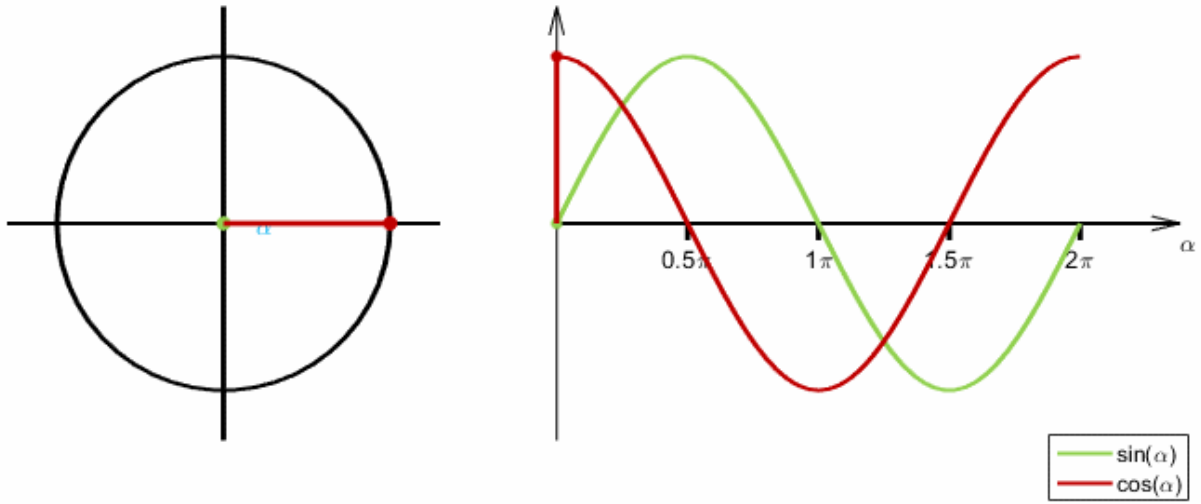
Annual Modulation Searches

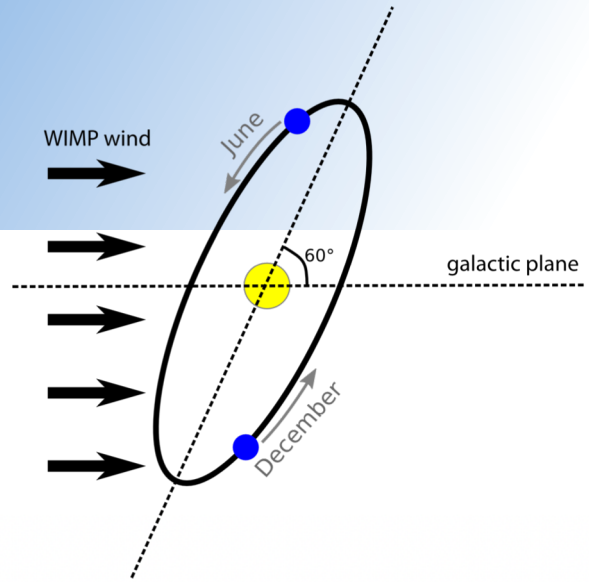


Florian Reindl
HEPHY & TU Vienna

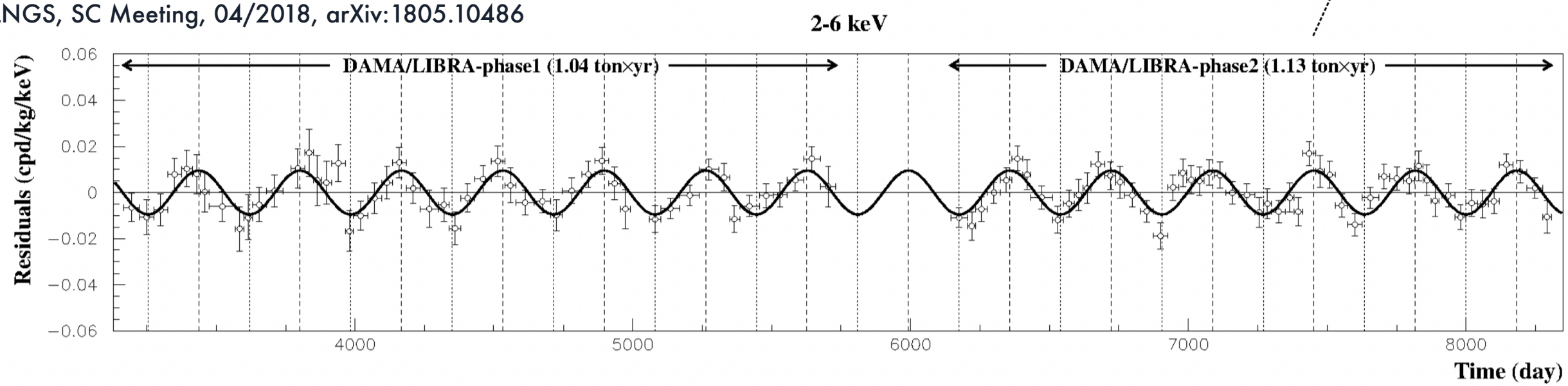
The puzzle of dark matter - assembling the pieces
October 2018, DESY, Hamburg

NO SIGNAL

DAMA/LIBRA Modulation Signal
Time distribution



LNGS, SC Meeting, 04/2018, arXiv:1805.10486



DAMA/LIBRA Phase 1 + 2 : 2.17 tonne years
Statistical significance: 11.9σ

THE SMOKING GUN EVIDENCE ???

Statistics: 12.9σ ✓

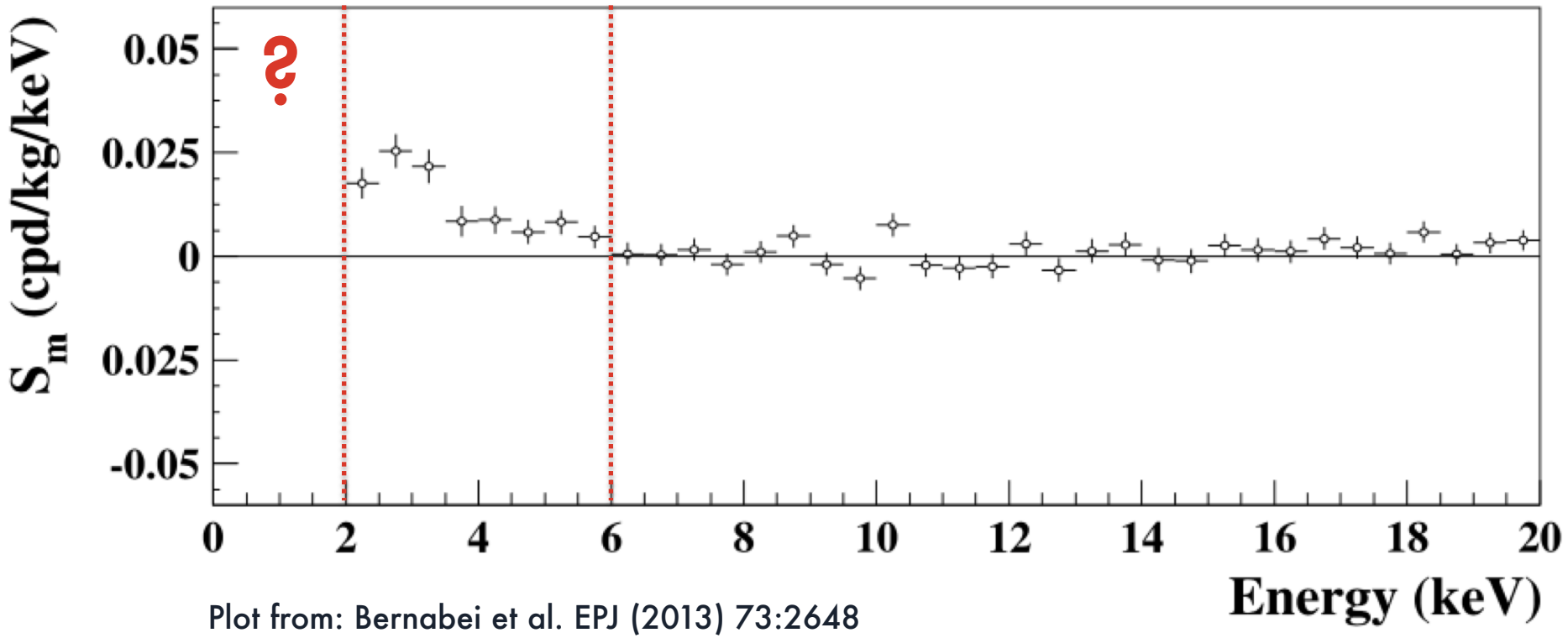
Period: 0.999 ± 0.001y* ✓

Phase: 25th May +/- 5 days ✓

(cosine peaking June 2nd)

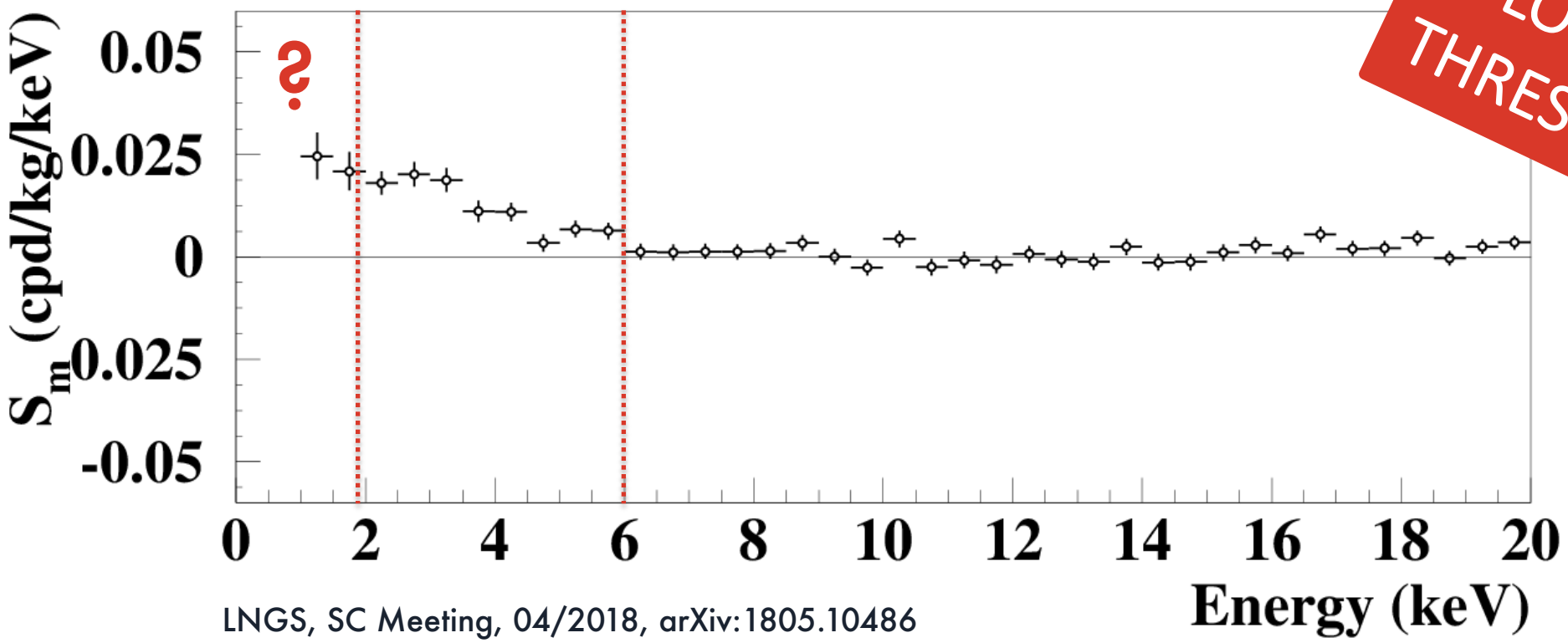
Convincing non-DM explanation ✗

DAMA/LIBRA Modulation Signal
Energy distribution



Plot from: Bernabei et al. EPJ (2013) 73:2648

DAMA/LIBRA Modulation Signal
Energy distribution



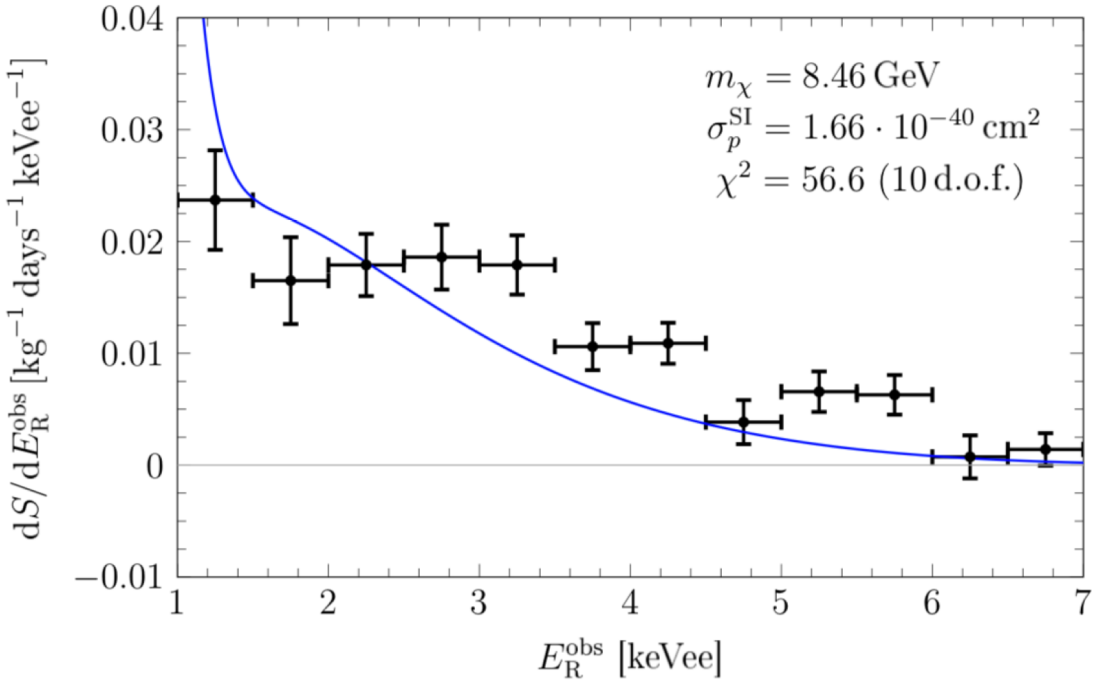
NEW LOWER THRESHOLD

LNGS, SC Meeting, 04/2018, arXiv:1805.10486

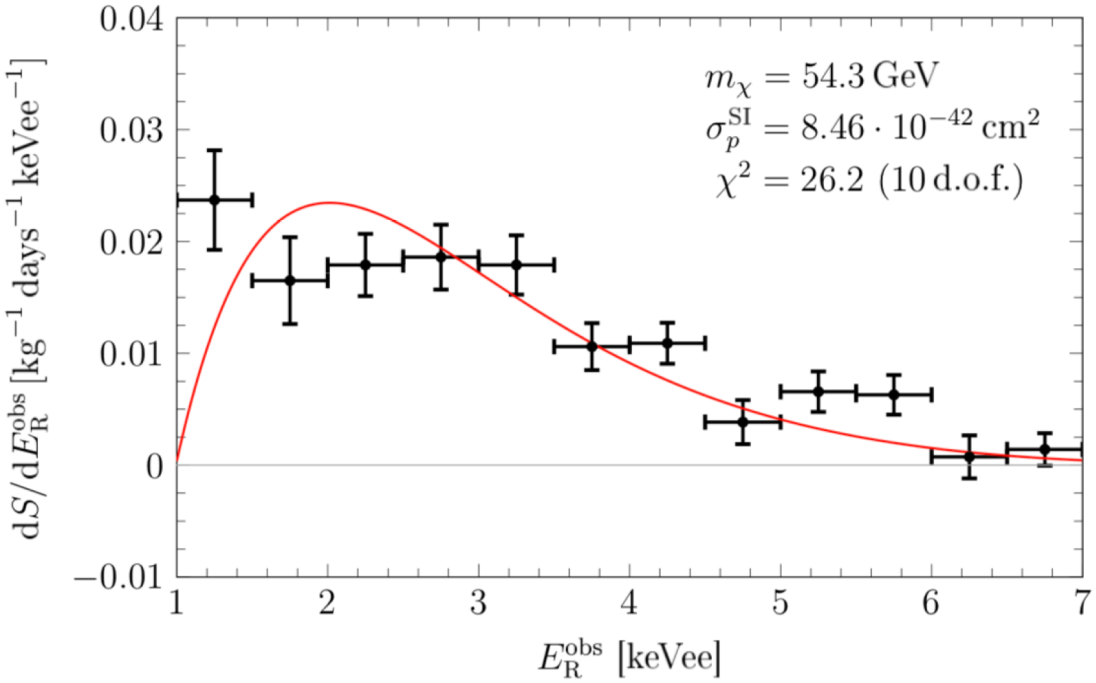
(Felix Kahlhoefer, FR et al JCAP05(2018)074)

DAMA IN THE STANDARD SCENARIO

Best fit for scattering off Na



Best fit for scattering off I



Warning: Depends on Quenching Factors

WHAT ARE THE UNKNOWNS?

Astro physics

Dark matter halo ←→

Velocity distribution

Particle physics

Interaction mechanism

galactic escape velocity

velocity distribution

WIMP-nucleon cross section

$$\frac{dR}{dE_R} = \frac{\rho_\chi}{m_N m_\chi} \cdot \int_{v_{\min}}^{v_{\text{esc}}} d^3\nu \, f(\vec{\nu}) \nu \frac{d\sigma(\vec{v}, E_R)}{dE_r}$$

minimal velocity to produce a recoil above E_R

~ A^2

~ form factor

→ Target material dependence

clarified open

~~NaI~~

NaI

STANDARD SCENARIO

clarified open

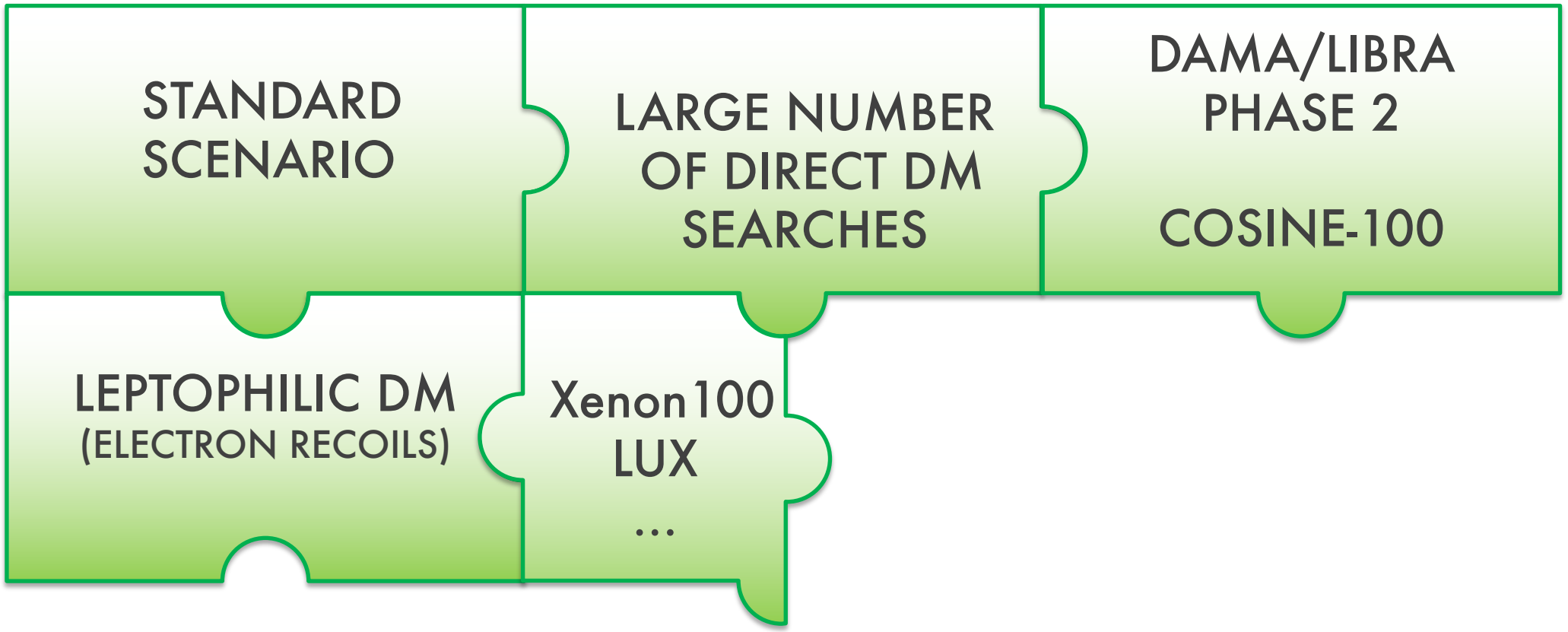
~~NaI~~

NaI

clarified open

~~NaI~~

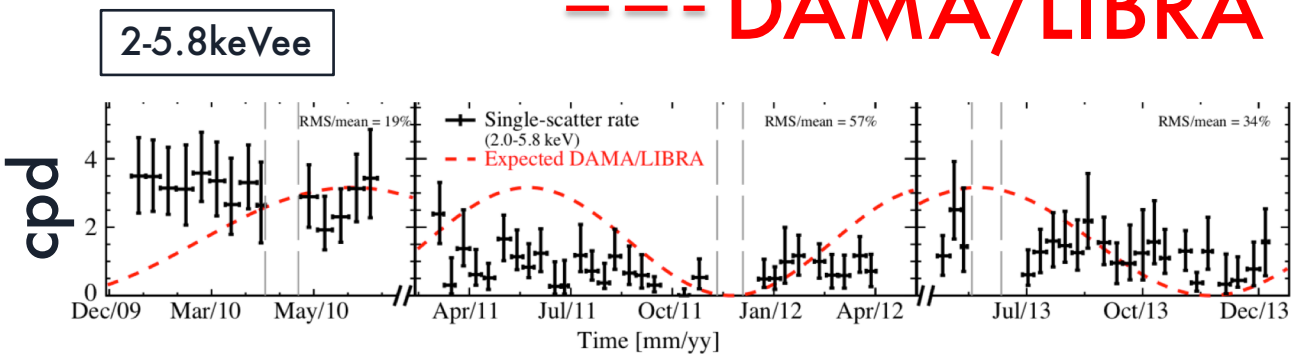
NaI



LEPTOPHILIC DARK MATTER

XENON100

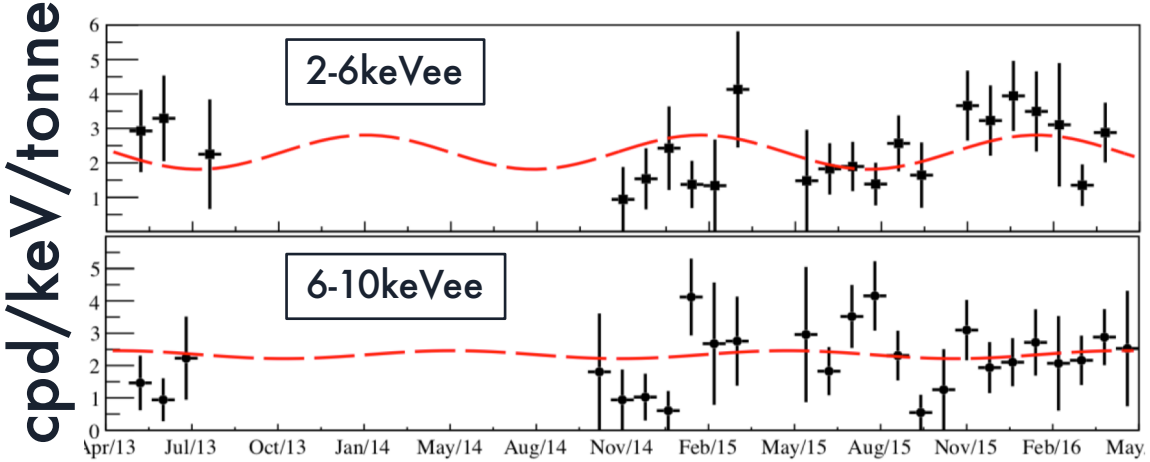
– – – DAMA/LIBRA



PRL 118 (2017)

LUX

– – – best fit

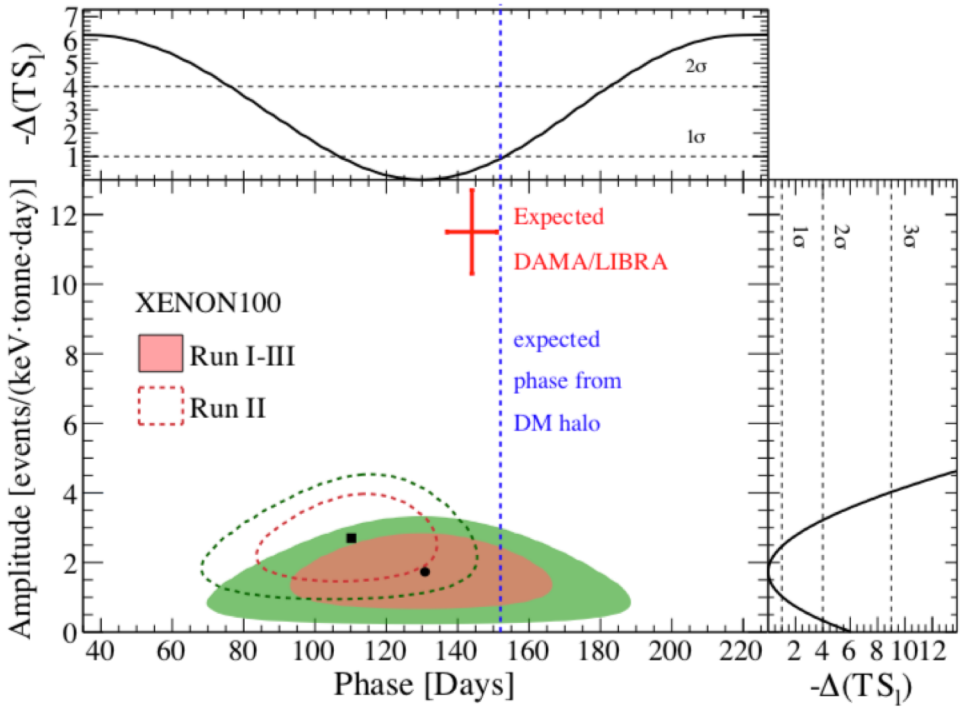


PRD 98 (2018)

LEPTOPHILIC DARK MATTER

XENON100

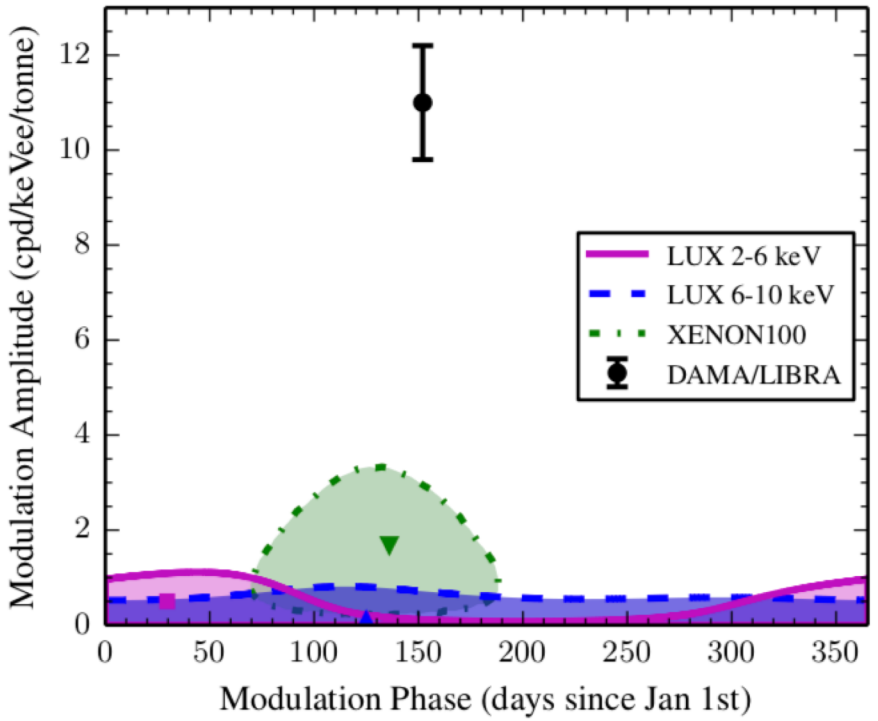
PRL 118 (2017)



>5σ tension with DAMA*

LUX

PRD 98 (2018)



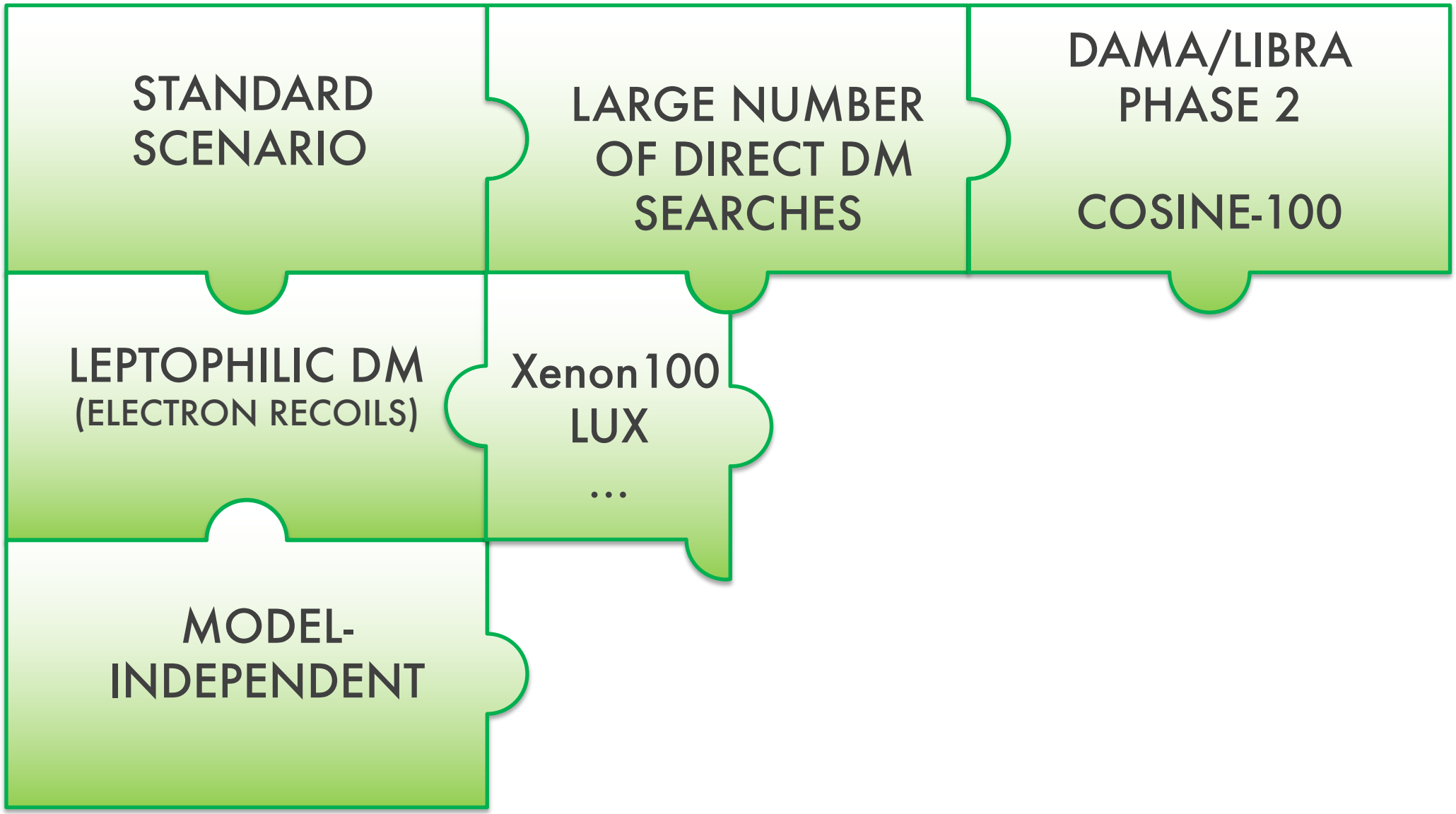
>9σ tension with DAMA*

*DAMA/LIBRA phase 1 for leptophilic DM

clarified open

~~NaI~~

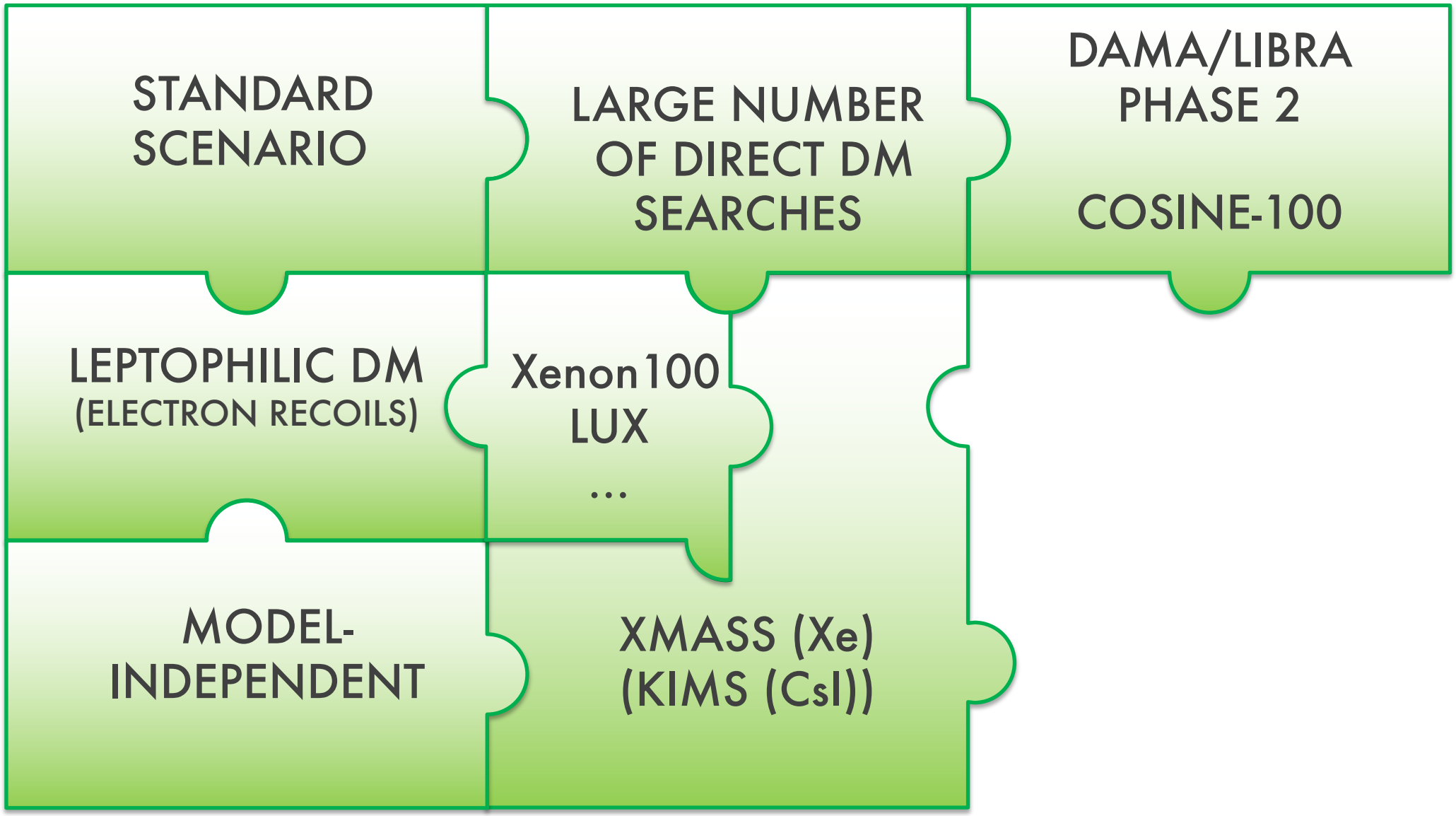
NaI



clarified open

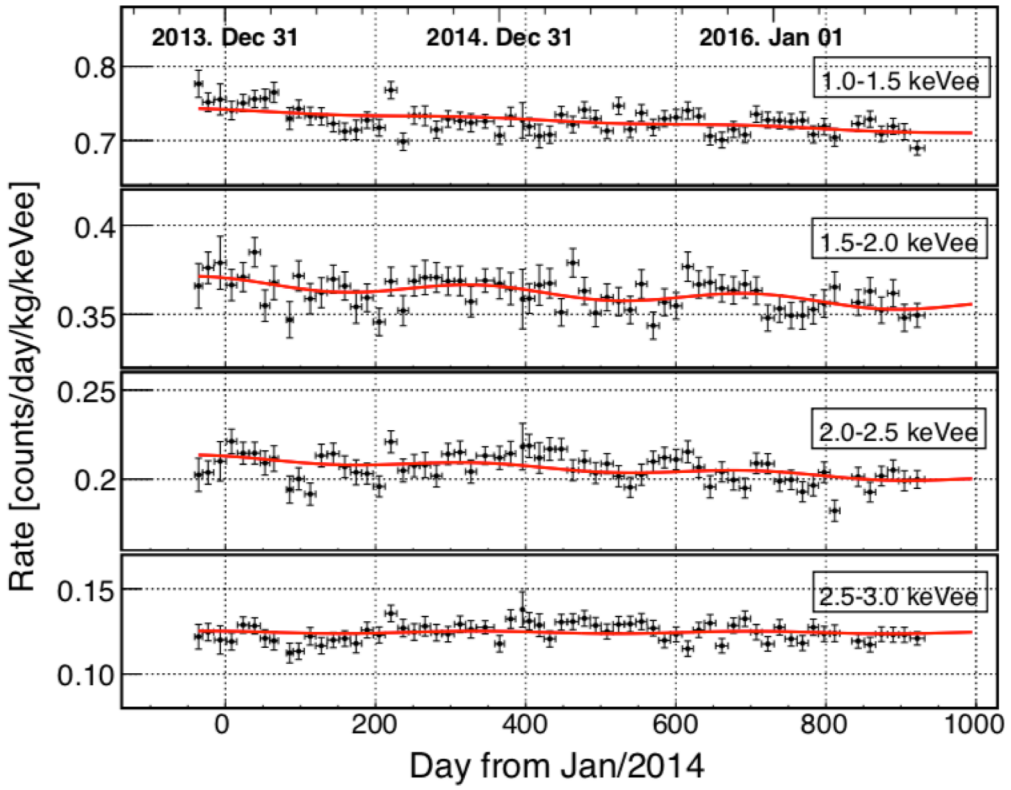
~~NaI~~

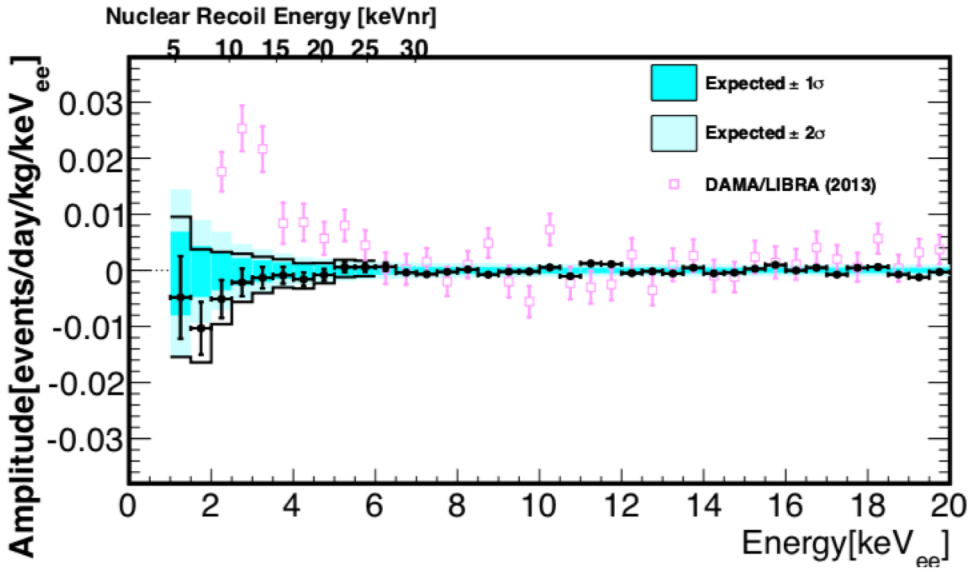
NaI



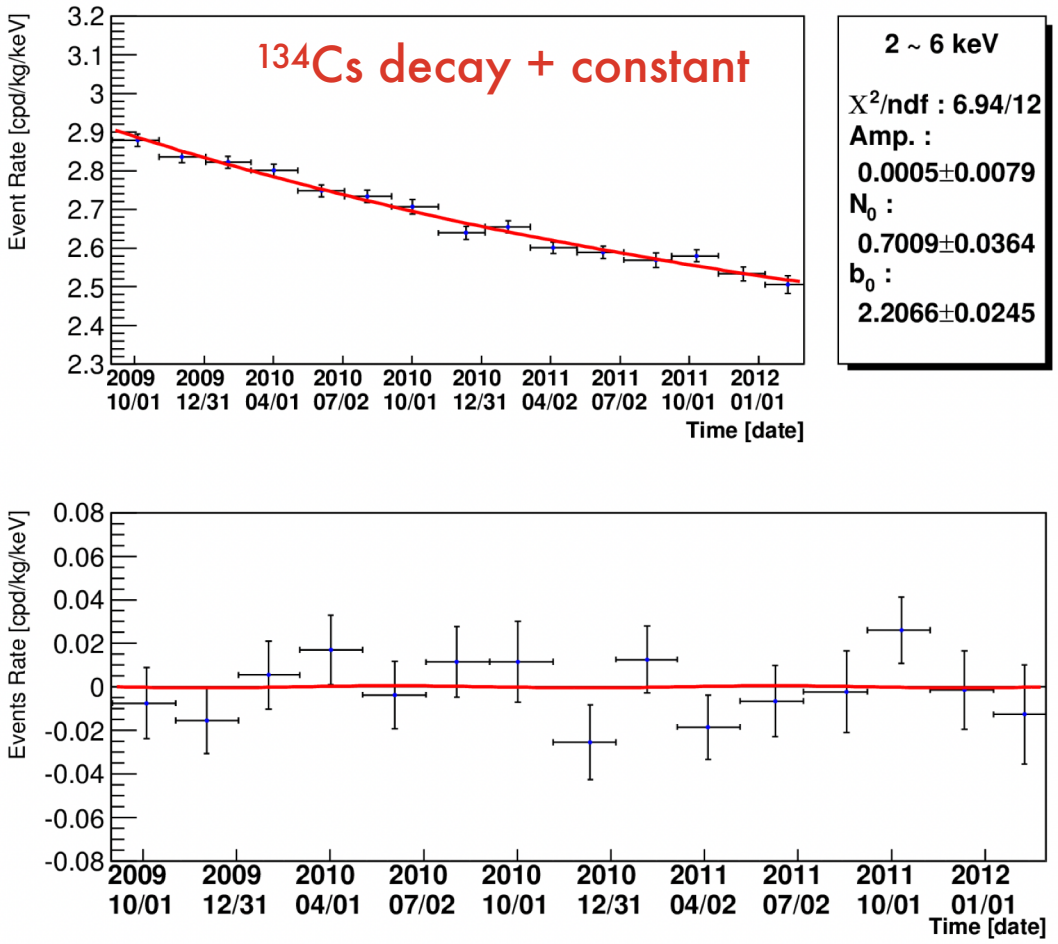
XMASS: SINGLE-PHASE LXE DETECTOR

Threshold: 1keVee (4.8keVnr)





KIMS (CsI)



90% limit on modulation amplitude in 3-6keVee:

0.0119cpd/kg/keV

QF

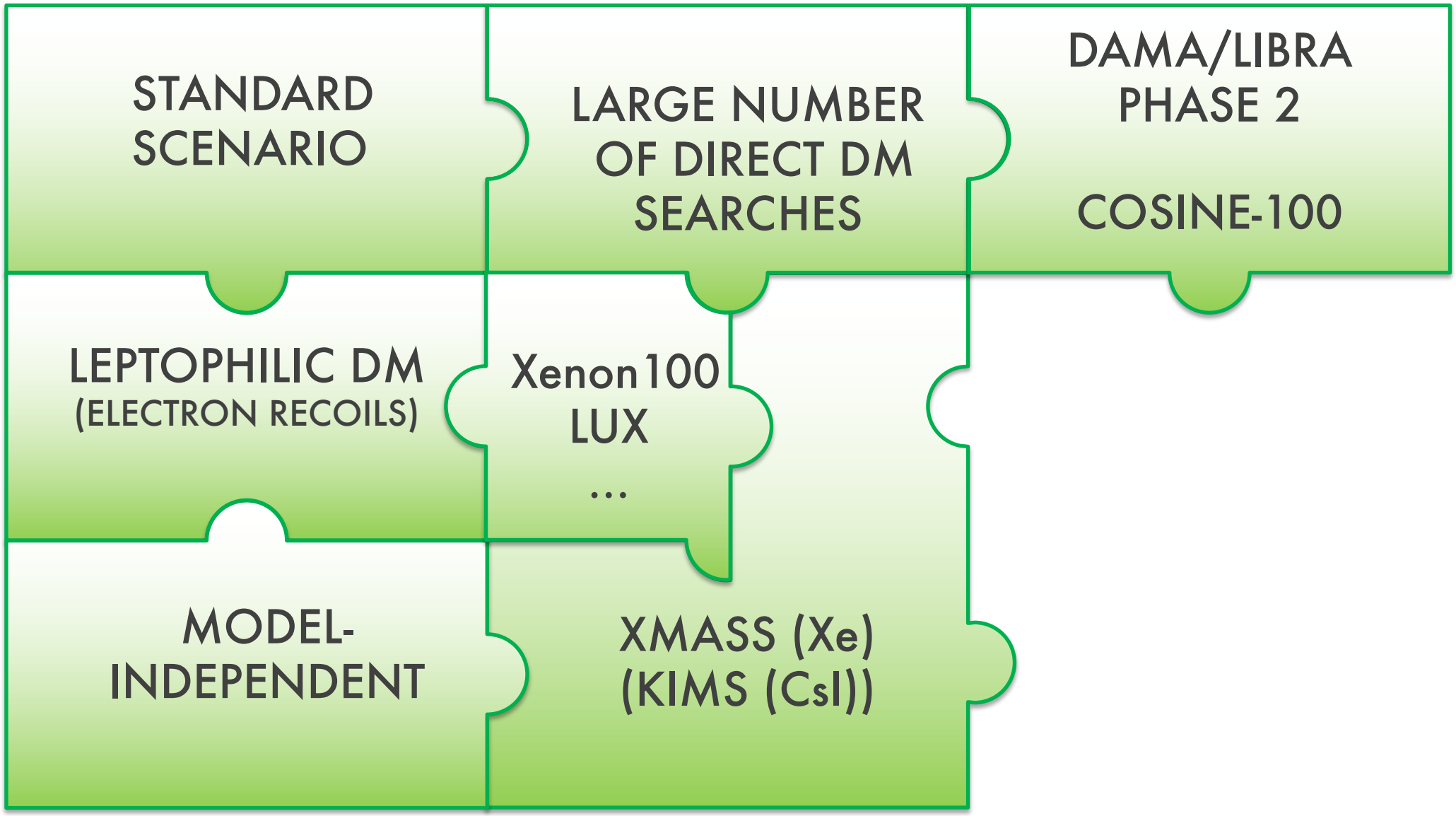
DAMA/LIBRA phase 1 + DAMA/NaI, 2-4keVee:

0.0179 ± 0.0020 cpd/kg/keV

clarified open

~~NaI~~

NaI



clarified open

~~NaI~~

NaI

STANDARD SCENARIO

LARGE NUMBER OF DIRECT DM SEARCHES

DAMA/LIBRA PHASE 2

COSINE-100

LEPTOPHILIC DM (ELECTRON RECOILS)

Xenon100
LUX
…

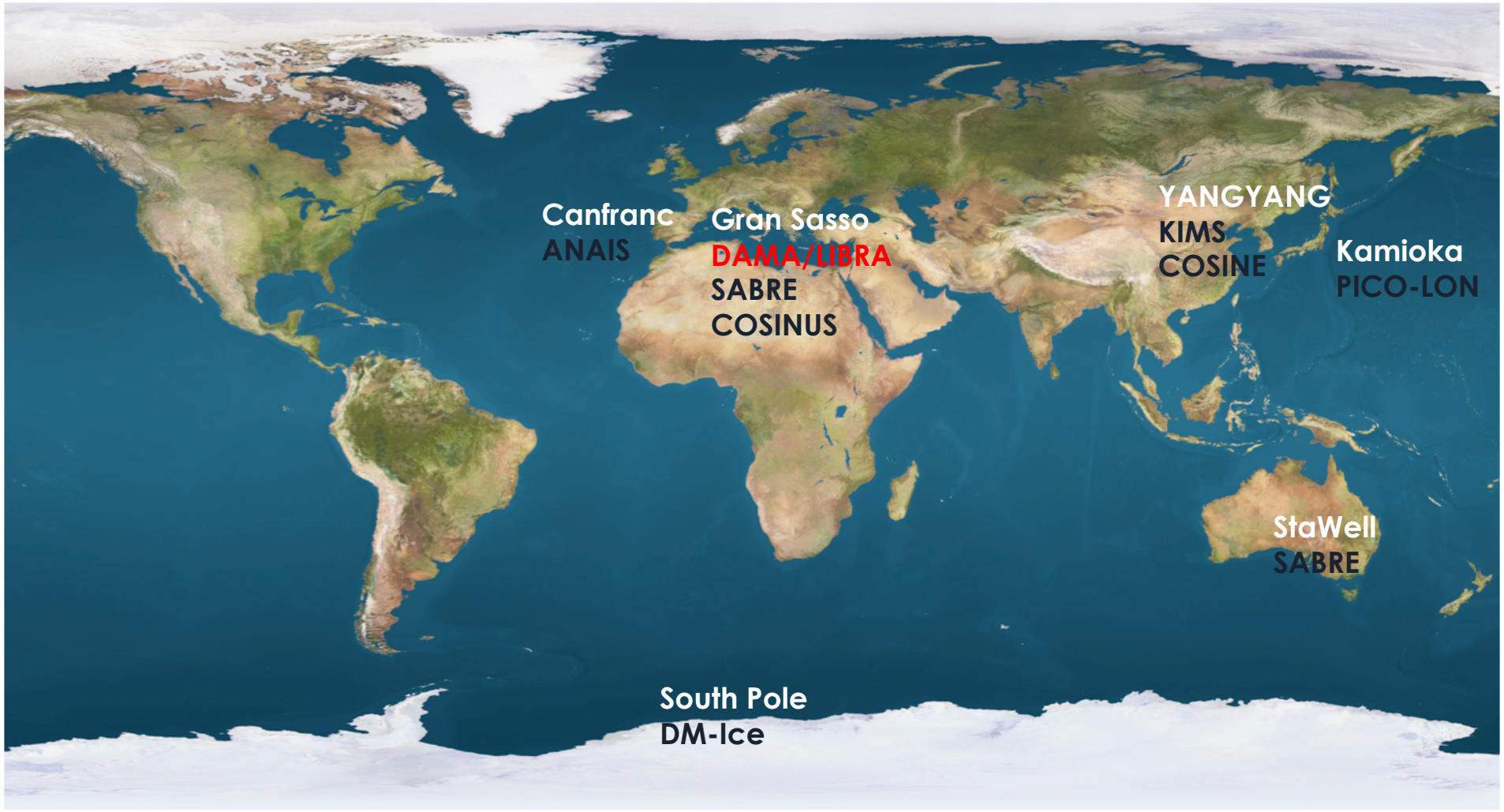
ANAIS, COSINE
SABRE, PICO-LON

MODEL-INDEPENDENT

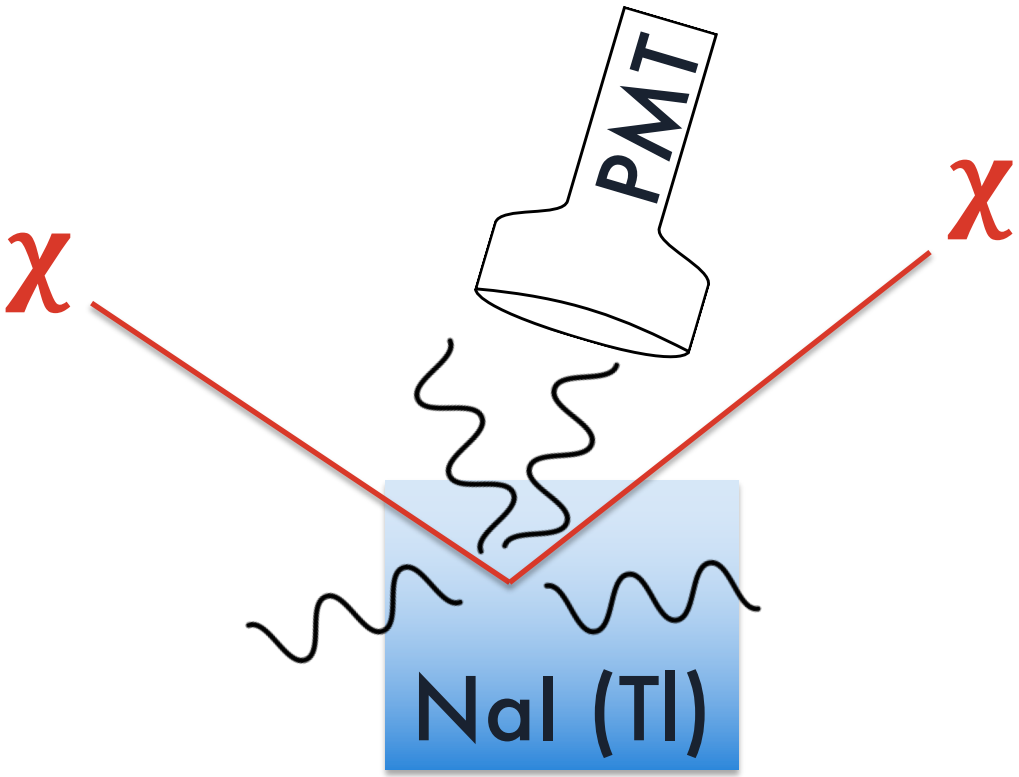
XMASS (Xe)
(KIMS (CsI))

COSINUS
1π
(NUCLEAR RECOIL)

NaI EXPERIMENTS



"DAMA-LIKE" SETUPS



Single channel: Scintillation light
→ Electron-equivalent energy scale
→ No event-by-event discrimination
between electron recoils and nuclear recoils off Na and I

Room temperature
Tl-doped crystal

Must Have for "DAMA-Like" Setups

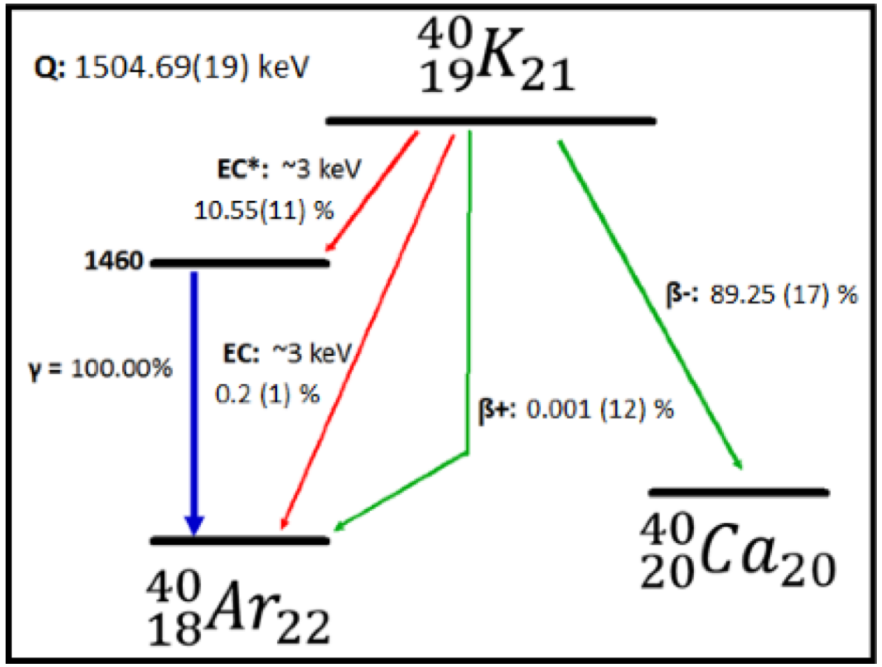
- energy threshold of ≤1 keVee
- radiopure crystal: ~ 1 count / (keV kg day)
  ~ 600μBq/kg ^{40}K
- large detector mass $\mathcal{O}$ (10 kg)

- liquide scintillator veto to suppress ^{40}K background
- muon veto to reject muon-induced background

"DAMA-LIKE" SETUPS - CHALLENGES

No event-by-event discrimination:

Radiopurity is the key factor

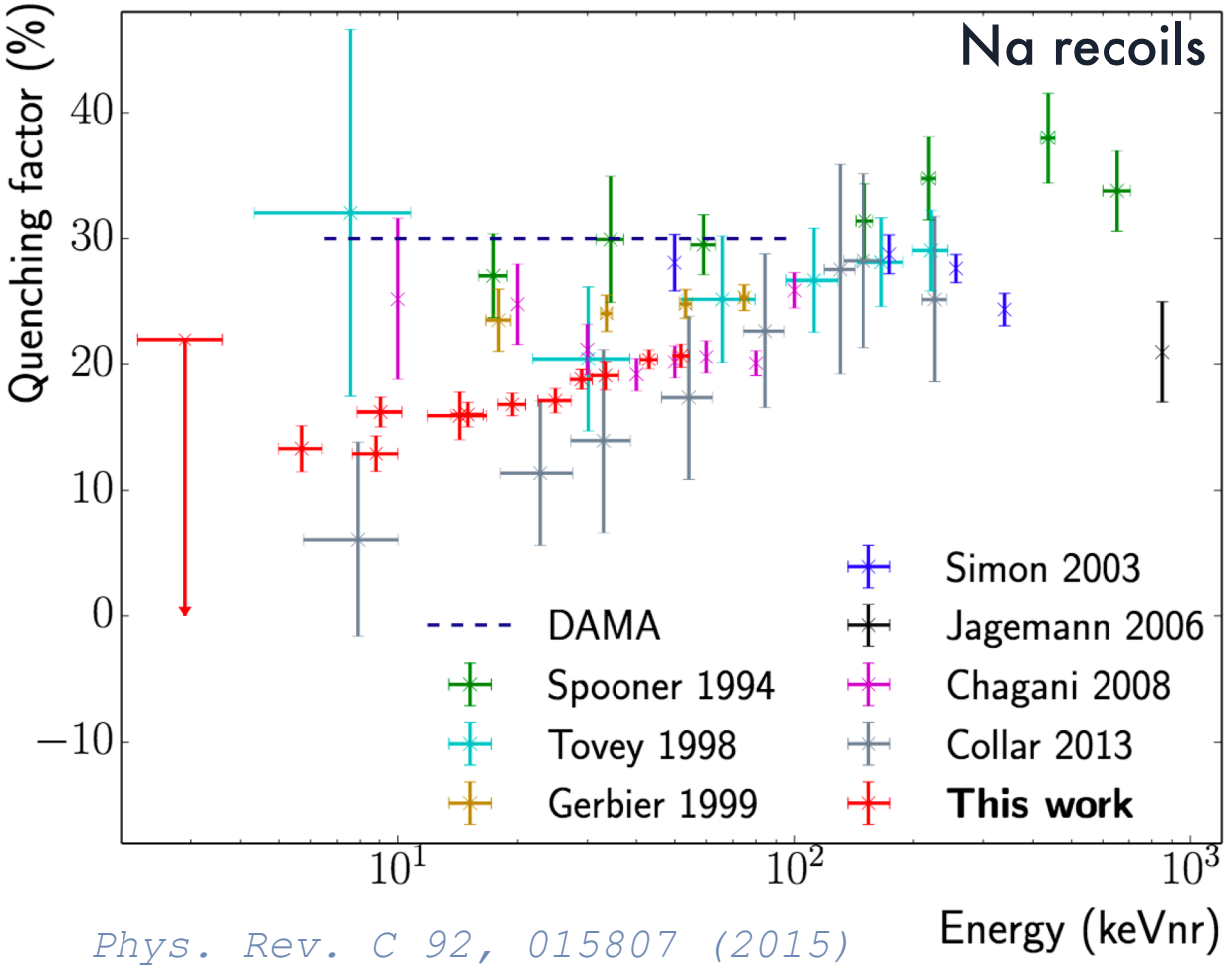


3keV Auger: in ROI

Suppression possible via measurement of 1.46MeV gamma:

- Adjacent crystals
- Liquid scintillator

"DAMA-LIKE" SETUPS - INTERPRETATION



Phys. Rev. C 92, 015807 (2015)

Quenching factors are uncertain

→

Uncertainty on nuclear recoil energy scale

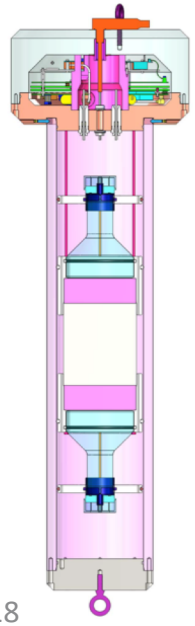
NaI EXPERIMENTS

DM-Ice17

South pole
17 kg NaI

threshold: 4 keV_{ee}

3.5 y physics run
no hint

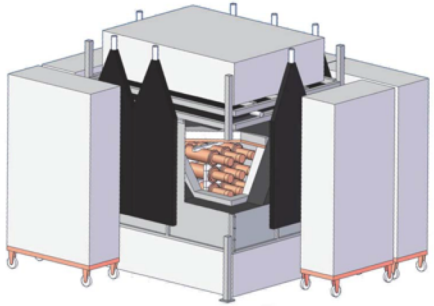


ANAIS-112

LSC - Spain
112.5 kg NaI

threshold: < 1 keV_{ee}

since spring 2017



COSINE-100

Y2L Korea
KIMS NaI + DM-Ice
106 kg

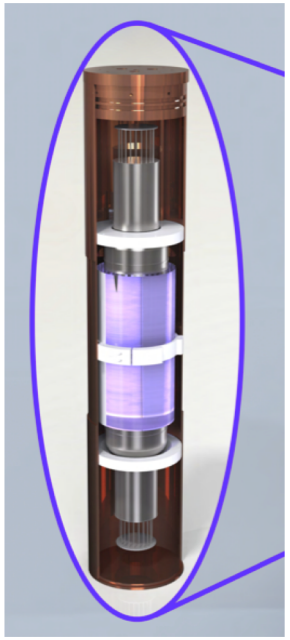
threshold: ~2 keV_{ee}

since Sept. 2016

SABRE

Gran Sasso/Australia
40-50 kg NaI

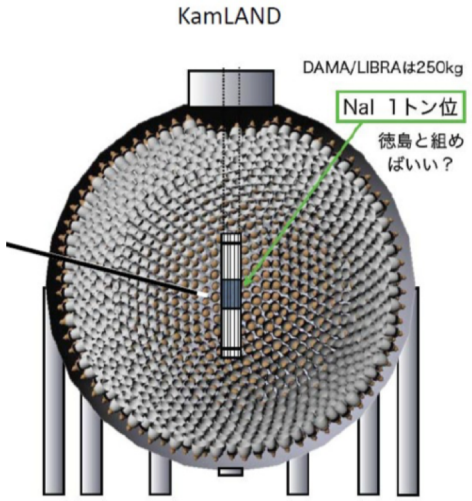
construction phase



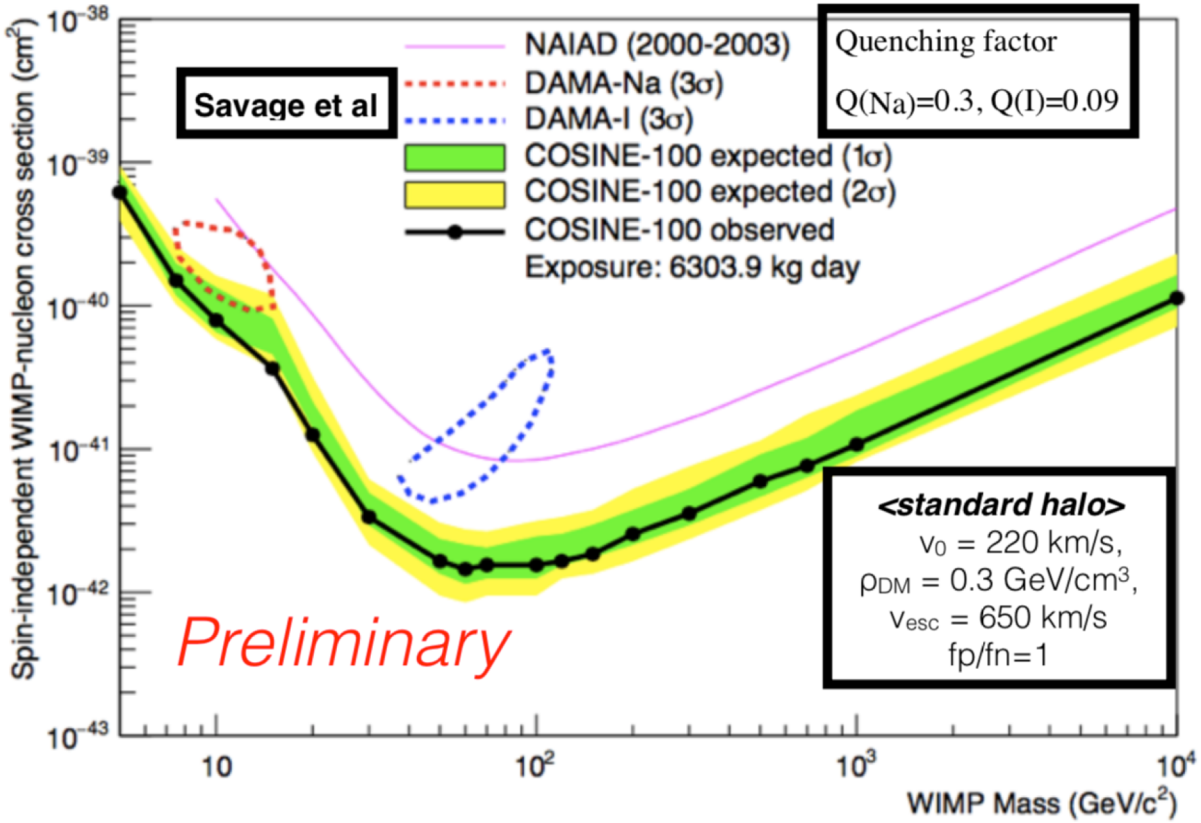
KamLand-PICO

KamLand/Japan
1t NaI

planning/
prototyping phase



Spin independent WIMP-nucleon cross section limit (59.5 days of the COSINE-100 data)



- Spectrum with known sources of backgrounds
- COSINE-100 excludes DAMA/LIBRA-phase1's signal as spin-independent WIMP with Standard Halo Model in NaI(Tl)
- Consistent with null results from other direct detect experiments with different target medium

clarified open

~~NaI~~

NaI

STANDARD SCENARIO

LARGE NUMBER OF DIRECT DM SEARCHES

DAMA/LIBRA PHASE 2

COSINE-100

LEPTOPHILIC DM (ELECTRON RECOILS)

Xenon100
LUX
…

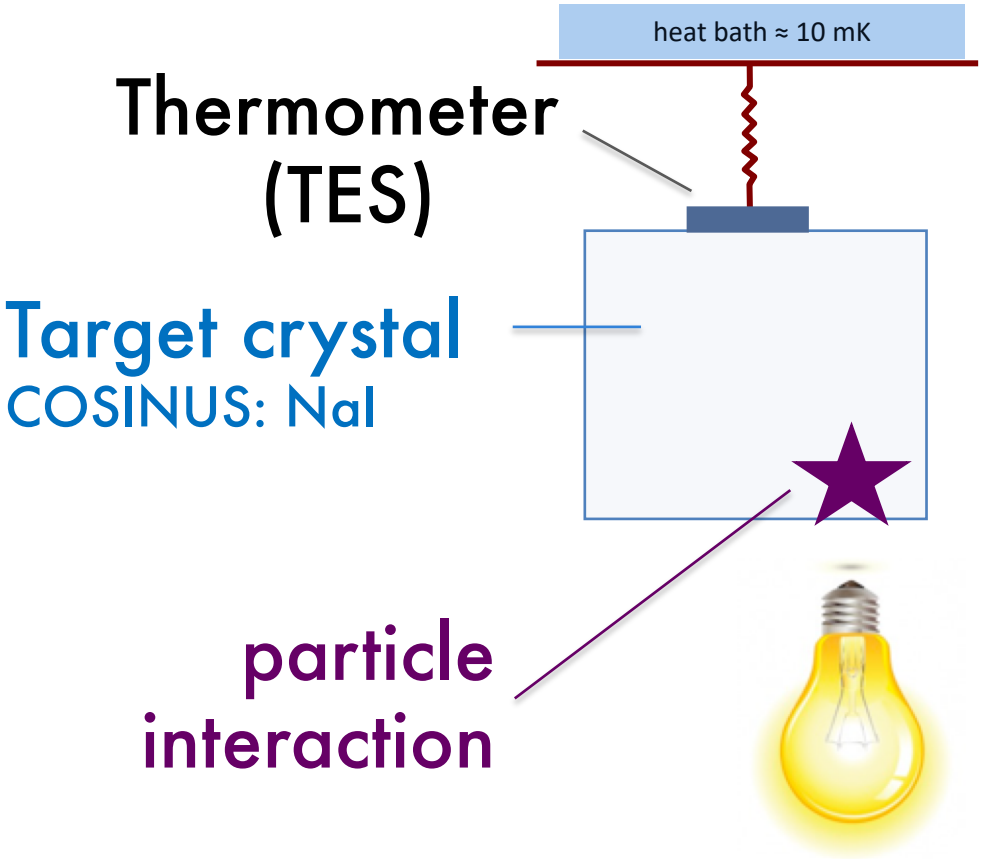
ANAIS, COSINE
SABRE, PICO-LON

MODEL-INDEPENDENT

XMASS (Xe)
(KIMS (CsI))

COSINUS
(1π NUCLEAR RECOIL)

COSINUS: NaI SCINTILLATING CALORIMETER



Phonon signal (~90 %)

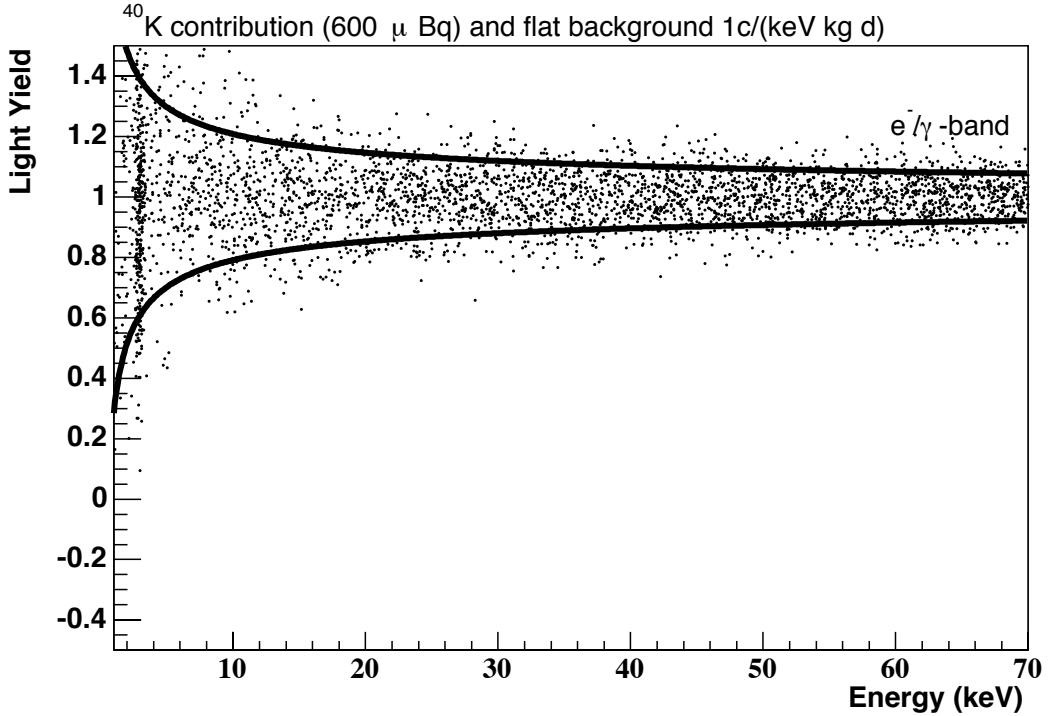
(almost) independent of particle type

precise measurement of the deposited energy

Scintillation light (few %)

Particle-type dependent
→ LIGHT QUENCHING

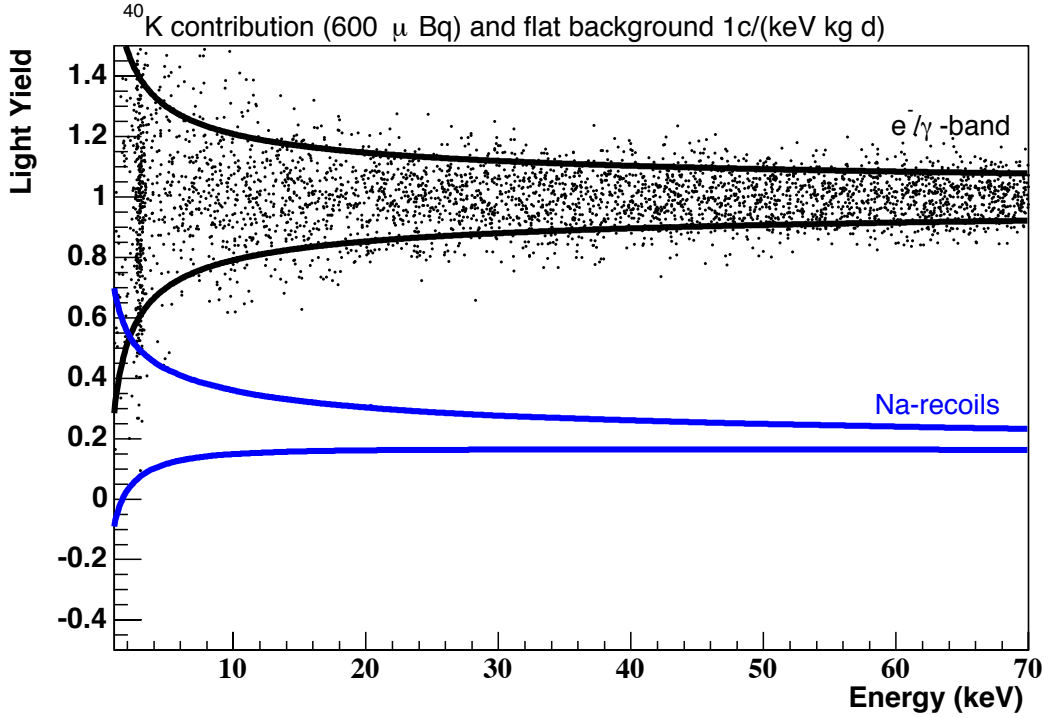
SIMULATION
100 KG-DAYS BEFORE CUTS



Black: β/γ-background
flat 1c /(keV kg day)
+ ^{40}K: 600μBq/kg

Eur. Phys. J. C (2016) 76:441
DOI 10.1140/epjc/s10052-016-4278-3

SIMULATION
100 KG-DAYS BEFORE CUTS



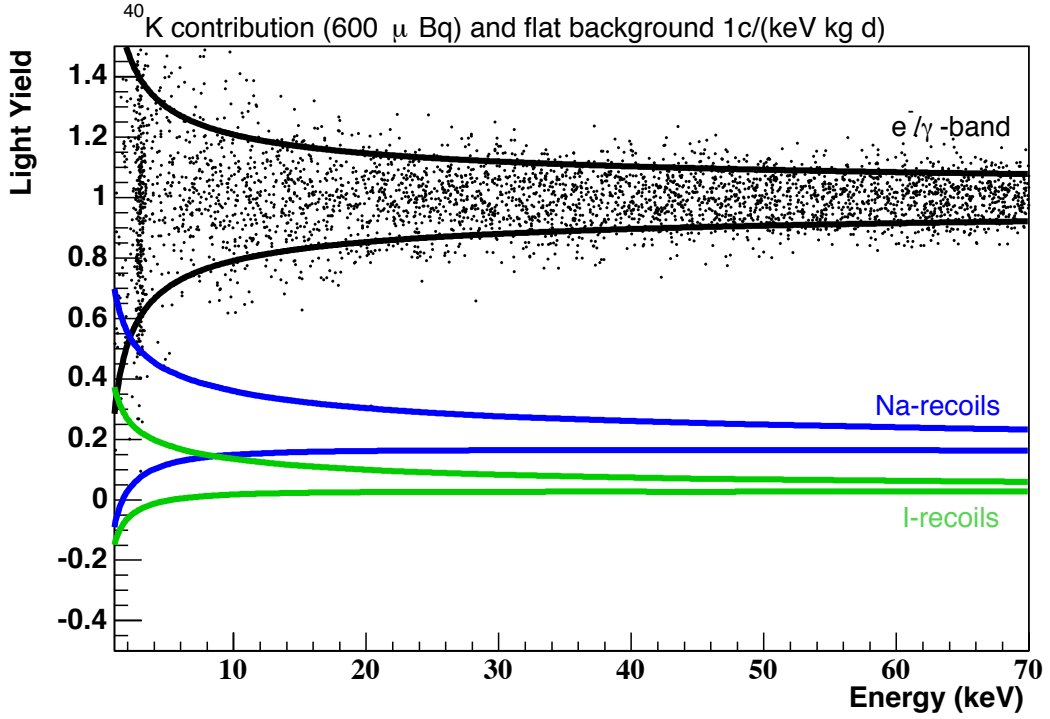
Eur. Phys. J. C (2016) 76:441
DOI 10.1140/epjc/s10052-016-4278-3

Black: β/γ-background
flat 1c /(keV kg day)
+ ^{40}K: 600μBq/kg

Recoils off Na

Quenching factors by
V. Tretyak, Astropart.
Phys. 33, 40 (2010)

SIMULATION
100 KG-DAYS BEFORE CUTS



Eur. Phys. J. C (2016) 76:441
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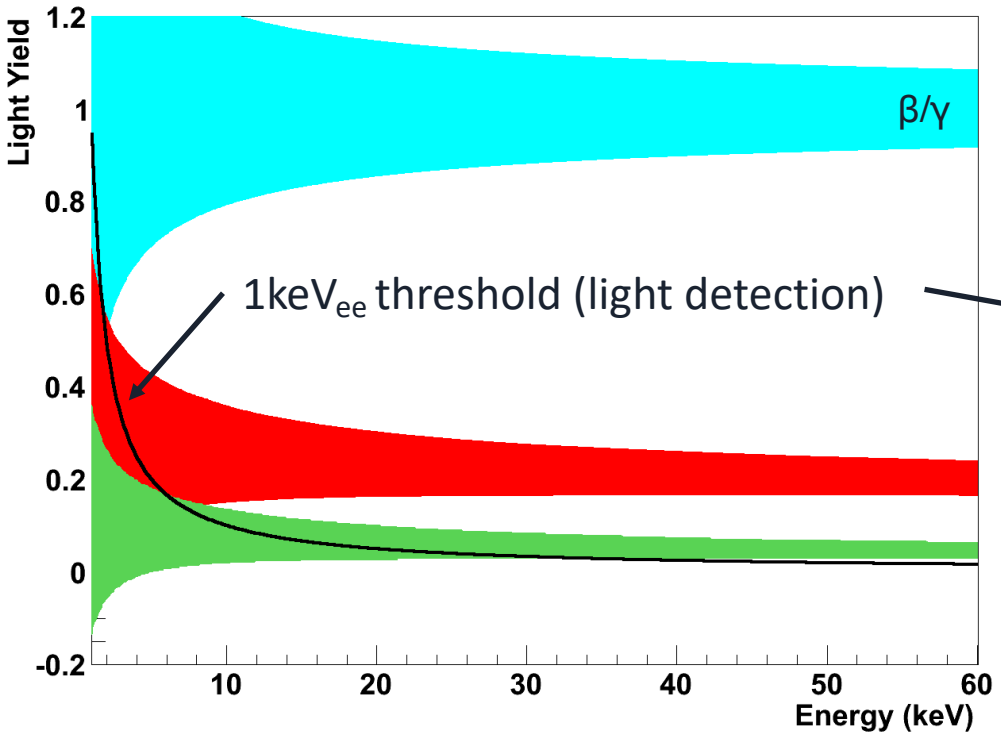
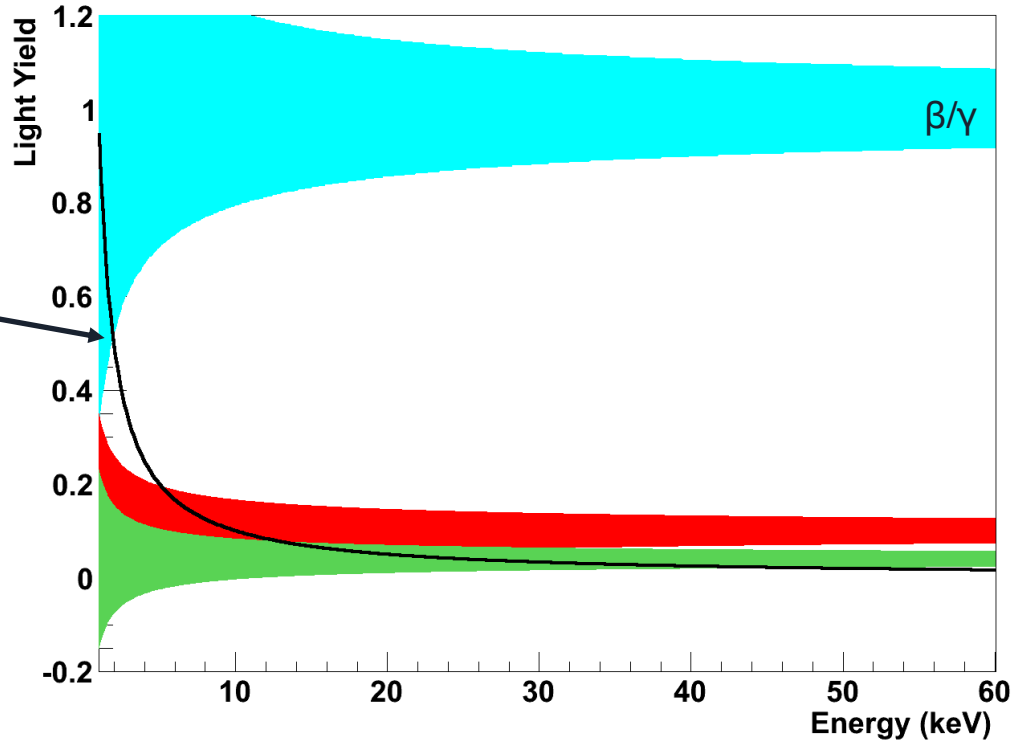
Black: β/γ-background
flat 1c /(keV kg day)
+ ^{40}K: 600μBq/kg

Recoils off Na
Recoils off I

Quenching factors by
V. Tretyak, Astropart.
Phys. 33, 40 (2010)

QUENCHING FACTORS





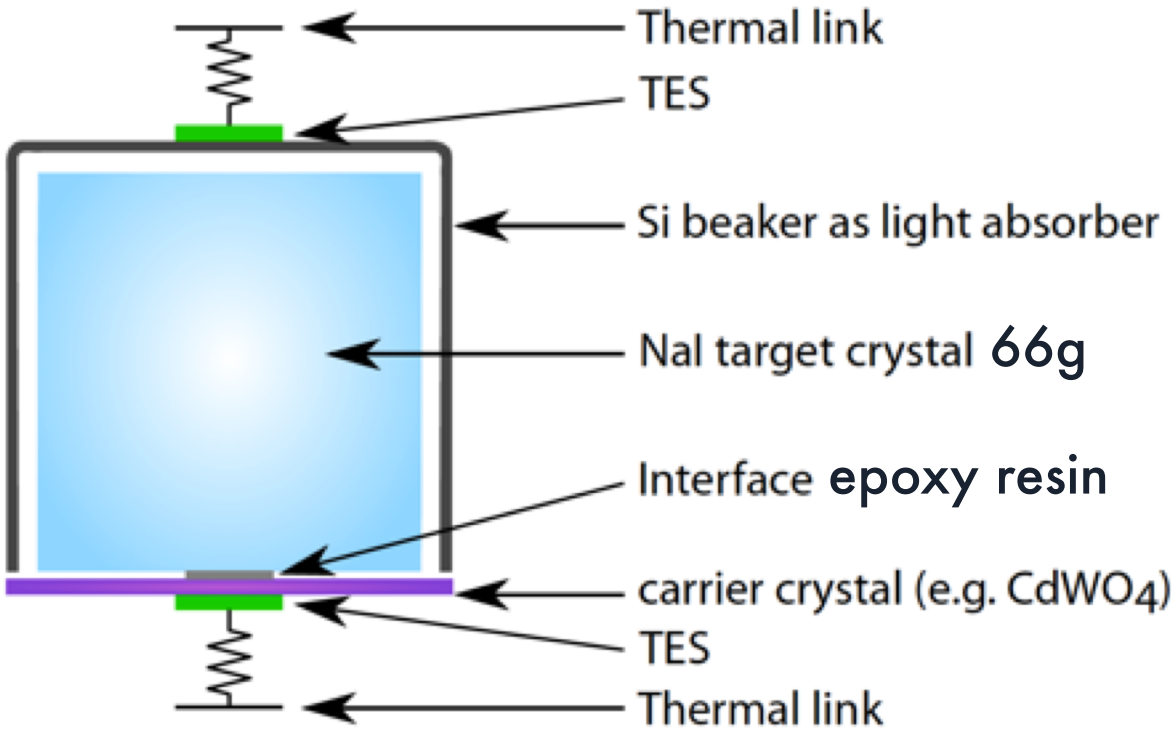
recoils off Na → factor ~ 0.3

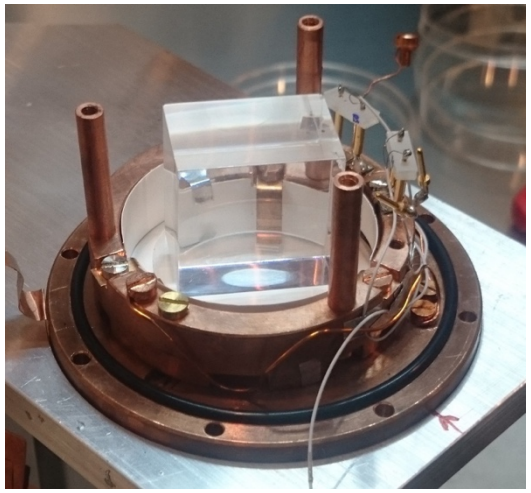
recoils off I → factor ~ 0.1

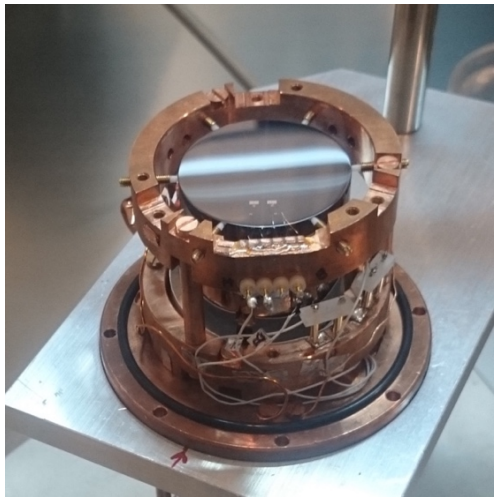
recoils off Na → factor ~ 0.1

recoils off I → factor ~ 0.04

Now Real Data: 2nd Prototype



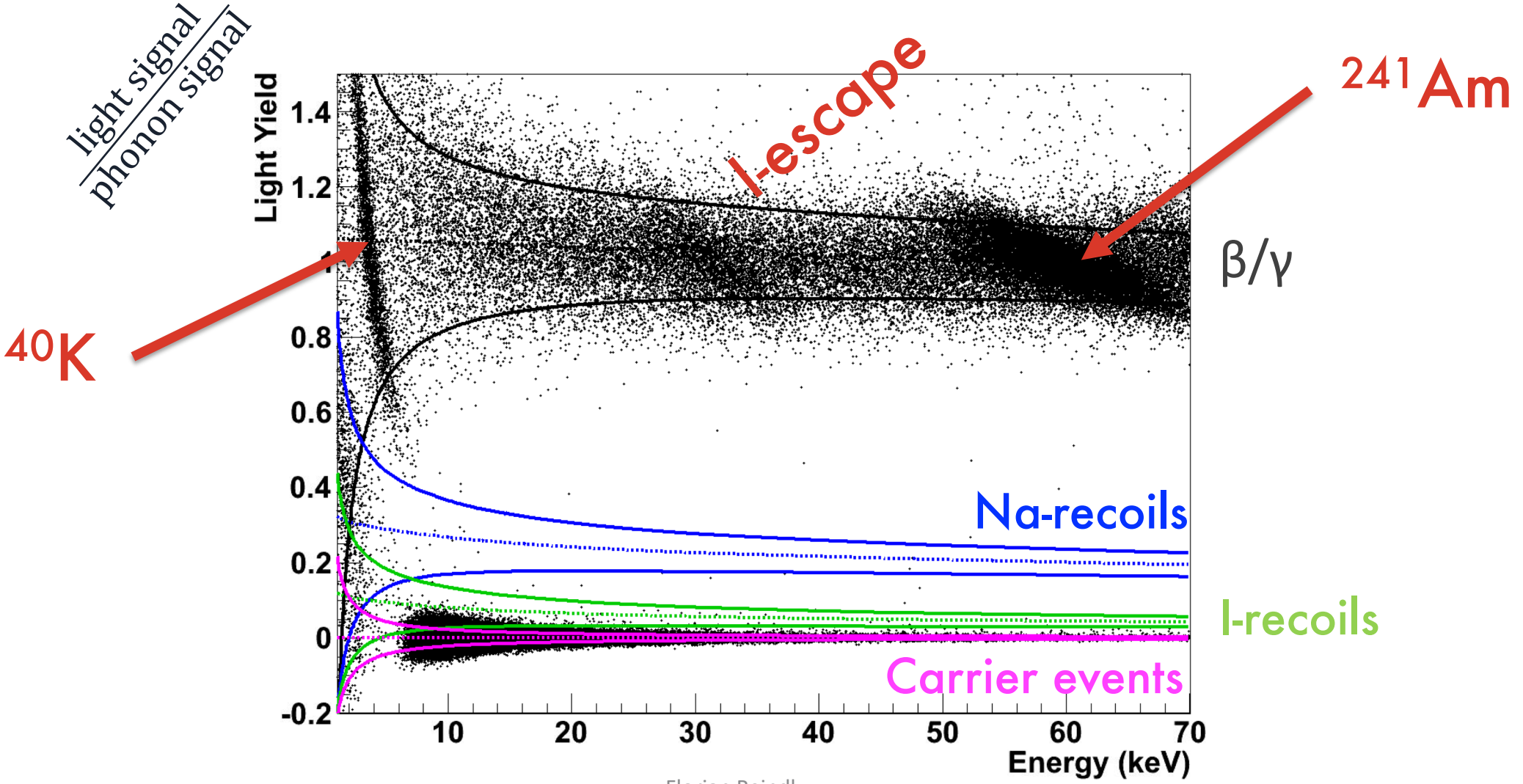




^{241}Am Gamma calibration Data
2nd prototype (2016/17)

Schäffner, K. et al. J Low Temp Phys (2018).
https://doi.org/10.1007/s10909-018-1967-3

F. Reindl et al., arXiv 1711.01482



QF from Tretyak, Astropart. Phys. 33, 40 (2010

TODO LIST FOR A COSINUS DM MODULE

- ✓ Operate NaI as cryogenic detector
- ✓ Beaker-shaped light detector
- ✓ Clean (enough) NaI crystals

- ❑ Phonon threshold of 1keV: 10keV→8.5 keV→6.5keV
- ❑ Particle discrimination: Under investigation

Prototype measurement results:
G. Angloher et al. JINST 12 P11007 (2017)
F. Reindl et al., arXiv 1711.01482
Schäffner, K. et al. J Low Temp Phys (2018)

WHAT COSINUS CAN DO WITH A DM MODULE

DAMA (&COSINE,SABRE …?) signal

COSINUS has the unique potential to clarify a nuclear recoil origin

Confirm

O(100kgd) most probably sufficient

Rule-out

O(100kgd): Strong statement

O(1000kgd): Fully model-independent statement possible

(Felix Kahlhoefer, FR, et al JCAP05(2018)074)

COSINUS

Kick-Off Meeting October 2018

CSN5 of INFN

Funding for initial prototype development [2016-2018]

NEW!

K. Schäffner
Max-Planck-Research-Group

Funding for experimental setup

GSSI
UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA
INFN Istituto Nazionale di Fisica Nucleare
TU WIEN
HEPHY INSTITUTE OF HIGH ENERGY PHYSICS
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

www.cosinus.it

clarified open

~~NaI~~

NaI

STANDARD SCENARIO

LARGE NUMBER OF DIRECT DM SEARCHES

DAMA/LIBRA PHASE 2

COSINE-100

LEPTOPHILIC DM (ELECTRON RECOILS)

Xenon100
LUX
…

ANAIS, COSINE
SABRE, PICO-LON

MODEL-INDEPENDENT

XMASS (Xe)
(KIMS (CsI))

COSINUS
(1π NUCLEAR RECOIL)

Conclusion

TAUP 1997:
DAMA reports first evidence for an annual modulation signal

Nature news (04/2016):
"This will get resolved," says Frank Calaprice [Princeton, SABRE]

My personal view (10/2018):
This will not take another two decades!

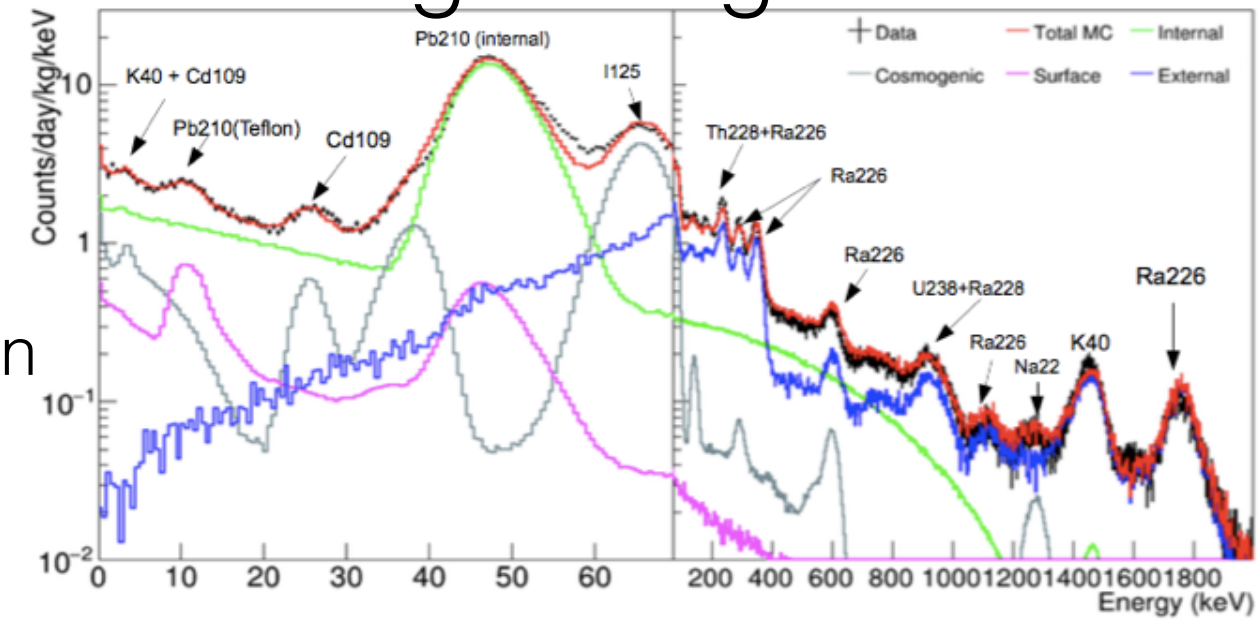
BACKUP

COSINE-100

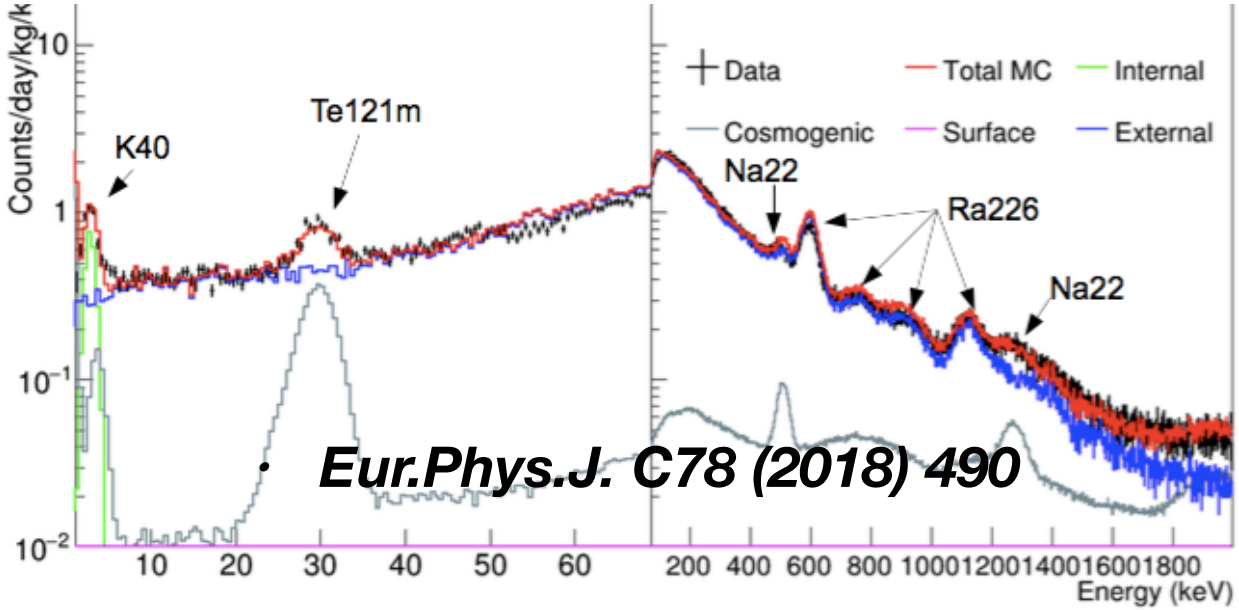
Understanding Background

Single-Hit

(2-6 keV region not used)



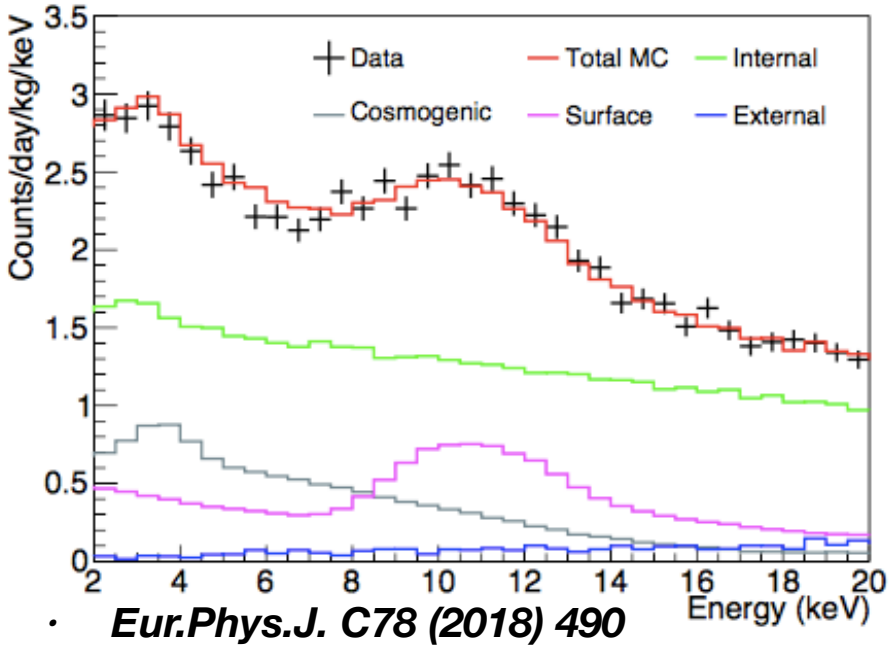
Multiple-Hit



- ***Eur.Phys.J. C78 (2018) 490***

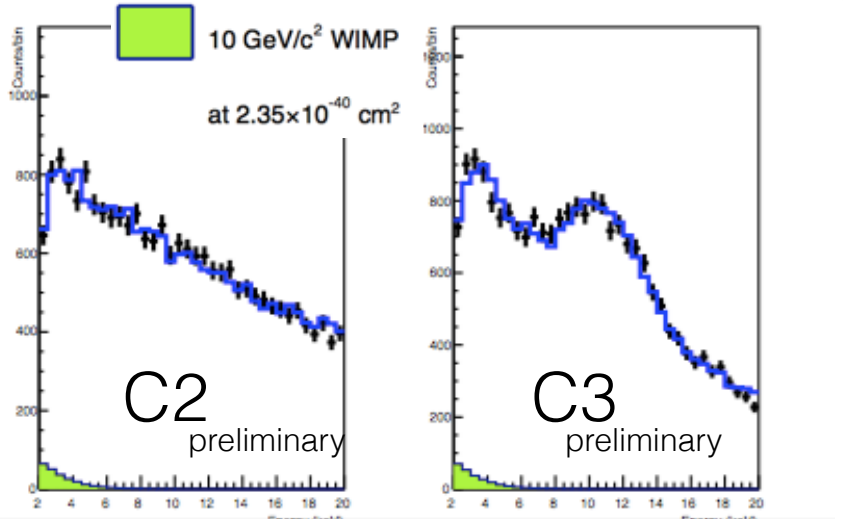
COSINE-100

WIMP Search, 59.5 days of Data

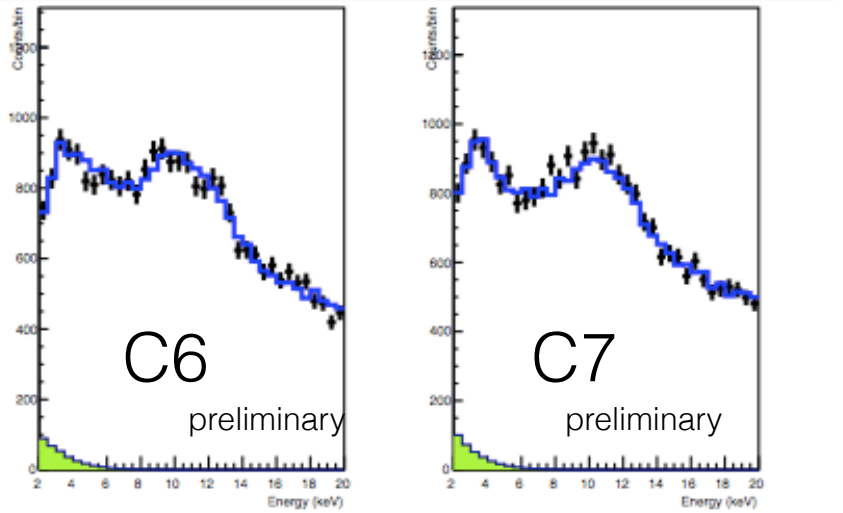


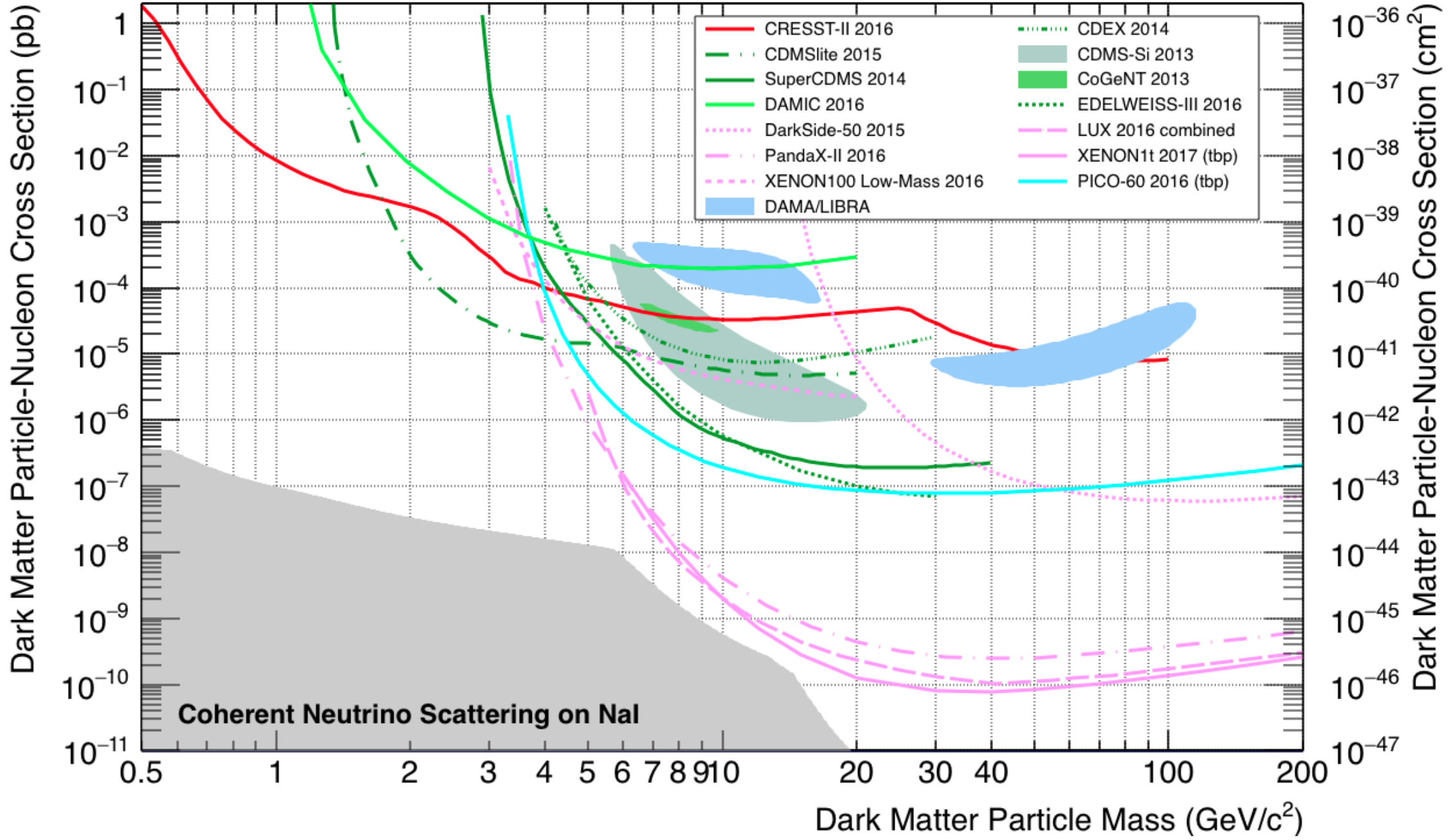
· ***Eur.Phys.J. C78 (2018) 490***

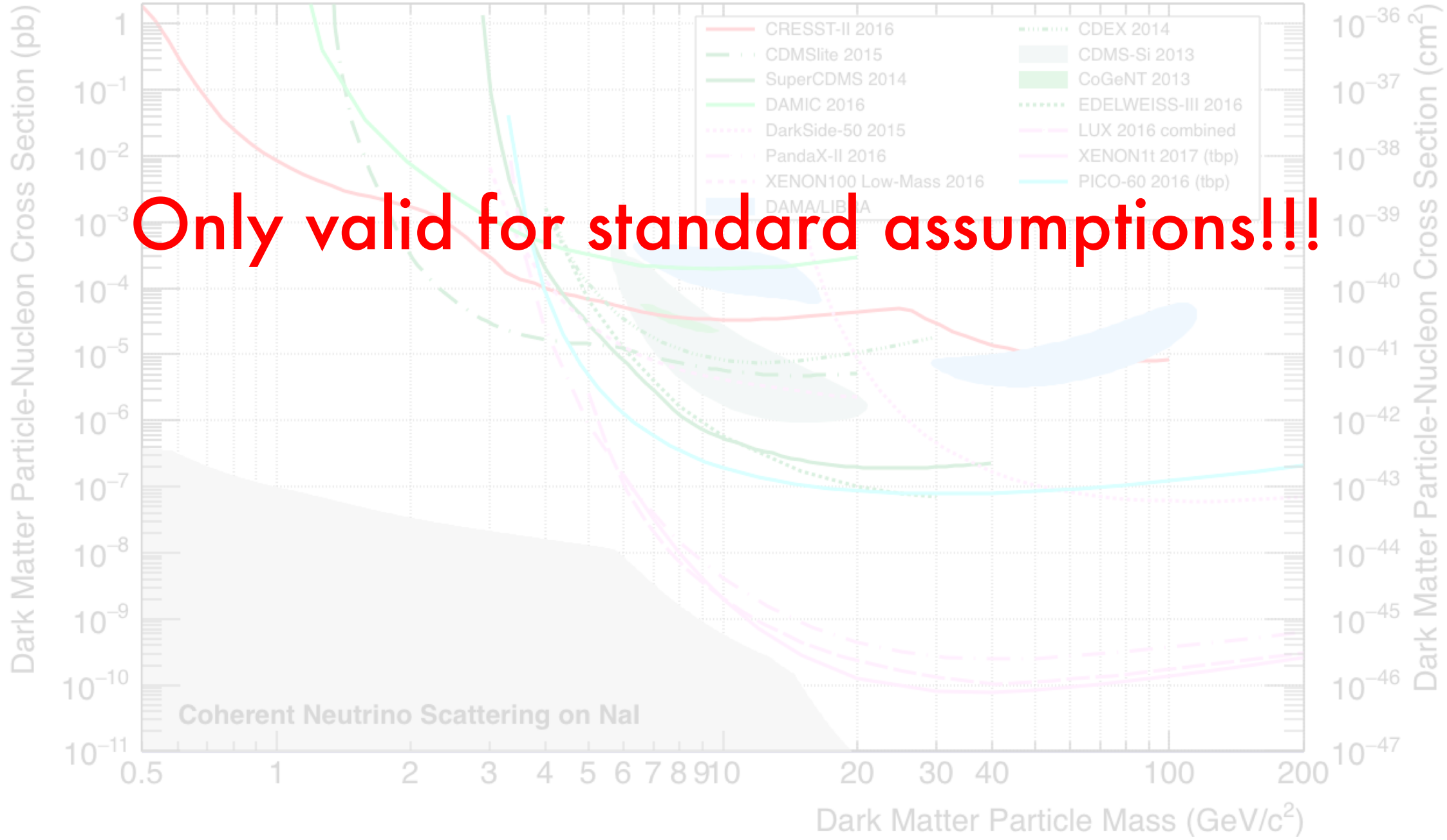
With bkg. understanding, 8 single-hit spectra are fit simultaneously with an assumed WIMP signal (SHM as described in Savage et al., Jounal of cosmology and astrophysics), Note that bkg. understanding consideration from Kudryavtsev et al. Astropart.Phys. 33 (2010) 91



Overlay of DAMA-Na Signal at 10 GeV/c2




CRESST-II 2016
CDMSlite 2015
SuperCDMS 2014
DAMIC 2016
DarkSide-50 2015
PandaX-II 2016
XENON100 Low-Mass 2016
DAMA/LIBRA
CDEX 2014
CDMS-Si 2013
CoGeNT 2013
EDELWEISS-III 2016
LUX 2016 combined
XENON1t 2017 (tbp)
PICO-60 2016 (tbp)
Coherent Neutrino Scattering on NaI
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm^2)
Dark Matter Particle Mass (GeV/c^2)

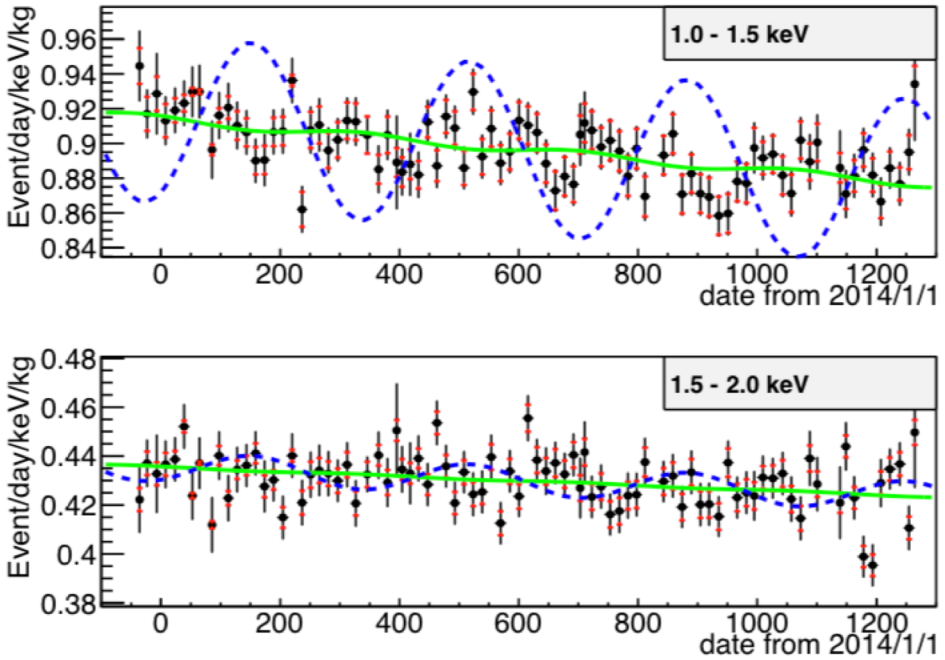


Only valid for standard assumptions!!!

arXiv: 1808.06177

XMASS: SINGLE-PHASE LXE DETECTOR

2.4 tonne years

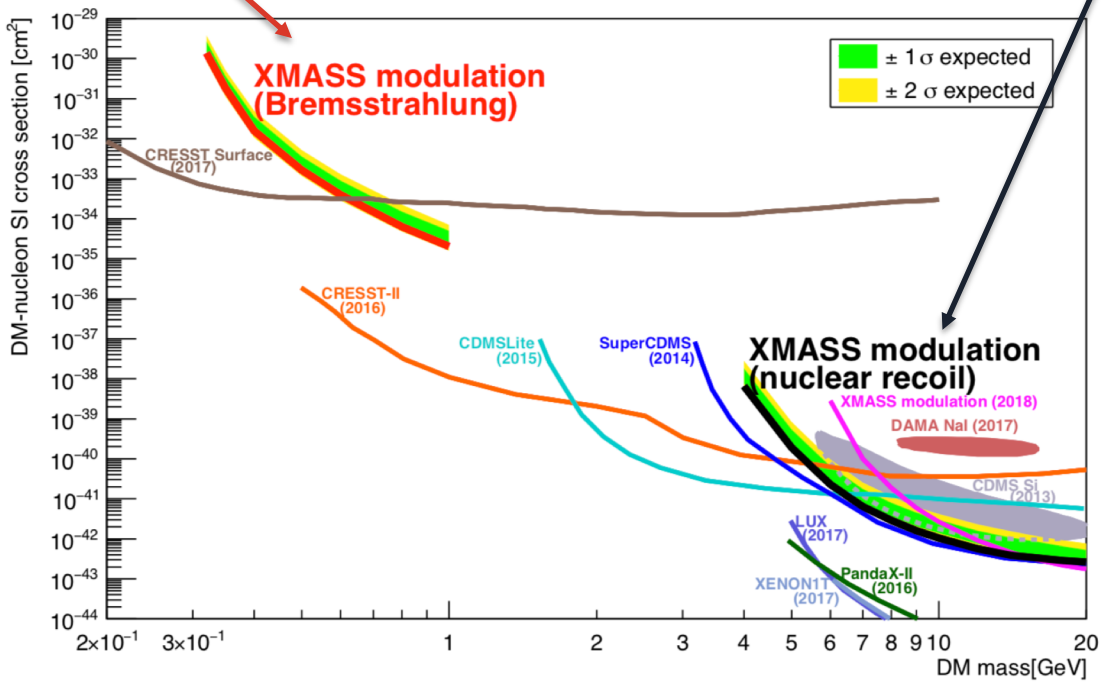


No significant modulation

Two interpretations of data

Bremsstrahlung emitted by acceleration of nucleus

Classic elastic nuclear recoil

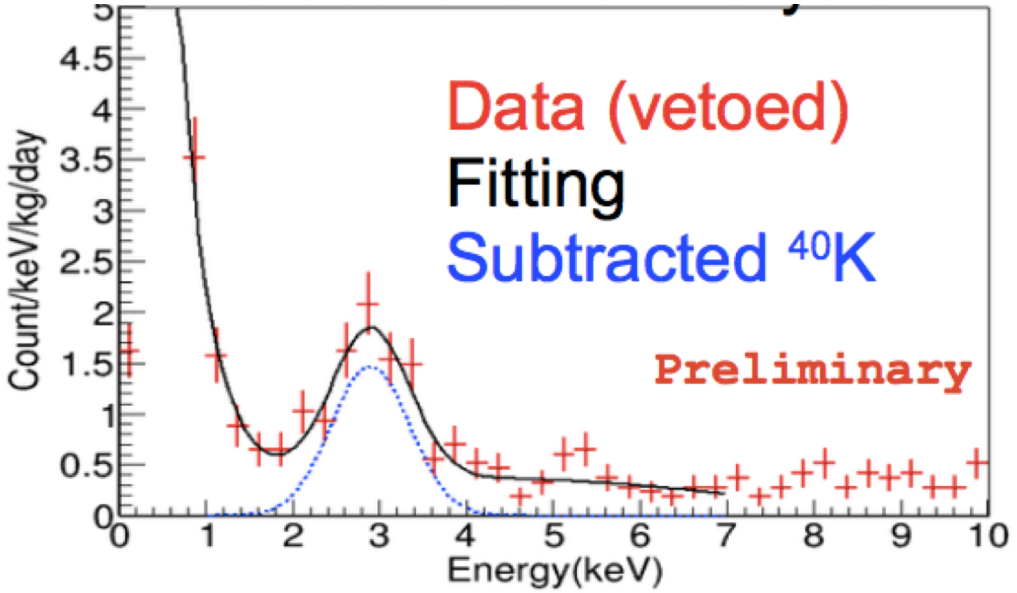


"DAMA-LIKE" SETUPS - CHALLENGES

No event-by-event discrimination:

Radiopurity is the key factor

Example from COSINE-100



3keV Auger: in ROI

Suppression possible via measurement of 1.46MeV gamma:

- Adjacent crystals
- Liquid scintillator

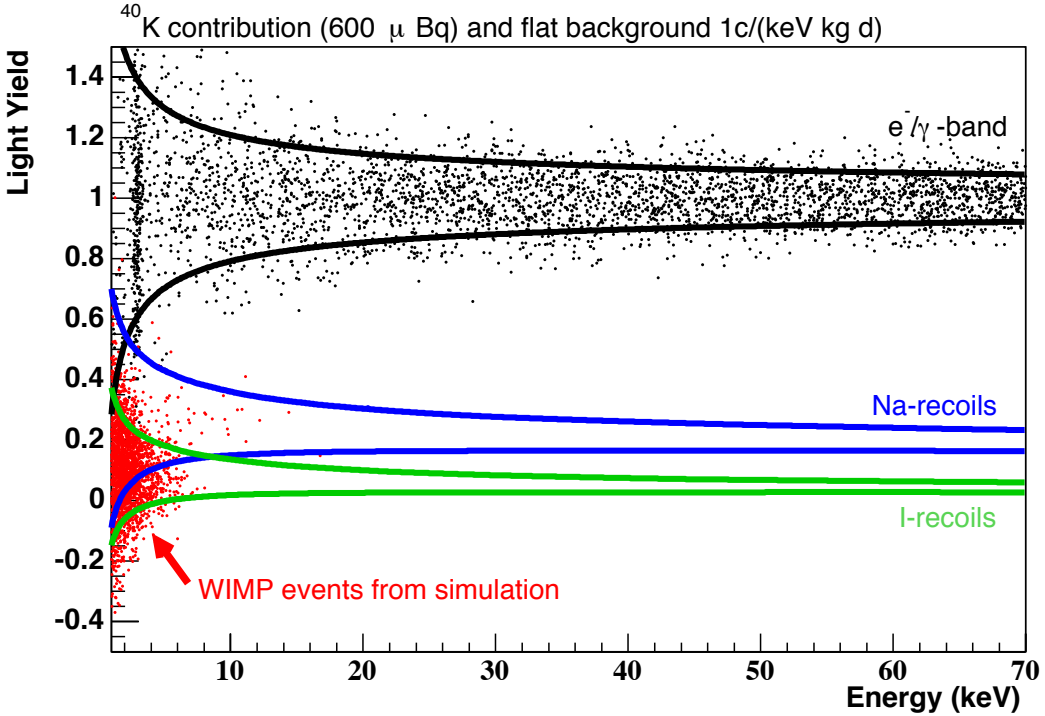
COSINUS PERFORMANCE GOALS

Bring NaI-based cryogenic detectors to level of existing ones (e.g. CRESST-II):

1keV nuclear recoil threshold

4% of deposited energy measured as scintillation light

SIMULATION
100 KG-DAYS BEFORE CUTS



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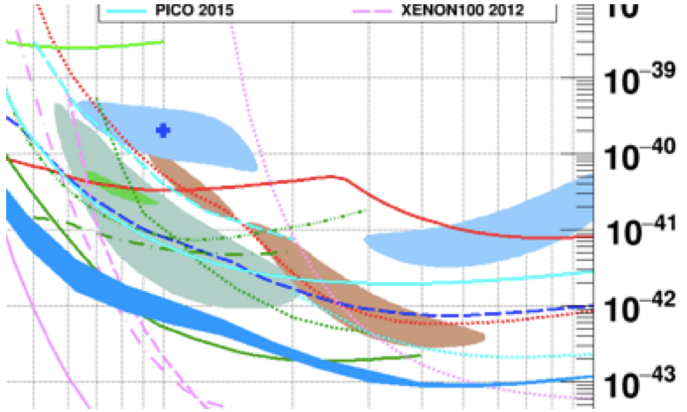
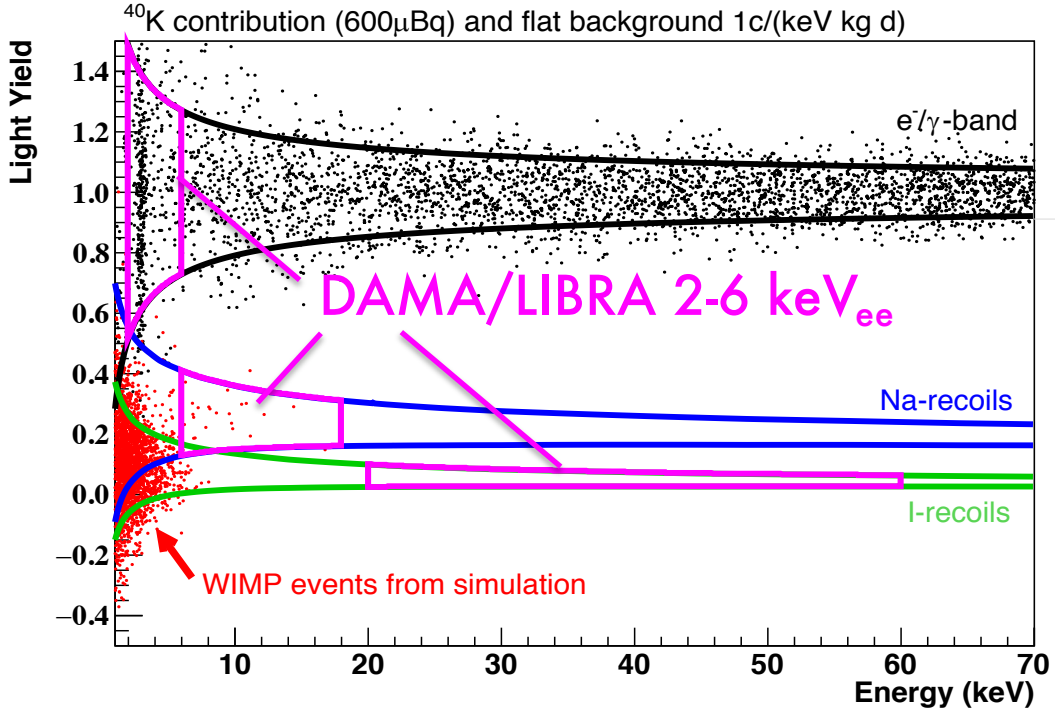
DOI 10.1140/epjc/s10052-016-4278-3

Black: β/γ-background
flat 1c /(keV kg day)
+ ^{40}K: 600μBq/kg

Red: 10 GeV/c^2 WIMP with 2E-04 pb as from Savage et al.



SIMULATION
100 KG-DAYS BEFORE CUTS



WIMP events

Energy	# Events	Fraction
1-2 keV	1078	45 %
2-6 keV	1262	53 %
> 6 keV	46	2 %
TOTAL	**2386**	**100 %**

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