Search for WIMP Annual Modulation in 3.2 years of CDEX data

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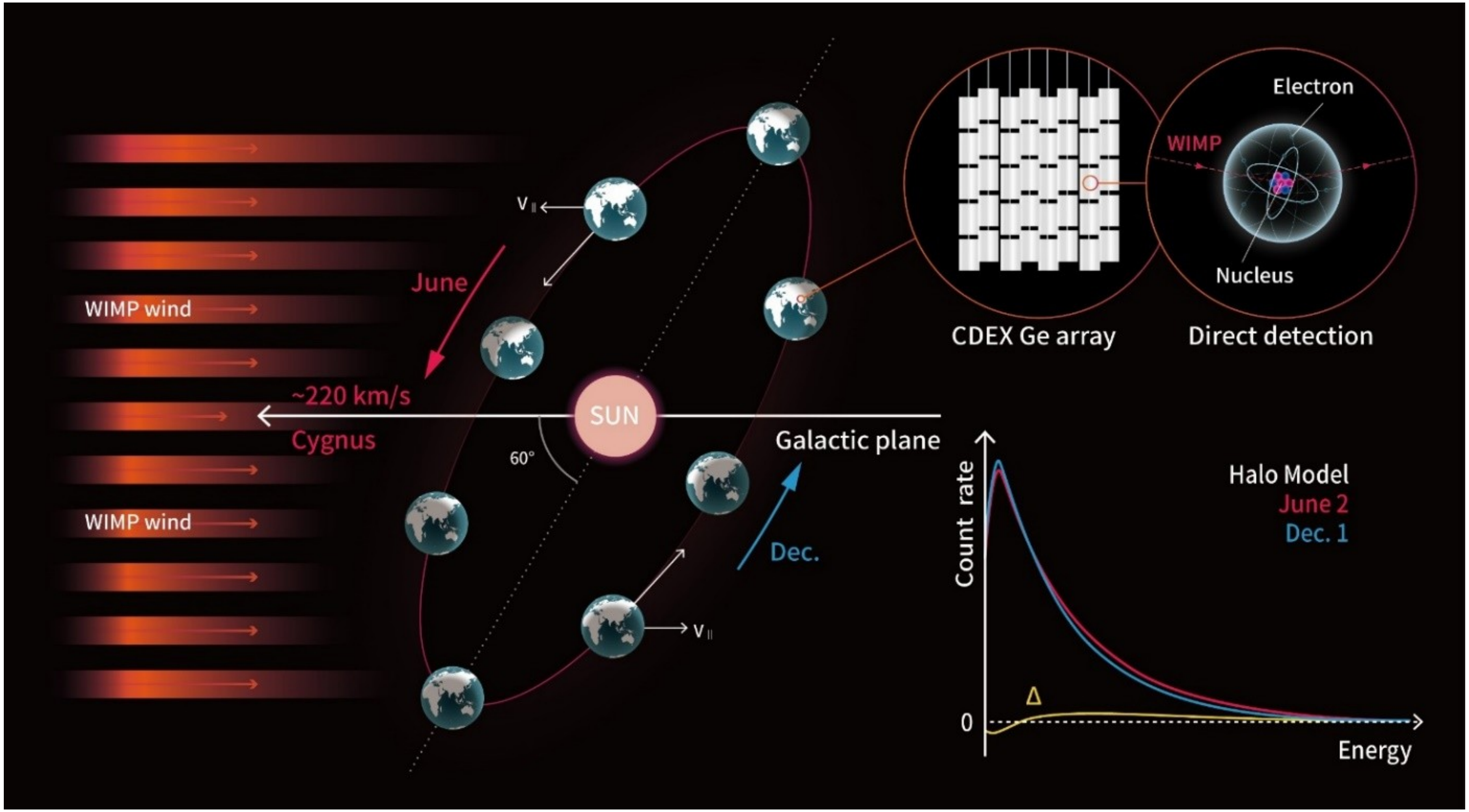
OUTLINE

- CDEX-1B experiment, data quality
- Annual Modulation (AM) analysis
- AM Results
- Migdal effect

NCTS Dark Physics Workshop 2020

Annual Modulation of WIMPs

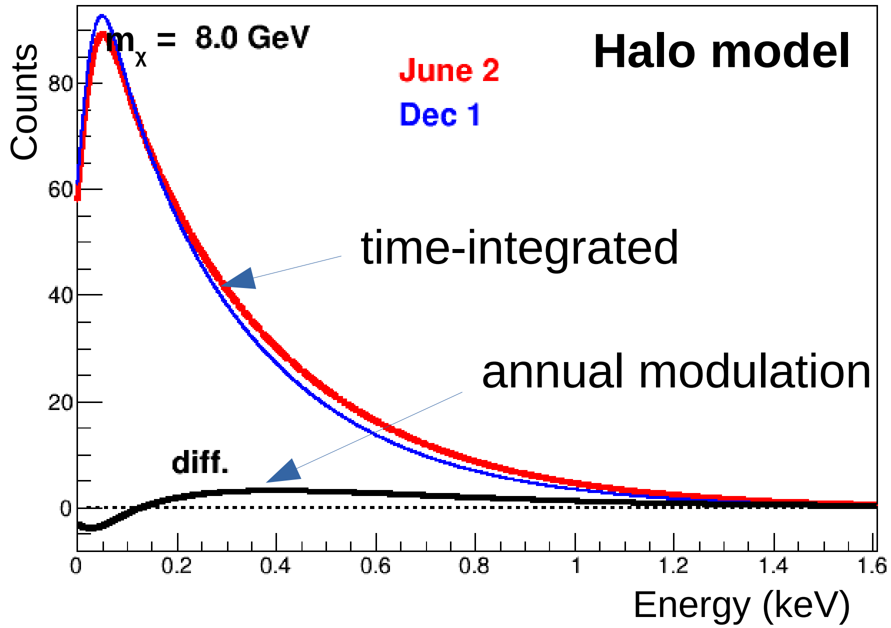
- velocity (earth ref.) of WIMP: max. at Jun, min. at Dec.
- look at Jun-Dec spec. diff.
- need stable run > 1 years
- decouple unexplained excess count



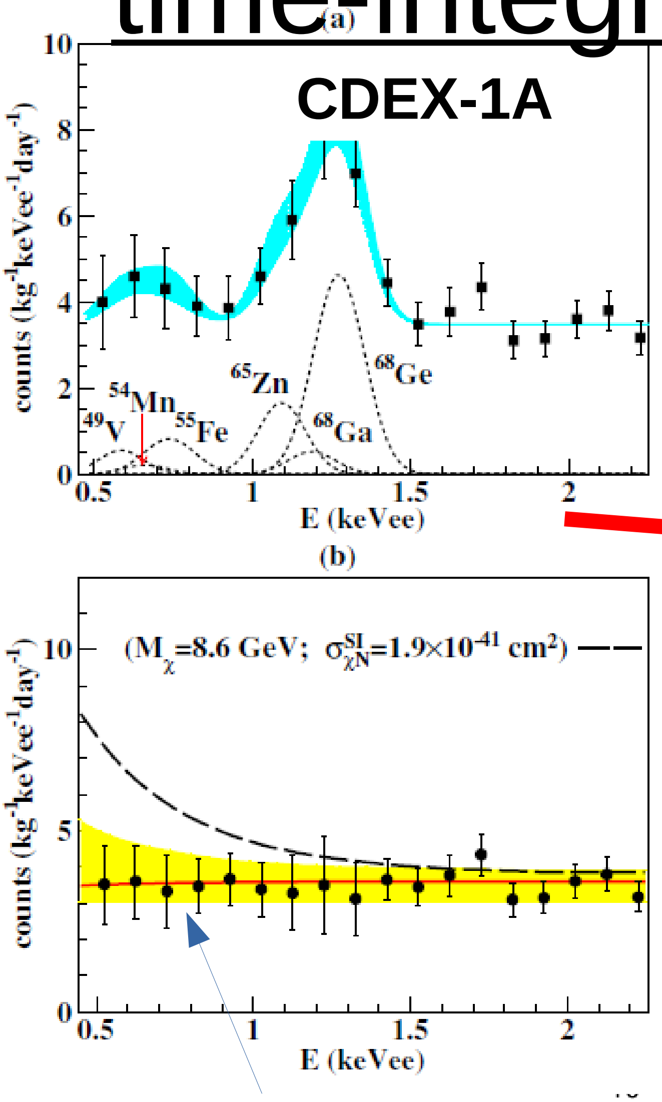
time-integrated vs. annual modulation

time-integrated	annual modulation
search for excess count (large)	search for different of count (small)
energy spectrum modeling (a lot of simulation → uncertainties)	time variation modeling (assume it is constant)
best sensitivities always at lowest energy (large uncertainties)	best sensitivities occur at higher energy (noise-free)

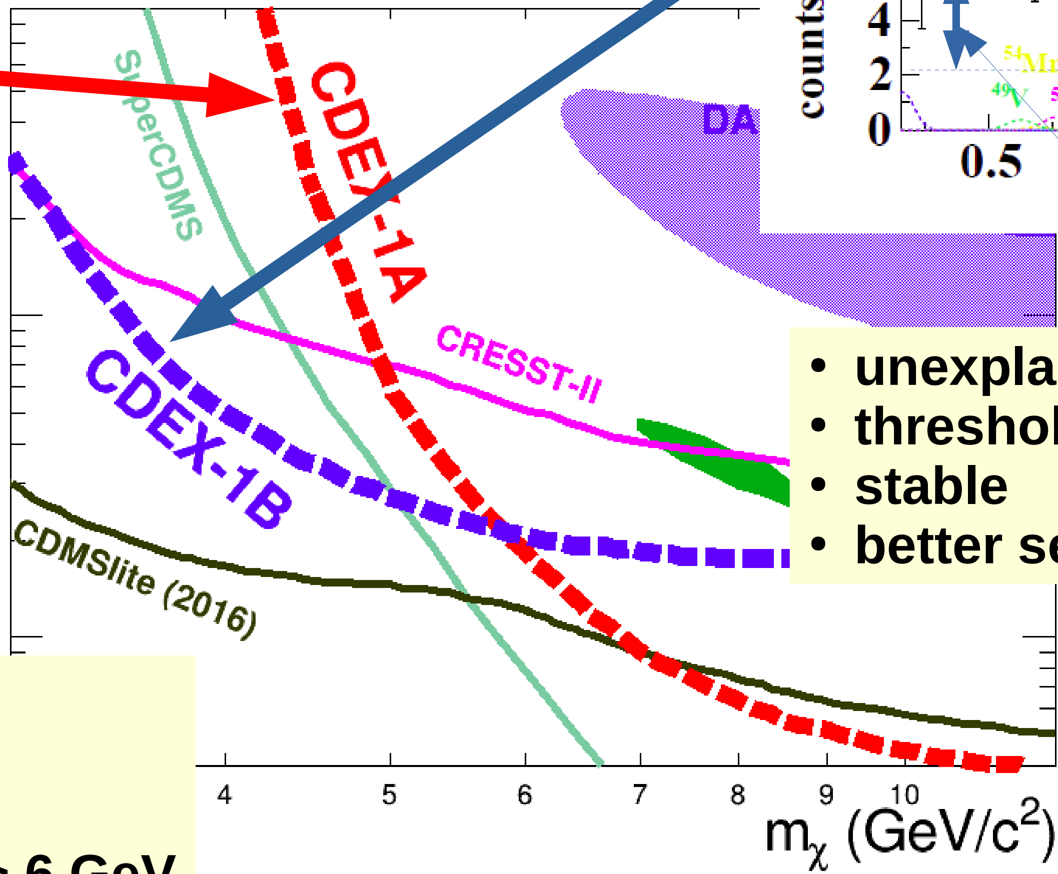
both are dark matter model dependent, both are needed for positive/negative results

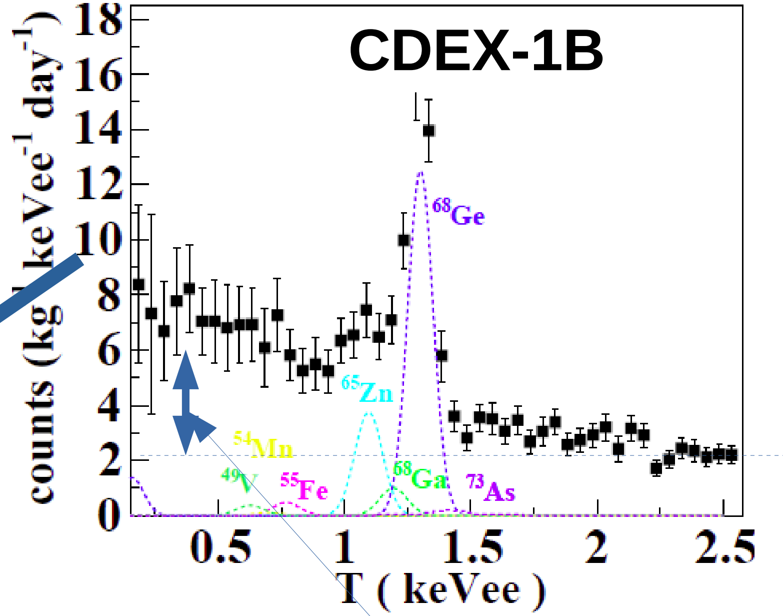


Compare with CDEX-1A: time-integrated vs. annual modulation



σSI sensitivities

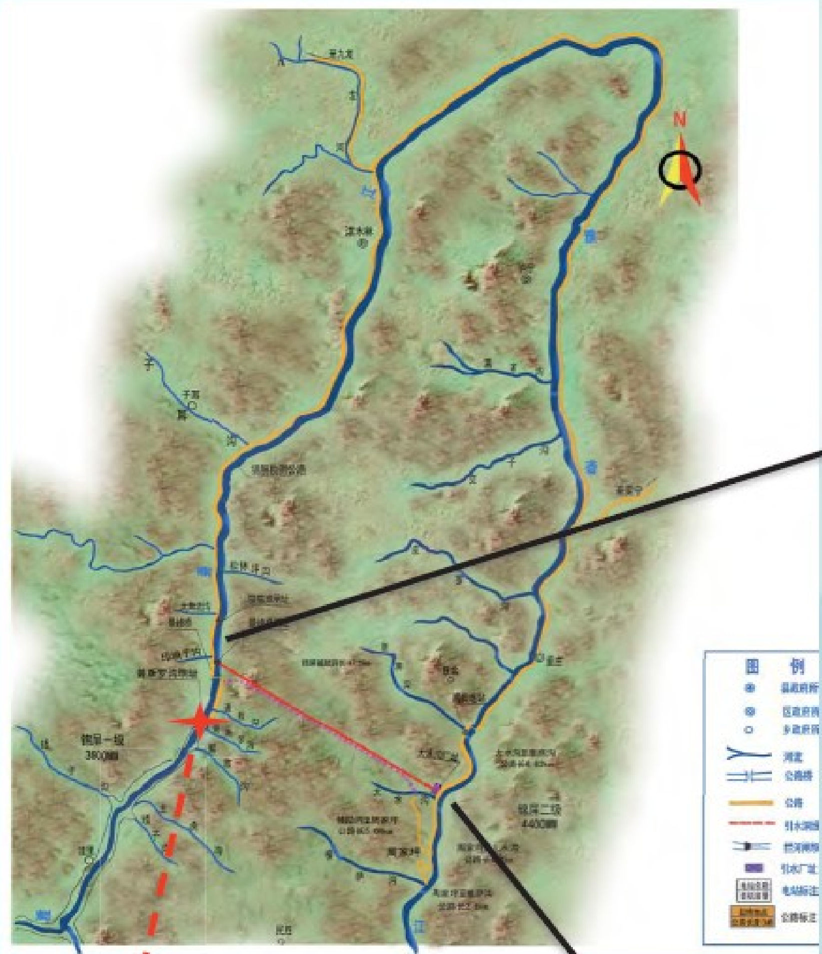




- unexplained excess count
- threshold ~ 160 eV
- stable
- better sensitivities < 6 GeV

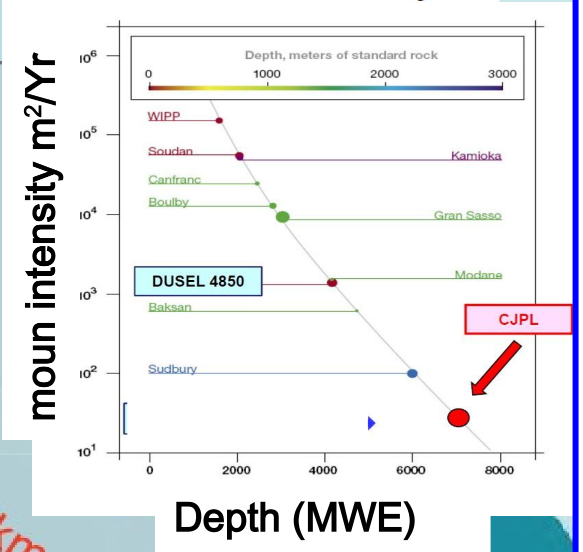
- no excess count
- Threshold ~ 475 eV
- unstable
- better sensitivities at > 6 GeV

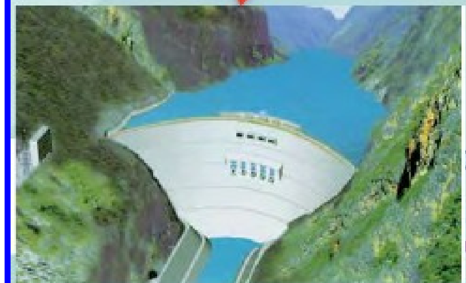
Jinping Hydroelectric Power Plants



4 hydraulic tunnels
Φ13m×16.6km

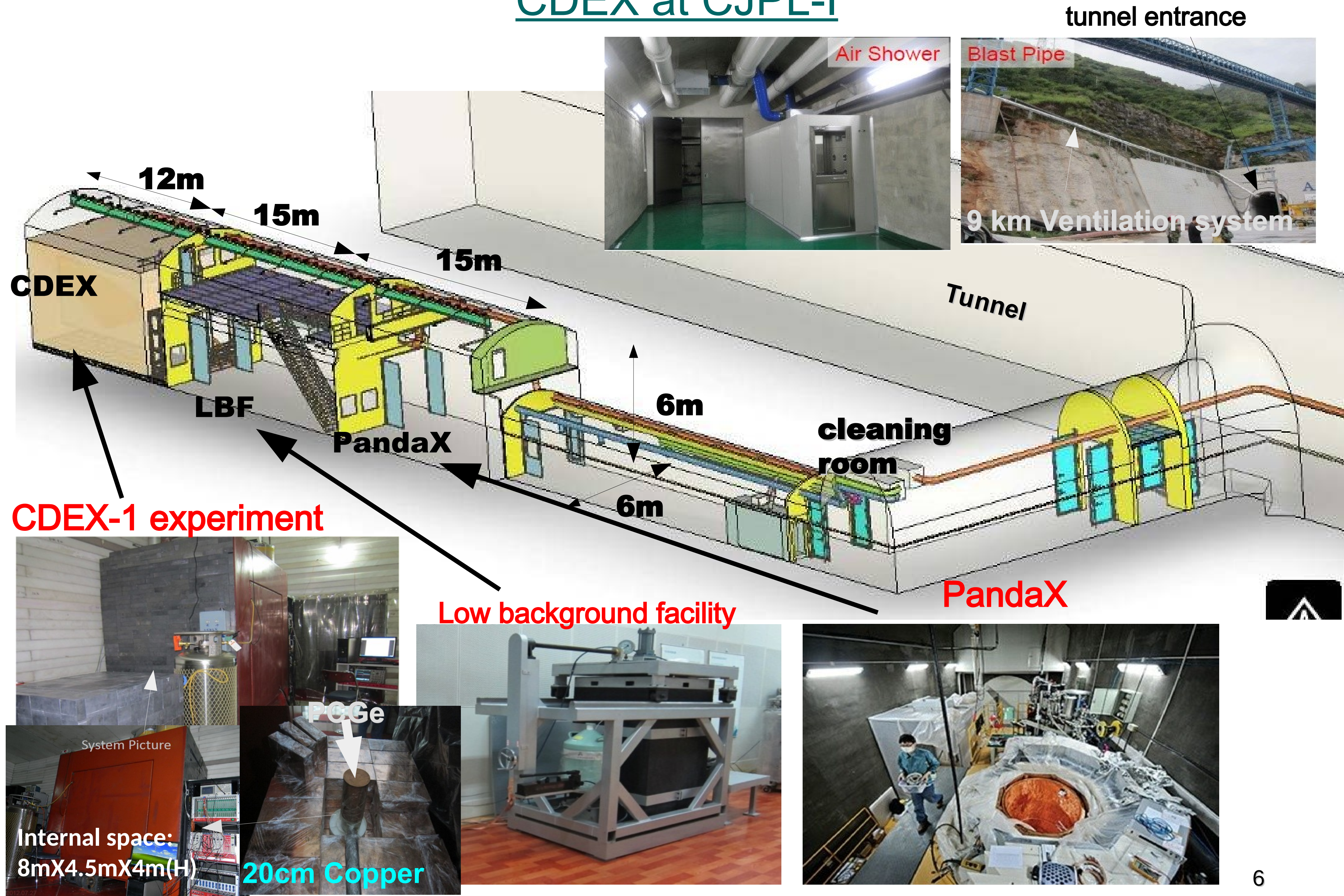
Jinping-II
Power Plant
4800MW
(8×600MW)





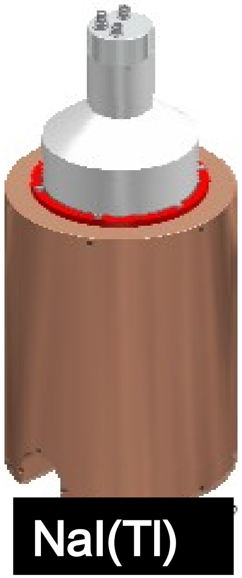
Jinping-I
Power Plant
3600MW
(6×600MW)

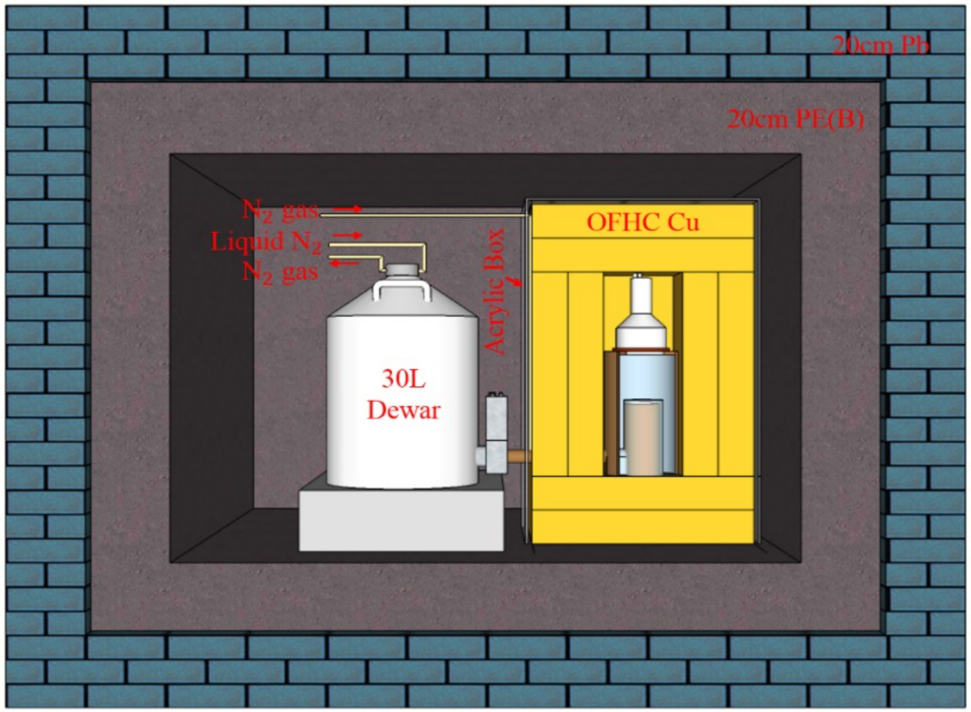
CDEX at CJPL-I



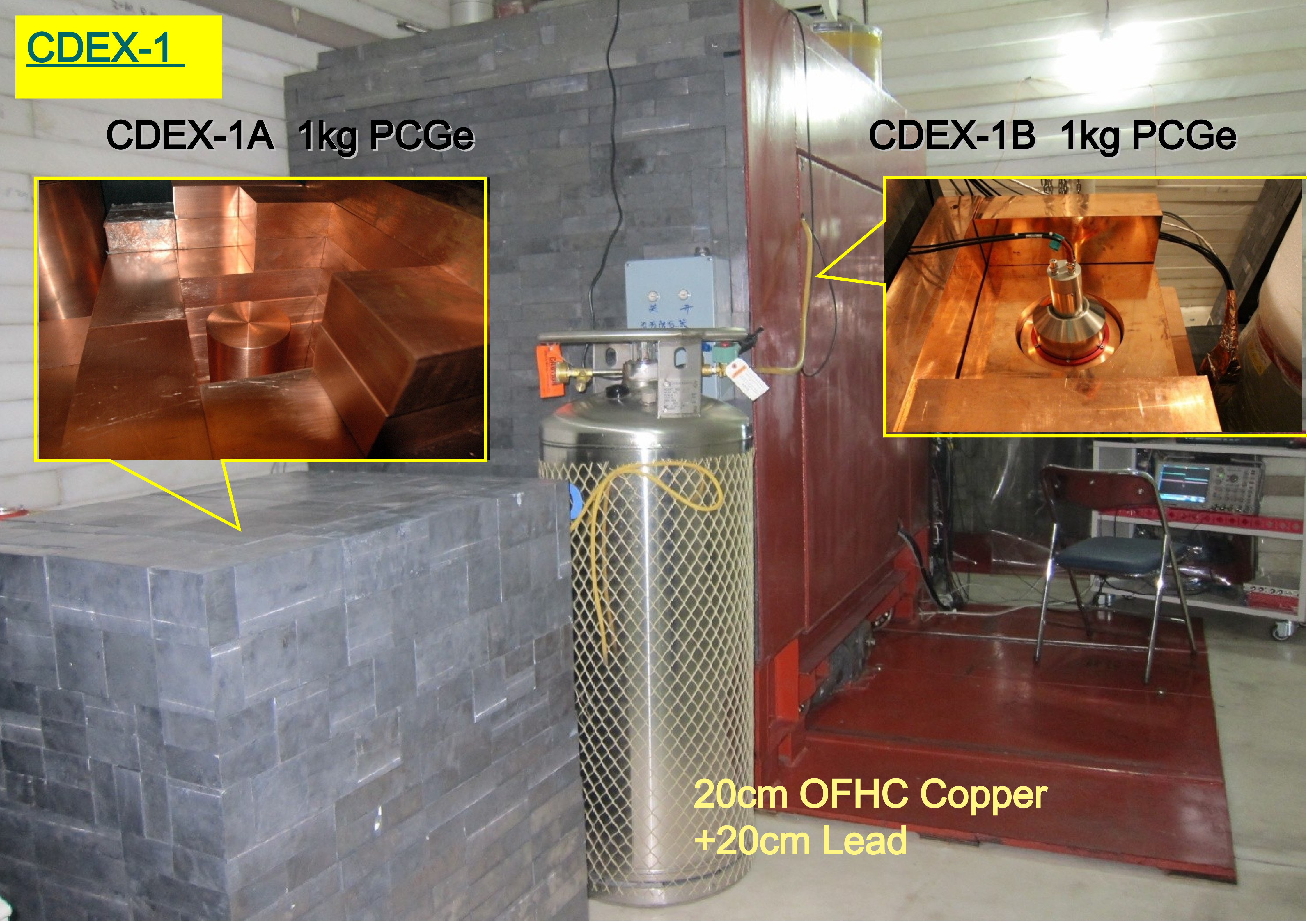
CDEX-1 experiment

1. HPGe technology
   - ✓ Designed the first one single module 1kg-scale p-type point-contact Ge detector (1kg-PPCGe) “prototype” CDEX-1A
   - ✓ Improved 1kg-PPCGe CDEX-1B
2. Active shielding technology: NaI(Tl) used as anti-Compton detector
   - ✓ CDEX-1A 1kg-PPCGe run
   - ✓ CDEX-1A 1kg-PPCGe + NaI(Tl) run (th~475 eV)
   - ✓ CDEX-1B 1kg-PPCGe + NaI(Tl) run (th~160 eV)



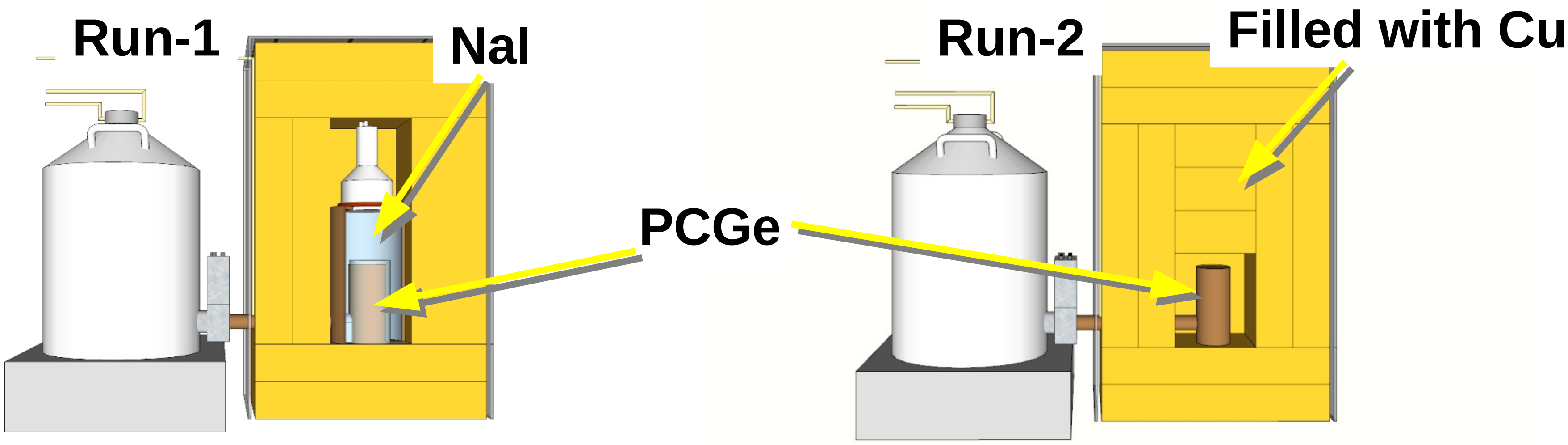


CJPL



CDEX-1
CDEX-1A 1kg PCGe
CDEX-1B 1kg PCGe
20cm OFHC Copper
+20cm Lead

CDEX-1B experiment

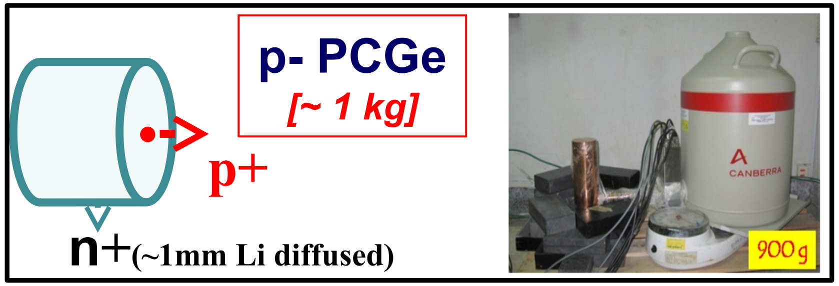


2014/09 – 2017/08
671 kg-days

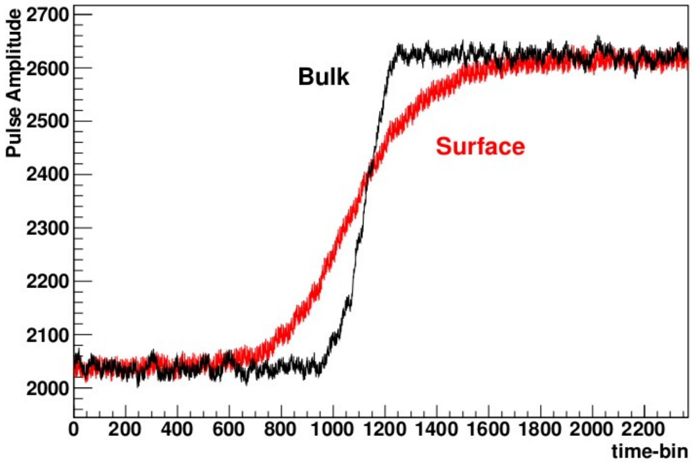
2017/08 – 2018/12 →
340 kg-days

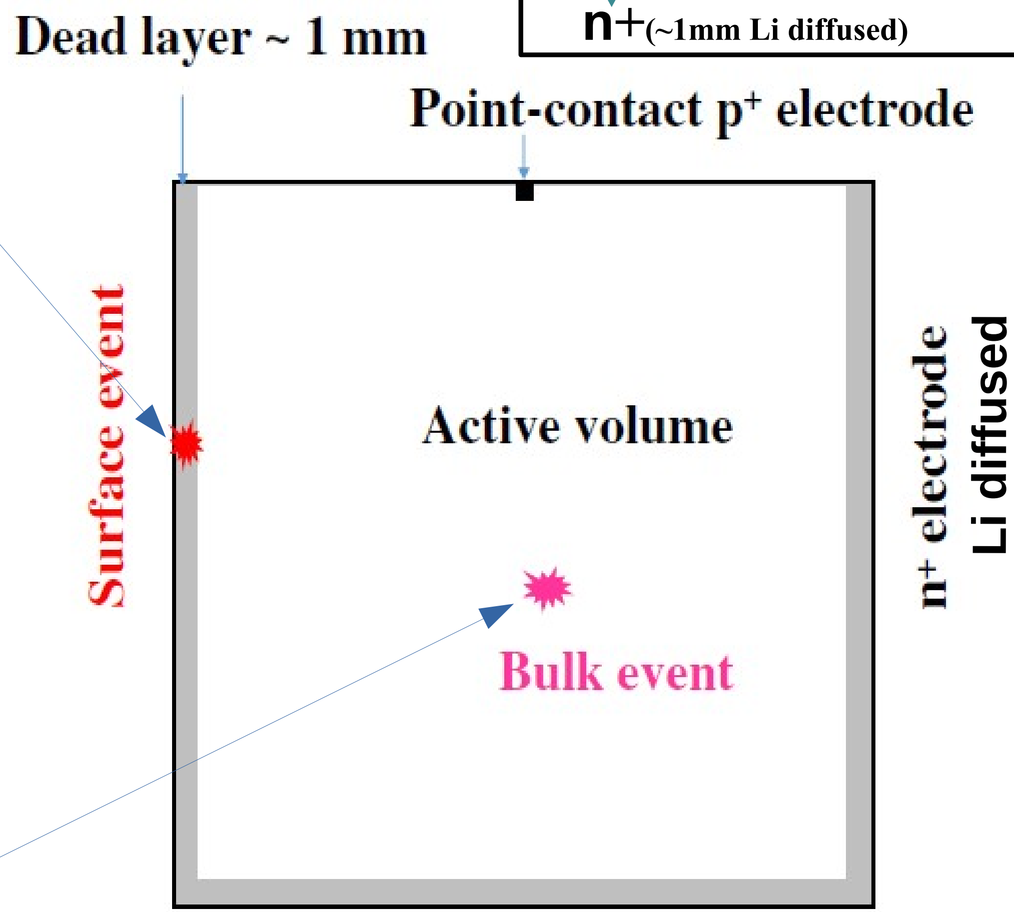
- 1 kg-scale-mass HPGe detector, cooled by cold finger.
- A NaI(Tl) detector is used as active shielding to veto the gamma-ray induced background events.
- The detector has been under stable data taking conditions since March 27th, 2014.
- Threshold ~ 160 eVee. For modulation analysis, threshold ~ 250 eVee.
- Largest analysis uncertainties: bulk/surface separation at low energy.

bulk/surface: largest sources of uncertainties



surface
- partial energy deposit
- diffuse and drift → slow

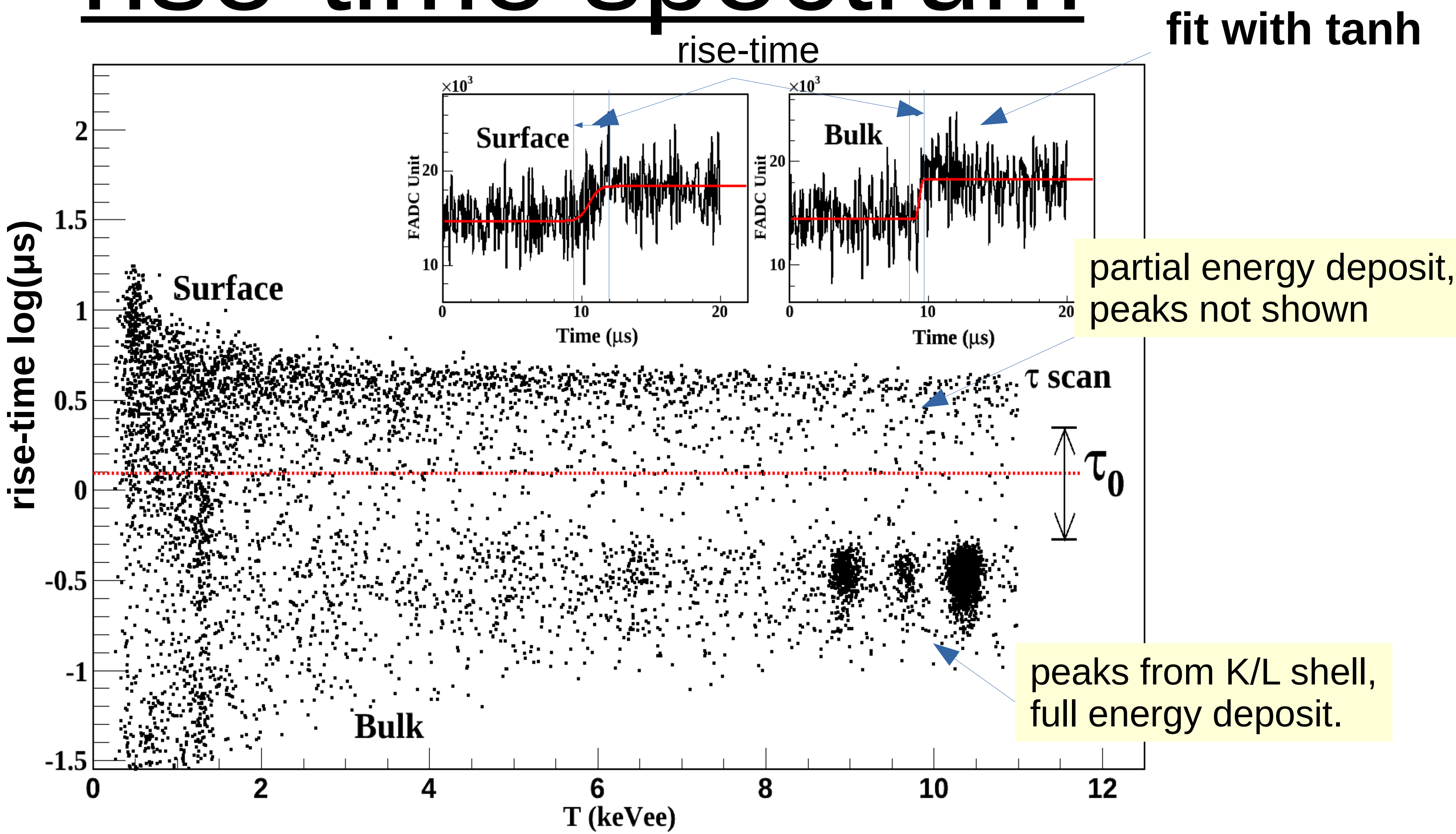




bulk
- full energy deposit
- drift → fast

- a bless : gamma background veto and
- a curse : contaminate low energy spectrum

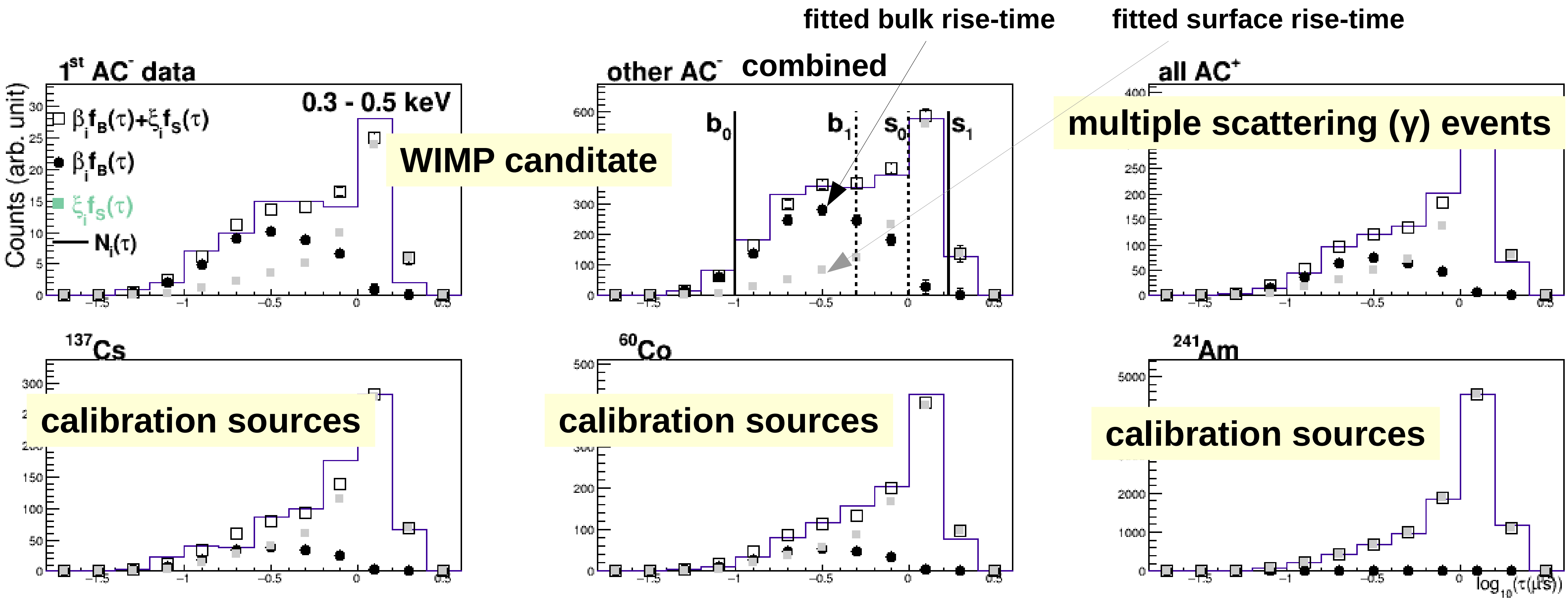
rise-time spectrum



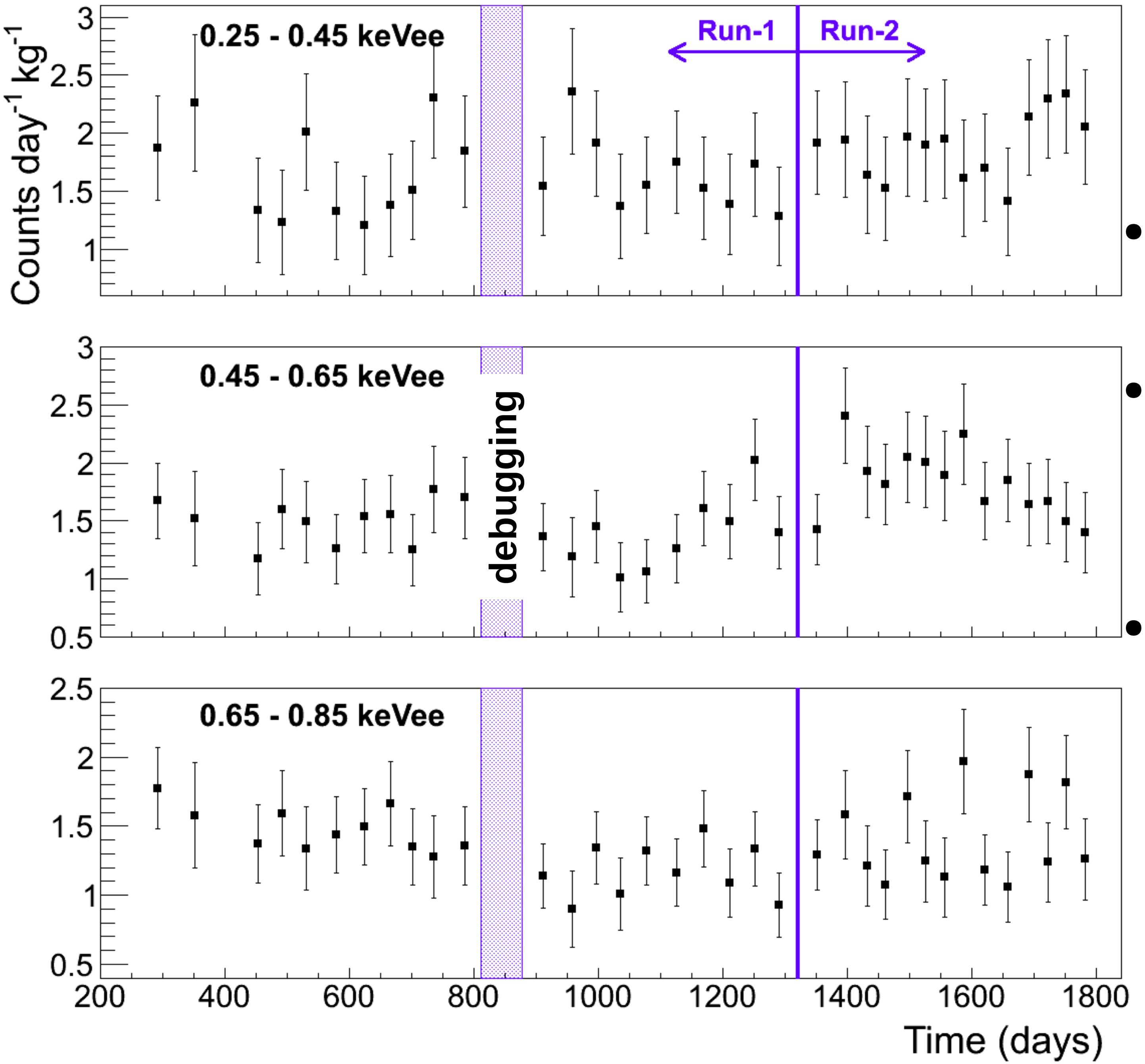
sample from typical DM/ν events (TEXONO), cosmic-vetoed + anti-Compton-vetoed

most probable rise-time distributions

- all the events samples share same bulk/surface rise-time distributions.
- unknown rise-time functions → bin-by-bin fitted.
- treat each month as individual sources.



CDEX-1B data < 0.85 keV



- run-1 to run-2: change of shielding.
- 0.25 – 0.85 keV: most important region for low mass WIMP
- χ2 test, (mean, RMS) consistent with null profile.

Model dependent/independent modulation analysis

fit the data to flat-bkg + cos (after K/L subtraction)

$$\chi^2_{ik} = \sum_{j \in \mathrm{Time}}^{N} \frac{\left(n_{ijk} - P_{ijk} - B_{ik} - A_{ik} cos\left(\frac{2\pi(t_j - \phi)}{T_{yr}}\right)\right)^2}{\Delta^2_{ijk}}$$

i, j, k : energy-bin, time-bin, number of run

n_{ijk} : count rates

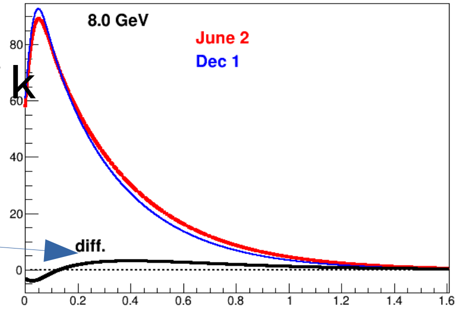
P_{ijk} : contributions from K/L-shells

B_{ik} : time-independent background level, to be fitted

A_{ik} : modulation amplitudes, to be fitted.

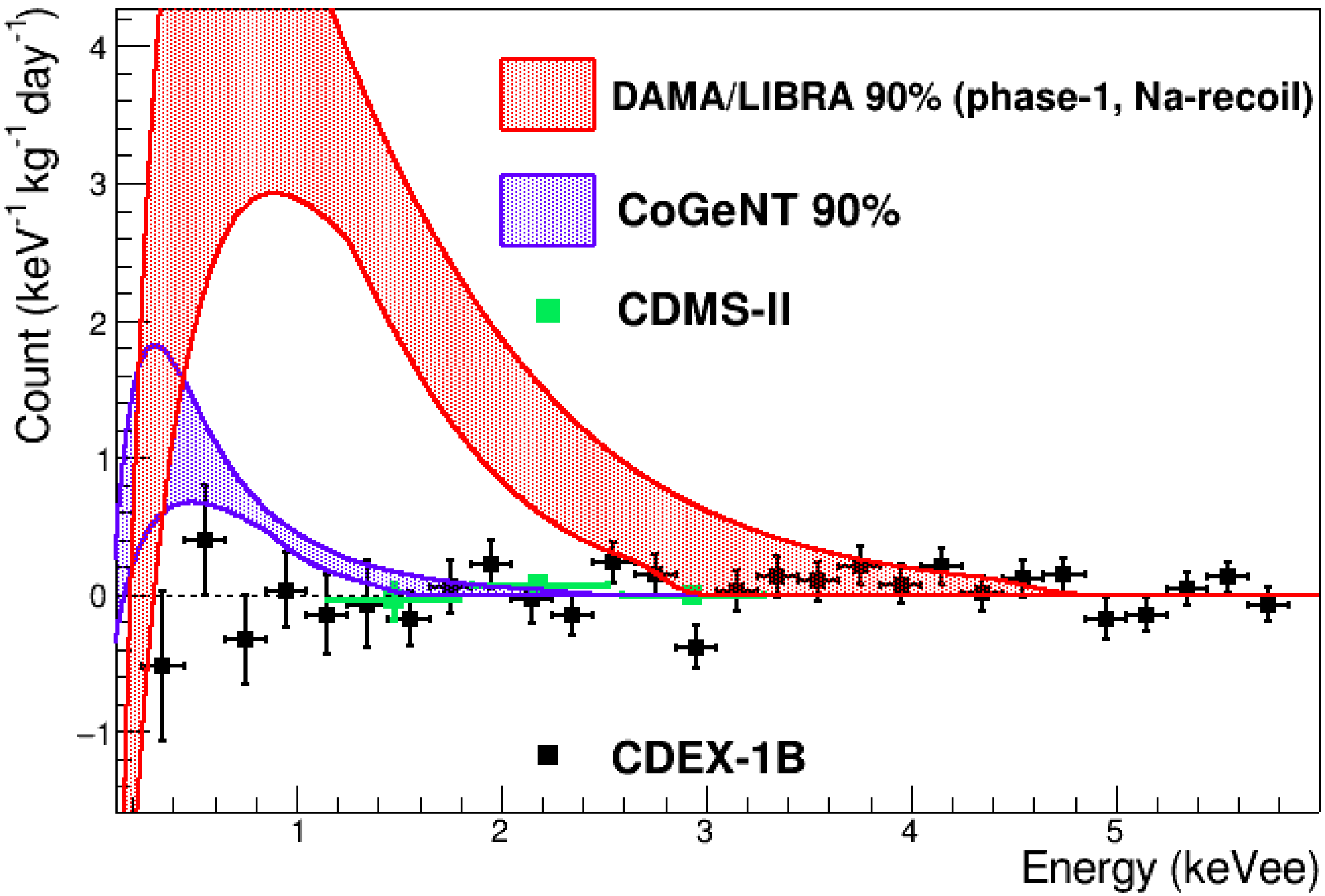
Model independent: modulation amplitudes of each χ^2_{ik}

Model dependent: astrophysics dependent A_{ik}, sum over χ^2_{ik}



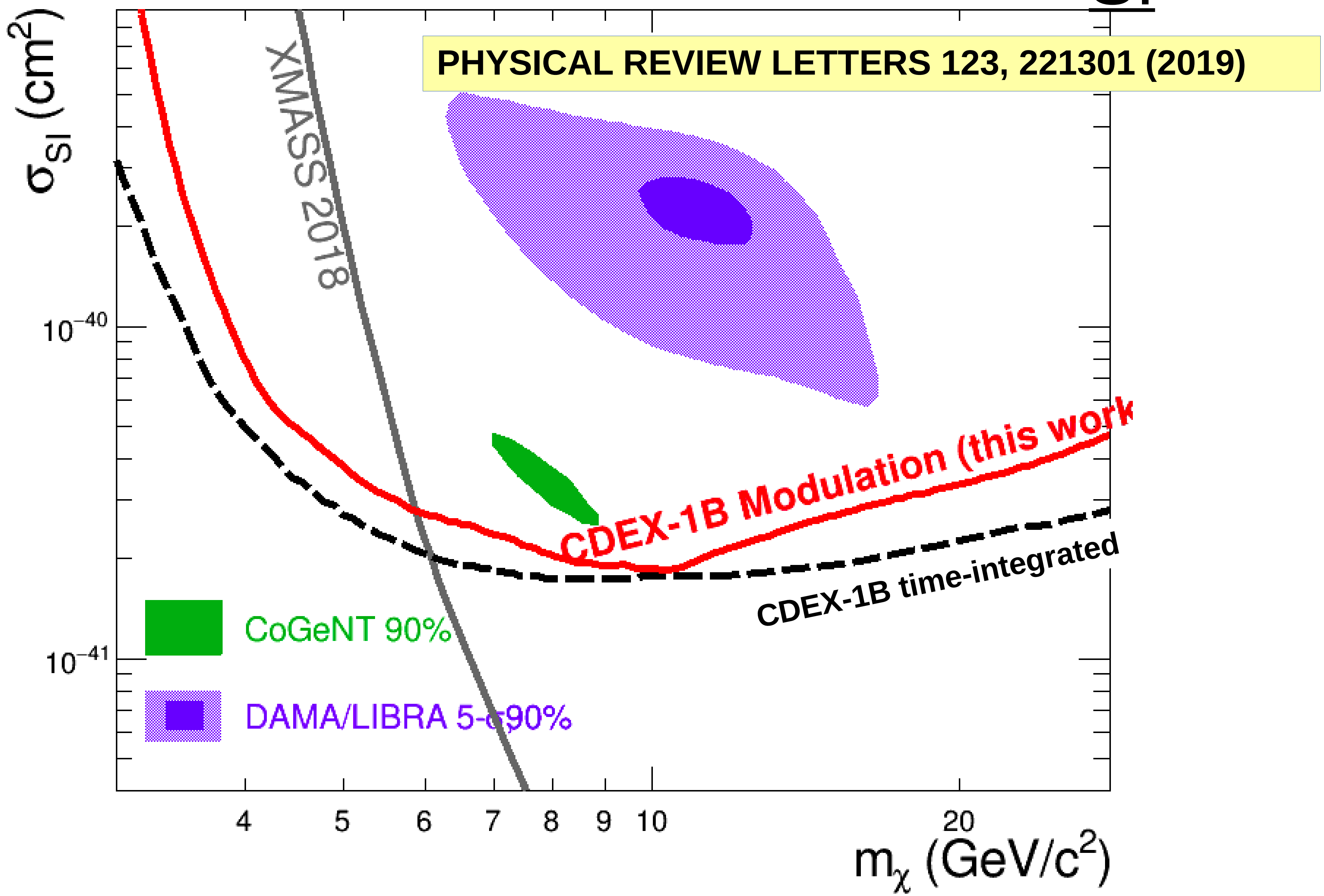
A_{ik} of Halo-model

Model independent modulation



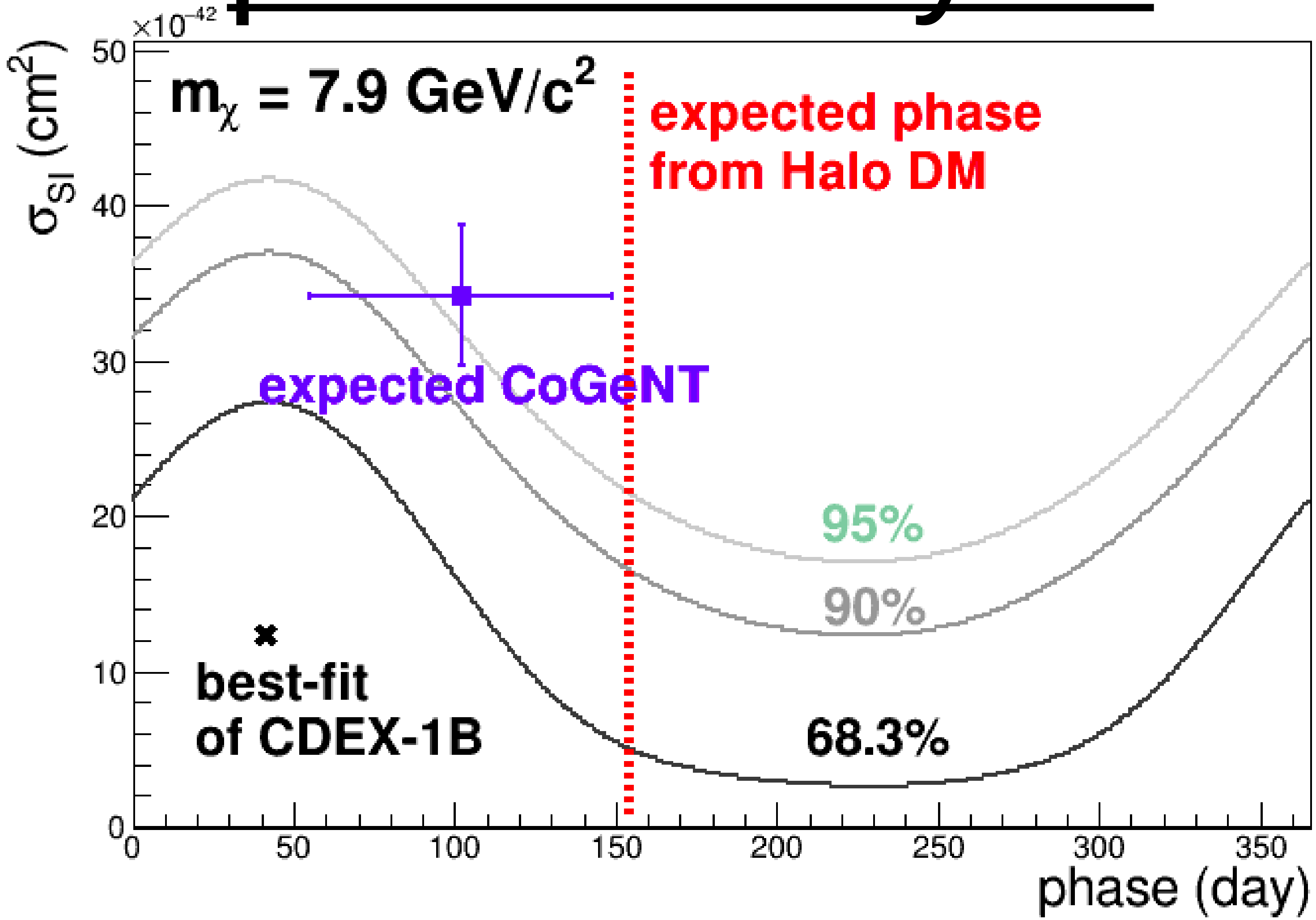
modulation amplitudes consistent with null-results by χ^2 test and (mean, RMS)

Model dependent results: σ_{SI}



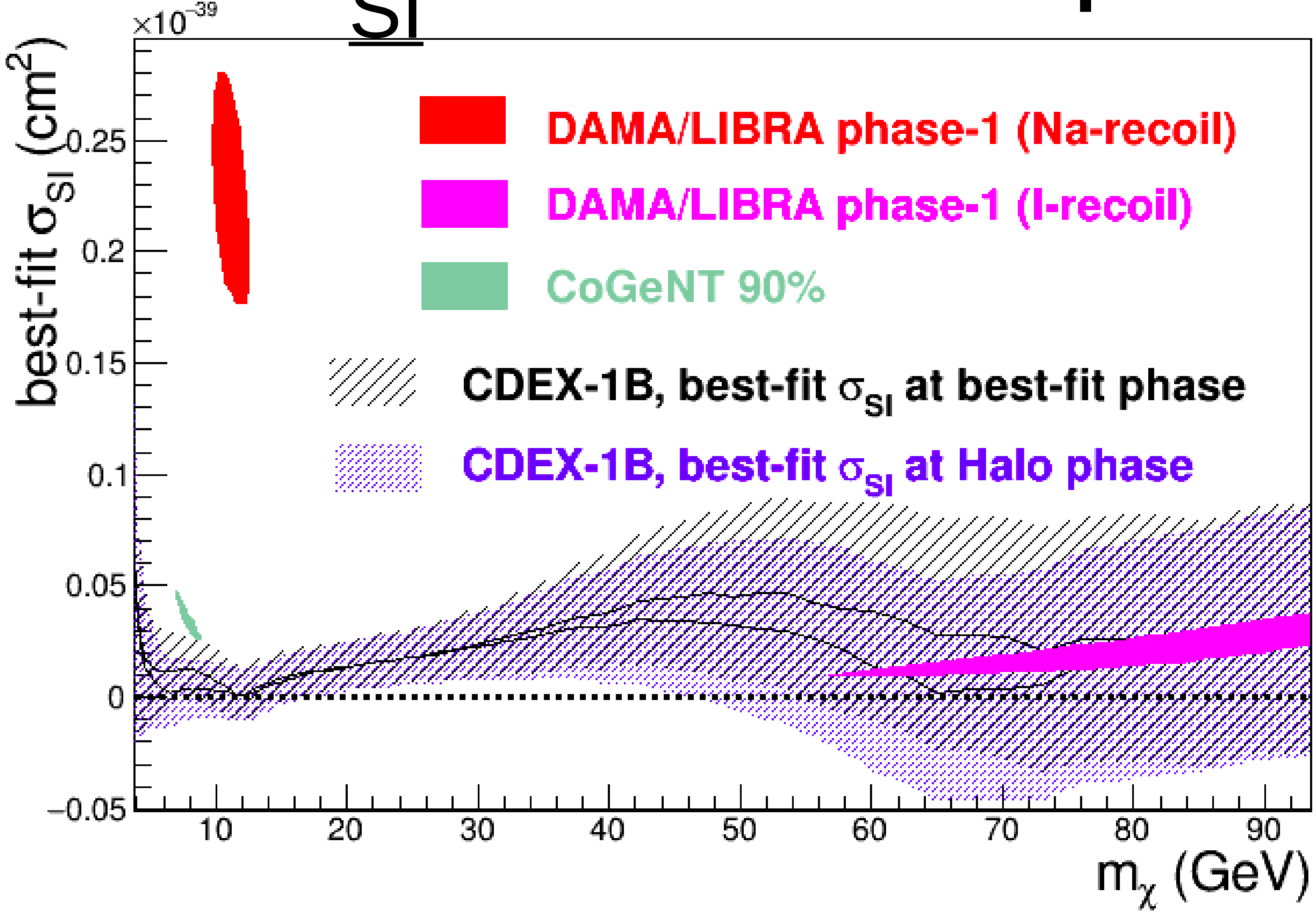
best annual modulation sensitivities < 6 GeV

phase analysis



at < 20 GeV, best fitted phase is off by ~100 days,
however Δφ > 0.5 years (any φ is within 1-σ)
data consistent with null-hypothesis at any φ

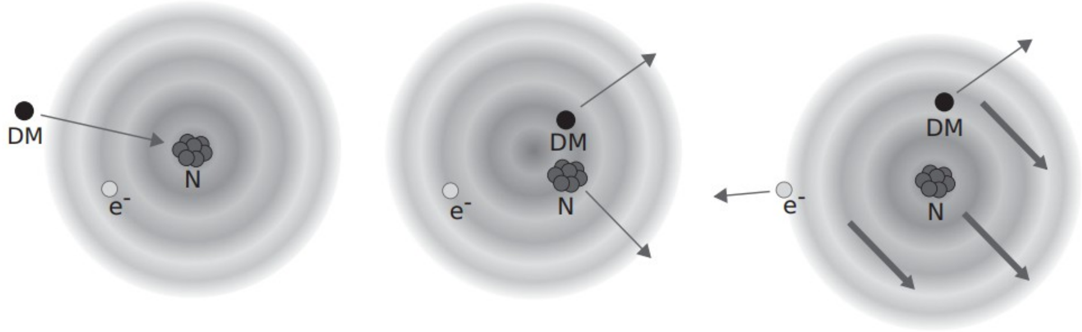
σ_{SI} at best-fit φ

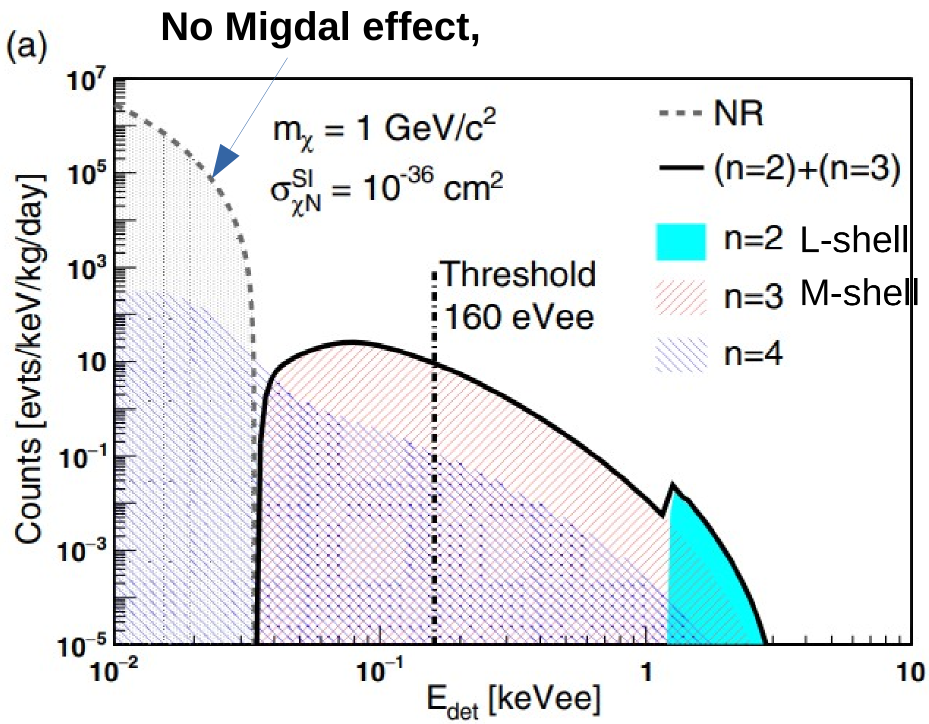


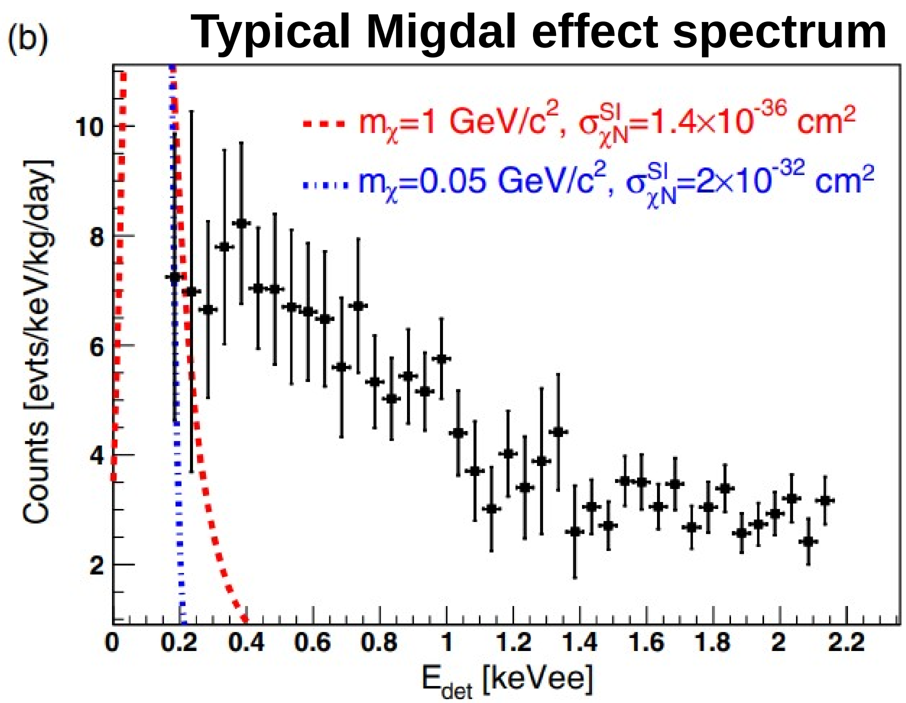
the results consistent with null-results at any phase (within 2-σ) up to 100 GeV

Migdal effect

nuclear recoil → electrons cloud move, except one e- → ionization







Migdal effect

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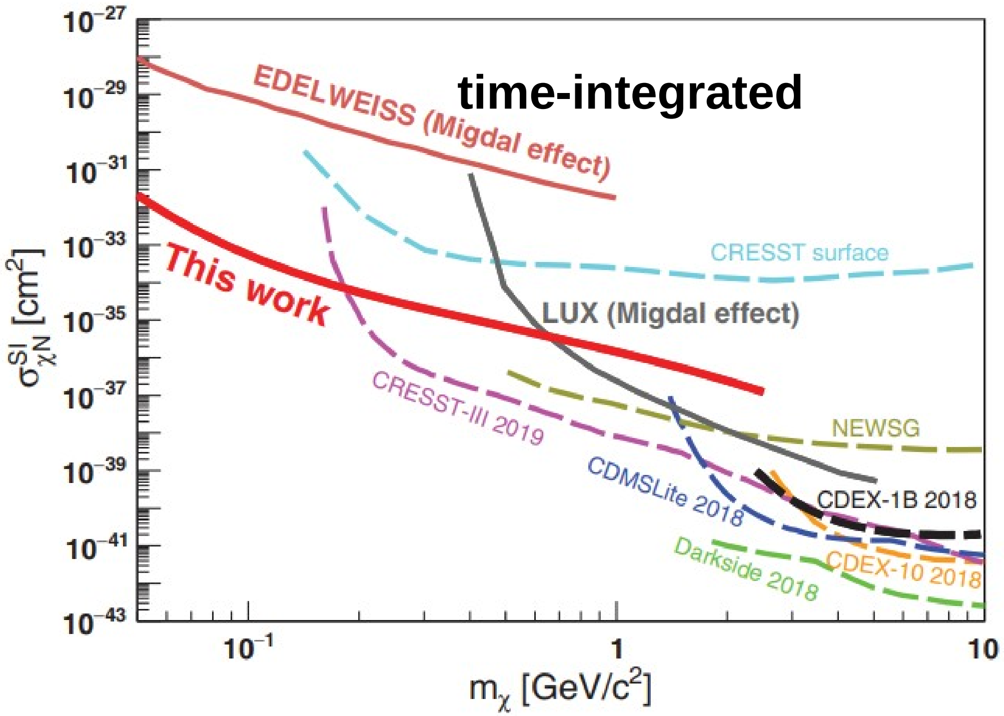
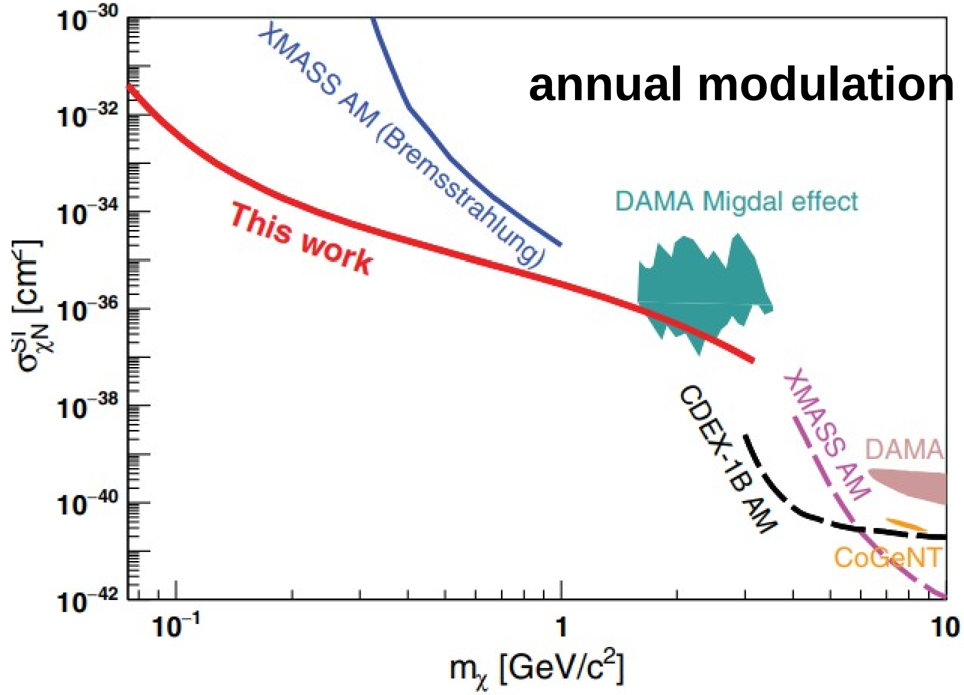
- probing m_χ to < 1 GeV,
- best time-integrated results < 0.1 GeV
- best annual modulation results < 1 GeV





summary

- best modulation (χN) results < 6 GeV.
- best Migdal effect results at < 1 GeV.
- unique stable low threshold (250 eVee) Ge data with long time-span ~ 3.2 years.
- exclude DAMA phase-1 and CoGeNT at > 99.99%, 98% C.L.
- data consistent with null-hypothesis.
- other results (e. g. dark photon search, Axion search) will be available soon.
- diurnal analysis, frequency analysis on the way.

Thanks