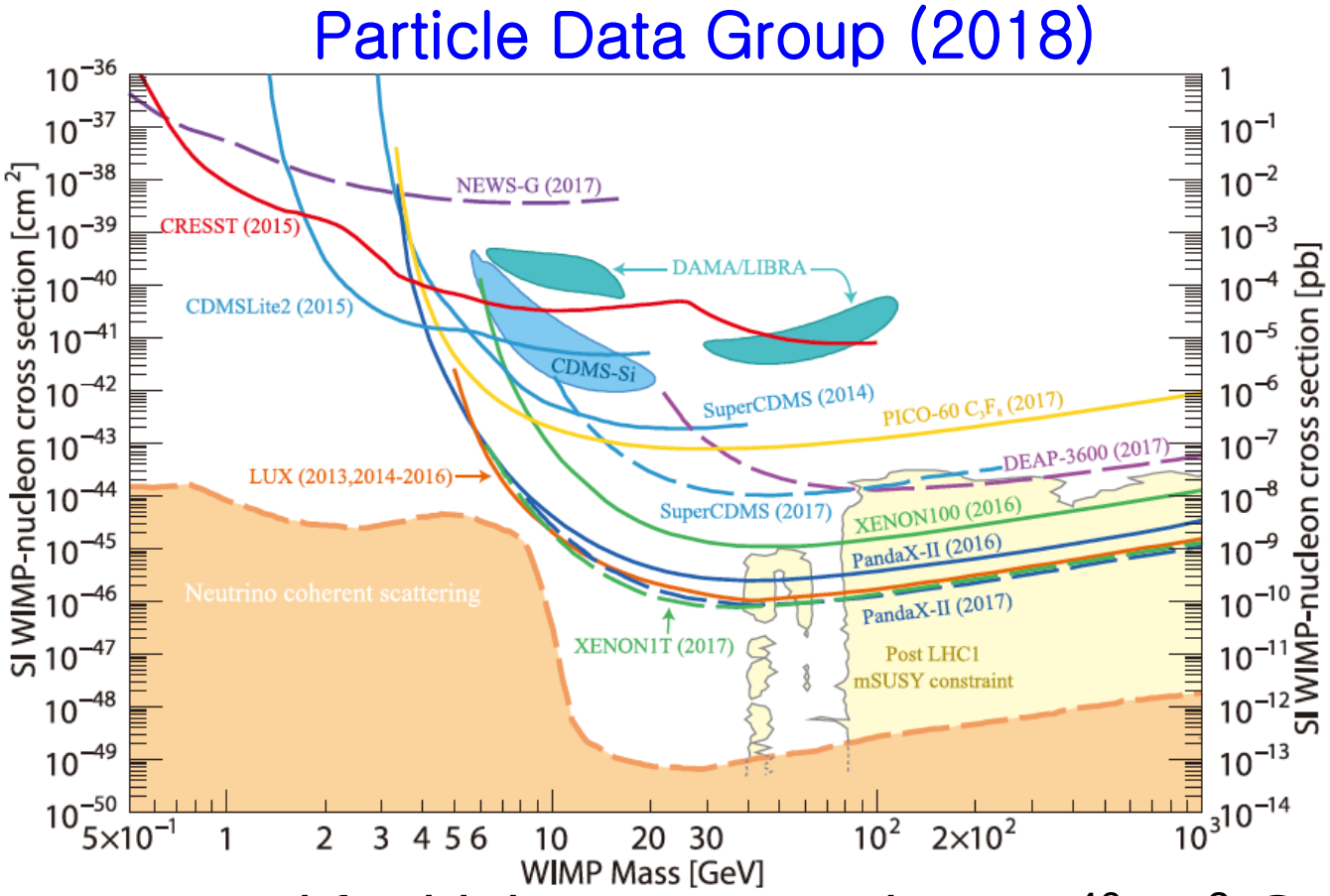

**Experiments**

Only a few...

Do not cover light dark matter, directional detectors..

**Apologize**

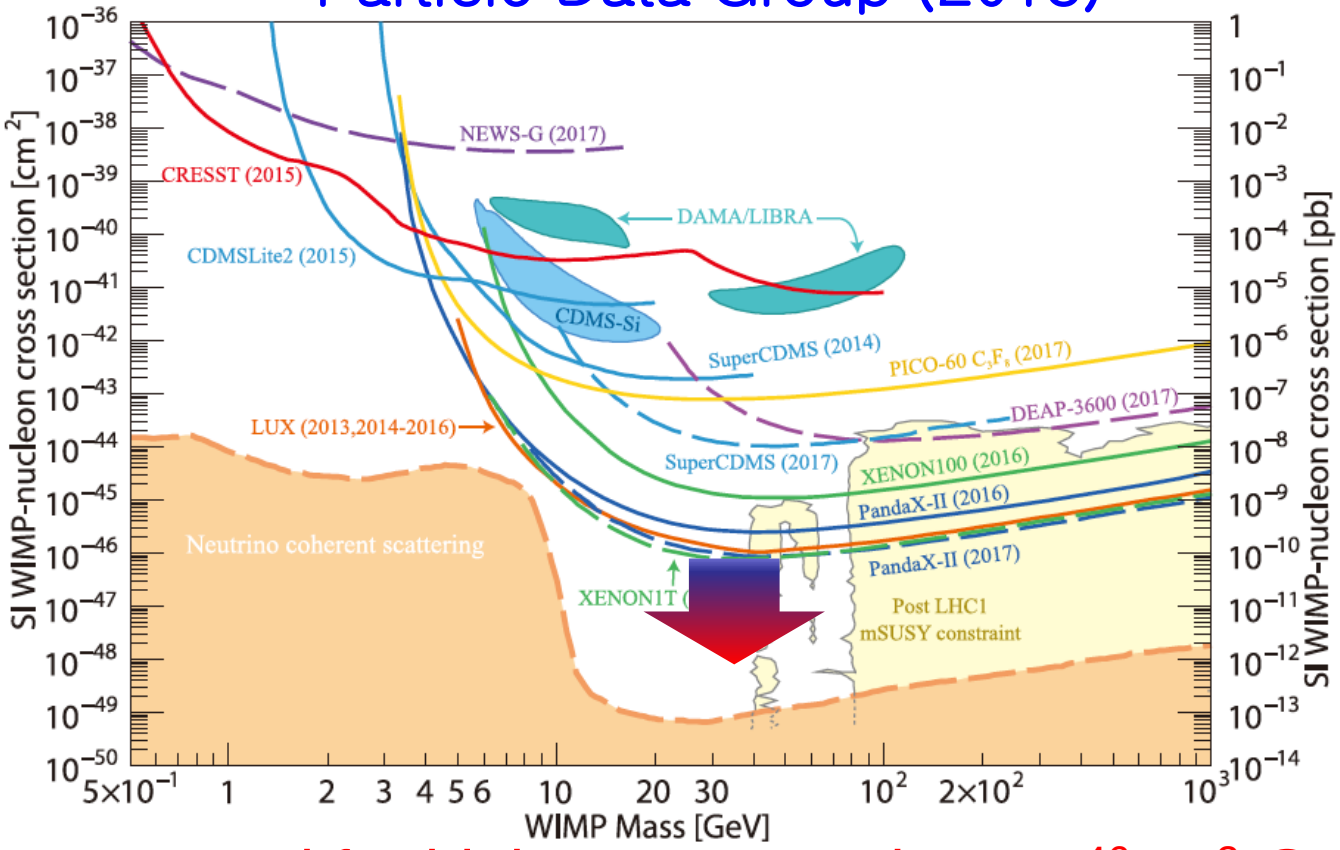
# Current status of direct dark matter searches




- Well progressed for high mass search to$10^{-46}$cm$^2$ @ 50 GeV
- Exploring low-mass dark matter
- Unresolved signal from DAMA

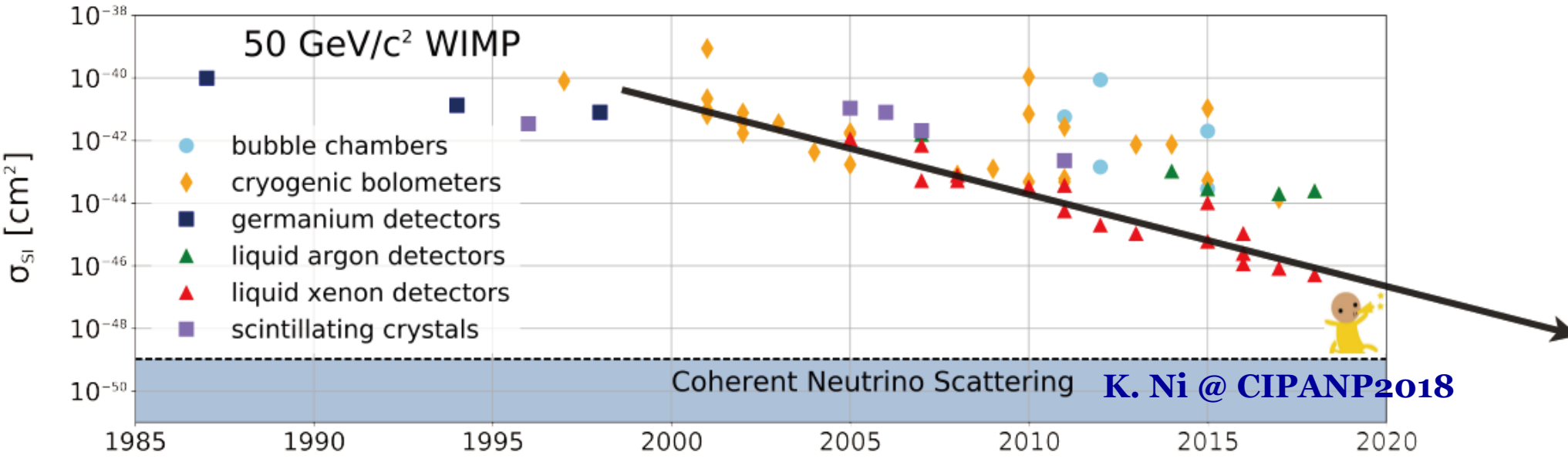
# High Mass Search

## Particle Data Group (2018)



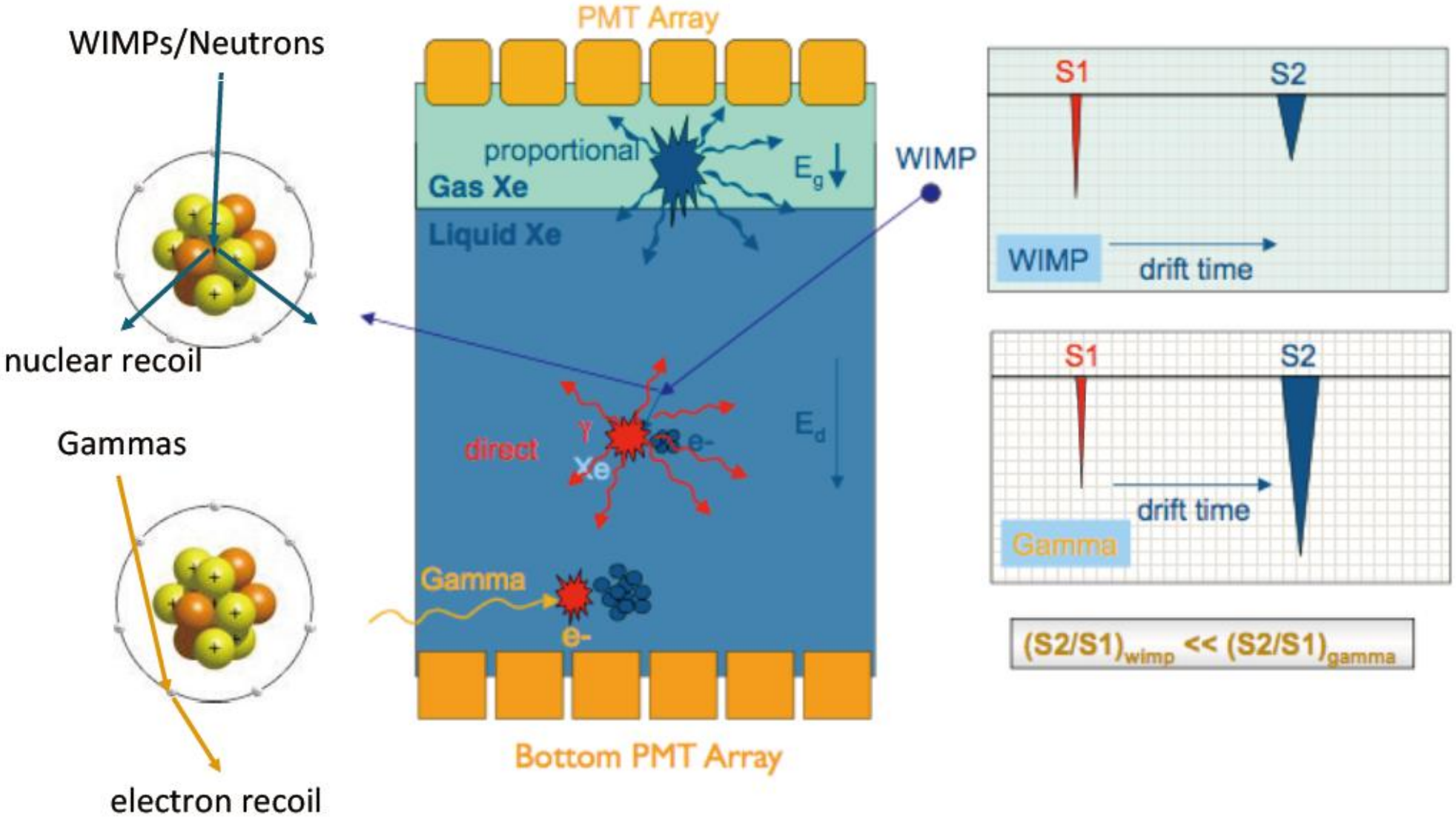

- Well progressed for high mass search to$10^{-46}$cm$^2$ @ 50 GeV
- Exploring low-mass dark matter
- Unresolved signal from DAMA

# Moore's Law in dark matter search

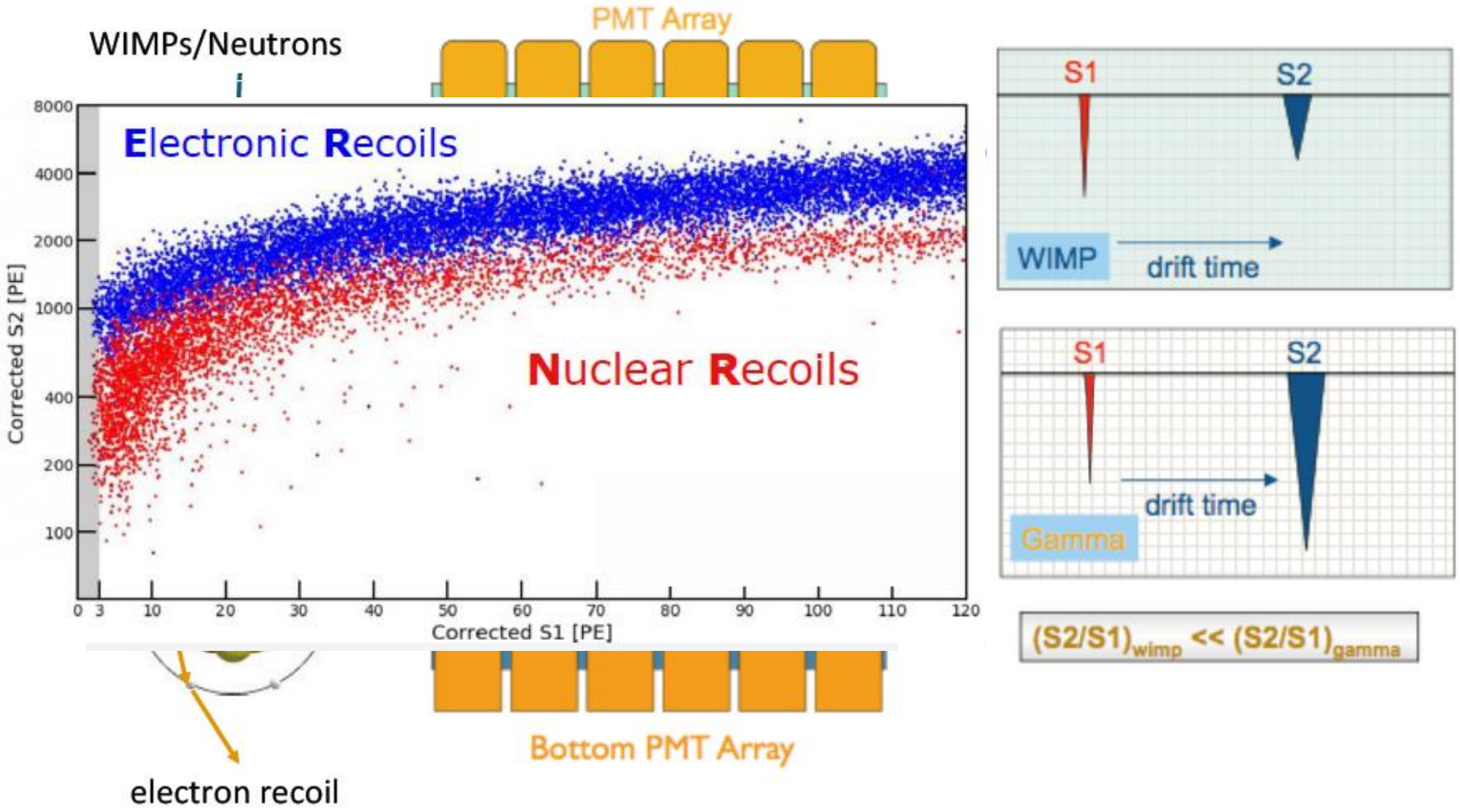



- Rapid progress
- Detector sensitivities improved about 5 order of magnitude during last 20 years
- Current best limits are given by liquid xenon TPC detector

# Dual phase Liquid TPC

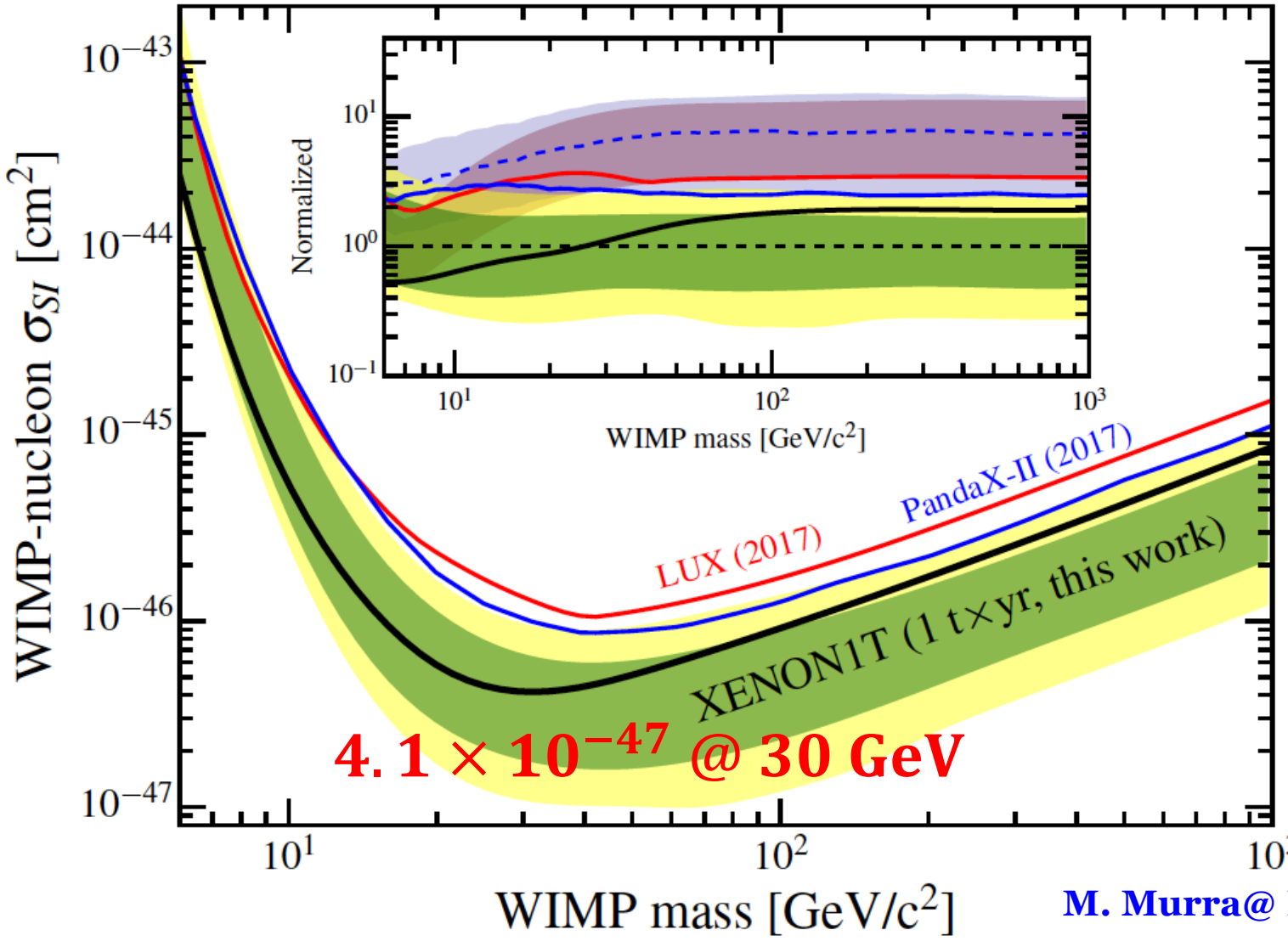


# Dual phase Liquid TPC



# Latest XENON1T result (1 ton-years)

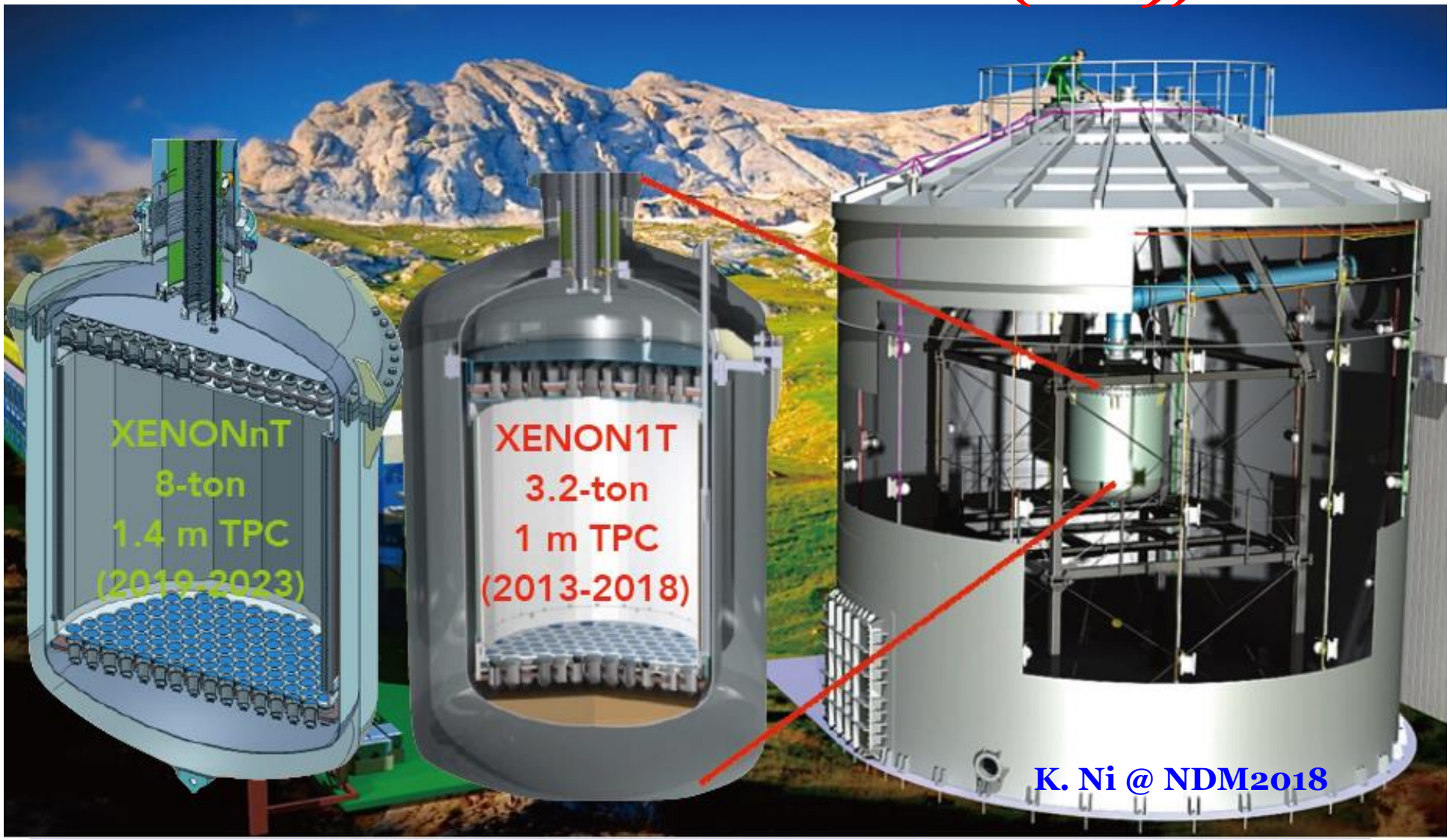
**arXiv:1805.12562**




**M. Murra@ ICHEP2018**

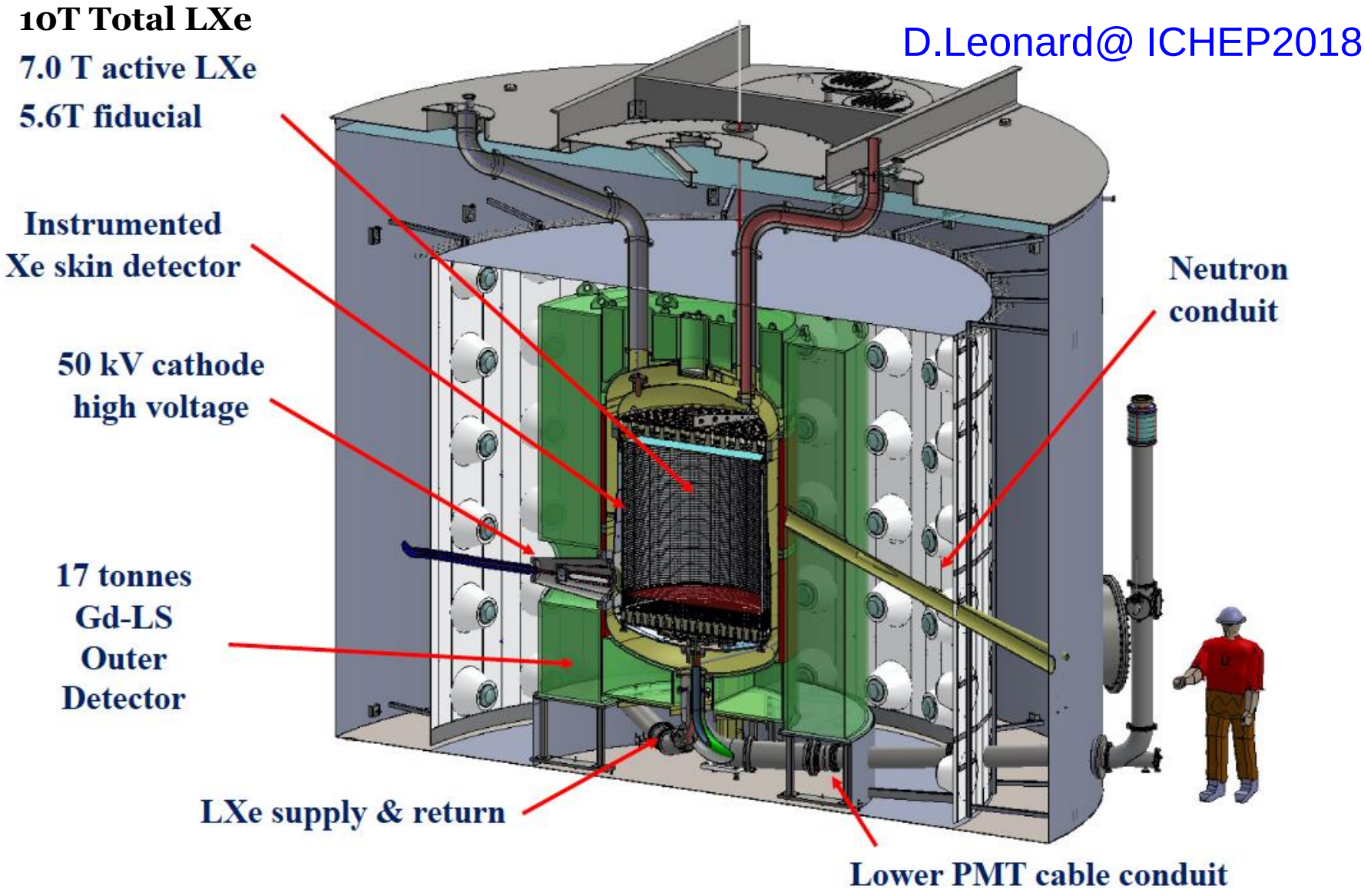
# Future : XENONnT

## XENON1T→XENONnT (2019)



# Future : LZ

D.Leonard@ ICHEP2018



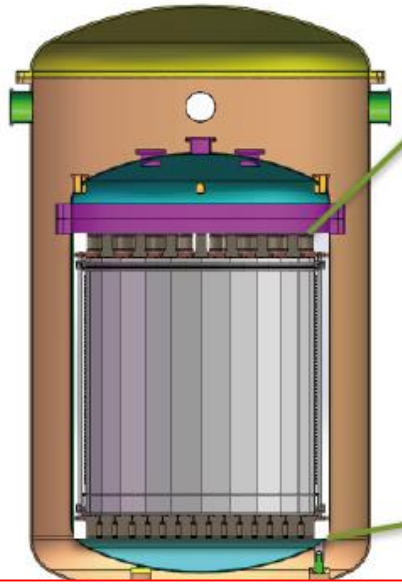
# Future : LZ

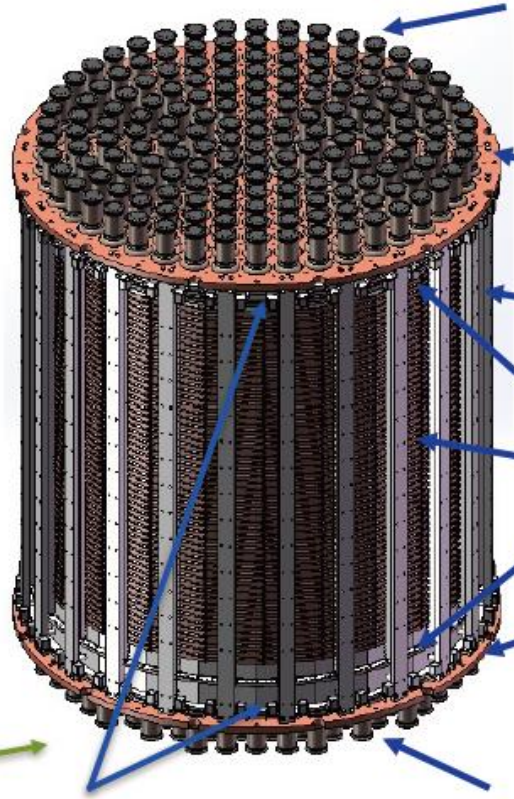



**Ready for operations**
**: 2020 Spring**

# Future : PandaX-4T

- Design goal:
  - High signal collection efficiency
  - Uniform *E* field in a large volume
  - Veto facility





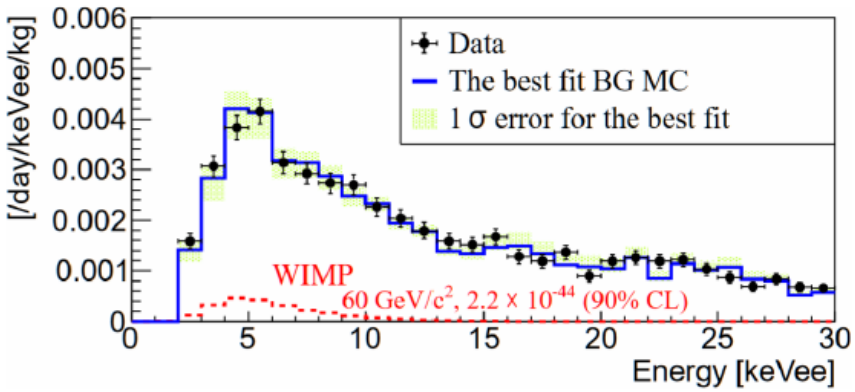

**Assembly & Commissioning: 2019-2020**

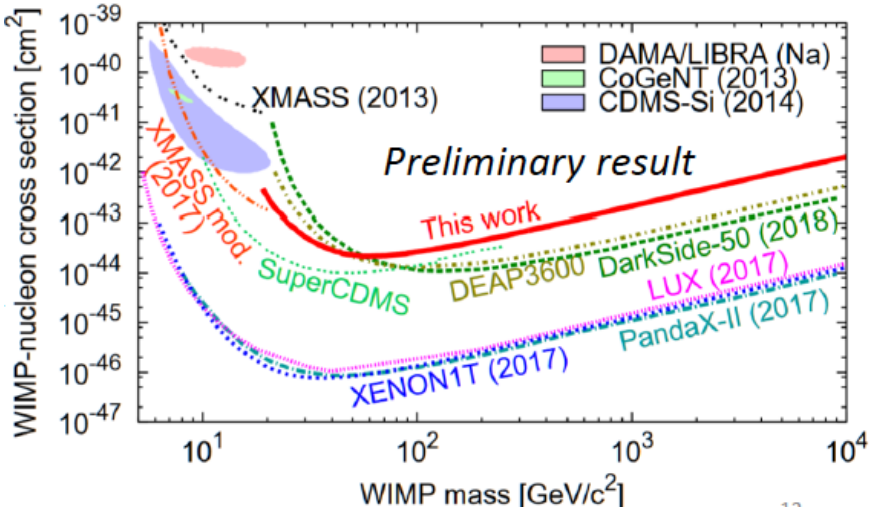
N. Zhou@ ICHEP2018

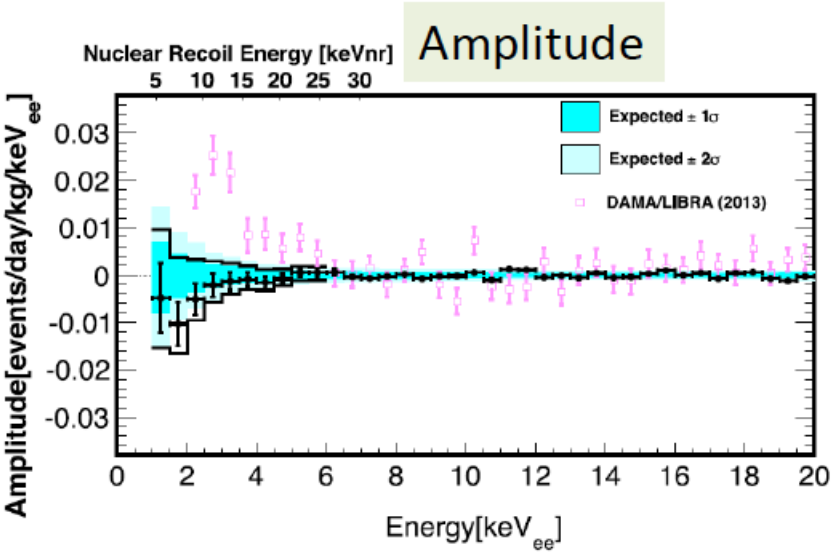
# XMASS

- Single phase liquid Xe detector, more than 4.5 year data

**arXiv:1804.02180**



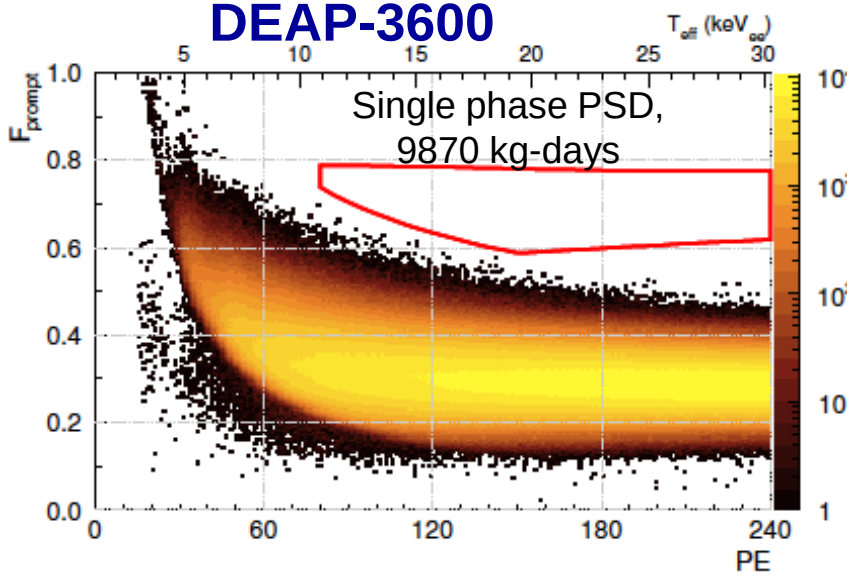

| Experiments | Amplitude(events/day/kg/keV$_{ee}$) |
|---|---|
| DAMA/LIBRA | ~0.02 at 2.0-3.5keV$_{ee}$ |
| XENON100 | 1.67±0.73 x 10$^{-3}$ at 2.0-5.8keV$_{ee}$ |
| XMASS | <(1.3-3.2) x 10$^{-3}$ at 2-6keV$_{ee}$ |

K. Kobayashi@ ICHEP2018

# Liquid Ar

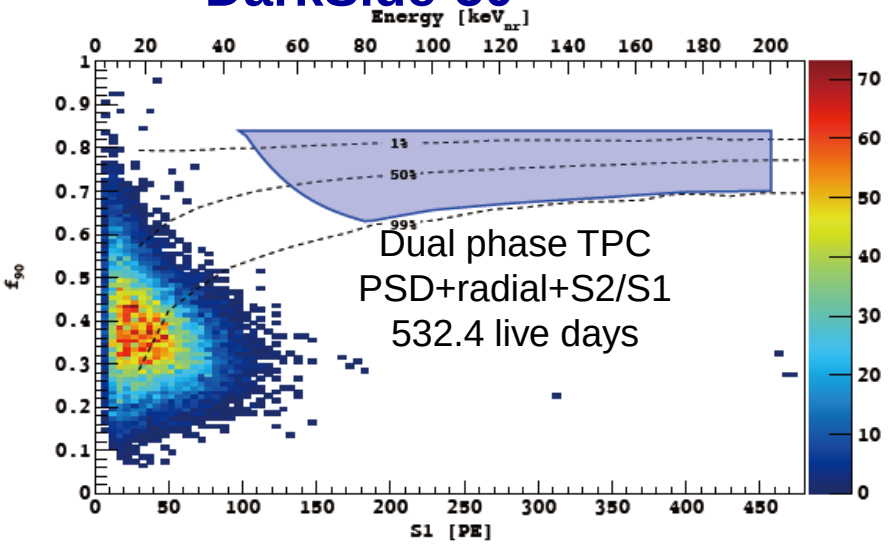
**arXiv:1707.08042**

**DEAP-3600**

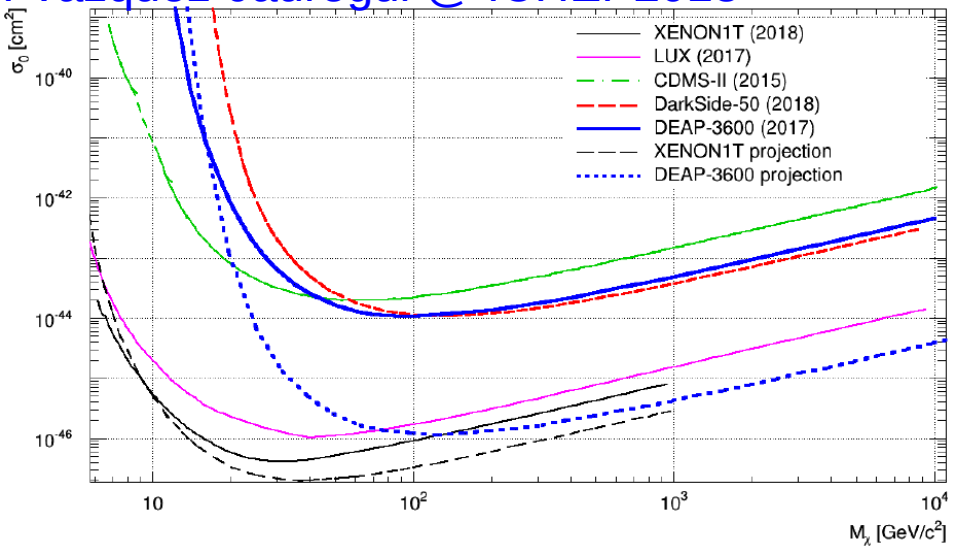



**arXiv:1802.07198**

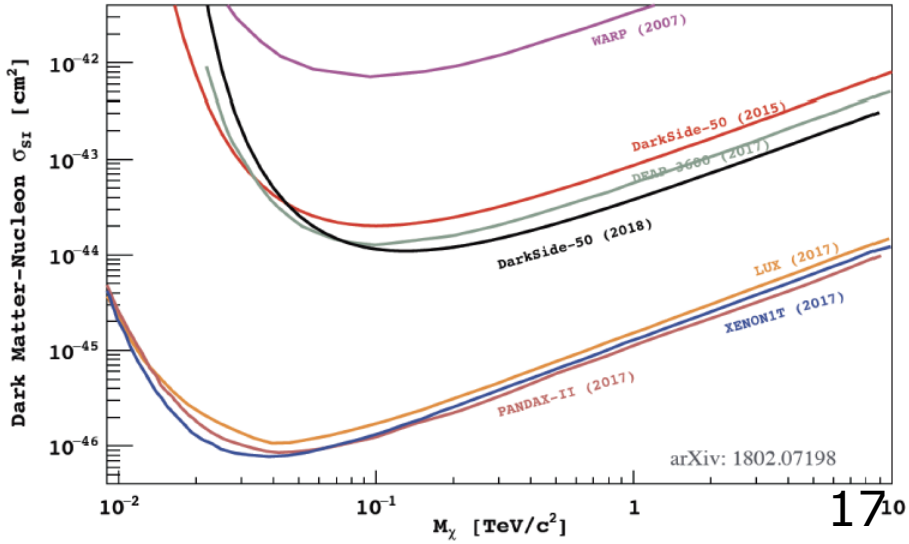
**DarkSide-50**




E. Vazquez-Jauregui @ ICHEP2018

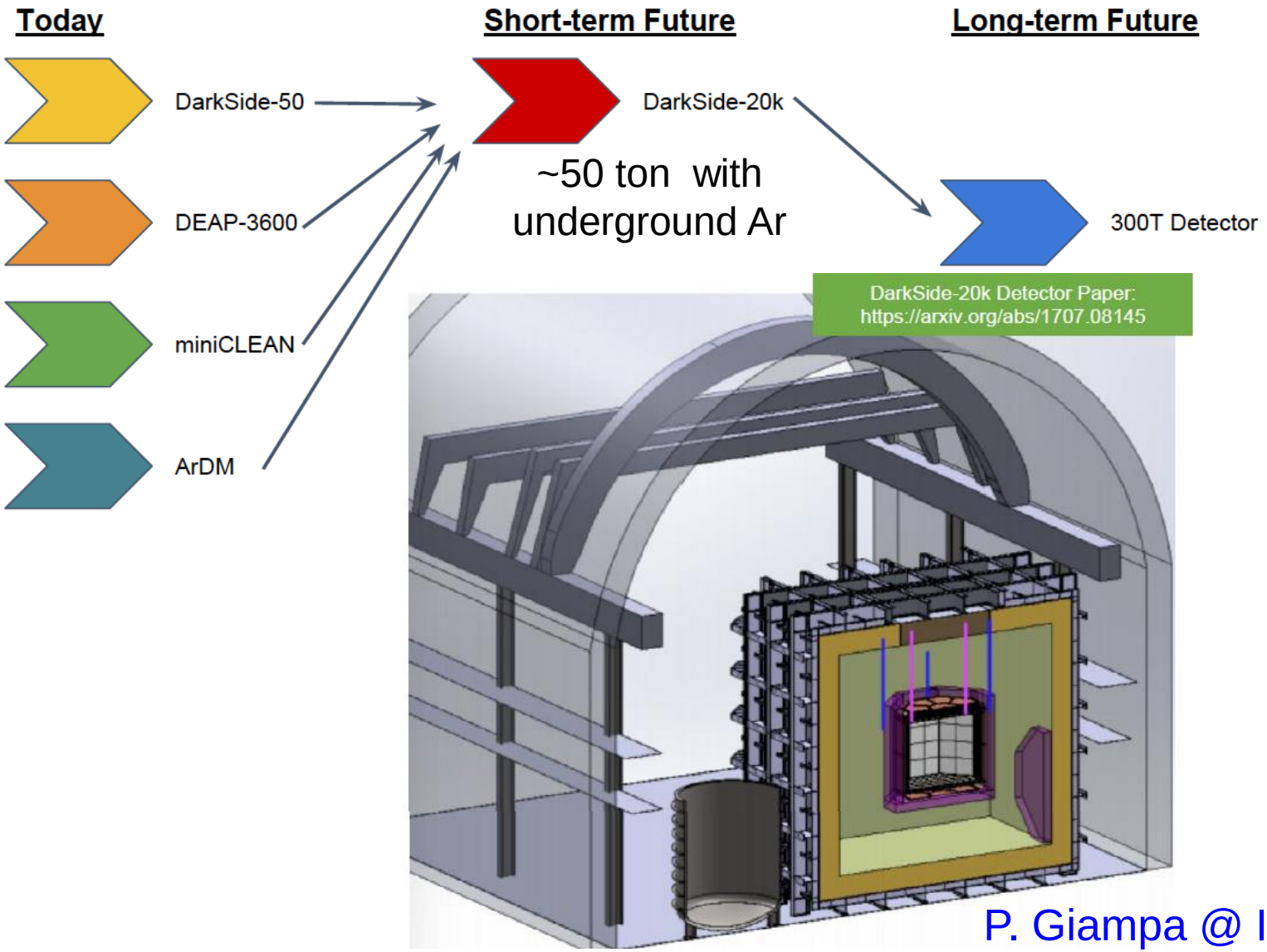



A.G. Cocos @ ICHEP2018



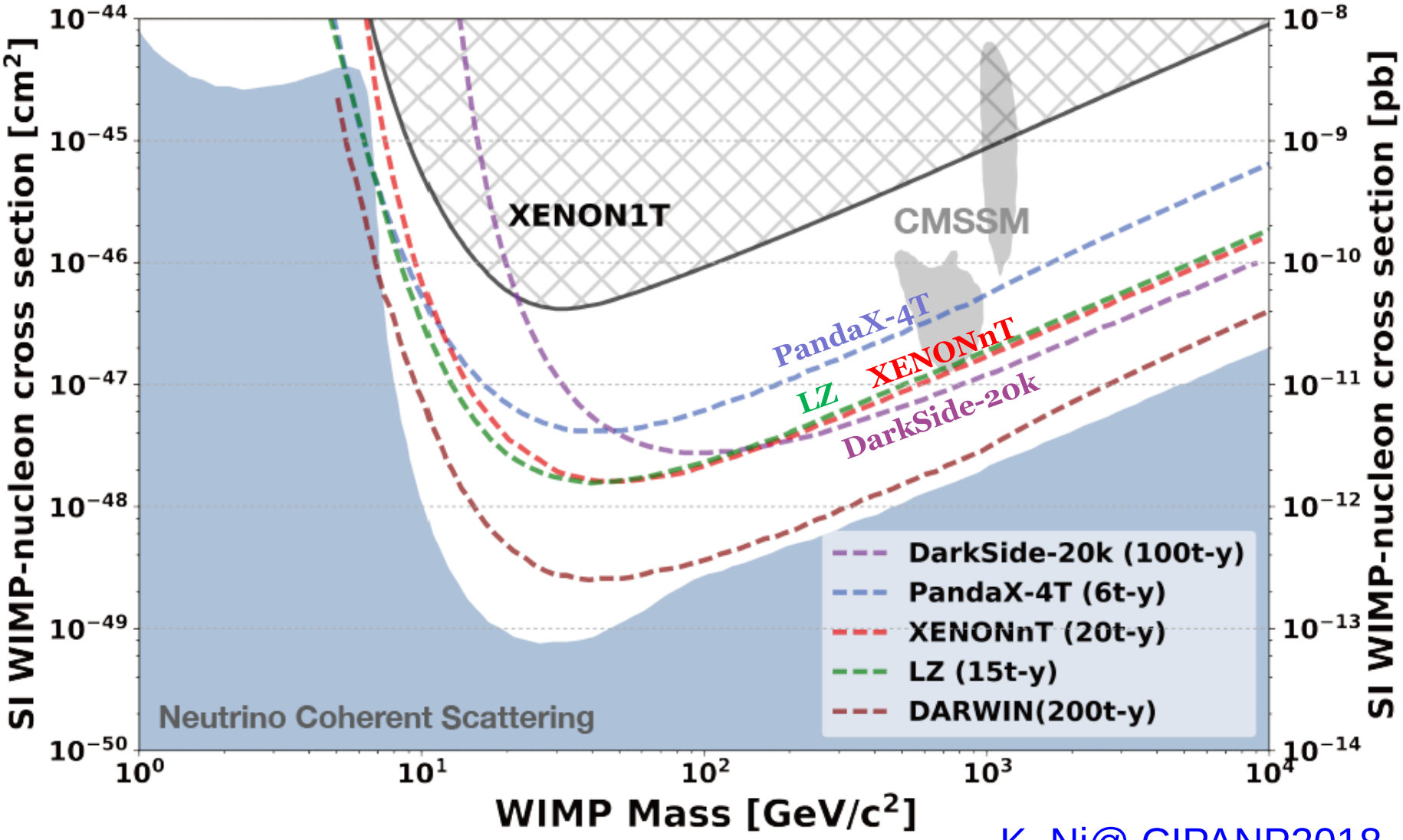

sics (Cl

# Global Argon Dark Matter Program



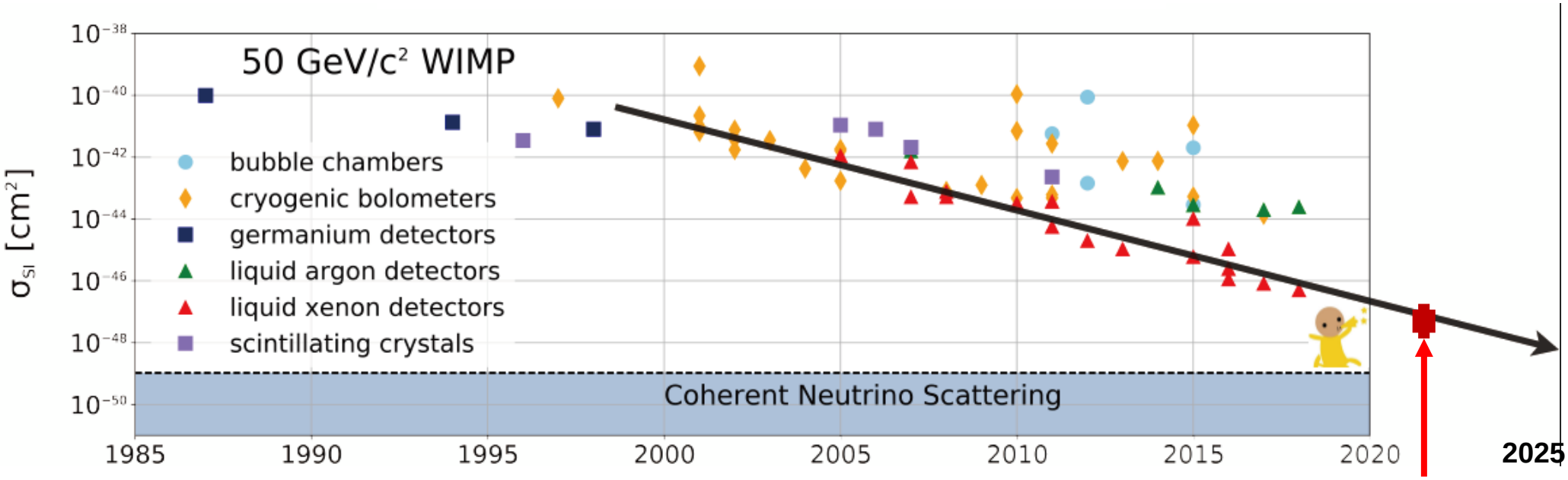

P. Giampa @ ICHEP2018

# Sensitivities for high mass region




K. Ni@ CIPANP2018

# Continuing Moore's Law?




- It is not only increasing volume of detectors but also reducing backgrounds

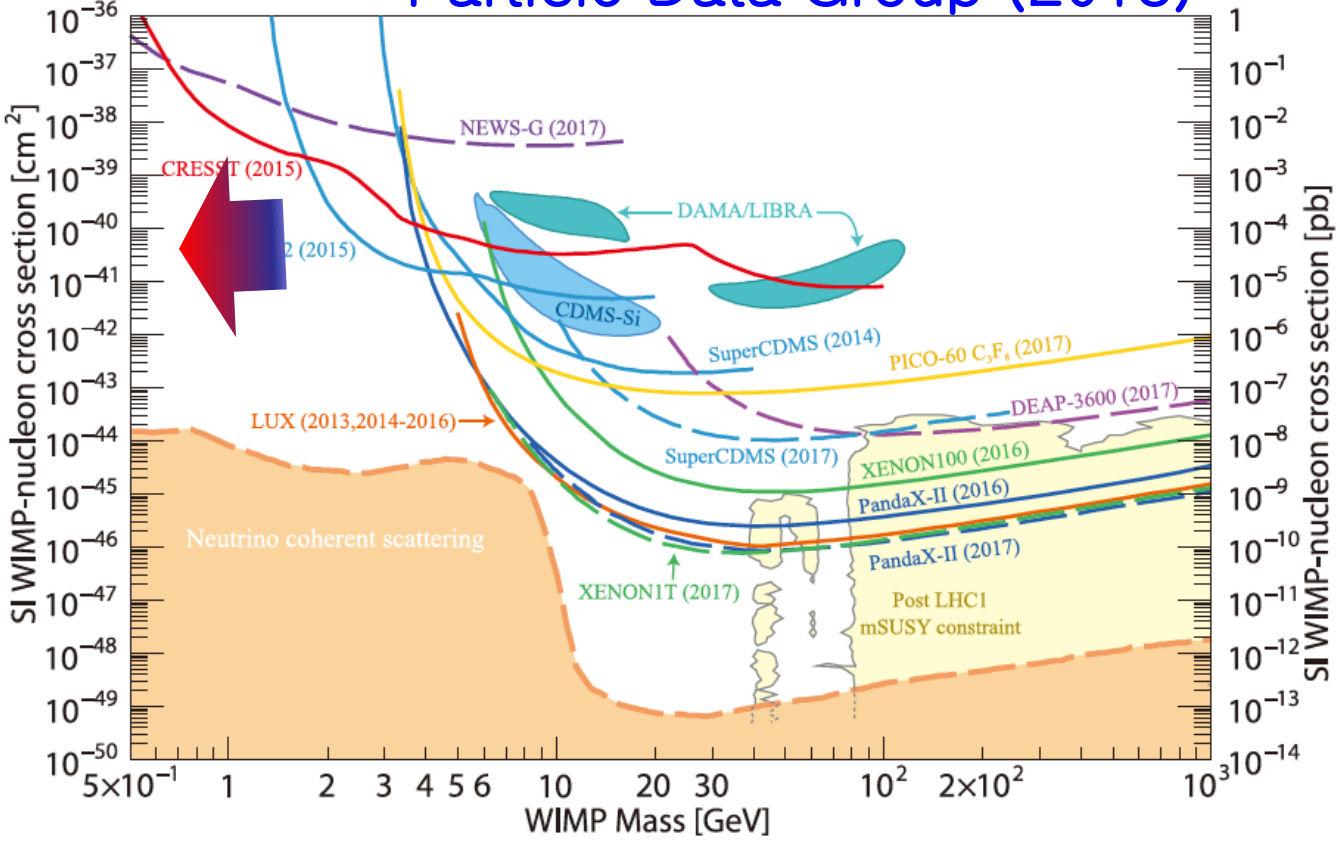
**XENONnT**

**LZ**

**+others**

# Low-mass searches

## Particle Data Group (2018)



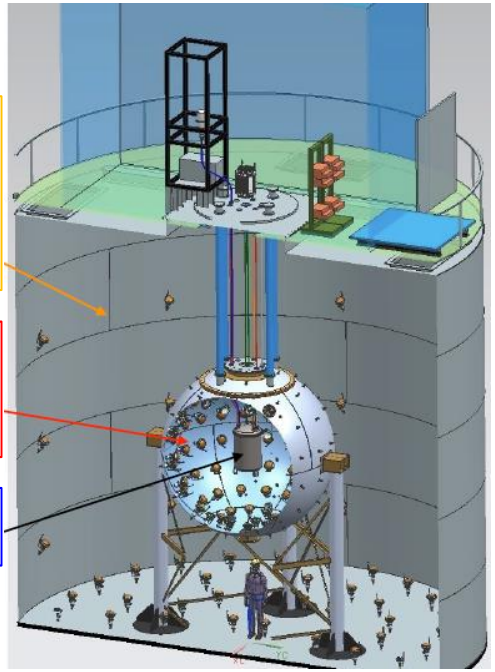

- Well progressed for high mass search$10^{-46}$cm$^2$ @ 50 GeV
- Exploring low-mass dark matter
- Unresolved signal from DAMA

# DarkSide50 : s2 only analysis

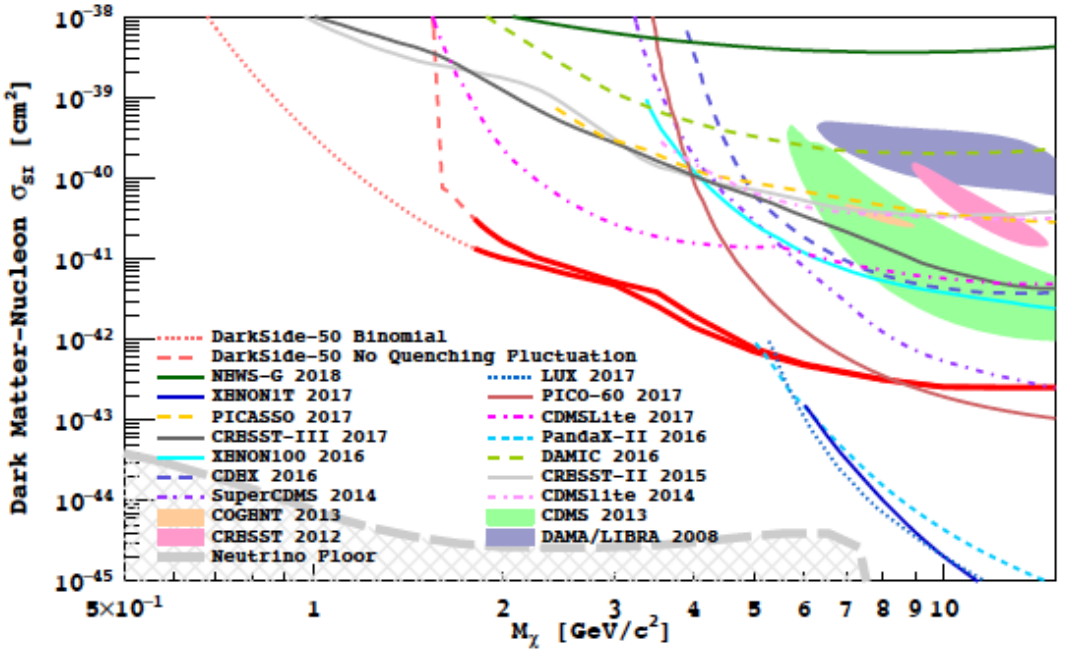
1 kton water Cherenkov detector

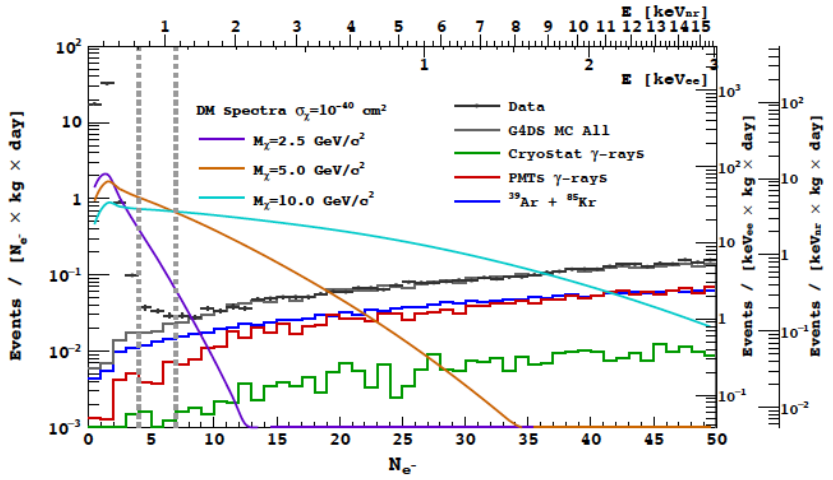
30 ton liquid scintillator

50 kg argon



arXiv:1802.06994




A.G. Cocos @ ICHEP2018

- Low threshold ~ 1 keV
- Spectral fit of low energy events
- Best limits in 2-6 GeV/c$^2$ WIMP

# CRESST-III

- Low temperature calorimetric detectors ($CaWO_4$ crystals)

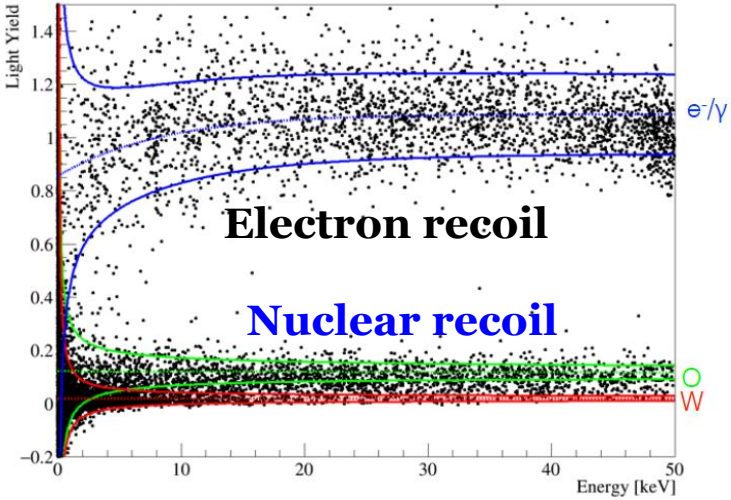
## CRESST-II

**Mass** : 300 g

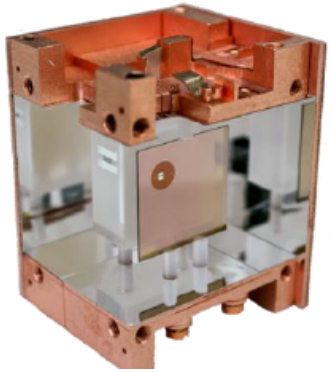
**Threshold** : 307 eV

**Crystal** : Commercial

**Exposure** : 52 kg-days




## CRESST-III

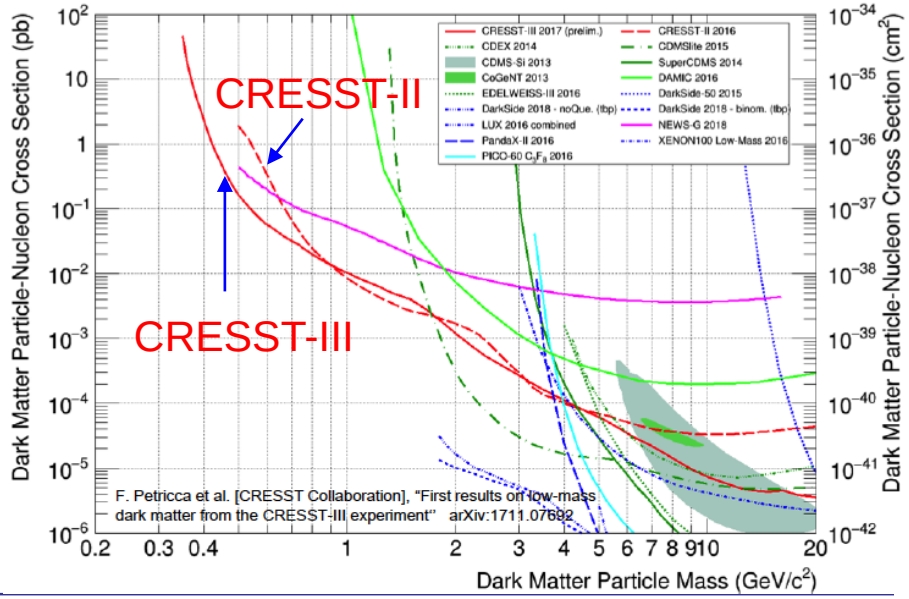


**Mass** : 25 g

**Threshold** : ≤ 100 eV

**Crystal** : TUM

**Exposure** : 2.39 kg-days



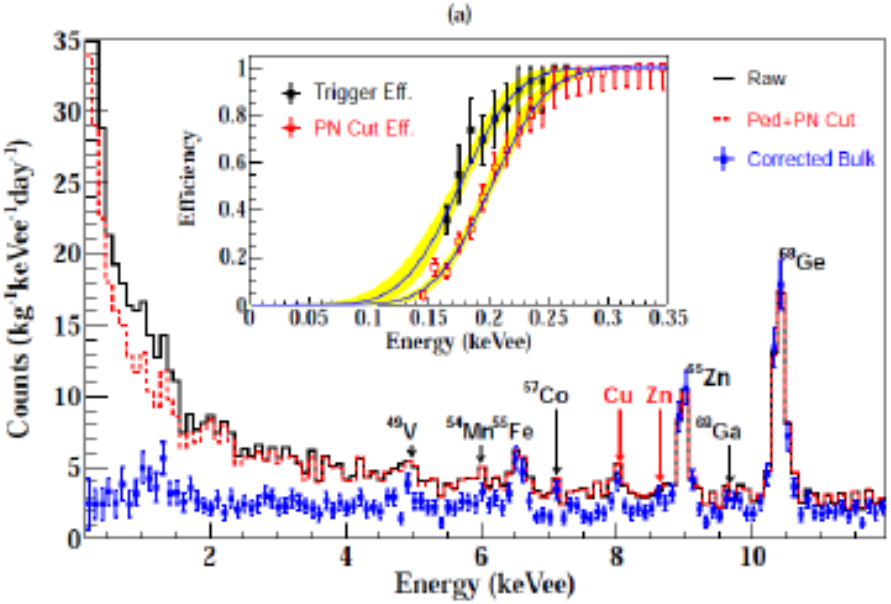

M. Mancuso@ ICHEP2018

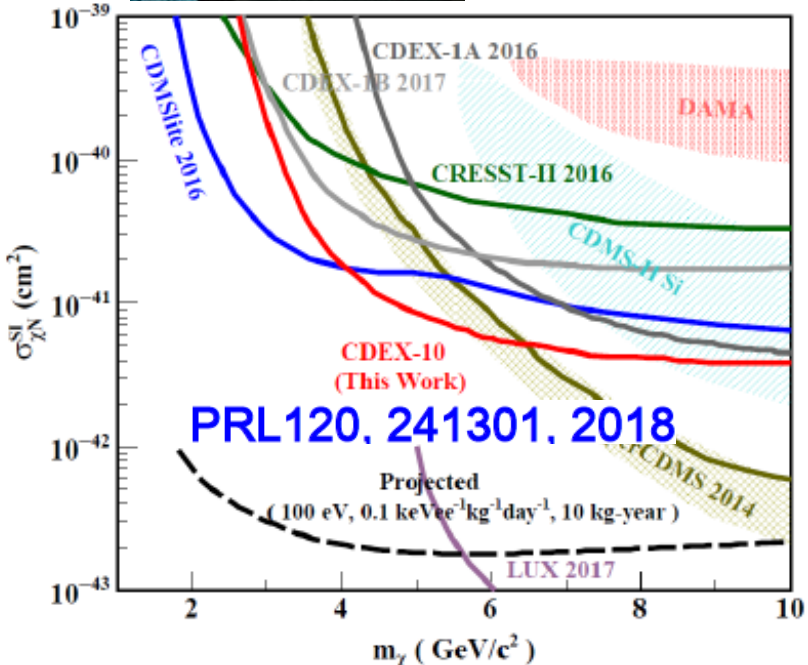
# CDEX

- CDEX-10, 102.8 kg-day (Ge detector)

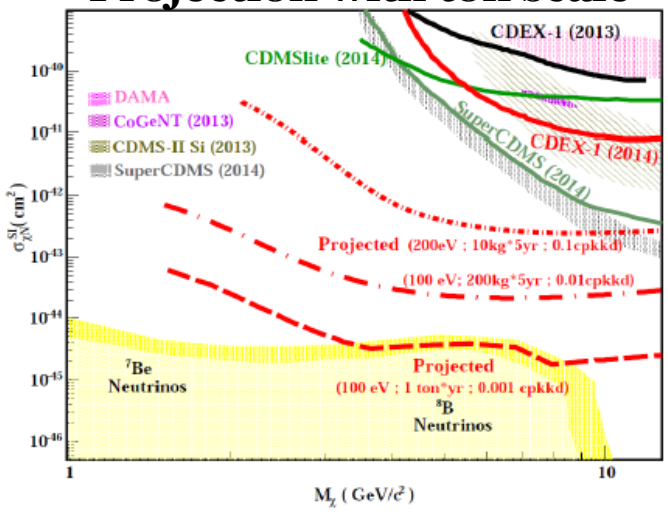
H.B. Li@ ICHEP2018

**160 eVee threshold**



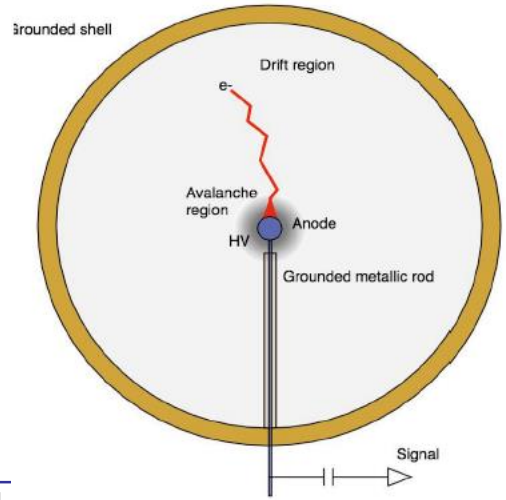




**Projection with ton scale**

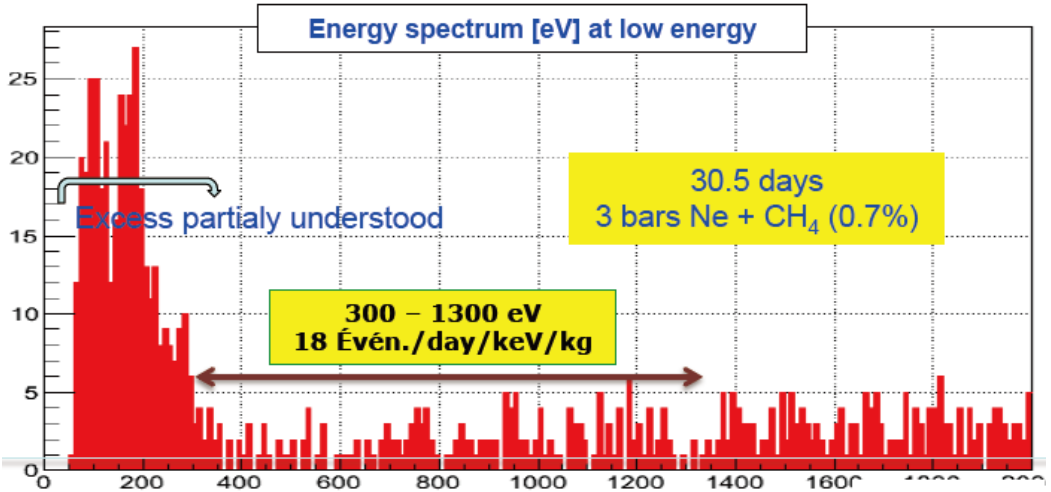


# NEWS-G

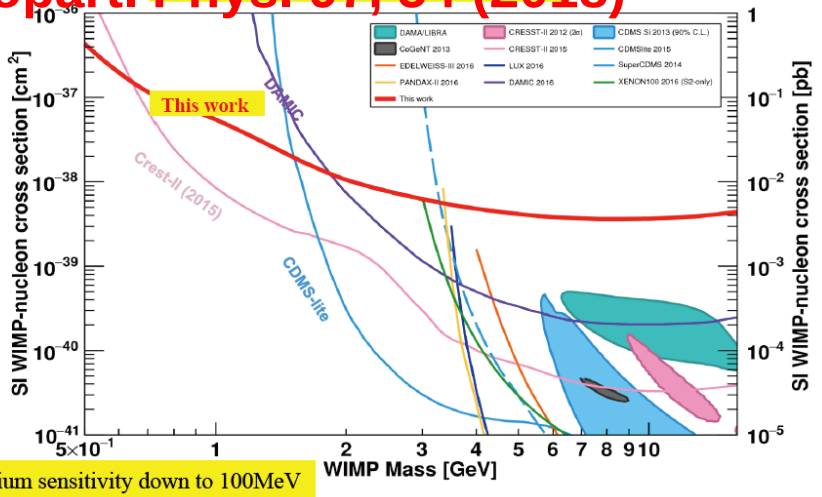
## Gases Spherical Proportional Detector




## I. Giomataris @ ICHEP2018




**Astropart. Phys. 97, 54 (2018)**

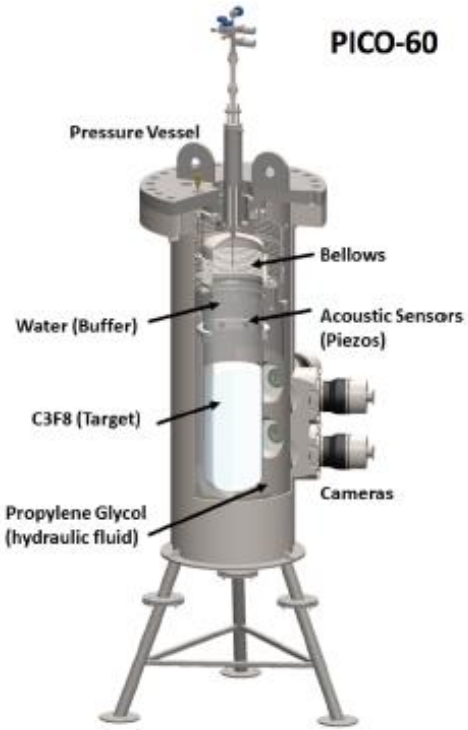



Next run in Helium sensitivity down to 100MeV

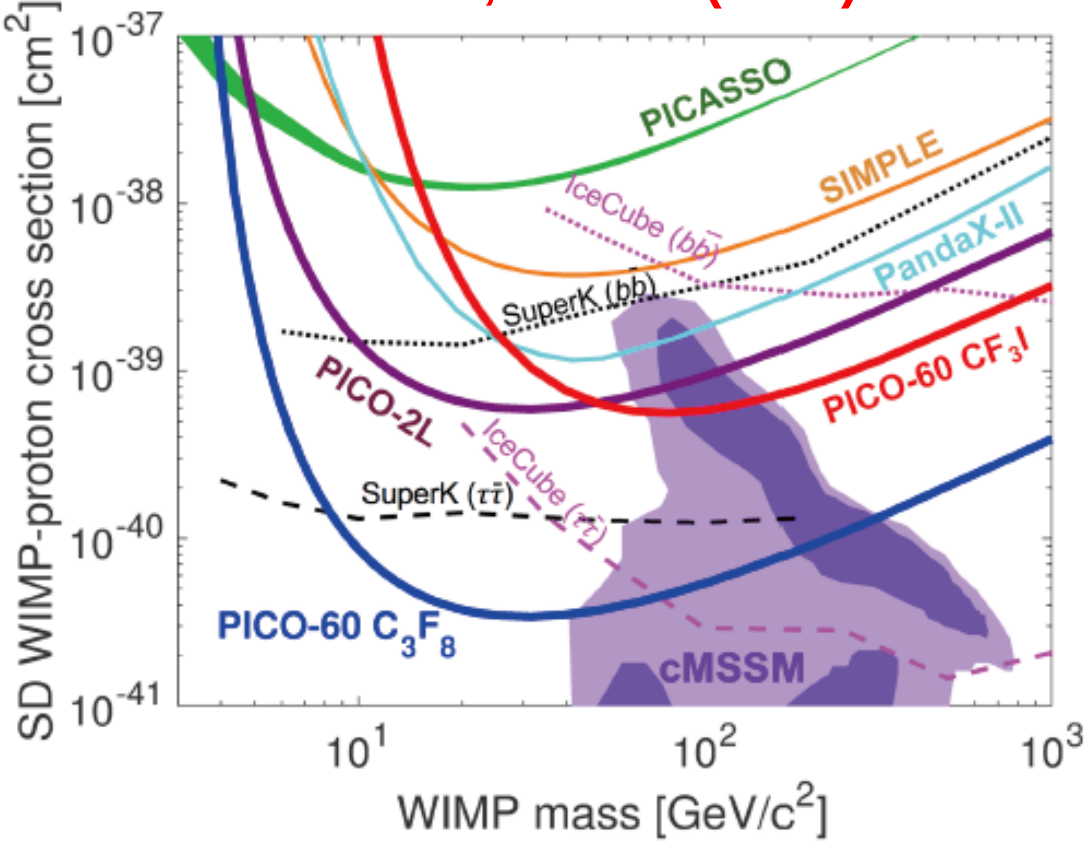
**August physics run in Helium**
**Goal: get sensitivity down to 100 MeV WIMP mass**

# PICO : Spin-Dependent WIMP-proton

- PICO-60, C3F8 Bubble Chamber



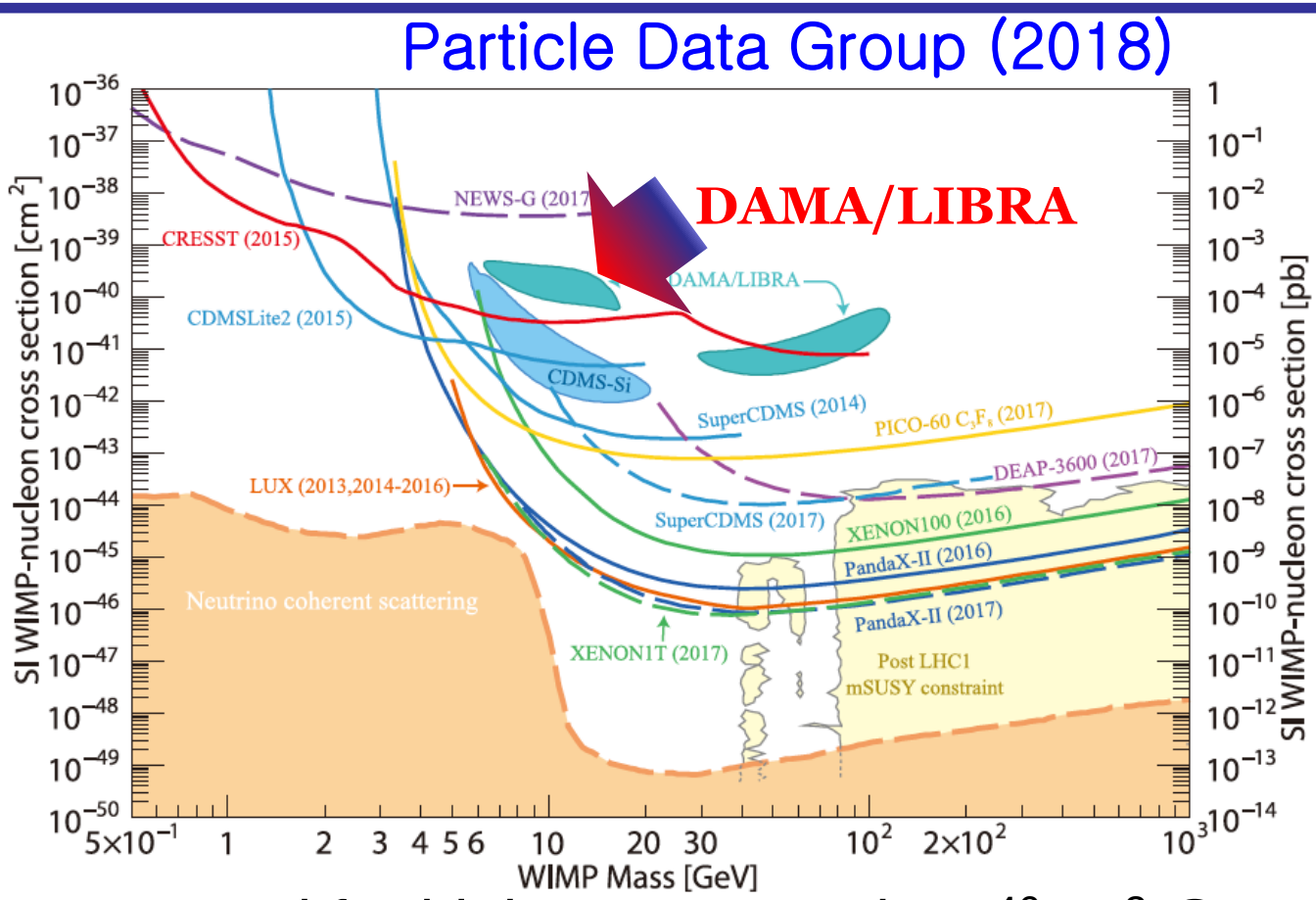

PRL 118, 251301 (2017)




- Consider next phase of PICO-500

E. Vazquez-Jauregui@ ICHEP2018

# DAMA conundrum



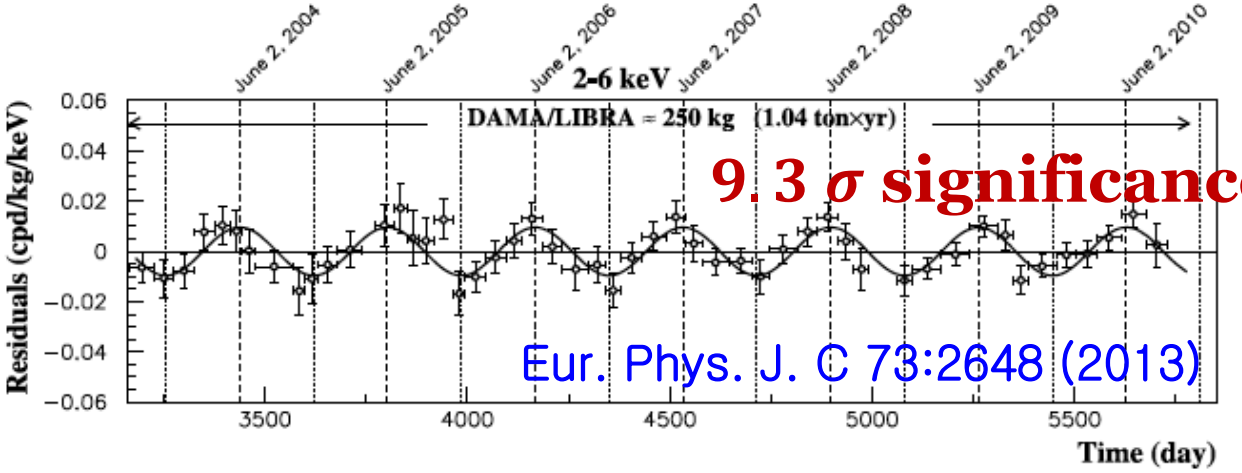

- Well progressed for high mass search$10^{-46}$cm$^2$ @ 50 GeV
- Exploring low-mass dark matter
- Unresolved signal from DAMA

# DAMA/LIBRA-phase1

## DAMA/LIBRA experiment

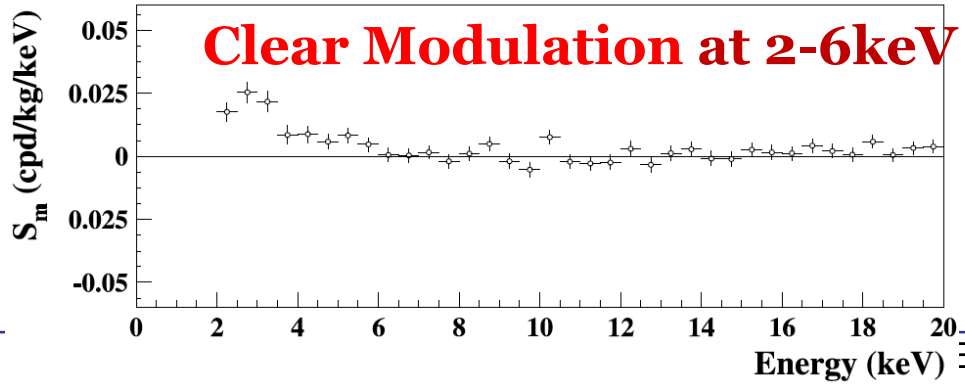
- Annual Modulation Searches with an array of NaI(Tl) crystals (250 kg)

**Claimed an observation of the dark matter**




**9.3 $\sigma$ significance**

Eur. Phys. J. C 73:2648 (2013)




**DAMA/LIBRA-phase1**

**1.33 ton-year**

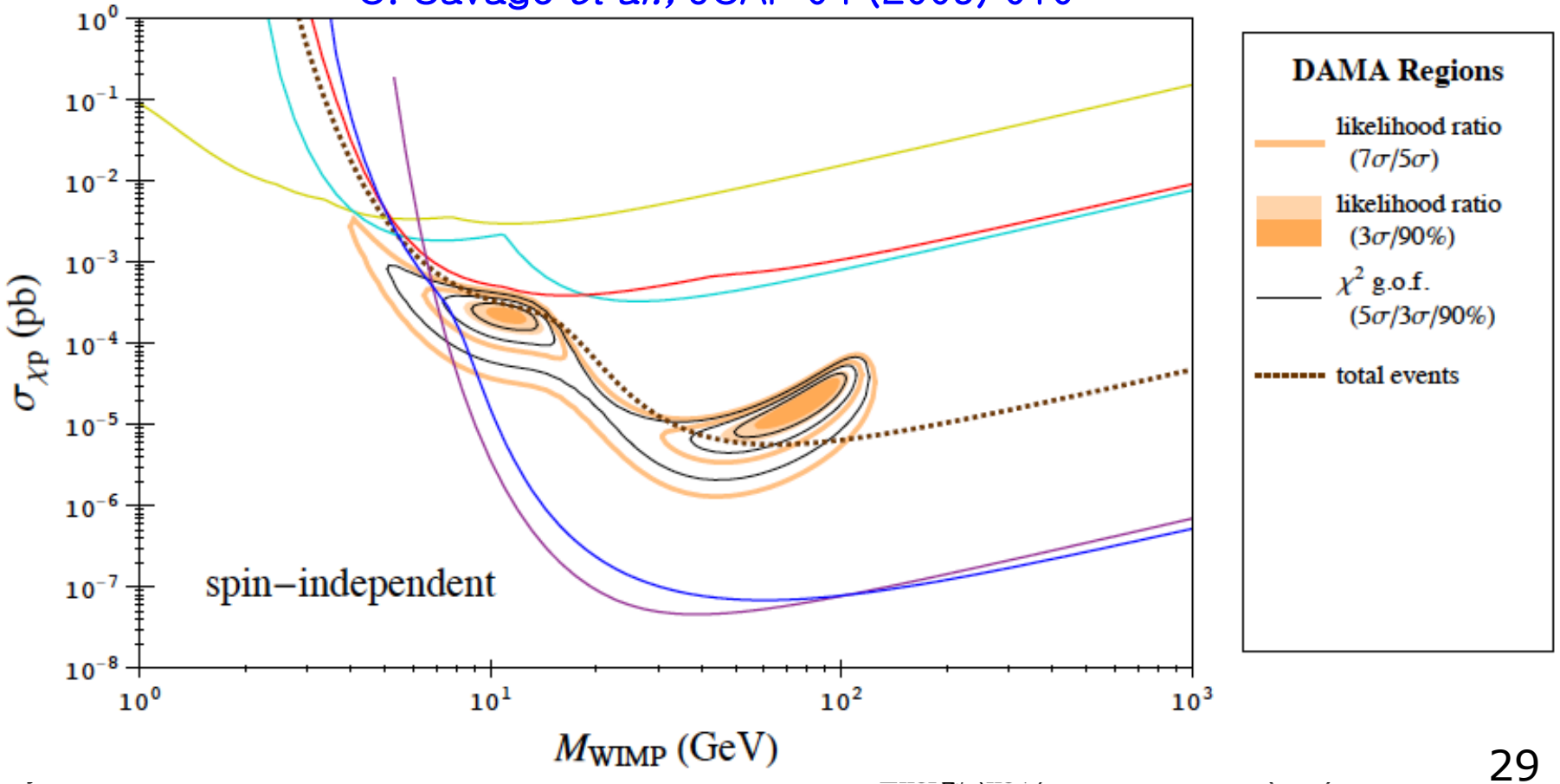
# DAMA/LIBRA phase1

## DAMA/LIBRA experiment

- Annual Modulation Searches with an array of NaI(Tl) crystals

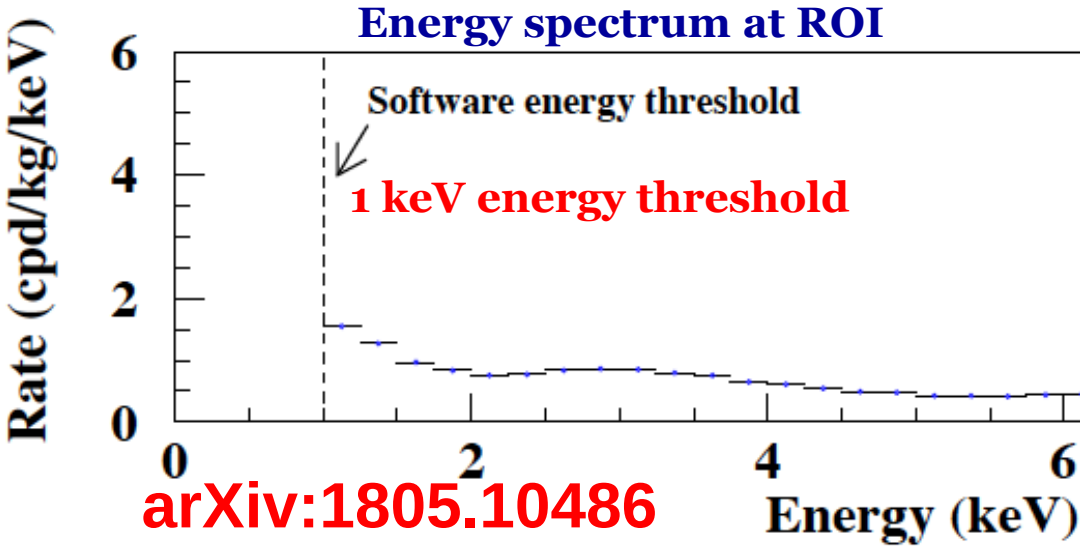
**Claimed**

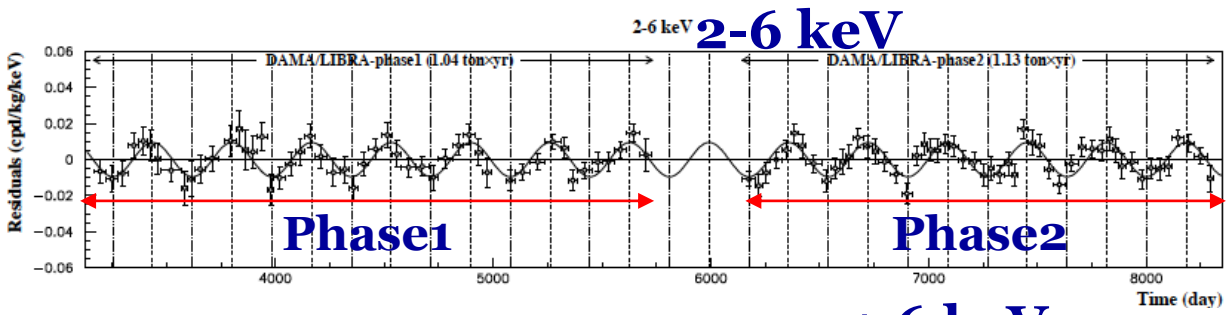
C. Savage *et al.*, JCAP 04 (2009) 010

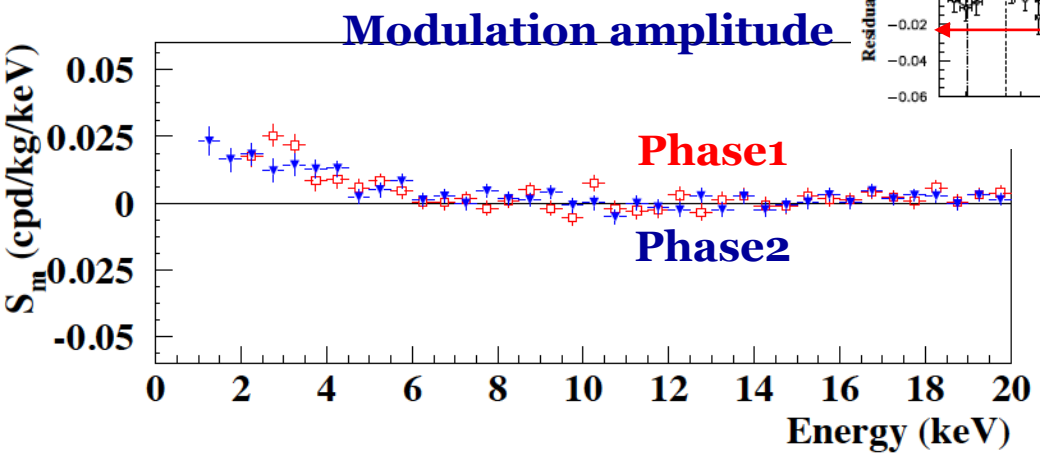


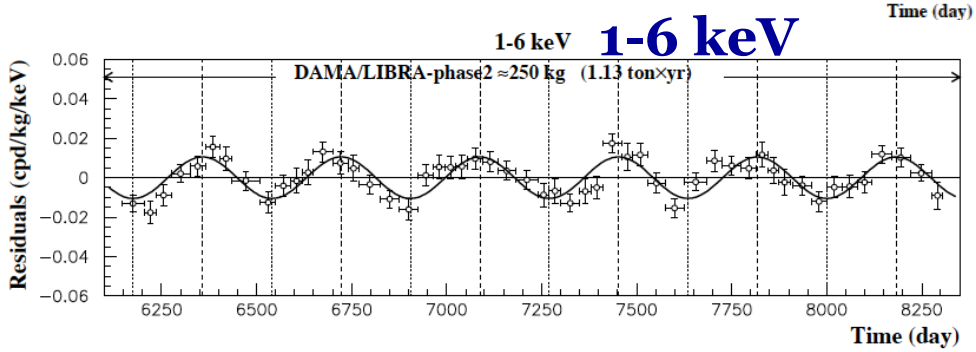
# DAMA/LIBRA-phase 2

- Energy threshold reached to 1 keV with better PMTs
- Still there is modulation
- **Significance**
  - ❖ 1-6 keV : **9.5 $\sigma$** (phase 2)
  - ❖ 2-6 keV : **12.9 $\sigma$** (phase 1+2)
- Increased modulation amplitude below 2keV



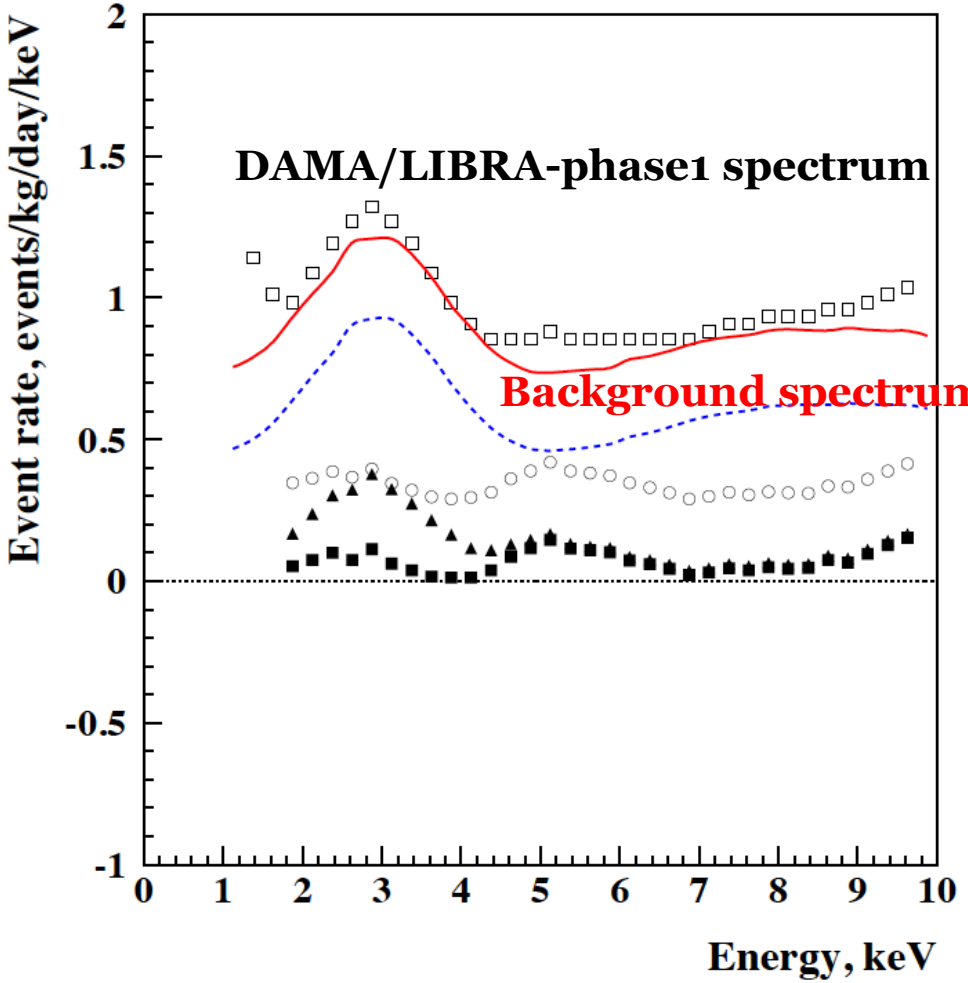



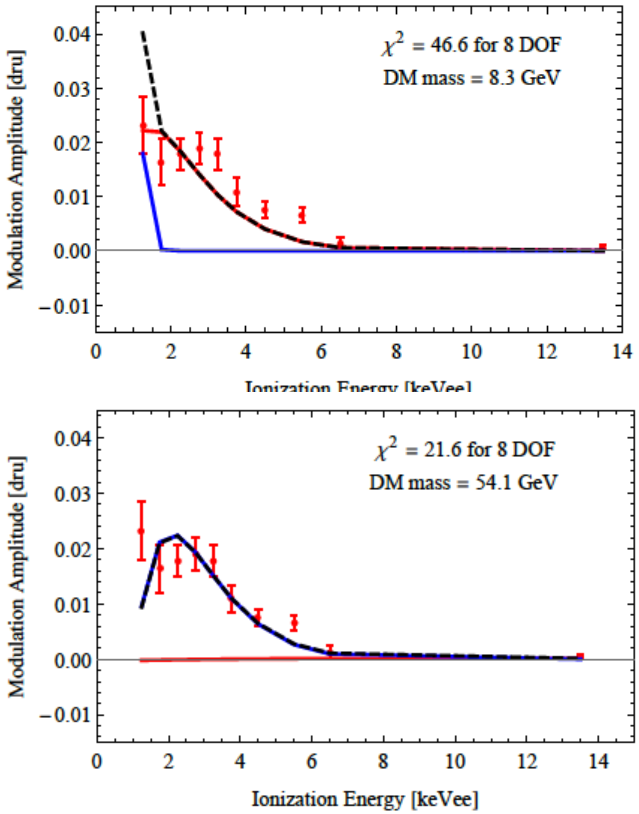



# Issues on typical DM interpretation with DAMA/LIBRA

**Astropart. Phys. 33 (2010) 91**



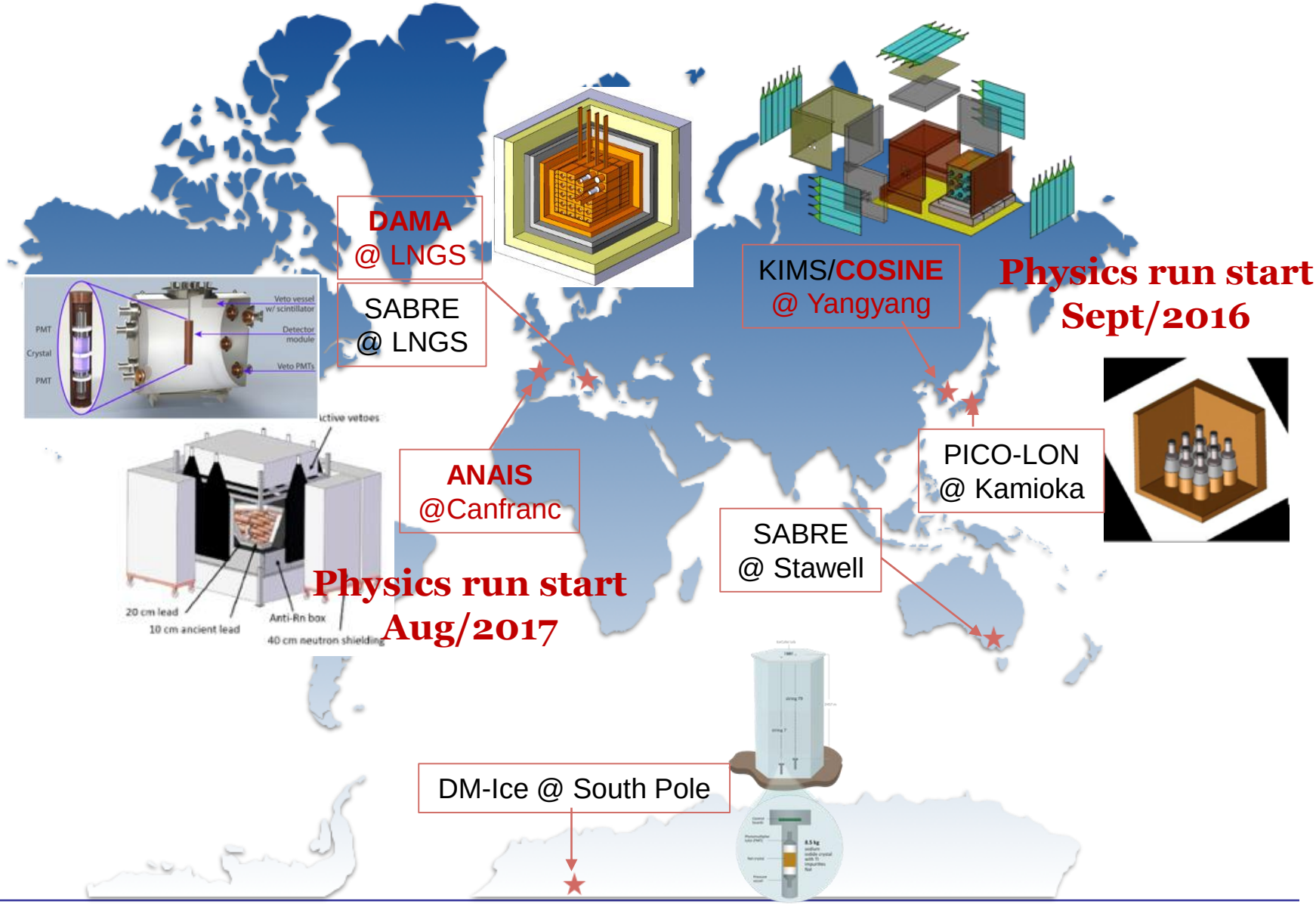

**arXiv:1804.01231**



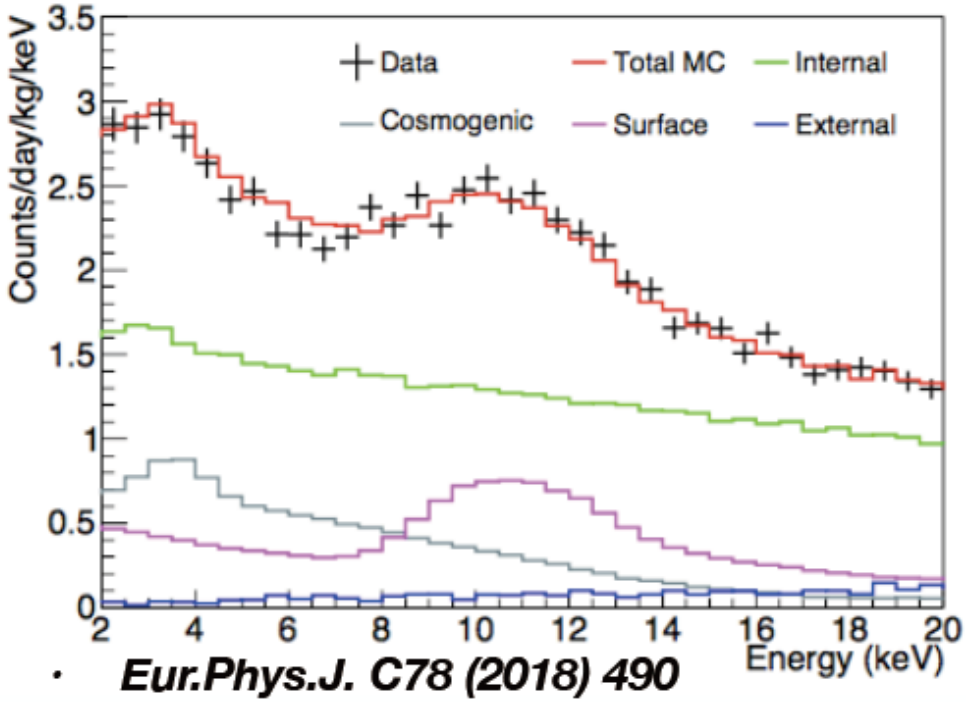

DAMA/LIBRA-phase2 can not be explained by typical spin-independent WIMP-nucleon interaction

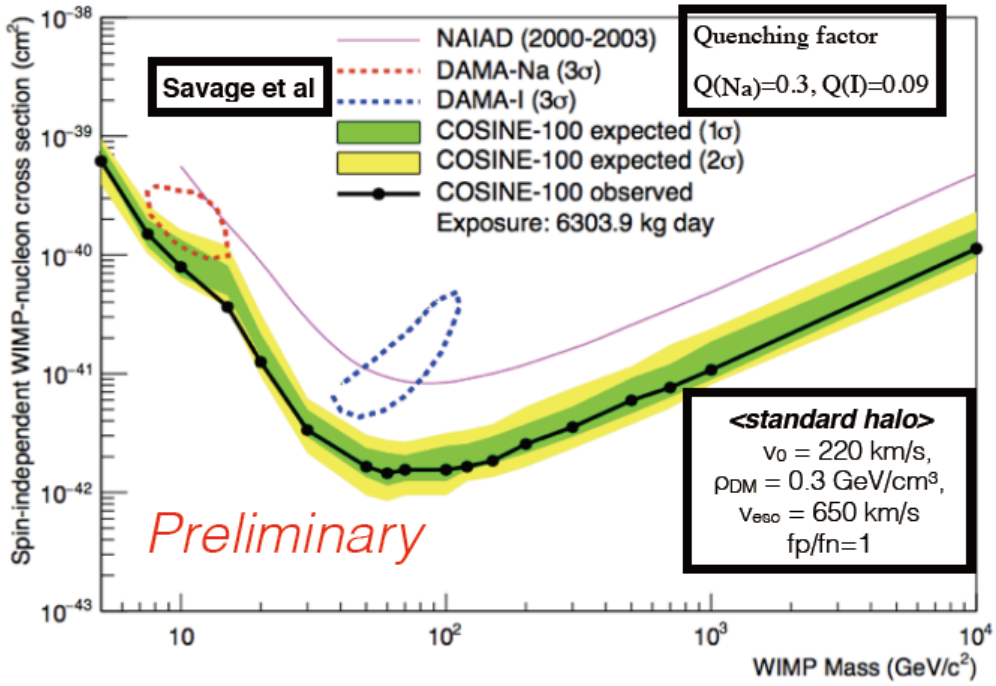
**Independent NaI(Tl) experiments are highly required**

# Global NaI(Tl) efforts



# COSINE-100 (59.5 days data) spectral fit and limits




- Spectrum with known sources of backgrounds

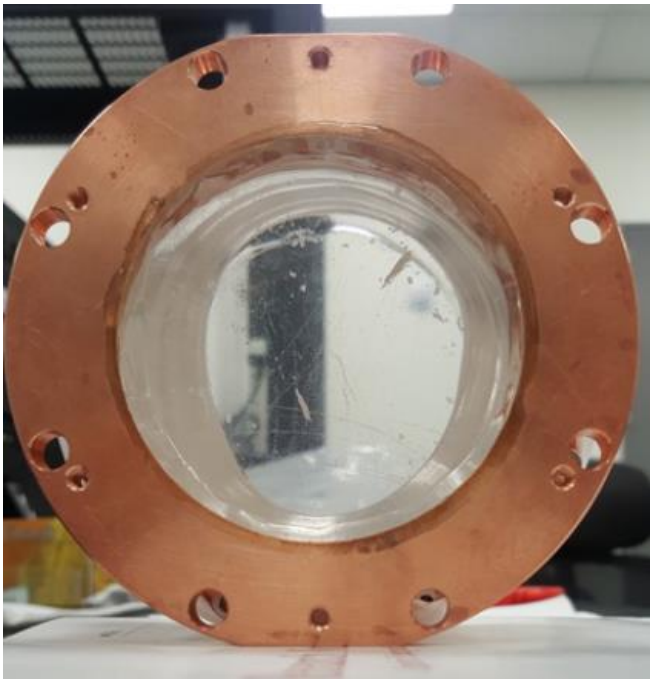
**C. Ha @ICHEP2018**

- COSINE-100 excludes DAMA/LIBRA-phase1's signal as spin-independent WIMP-nucleon interaction with Standard Halo Model (Savage et al.'s interpretation)
- Consistent with null results from other direct detection experiments
- Model independent test requires annual modulation search. Analyses with 585 days underway

# NaI crystal developments

- Goal to have crystals better than DAMA/LIBRA

**COSINE**



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**PICO-LON**

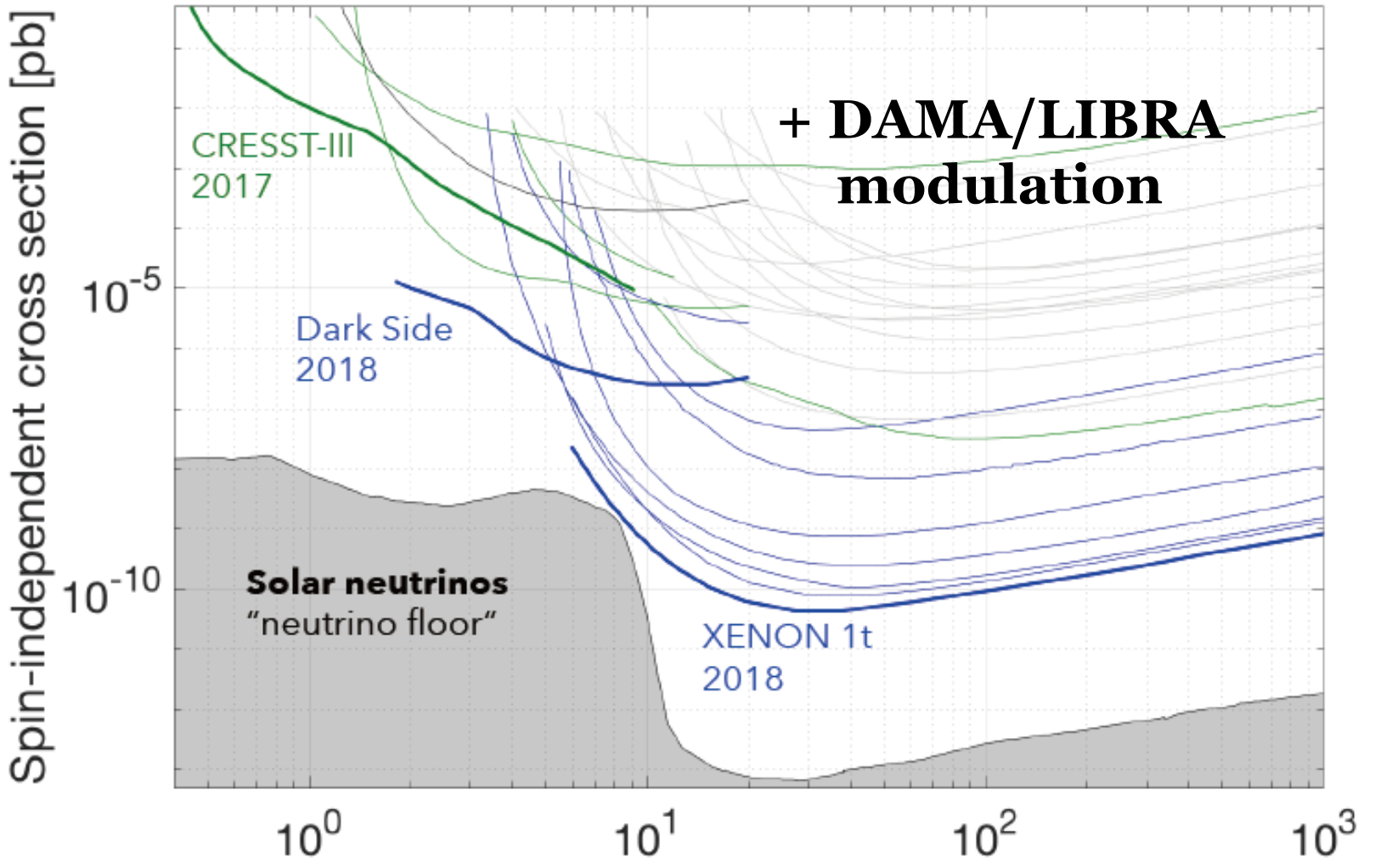
K. Fushimi @NDM2018

**SABRE**

G.D'Imperio@ICHEP2018

- Start new experiments around 2020 with better quality crystals than DAMA/LIBRA

# Current status of direct dark matter search




Moving fast!!

**R. Strauss @ NDM2018**

# Conclusions

- Searches for high mass region are lead by dual phase liquid TPC detectors and have incredibly fast progresses
- Various techniques are developed for low-mass dark matter searches
- Next generation experiments are well underway
- DAMA/LIBRA signal is now overwhelming, $12.9\sigma$
- Independent verification of the DAMA/LIBRA, now underway, is of critical importance

- Field has a healthy mix of well-established projects and frontier technologies.
- **Discovery** can be made anytime, anywhere…