Recent Results in Direct Dark Matter Detection

INVISIBLES24

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INFN Bologna

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Outline

- Quick review of WIMP model (no Axions/others in this talk)
- Generalities on signal and backgrounds
- Most effective detection techniques
- Selection of recent results from direct DM detection experiments

* many thanks to
E. Aprile, L. Baudis, P. Belli, R. Bernabei, M. Cadeddu, G. De Lellis, G. Fiorillo, P. Gorla,
T. Marrodan, K. Palladino, D. Pinci, K. Ni, M. Schumann, K. Schaeffner, C. Vignoli
for useful materials used in this review

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Usual, but correct, disclaimers of these kinds of review talks:
not complete, biased, personal view, etc

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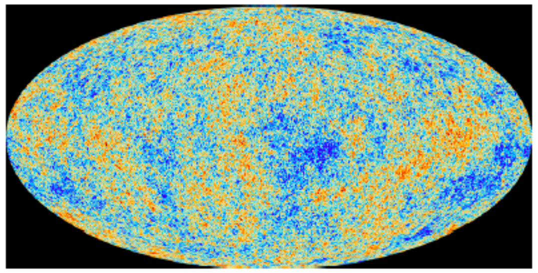
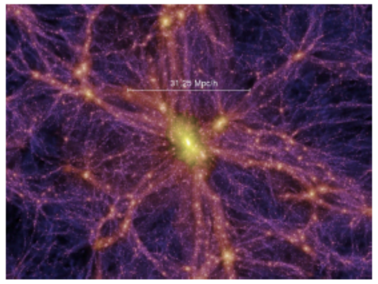
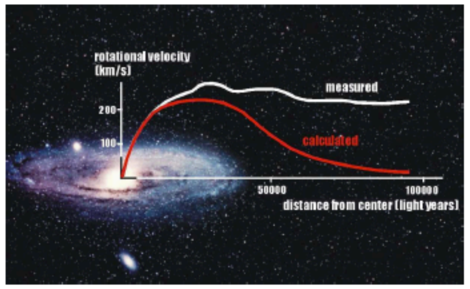
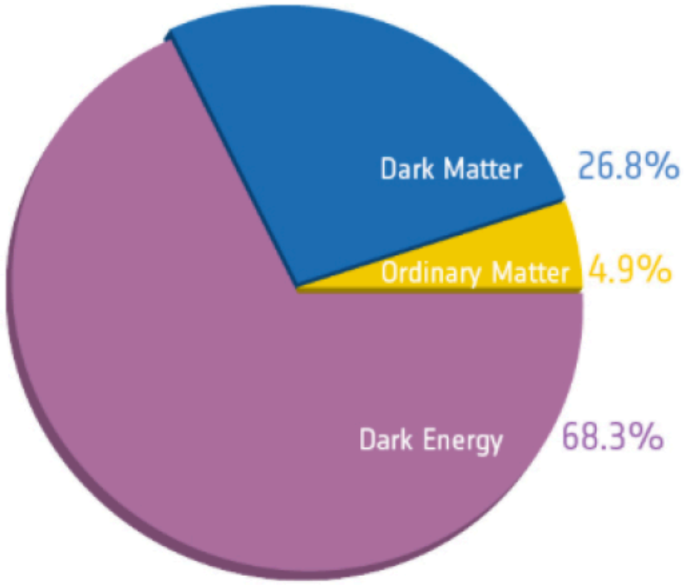
Particle Dark Matter









After Planck

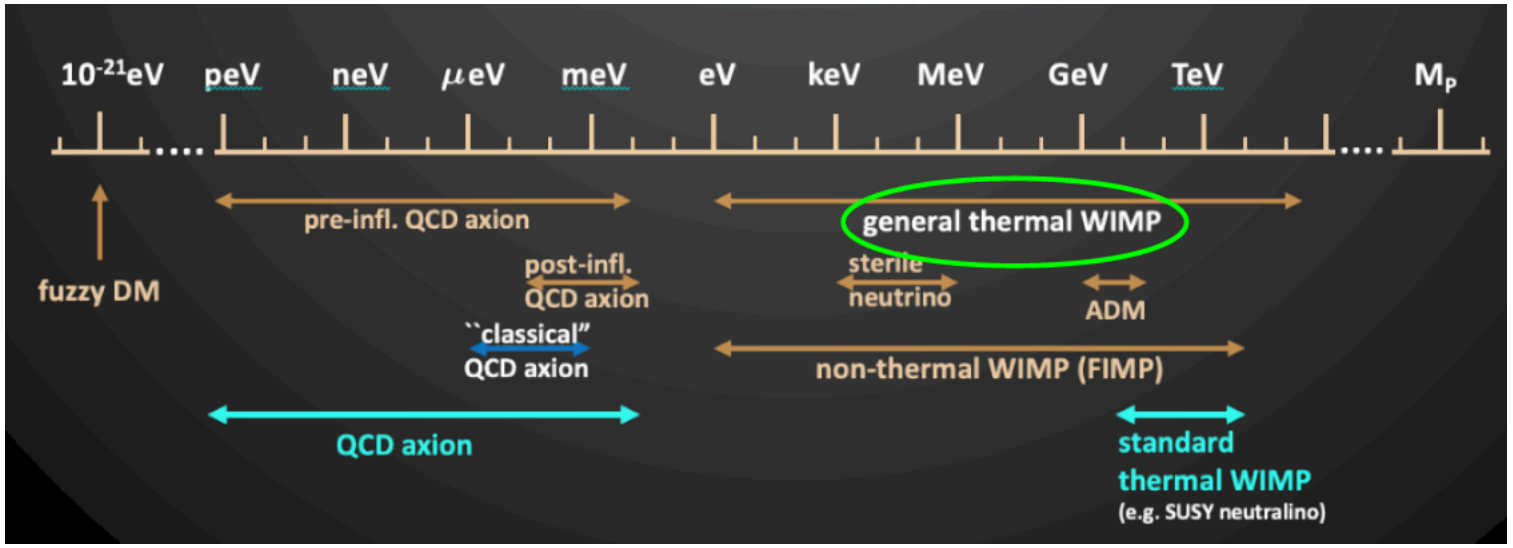
Well motivated theoretical approach:

WIMP

(**W**eakly **I**nteracting **M**assive **P**article)

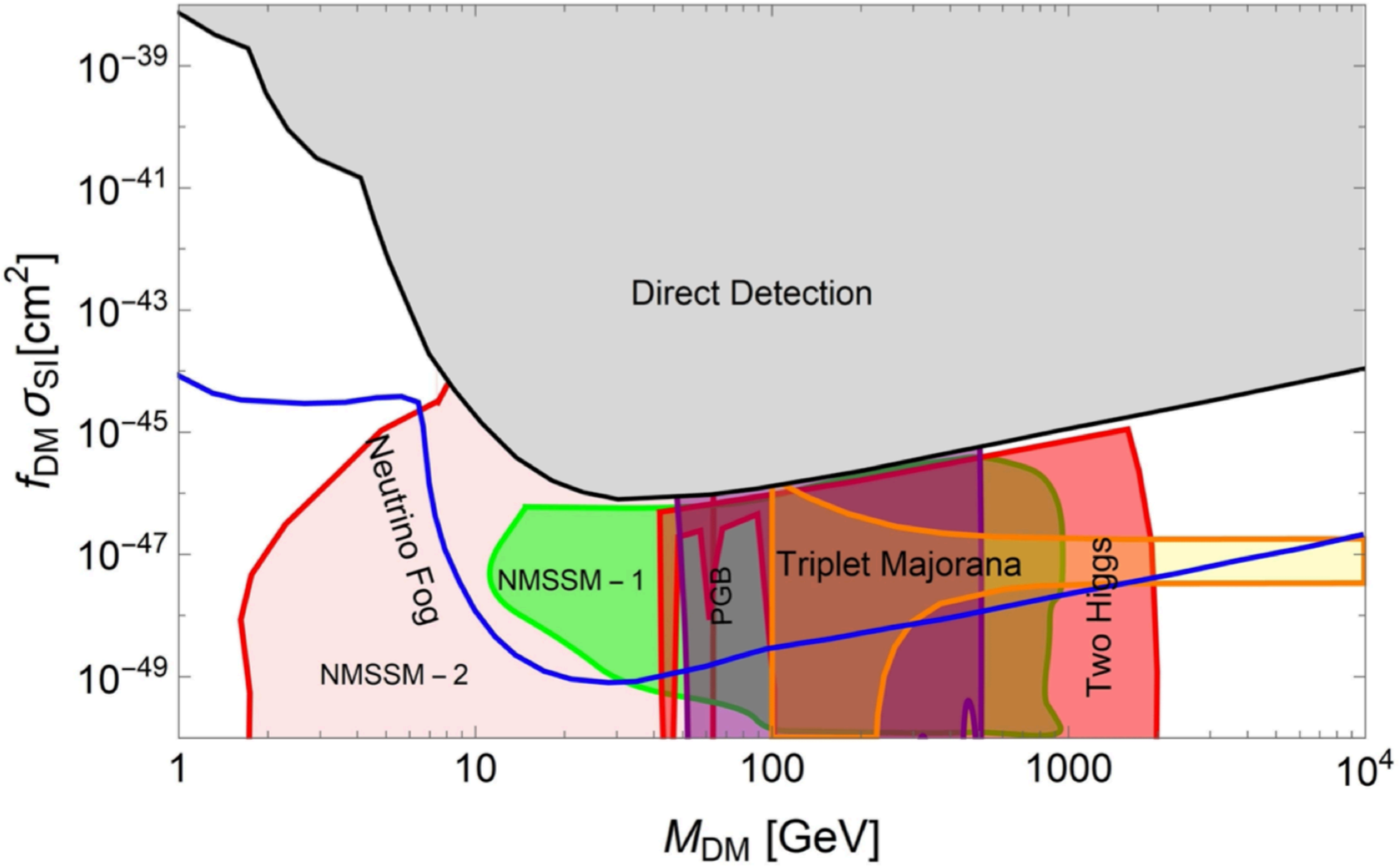
But dark matter could be non weakly-interacting or a completely different type of particle

→ This talk is mainly focus on searches for WIMPs



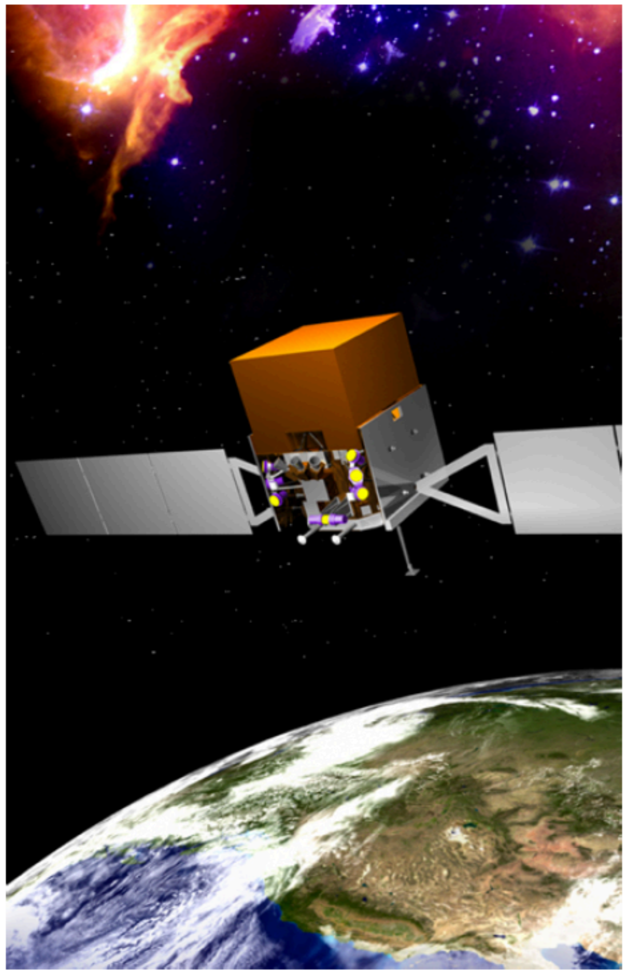
WIMP hypothesis is still alive

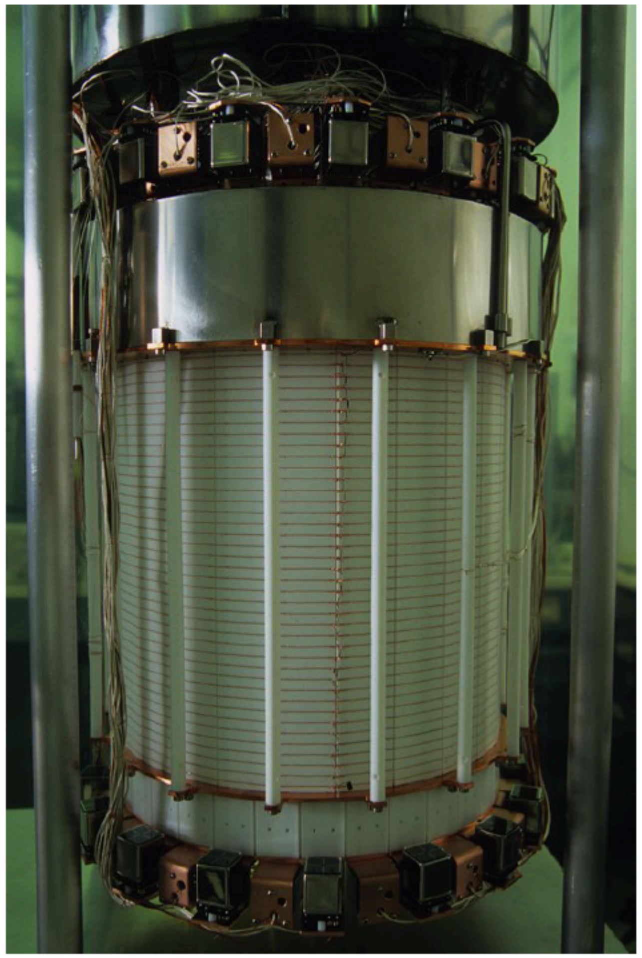
CF1 WP1 arXiv:2203.08084
Thanks to Ben Loer, PNNL +
Graciela B. Gelmini, UCLA



Dark Matter searches

- Production at LHC
- Indirect detection
- Direct detection



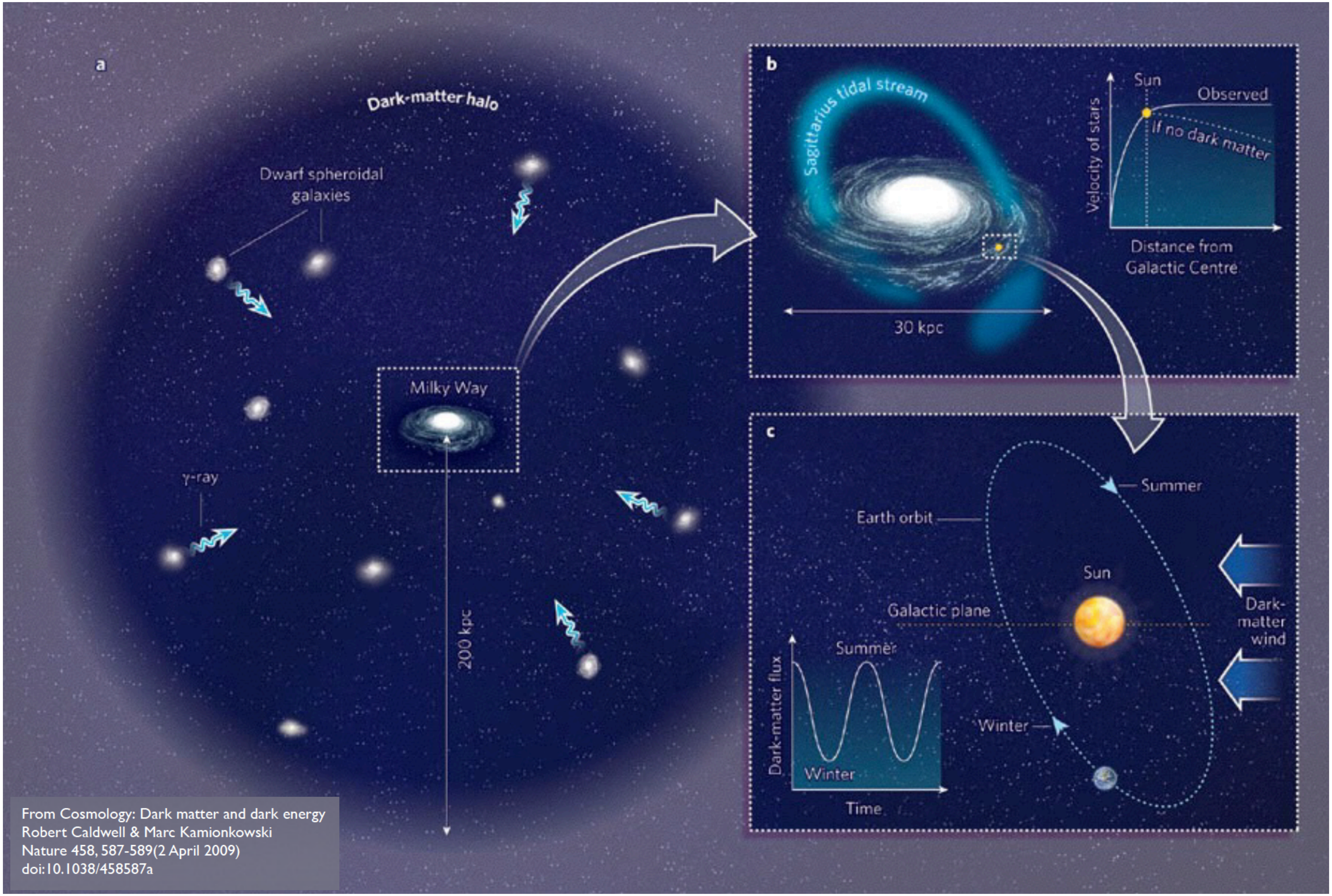


$p + p \rightarrow \chi\overline{\chi}$ + a lot

$\chi\chi \rightarrow \gamma\gamma, q\overline{q}, \ldots$

$\chi\,\mathrm{N} \rightarrow \chi\,\mathrm{N}$

We live in a dark matter halo

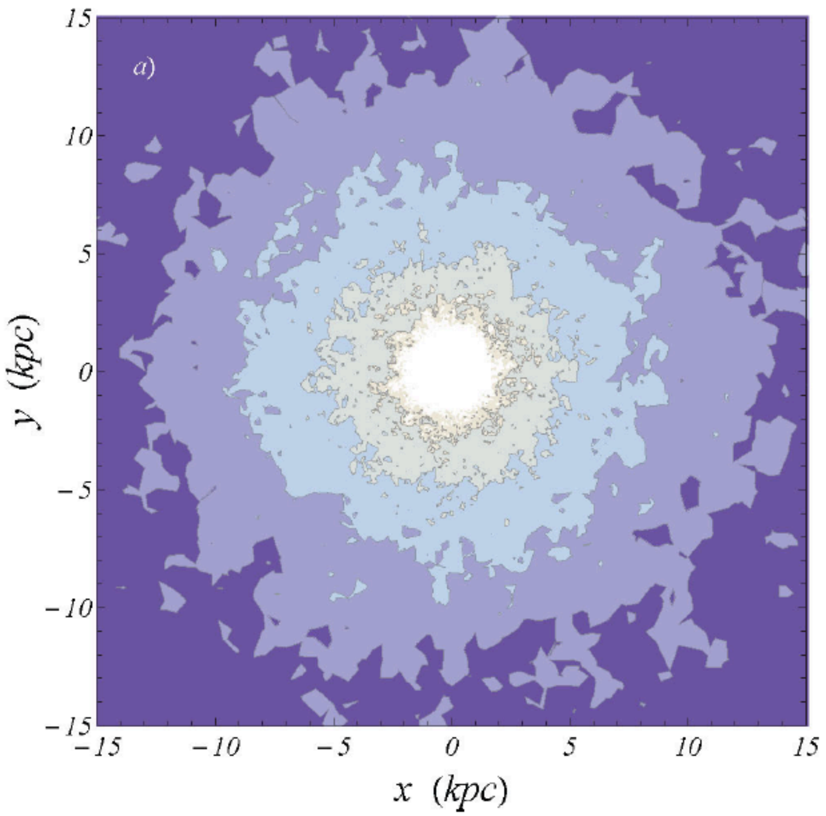


From Cosmology: Dark matter and dark energy
Robert Caldwell & Marc Kamionkowski
Nature 458, 587-589(2 April 2009)
doi:10.1038/458587a

WIMP density and velocity distribution

WIMPs in the galactic halo

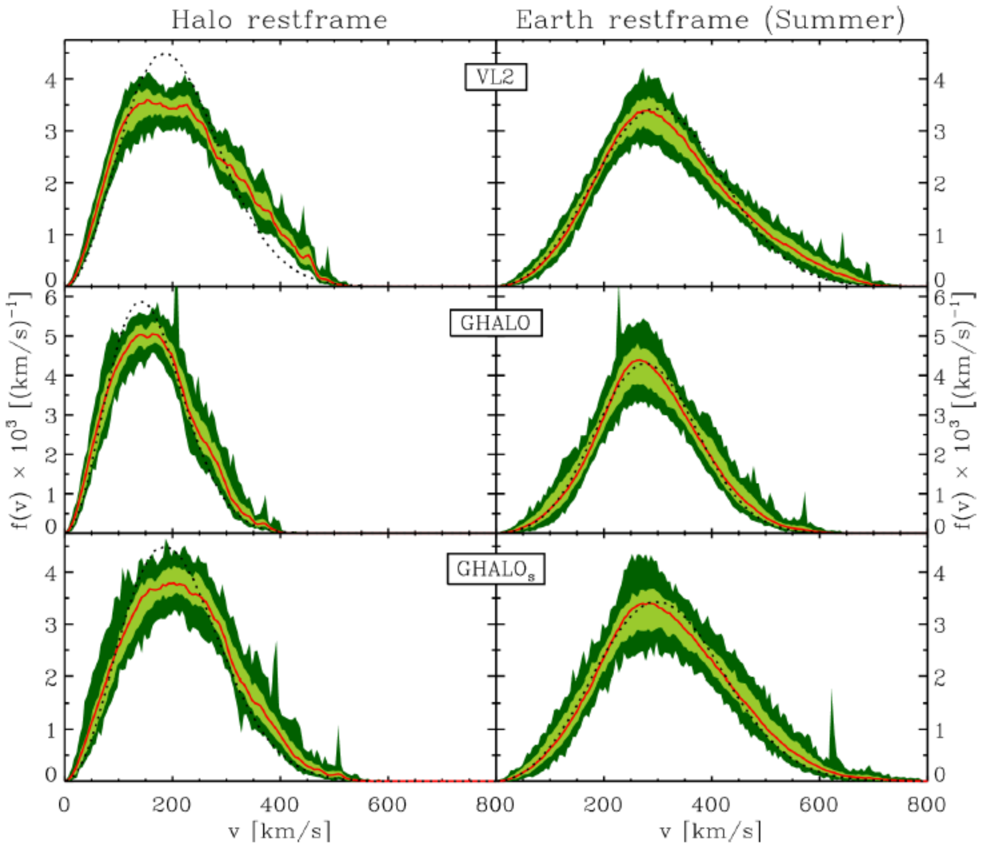
Density map of the dark matter halo
rho = [0.1, 0.3, 1.0, 3.0] GeV cm^{-3}



High-resolution cosmological simulation with baryons: F.S. Ling et al, JCAP02 (2010) 012

$$\rho_{local} \sim 0.3\,\mathrm{GeV}\cdot\mathrm{cm}^{-3}$$

Velocity distribution of WIMPs in the galaxy

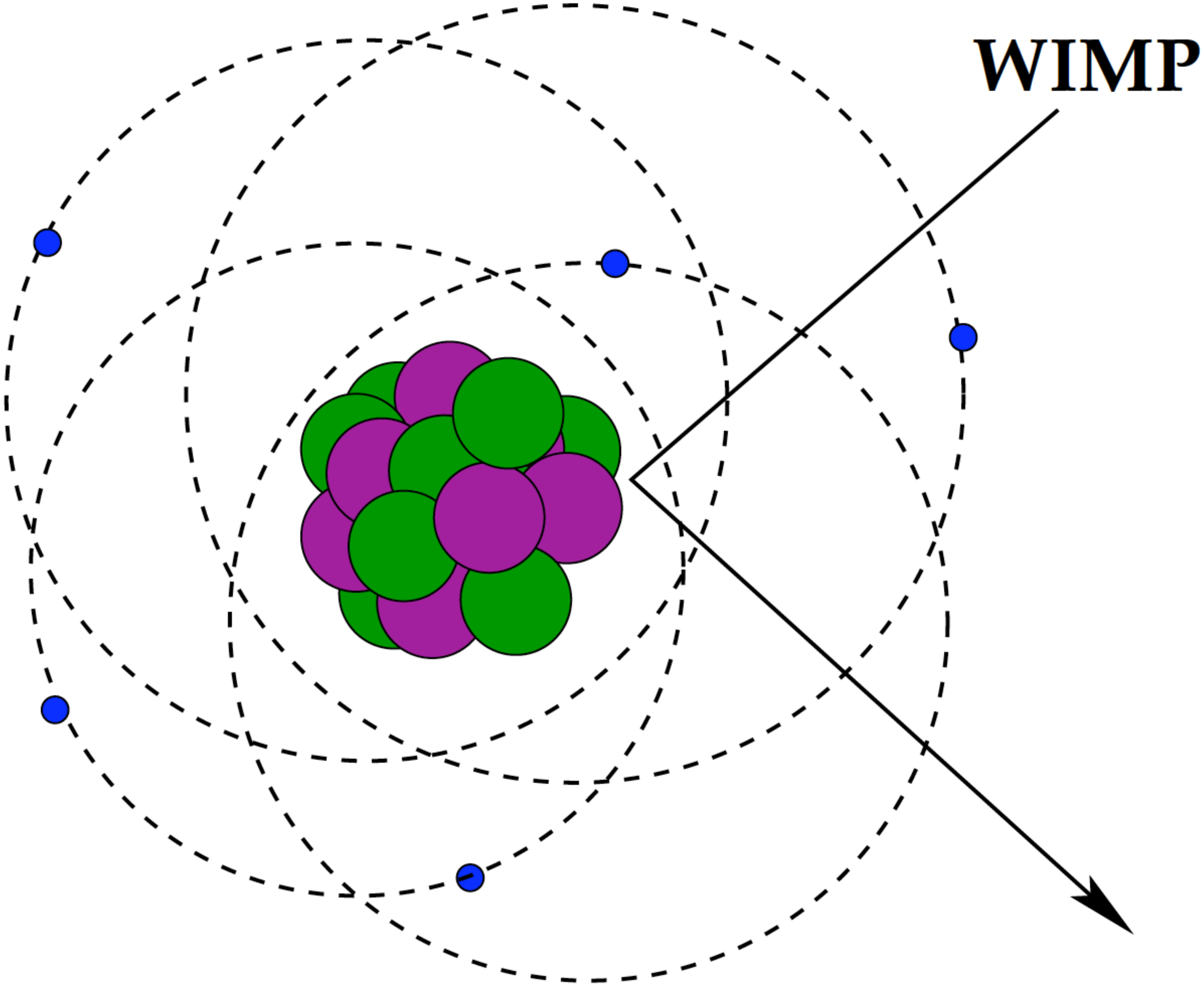


M. Kuhlen et al, JCAP02 (2010) 030

From cosmological simulations of galaxy formation: departures from the simplest case of a Maxwell-Boltzmann distribution

In direct detection experiments, mostly a simple MB distribution, truncated at v_{esc}, is used in the sensitivity calculation

Direct Dark Matter Detection



$$R \propto N_T \frac{\rho_0}{m_X} \sigma \langle v \rangle$$

$$E_R \sim \mathcal{O}(10\,\mathrm{keV})$$

also:

Electron recoils ? !

Dark Matter in the Milky Way

Expected interaction rates in a detector:

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\, \mathrm{d}^3 v$$

Credit: ESO/L. Calçada

Astrophysical parameters:

- ρ_0 = local density of the dark matter in the Milky Way

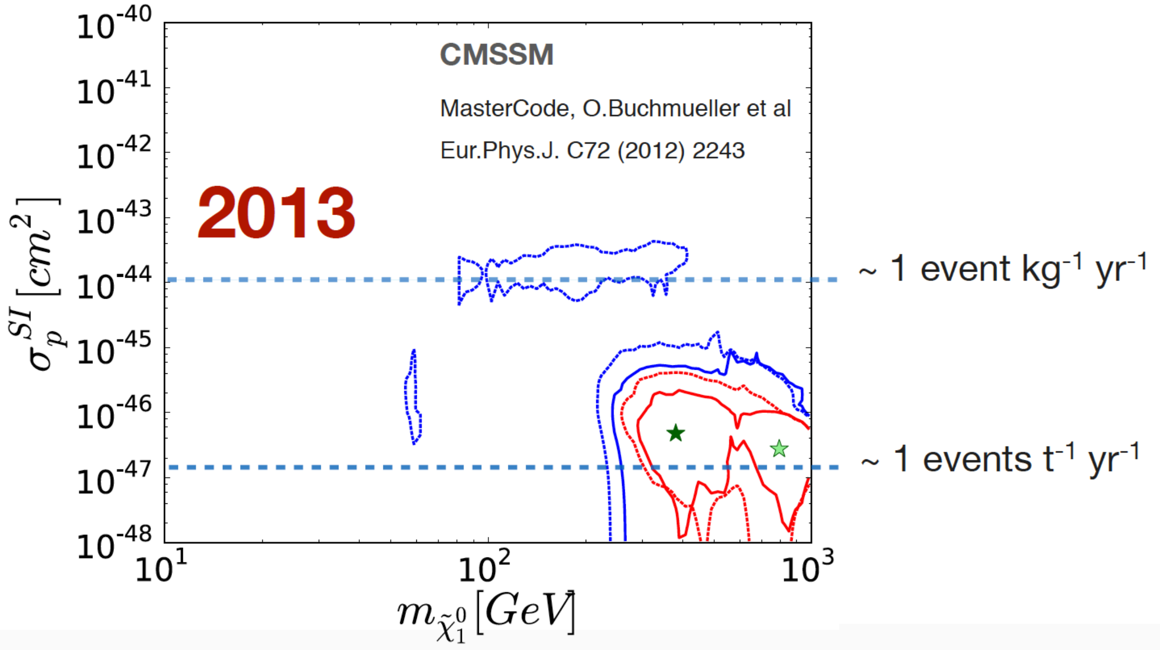
  'Standard' value: $\rho_\chi \simeq 0.3\,\mathrm{GeV/cm^3}$
- $f(\mathbf{v},t)$ = WIMP velocity distribution, $\langle v \rangle \sim 220\,\mathrm{km/s}$

Parameters of interest:

- m_χ = WIMP mass ($\sim 100\,\mathrm{GeV}$)
- σ = WIMP-nucleus elastic scattering cross section (SD or SI)

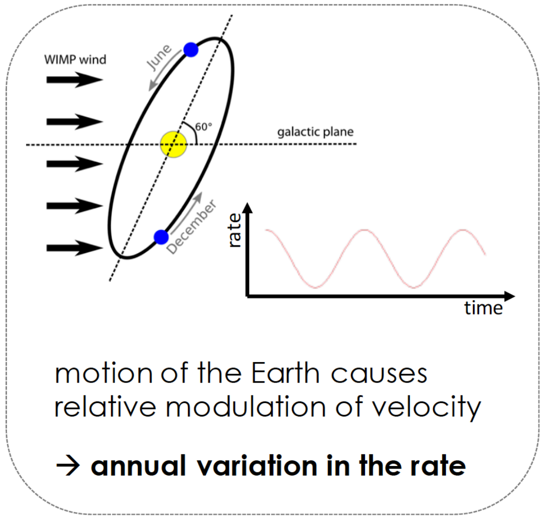
Detector requirements and signatures

- Requirements for a dark matter detector
  - Large detector mass
  - Low energy threshold ~ sub-keV to few keV's
  - Very low background and/or background discrimination
  - Long term stability



- Possible signatures of dark matter
  - Spectral shape of the recoil spectrum
  - Annual modulated rate
  - Directional dependance

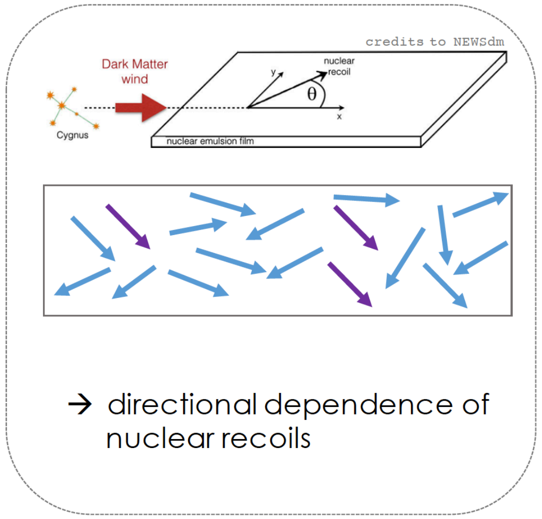
MODULATION



motion of the Earth causes relative modulation of velocity

→ **annual variation in the rate**

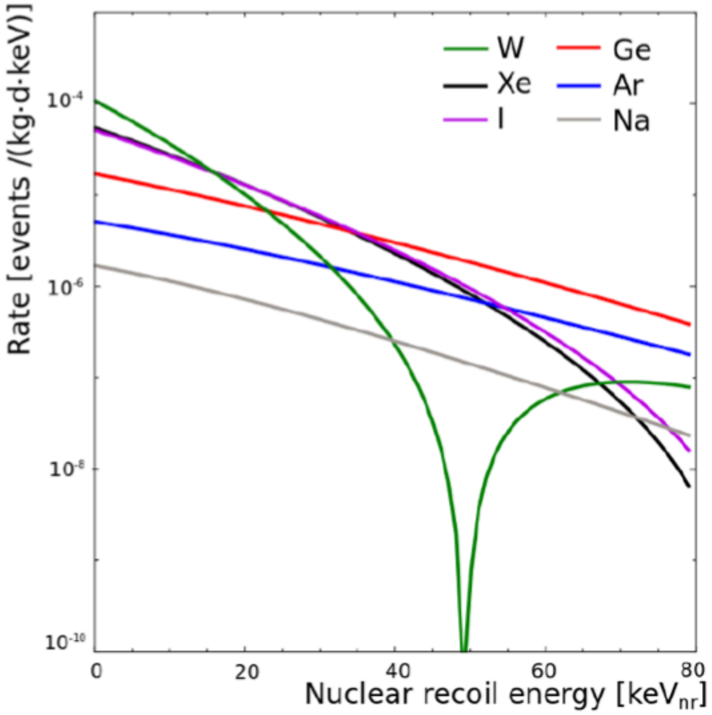
DIRECTIONALITY



→ directional dependence of nuclear recoils

Spectral Shape

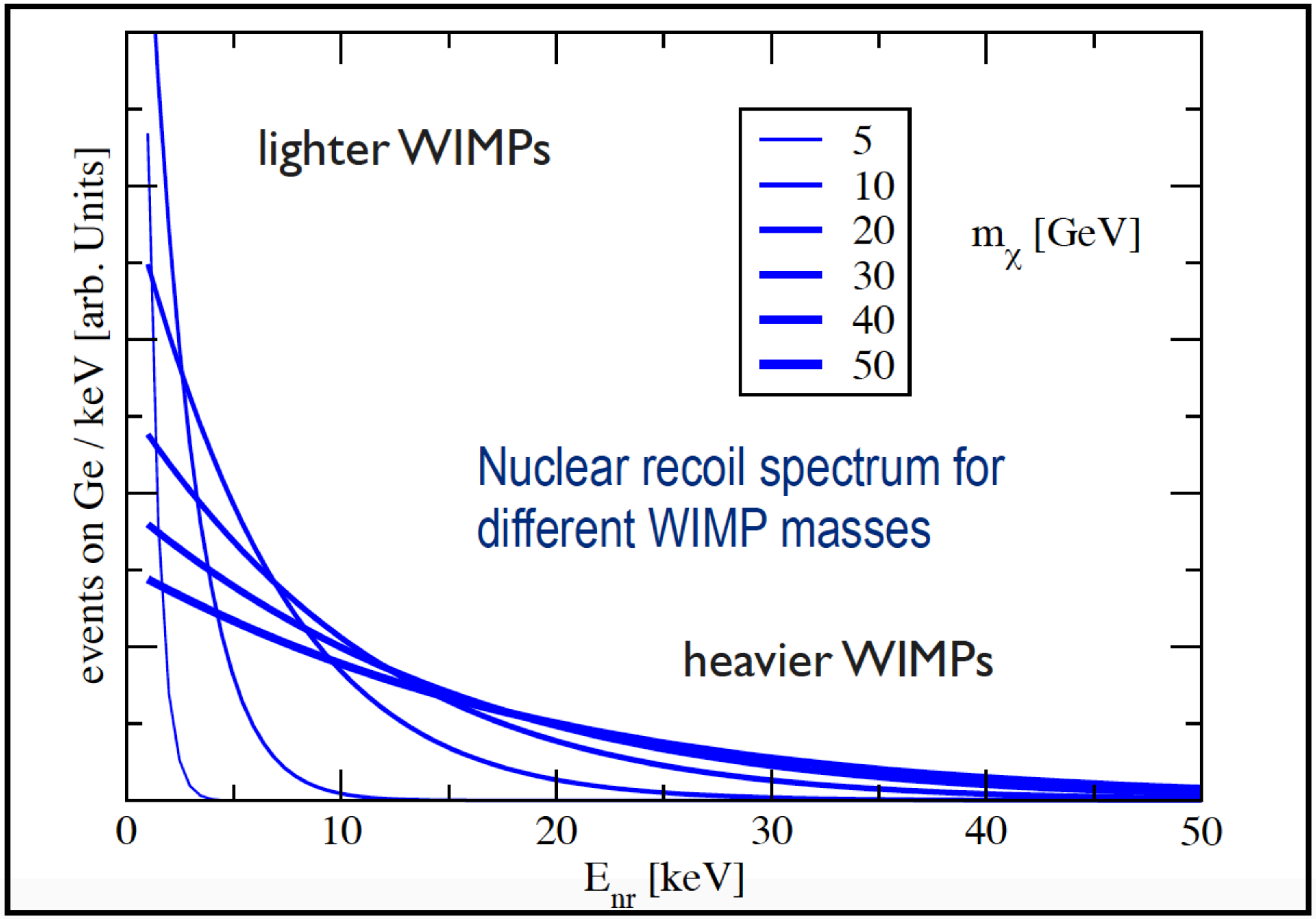
J. Phys. G: 43 (2016) 1, arXiv:1509.08767



Nuclear Recoil Energy Spectrum

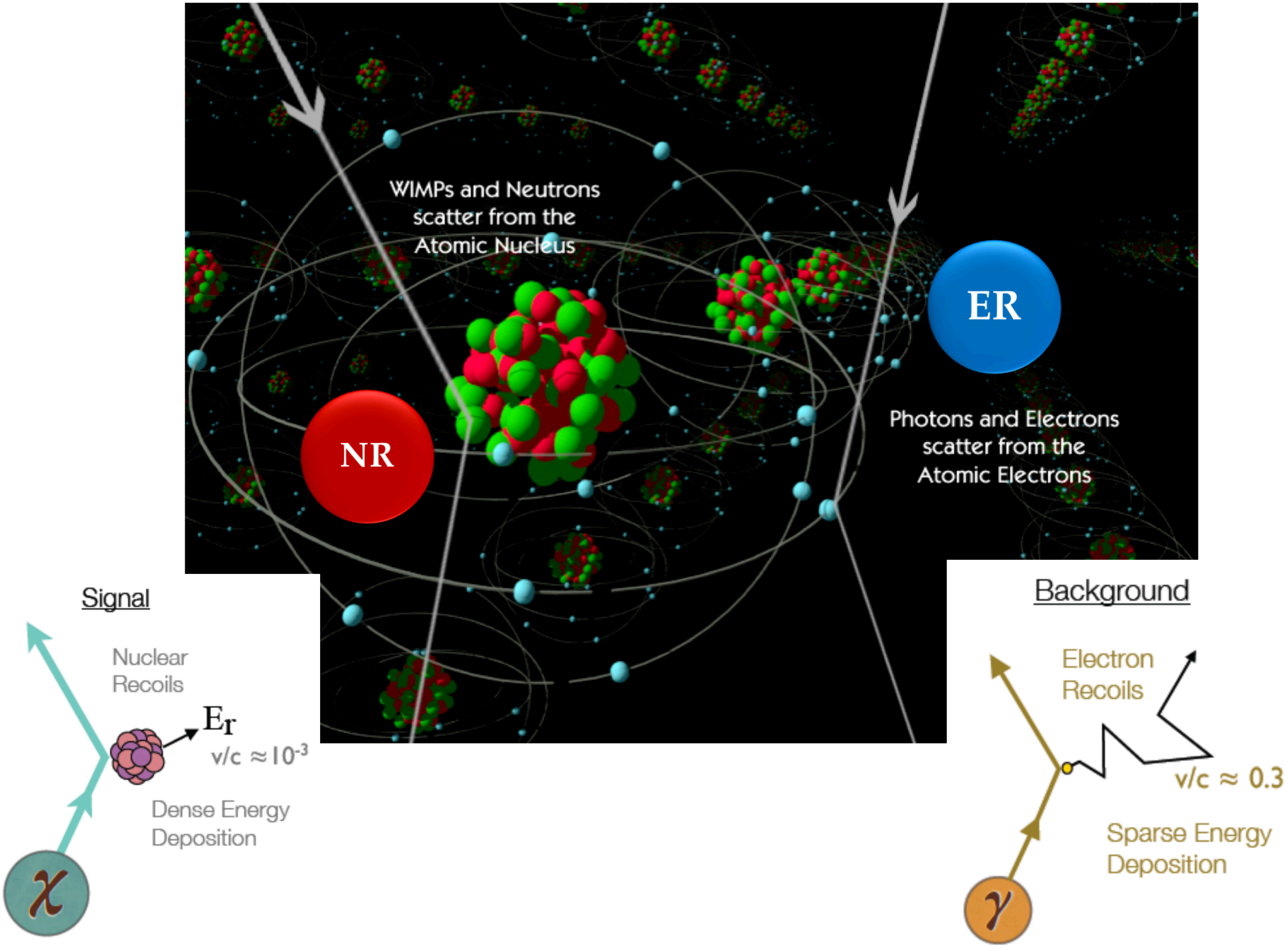
Rate after integration over WIMP velocity distribution

$$R \sim 0.13 \, \frac{\text{events}}{\text{kg year}} \left[\frac{A}{100} \times \frac{\sigma_{WN}}{10^{-38}\,\text{cm}^2} \times \frac{\langle v \rangle}{220\,\text{km}\,\text{s}^{-1}} \times \frac{\rho_0}{0.3\,\text{GeV}\text{cm}^{-3}} \right]$$

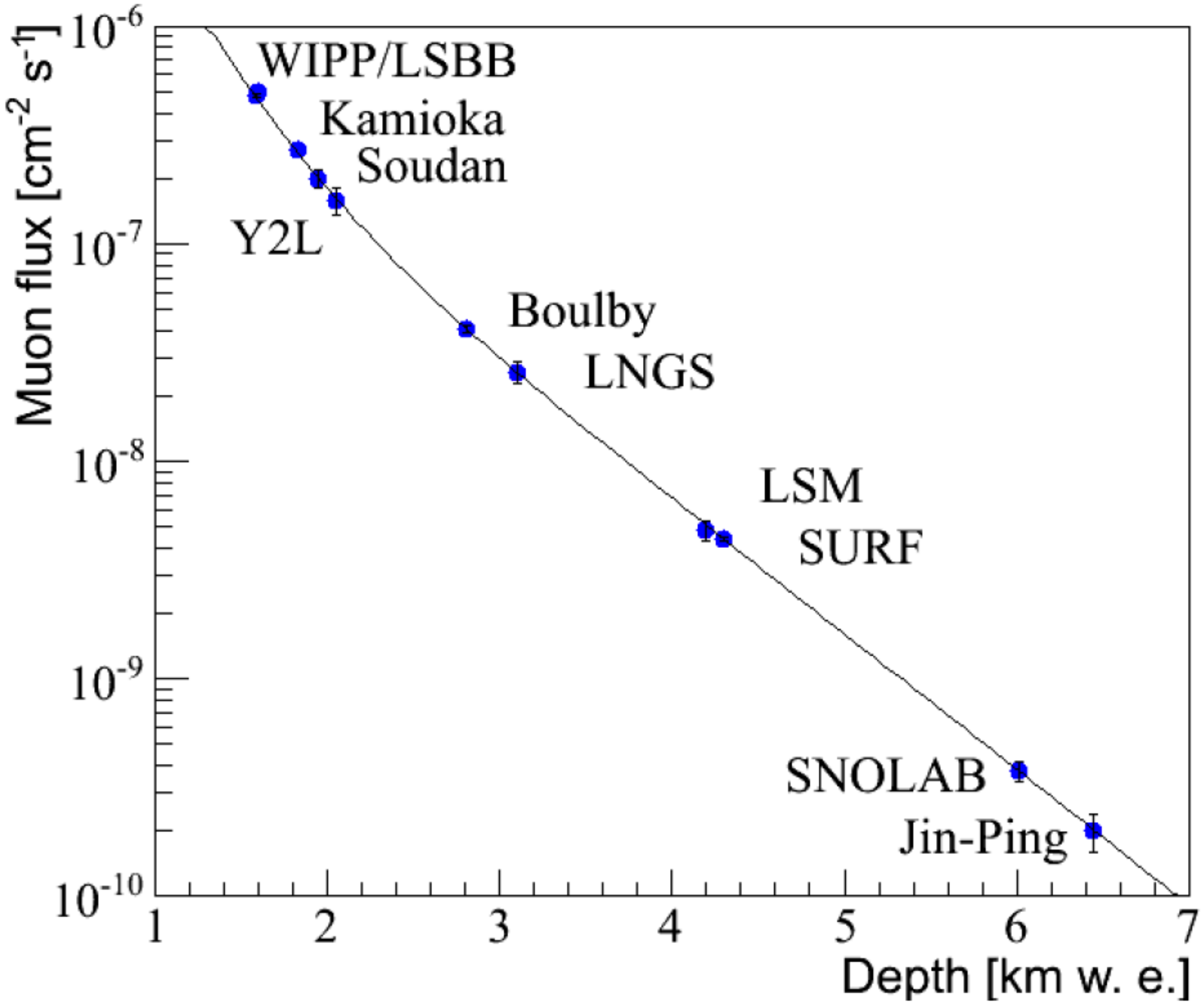


Nuclear recoil spectrum for different WIMP masses

Backgrounds: Electron & Nuclear Recoils



Underground laboratories

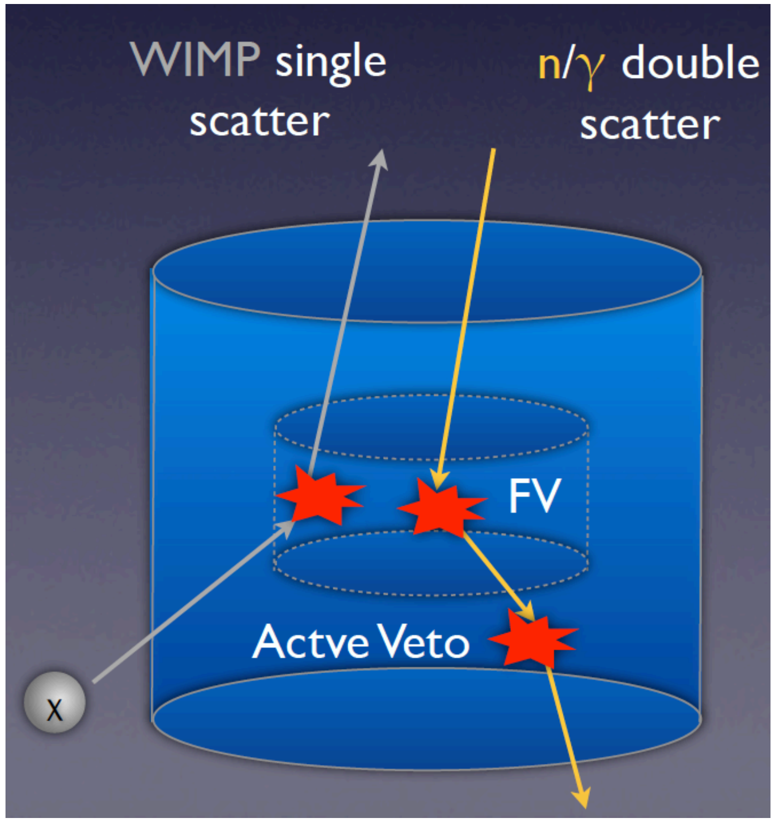


- WIPP in USA (DMTPC)
- LSBB in France (SIMPLE)
- Kamioka in Japan (XMASS, NEWAGE)
- Soudan in USA (SuperCDMS, GoGeNT)
- Y2L in Corea (KIMS)
- Boulby in UK (DRIFT, ZEPLIN)
- LNGS in Italy (XENON, DAMA, Cresst, DarkSide)
- LSM in France (Edelweiss, MIMAC)
- SURF in USA (LUX)
- SNOLAB in Canada (DEAP/CLEAN, PICASSO, COUPP)
- Jin-Ping in China (PandaX, CDEX)

Underground laboratories

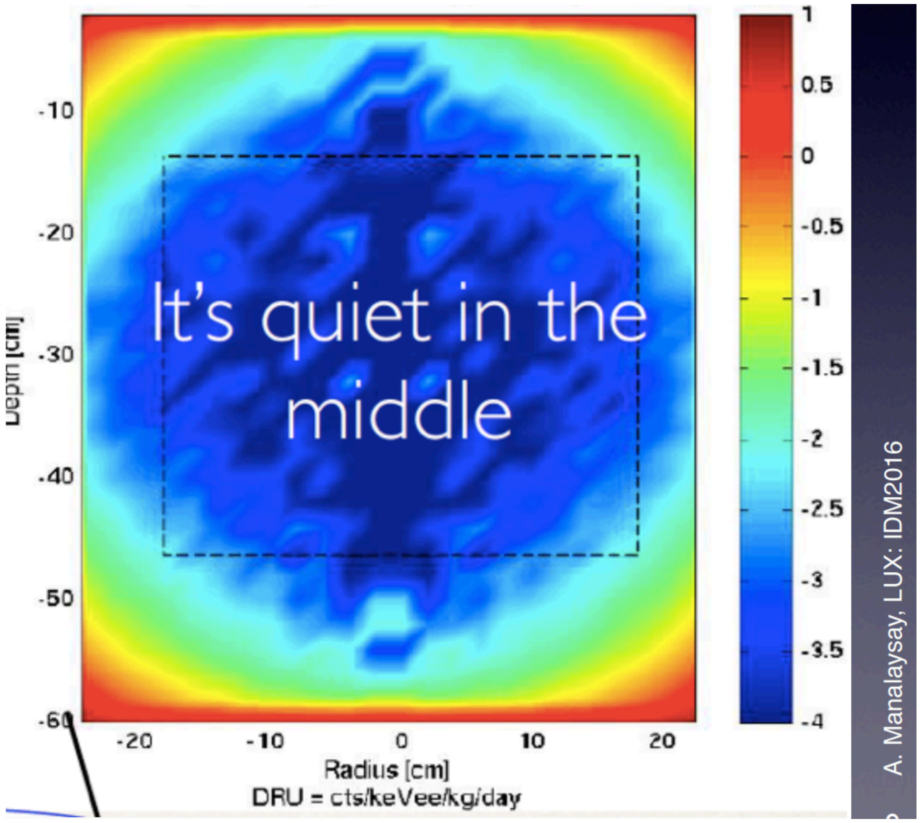
courtesy of Laura Baudis

Backgrounds: external sources

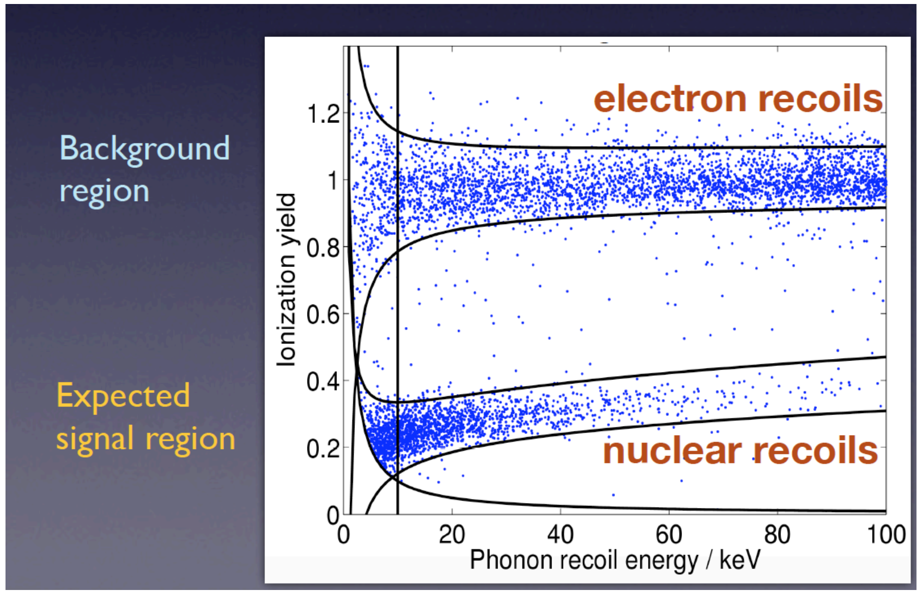


- External γ's from natural radioactivity:
  - Suppression via self-shielding of the target
  - Material screening and selection
  - Rejection of multiple scatters & discrimination

- External neutrons:
  muon-induced, (α, n) and from fission reactions
  - Go underground!
  - Shield: passive (polyethylene) or active (water/scintillator vetoes)
  - material selection for low U and Th contaminations



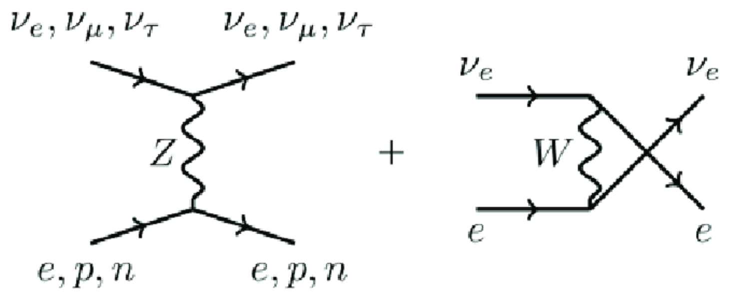
A. Manalaysay, LUX: IDM2016

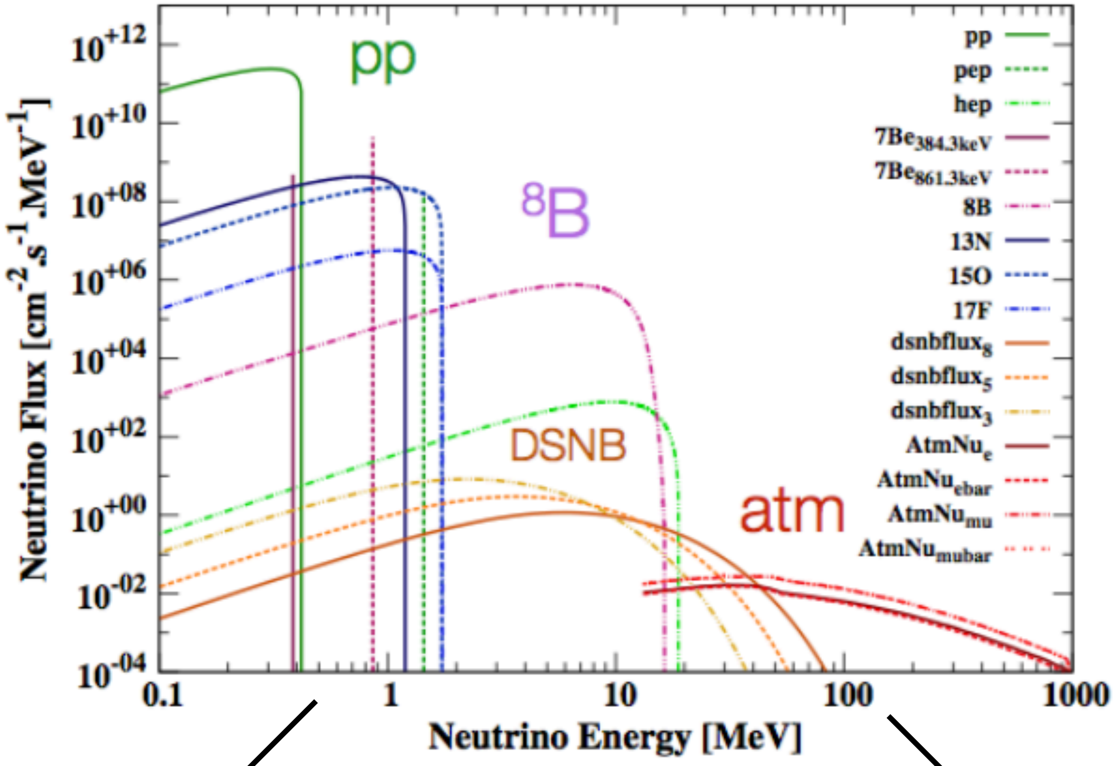


Backgrounds: internal and surface sources

- Internal contamination in liquids:
  - ^{85}Kr: removal by cryogenic distillation/chromatography/centrifuges
  - Rn: removal using activated carbon, distillation, dust removal
  - Argon: ^{39}Ar (565 keV endpoint, 1 Bq/kg), ^{42}Ar
  - Xenon: ^{136}Xe $\beta\beta$ decay ($T_{1/2} = 2.2 \times 10^{21}$ y) *long lifetime!*
- Surface background in solids:
  - Germanium detectors or solid scintillators grown out of high purity powders or melts → low intrinsic background
  - Cosmic activation
  - Surface events from α or β-decays

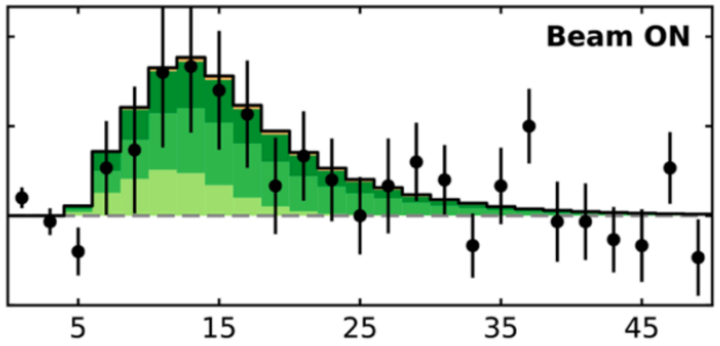
The ultimate background from neutrinos

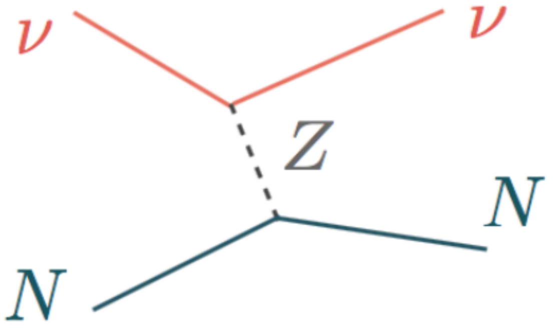




F. Ruppin et al., 1408.

COHERENT, Science, 2017

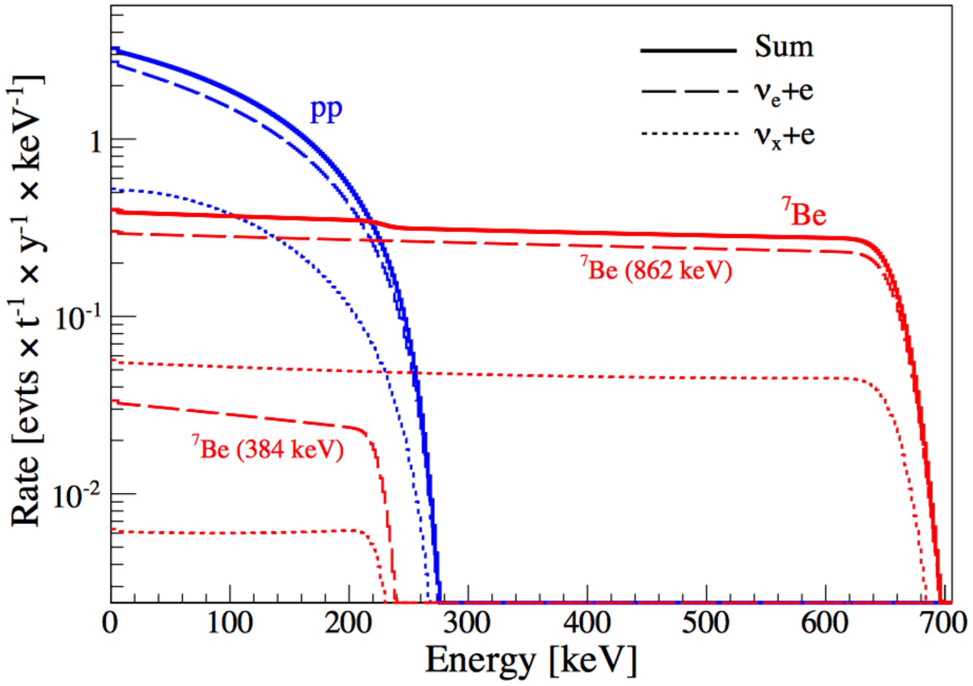


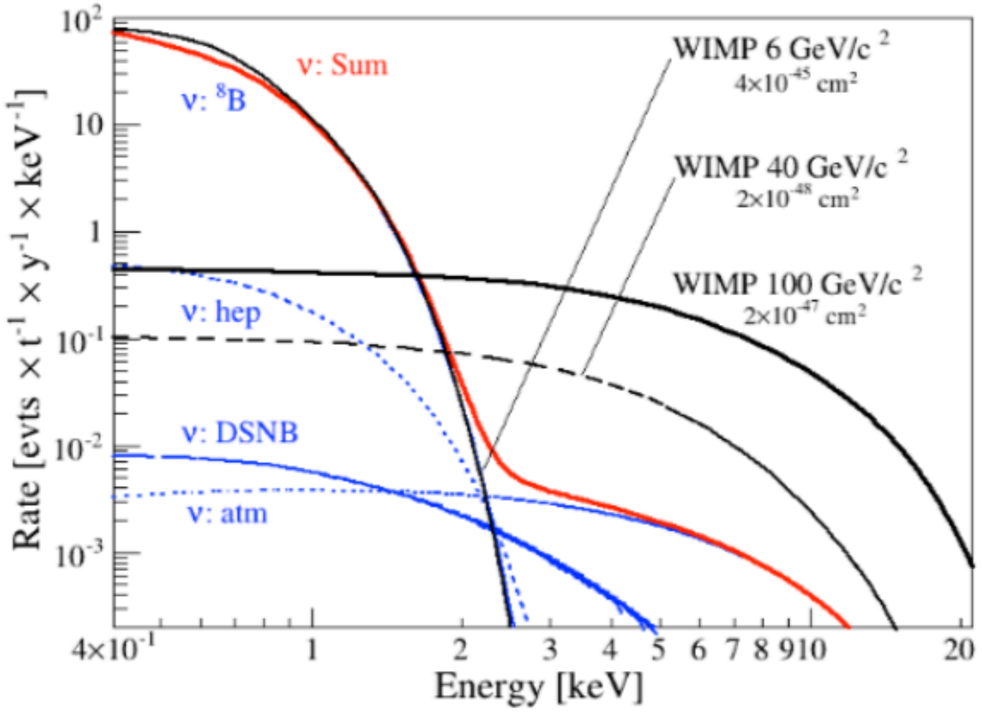


ER

NR

$\nu + N \longrightarrow \nu + N$

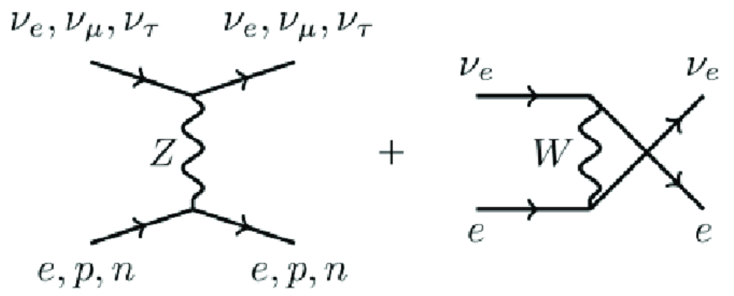


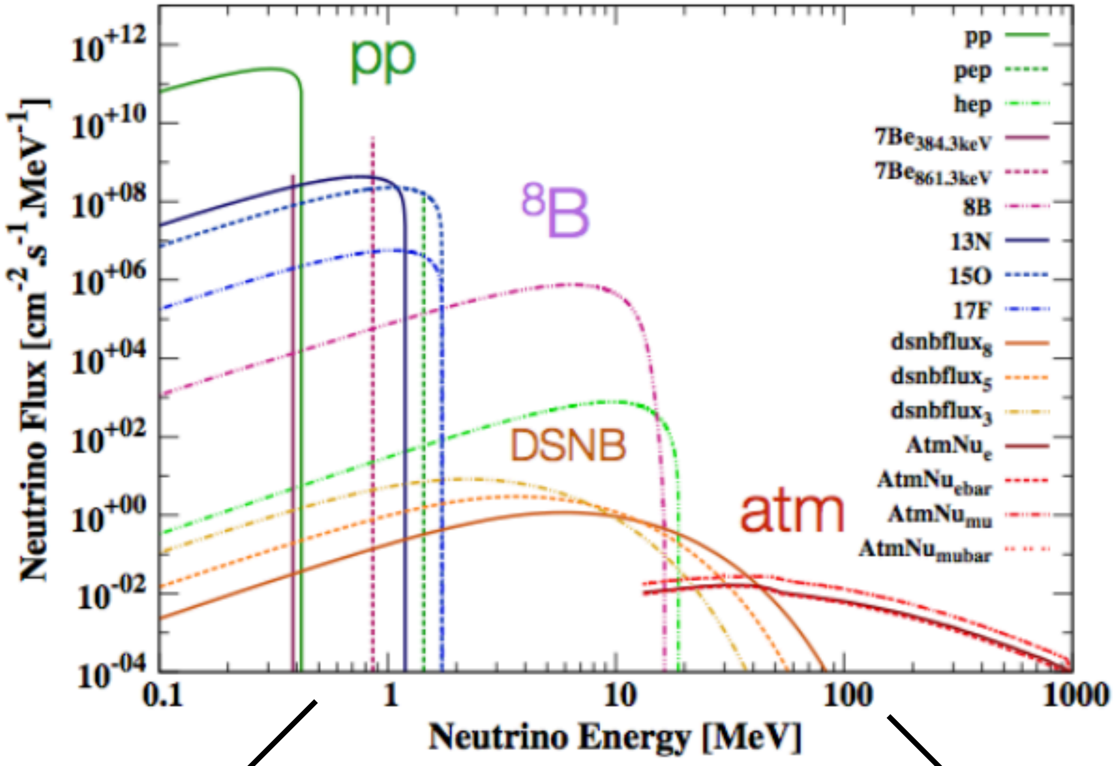


LB et al., JCAP01 (2014) 044

The ultimate background from neutrinos

Background of today
can be the signal
of tomorrow !





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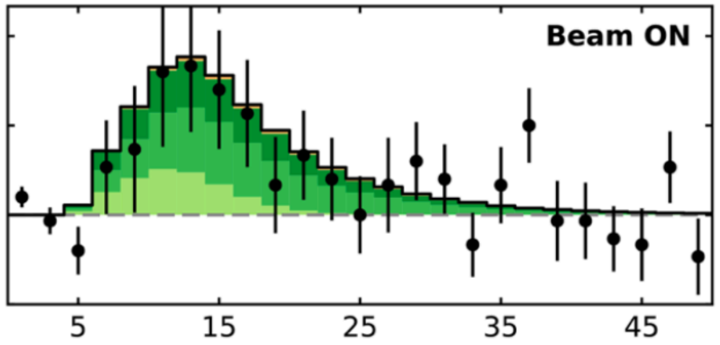
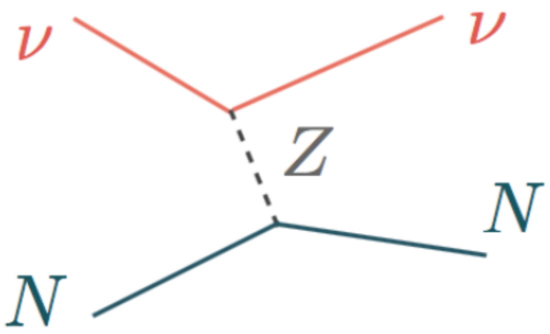
COHERENT, Science, 2017

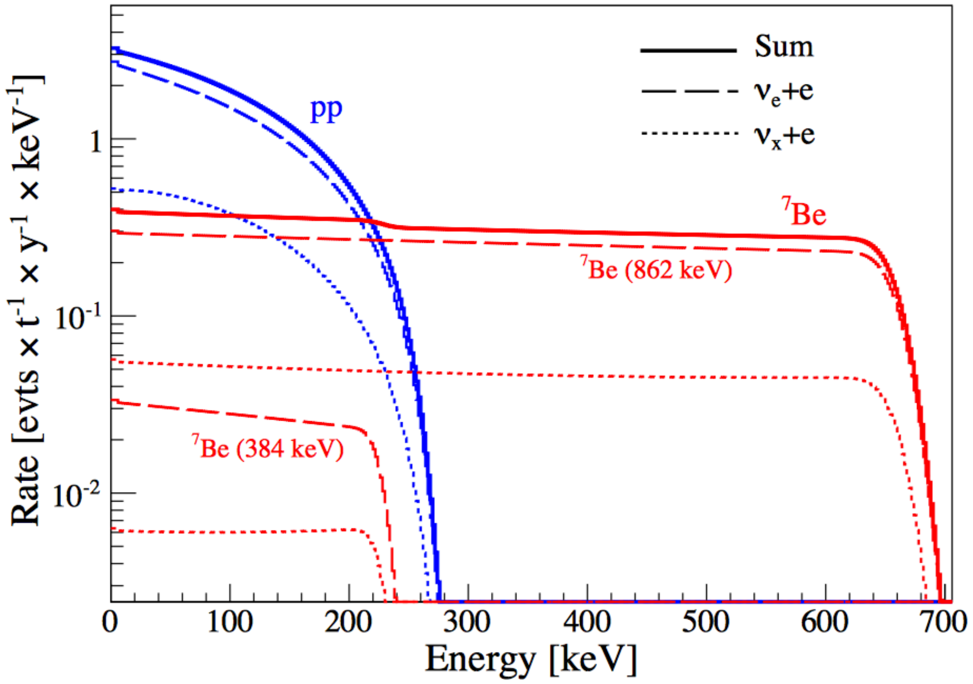


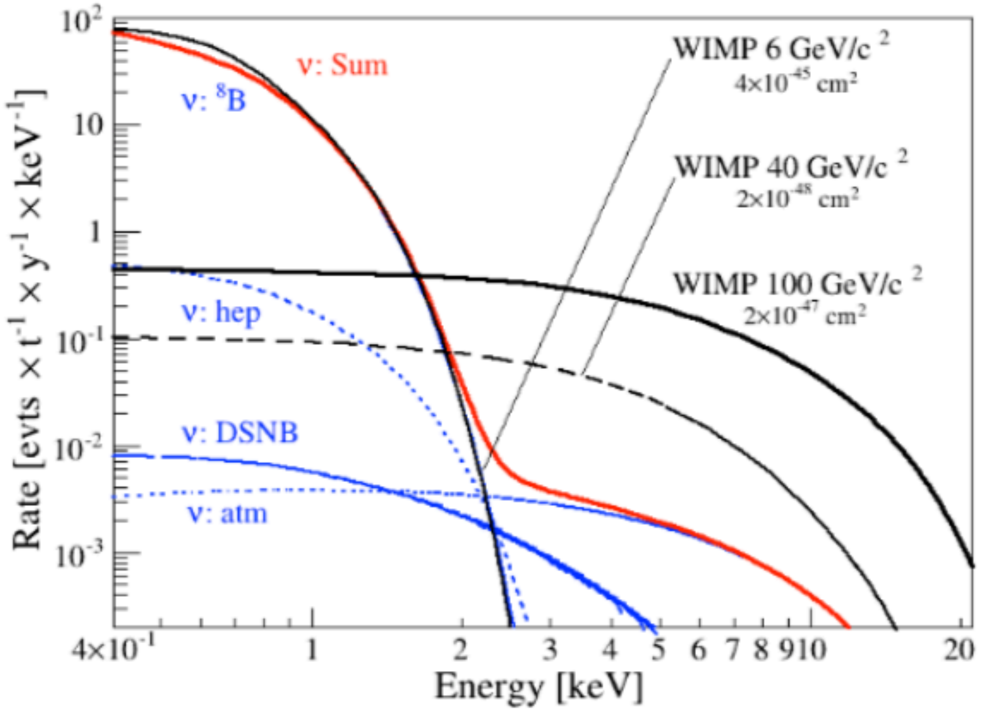


ER

NR

$\nu + N \longrightarrow \nu + N$





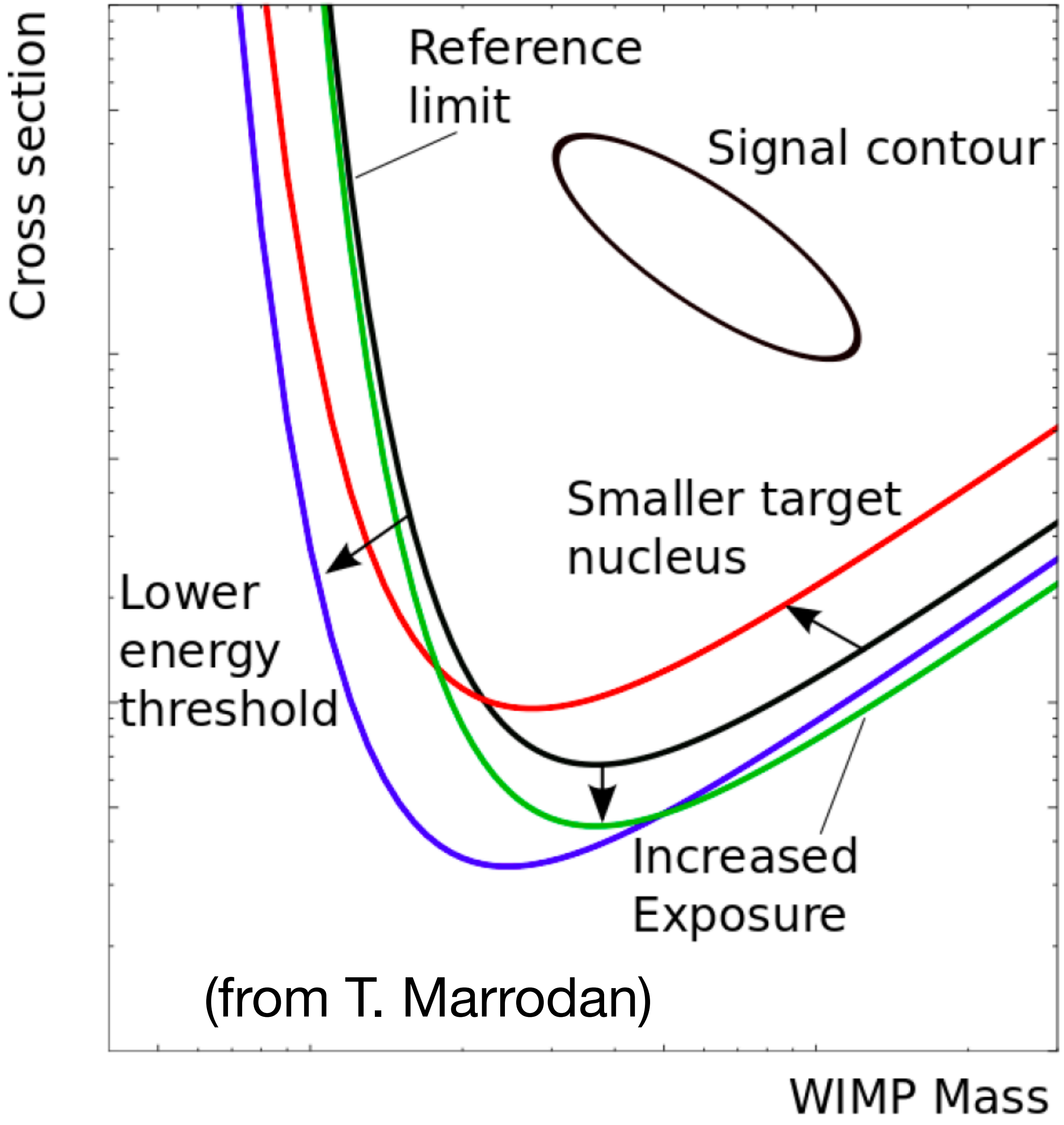
LB et al., JCAP01 (2014) 044

Sensitivity plot in direct DM experiments

→ Statistical significance of signal over expected background?

$$R \propto N_T \frac{\rho_0}{m_X} \sigma \langle v \rangle$$

J. Phys. G43 (2016) 1, 013001& arXiv:1509.08767



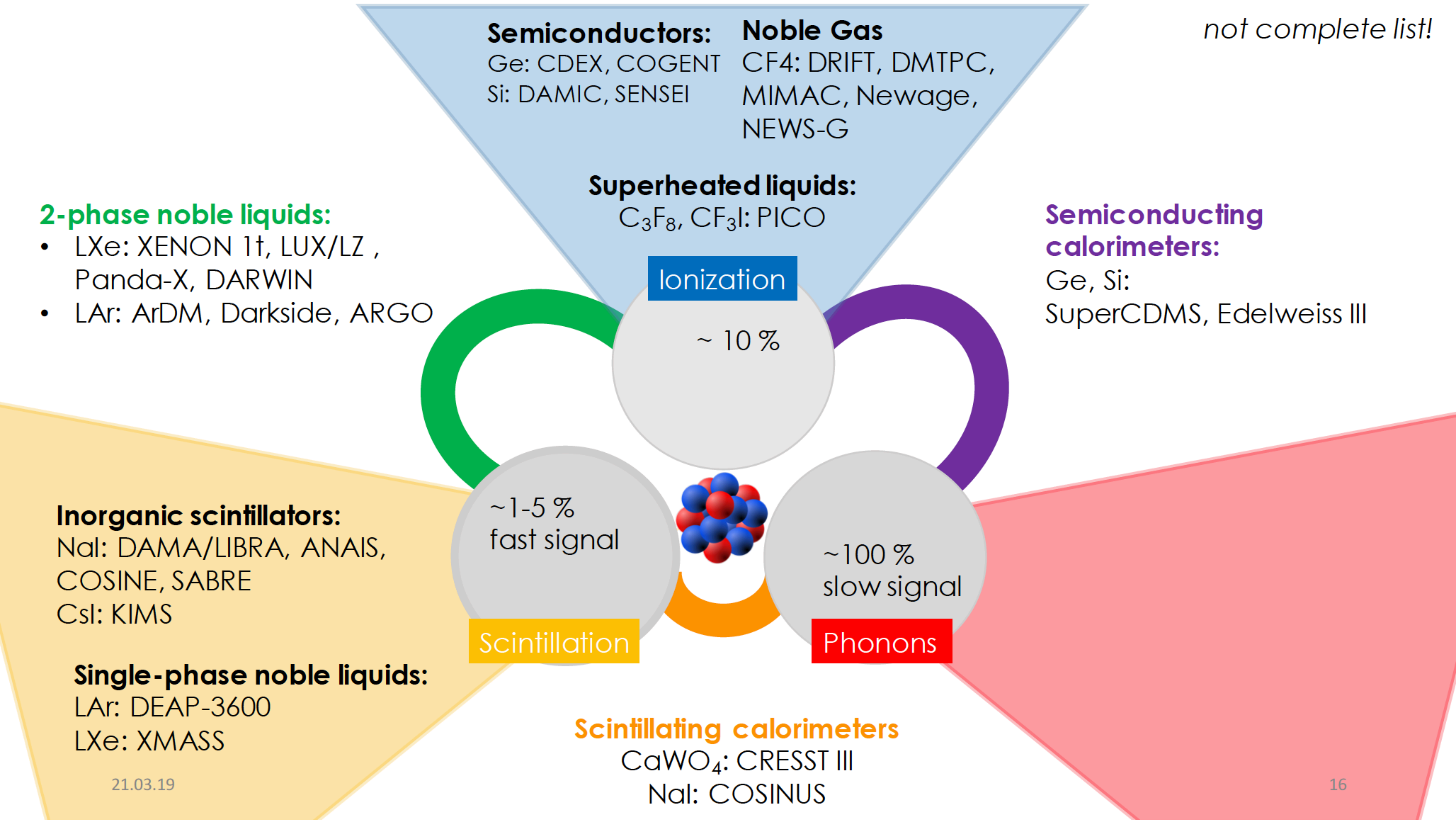
(from T. Marrodan)

- Positive signal
  - Region in σ_χ versus m_χ
- Zero signal
  - Exclusion of a parameter region

- Low WIMP masses: detector threshold matters
- Minimum of the curve: depends on target nuclei
- High WIMP masses: exposure matters $\epsilon = m \times t$

Direct detection Techniques

not complete list!



Semiconductors:
Ge: CDEX, COGENT
Si: DAMIC, SENSEI

Noble Gas
CF4: DRIFT, DMTPC, MIMAC, Newage, NEWS-G

Superheated liquids:
C_3F_8, CF_3I: PICO

2-phase noble liquids:
- LXe: XENON 1t, LUX/LZ , Panda-X, DARWIN
- LAr: ArDM, Darkside, ARGO

Semiconducting calorimeters:
Ge, Si:
SuperCDMS, Edelweiss III

Inorganic scintillators:
NaI: DAMA/LIBRA, ANAIS, COSINE, SABRE
CsI: KIMS

Single-phase noble liquids:
LAr: DEAP-3600
LXe: XMASS

Scintillating calorimeters
$CaWO_4$: CRESST III
NaI: COSINUS

21.03.19

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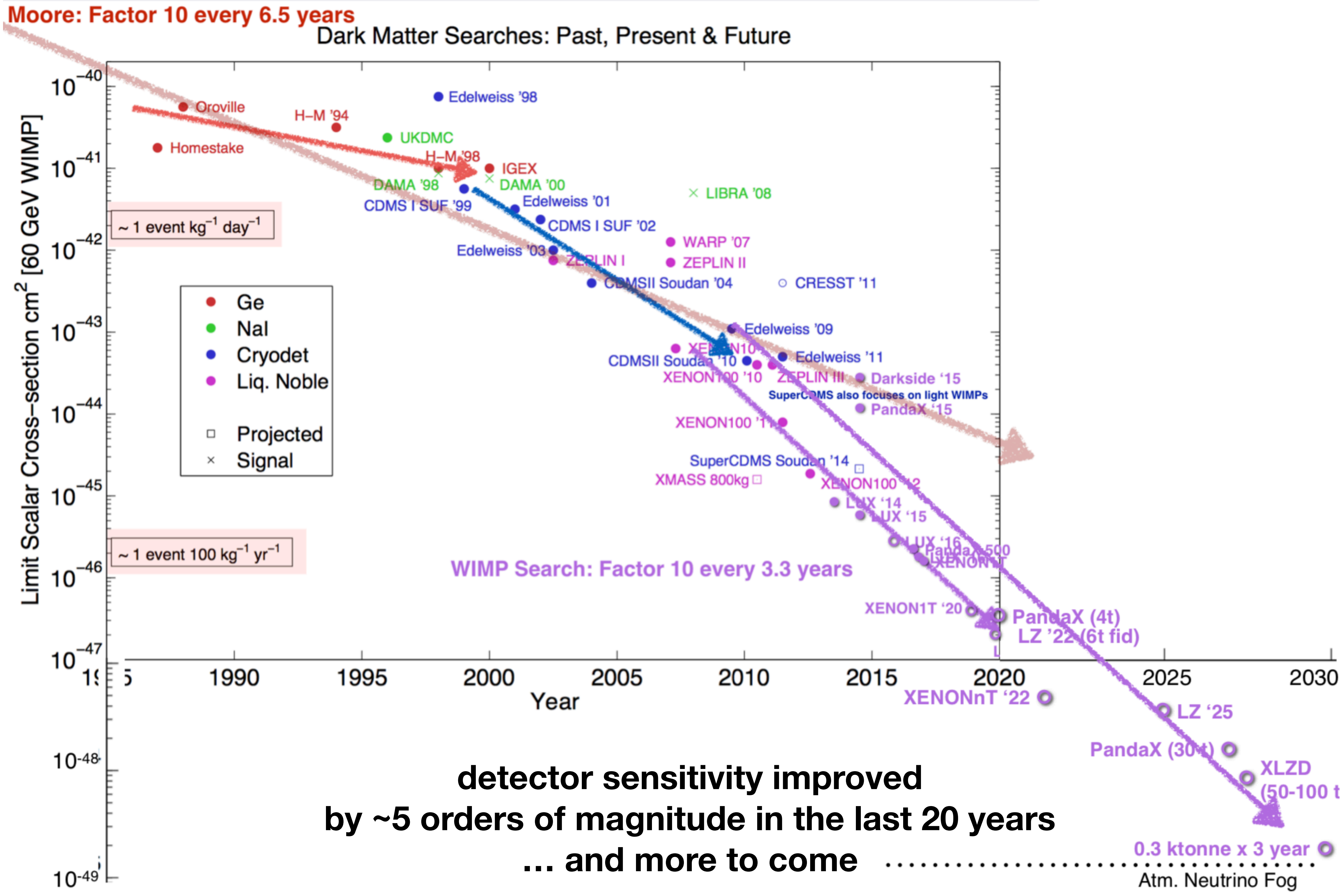
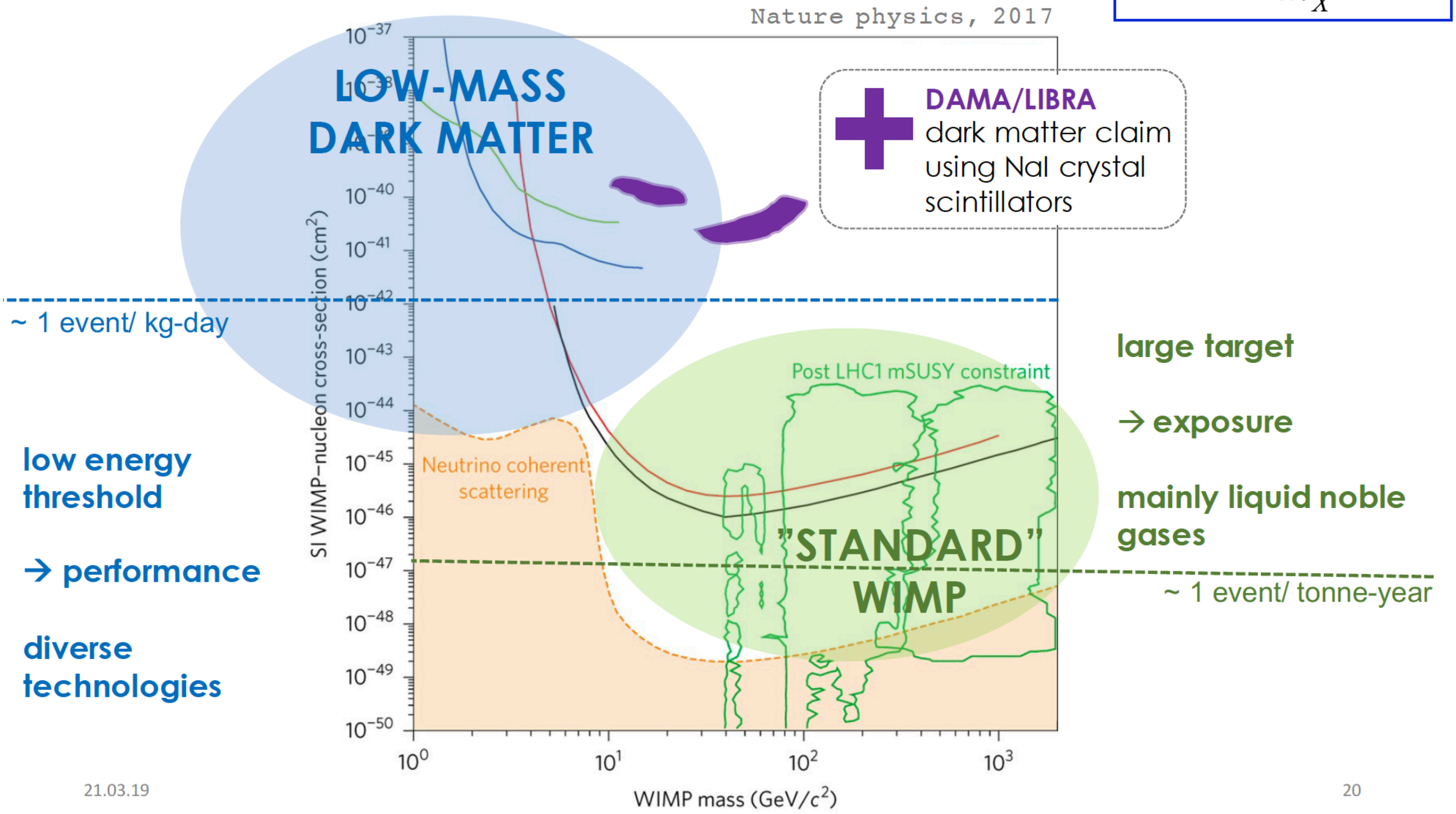
Competitive field, rapid progress



detector sensitivity improved
by ~5 orders of magnitude in the last 20 years
… and more to come

Two main lines of improvements (+ others)

$$R \propto N_T \frac{\rho_0}{m_X} \sigma \langle v \rangle$$



low energy threshold

→ performance

diverse technologies

large target

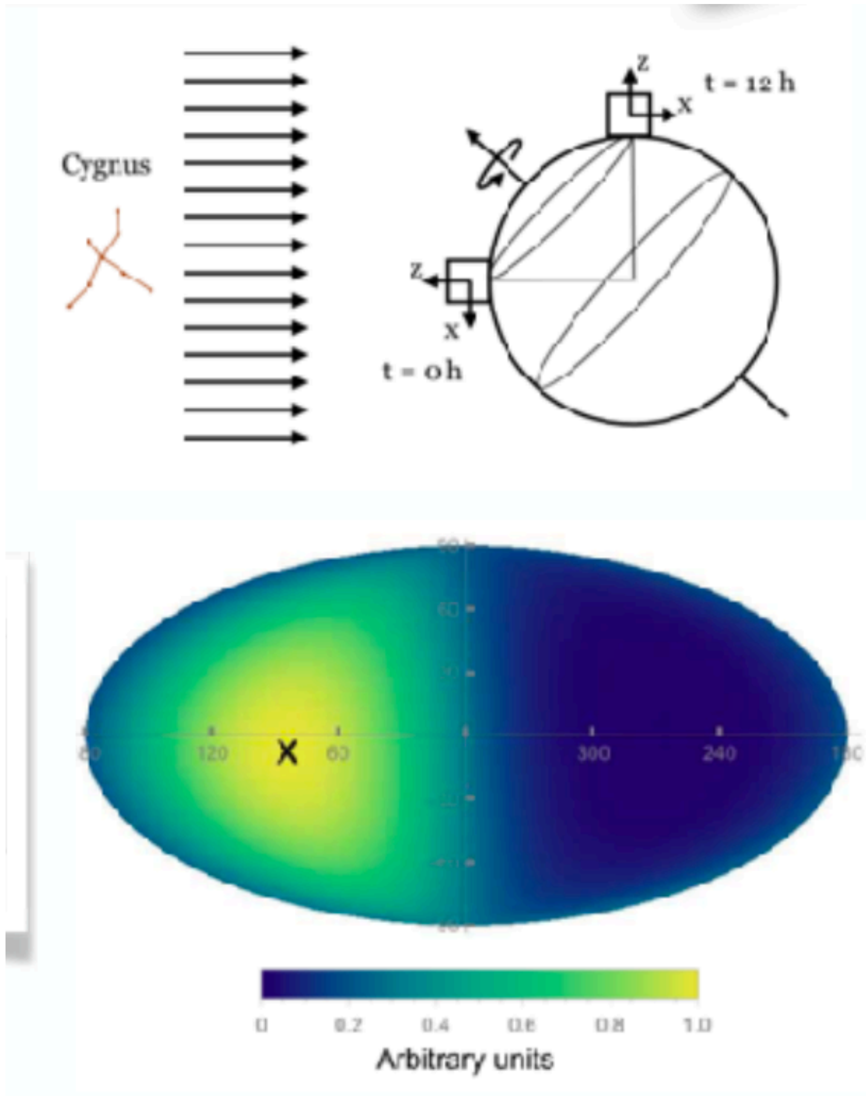
→ exposure

mainly liquid noble gases

Directional detectors

Various techniques:

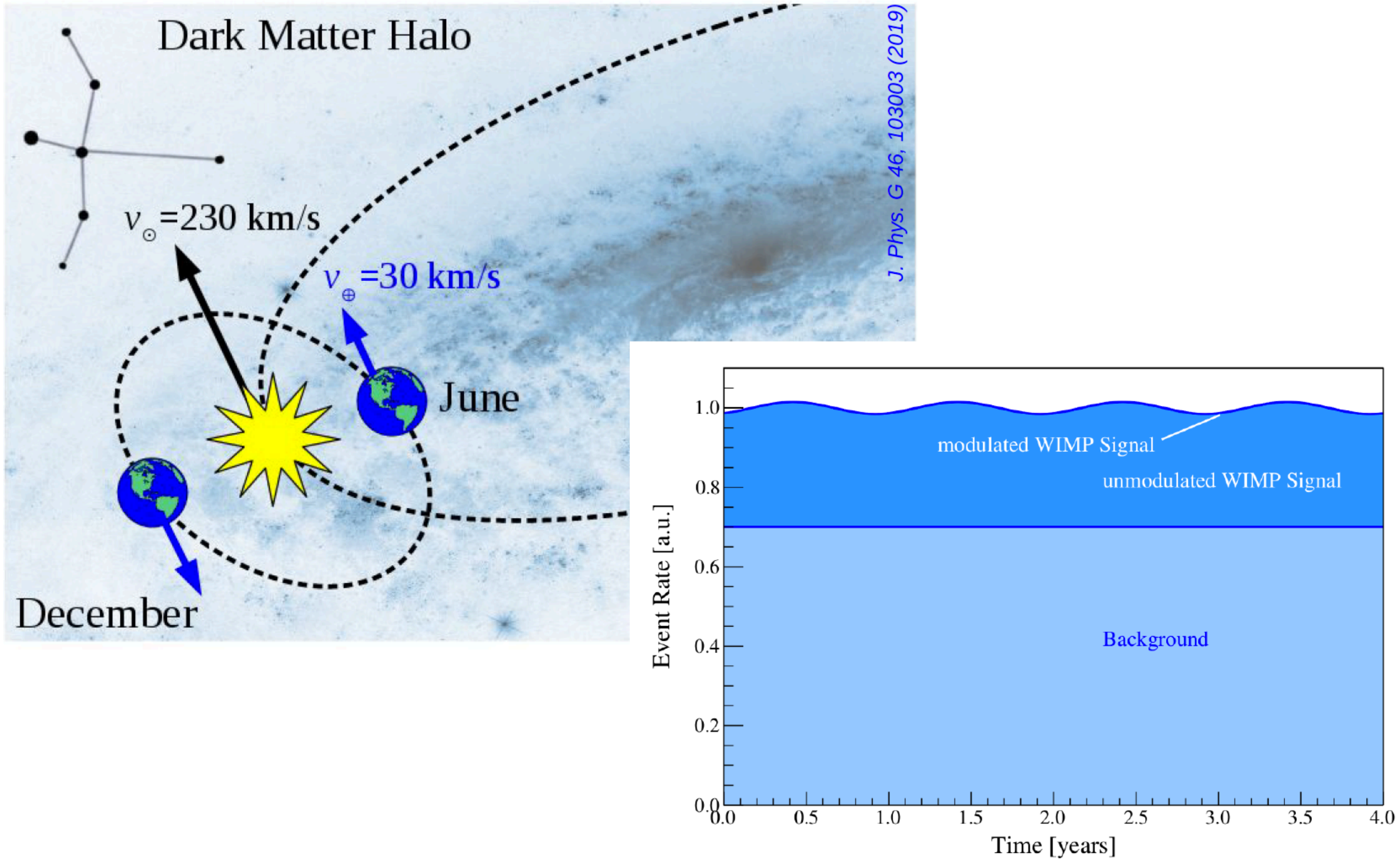
- Low pressure Gas TPC (Cygno, DRIFT, NEWAGE, D3, DMTPC, …)
- Nuclear Emulsion (NEWSdm)
- Columnar recombination in noble gas (RED: LAr)
- Crystals with Anisotropic Response (ADAMO: ZnWO4)
- Carbon NanoTubes
- …



Directional dependence: an O(100) forward/backward asymmetry that no background whatsoever can mimic

Scintillating crystals and annual modulation

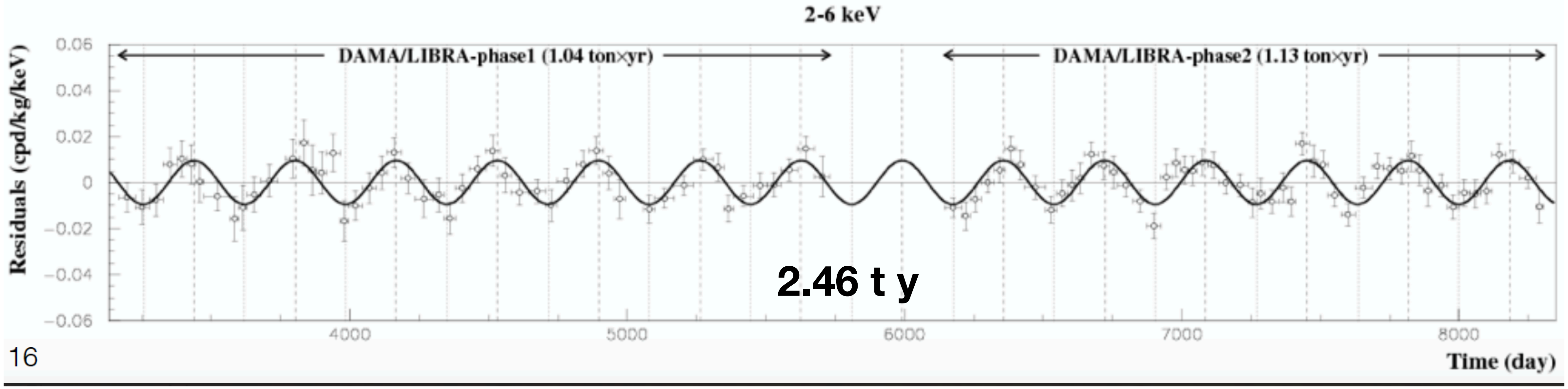
- Mostly NaI (Tl) and CsI (Tl) used in dark matter searches
- Arrays of several crystals at room temperature
  → simple operation, important for long-term stability
- No particle discrimination
  → Low radioactivity of the target material
  → Rejection of multiple scatters in different crystals



J. Phys. G 46, 103003 (2019)

DAMA-LIBRA

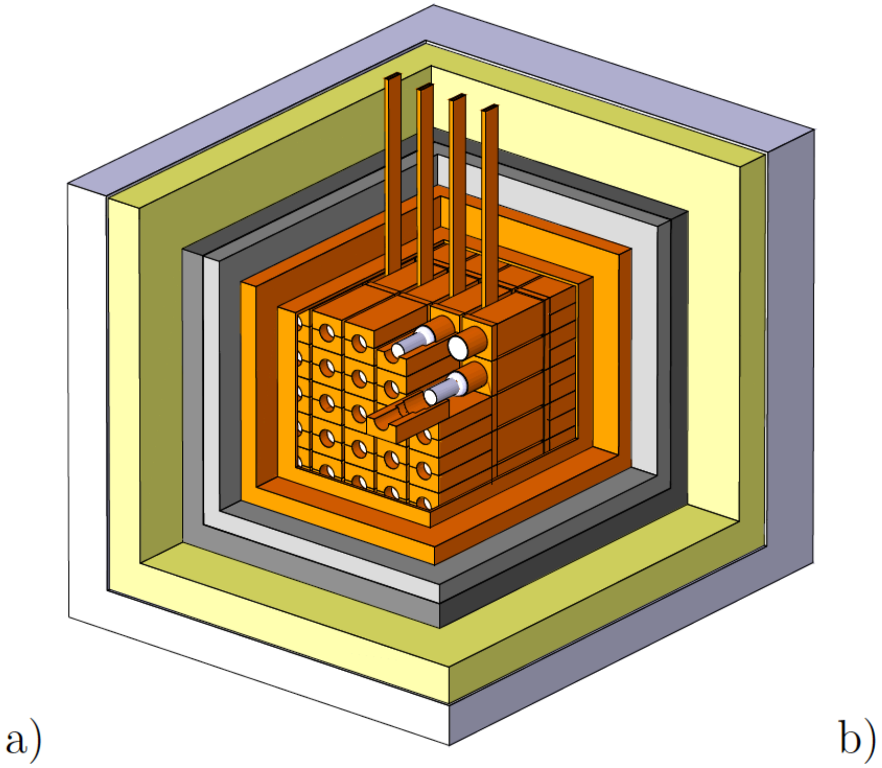
- DAMA and DAMA/LIBRA phase 1
  - 250-kg high-purity NaI(Tl) array collected data for 14 solar cycles
  - observed ~0.01 cpd/kg/keV modulation in 2 - 6 keV energy range
  - over 9 σ stat. significant; WIMP signal interpretation in tension with other experiments
- DAMA/LIBRA phase 2 arXiv:1805.10486
  - 250-kg high-purity NaI(Tl) array collected data for 6 solar cycles
  - 2-6 keV range combined now gives 12.9 σ stat. significant
  - Modulation clearly evident in lowest energy bins now too (1-3 keV)

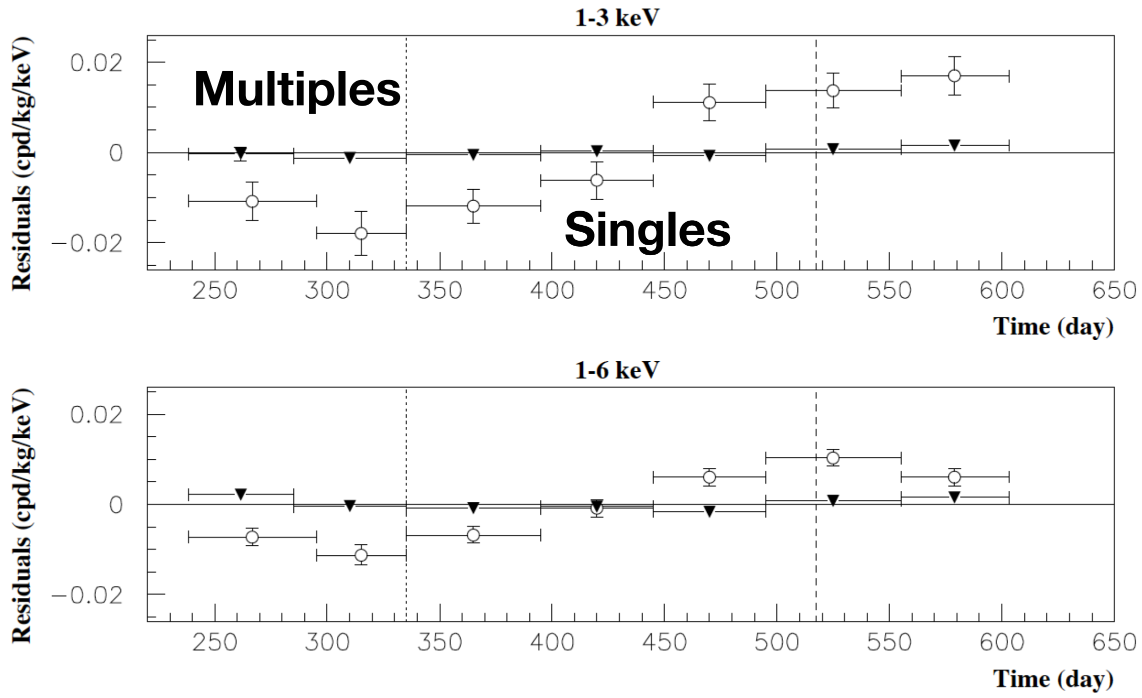


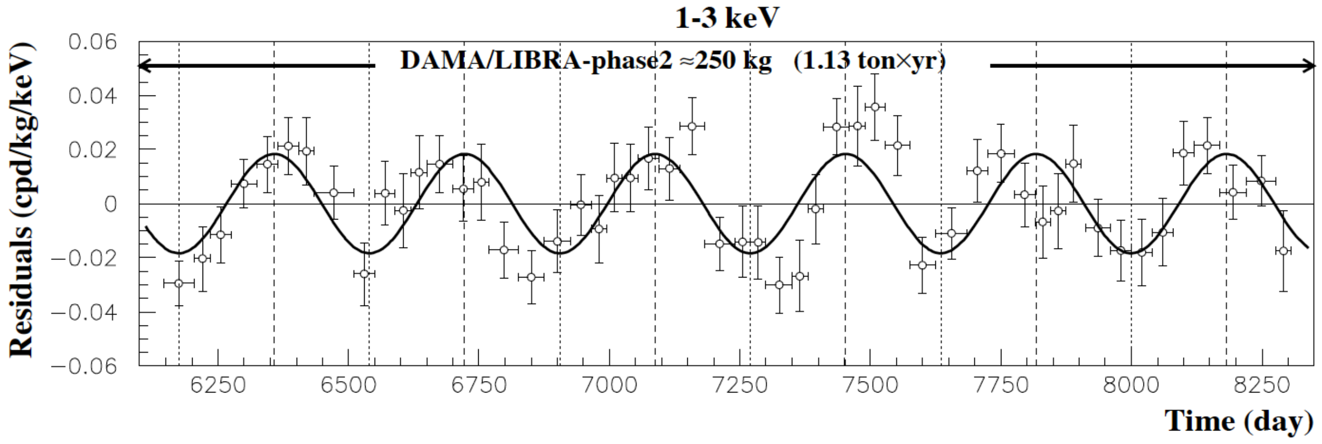
2.46 t y

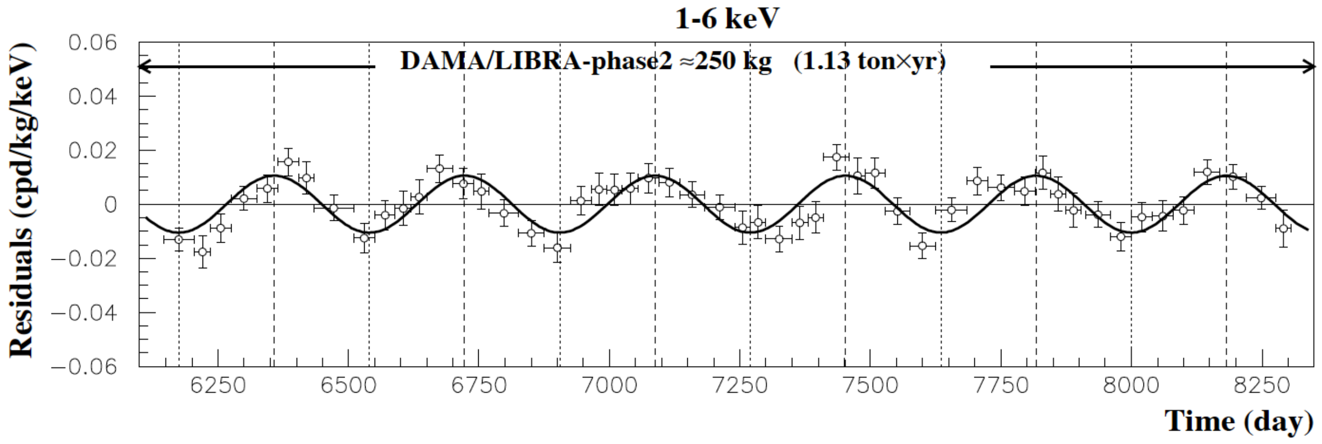
DAMA-LIBRA results

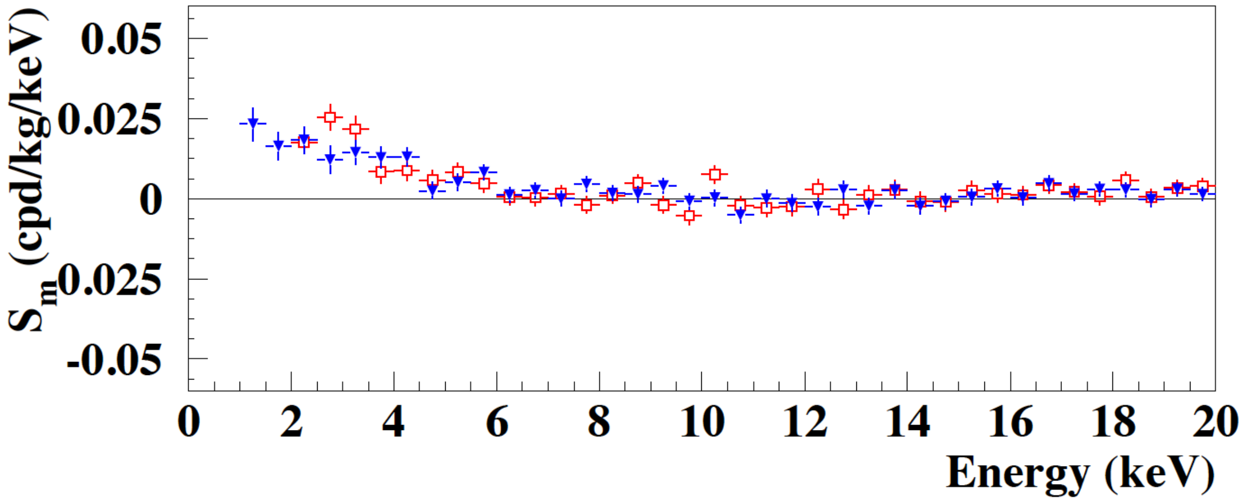
R. Bernabei et al., Nucl. Phys. At. Energy 19, 307 (2018)







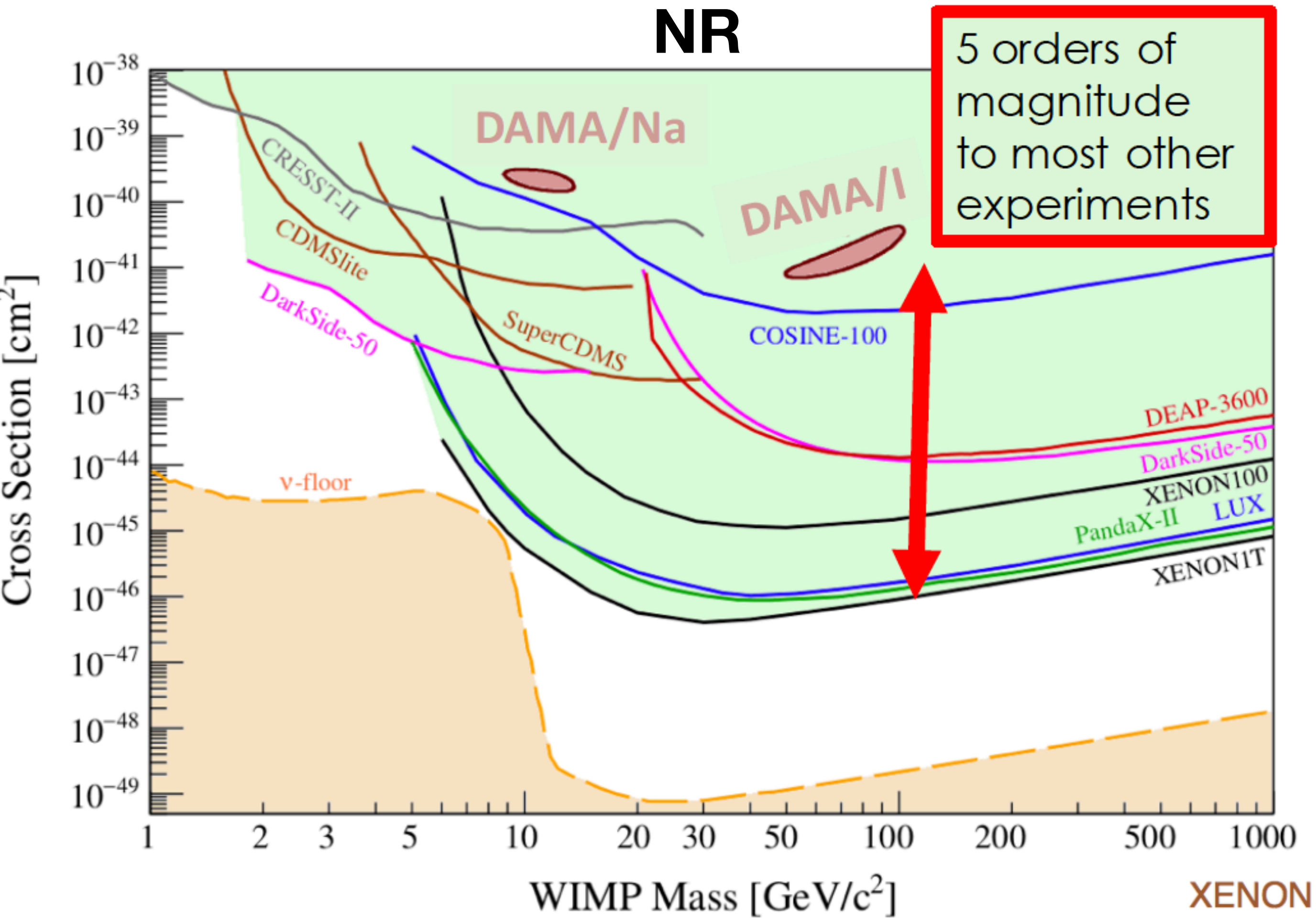




Very hard to attribute it to neutrons, muons, or worst … neutrinos !!!

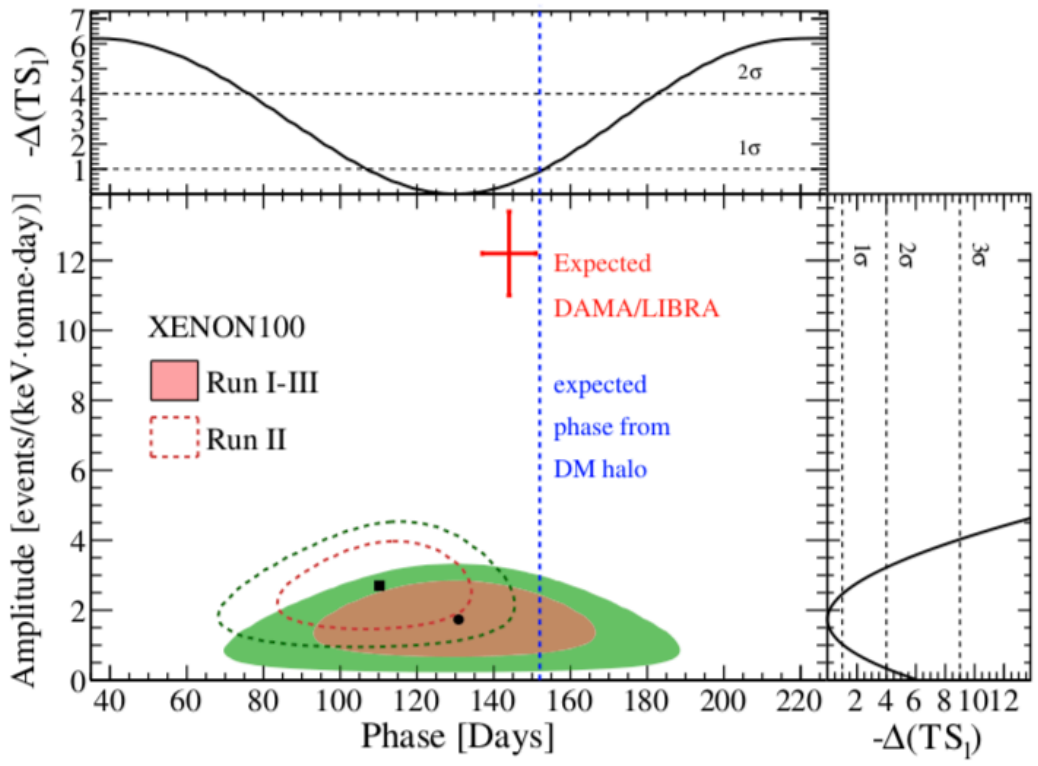
Comparing DAMA with others

- not compatible with experiments with other targets



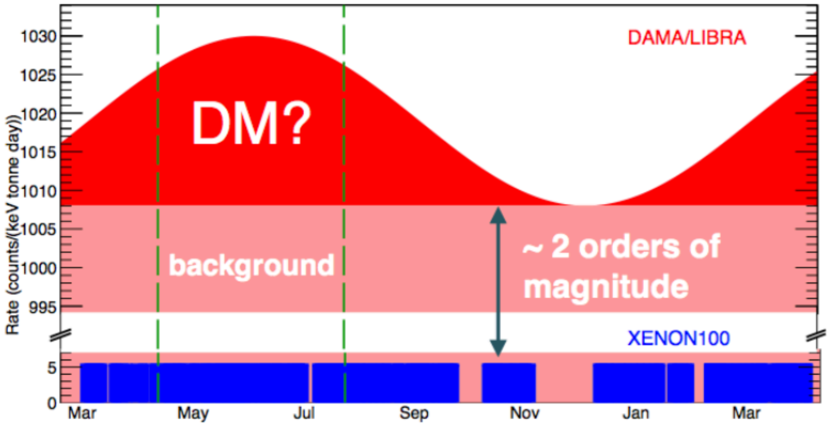
5 orders of magnitude to most other experiments

XENON100 4-year ER modulation study, PRL 118, 101101 (2017)

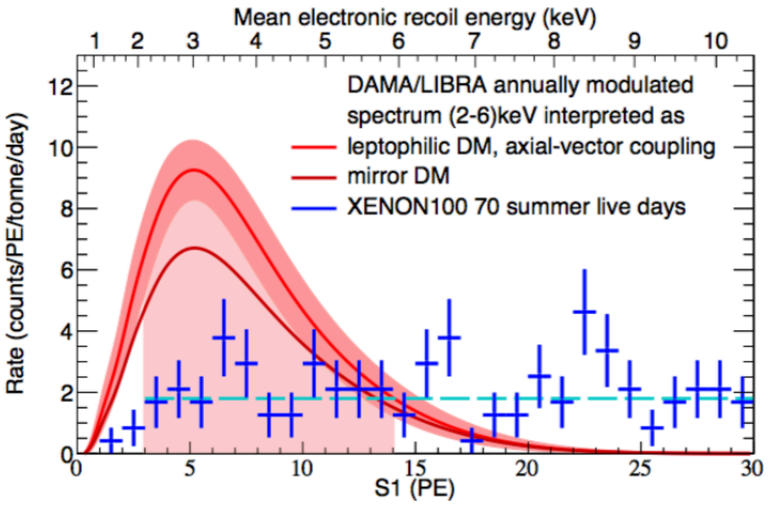


XENON collaboration, arXiv: 1507.07747, Science 349, 2015

…but also with ER models, i.e. leptophilic

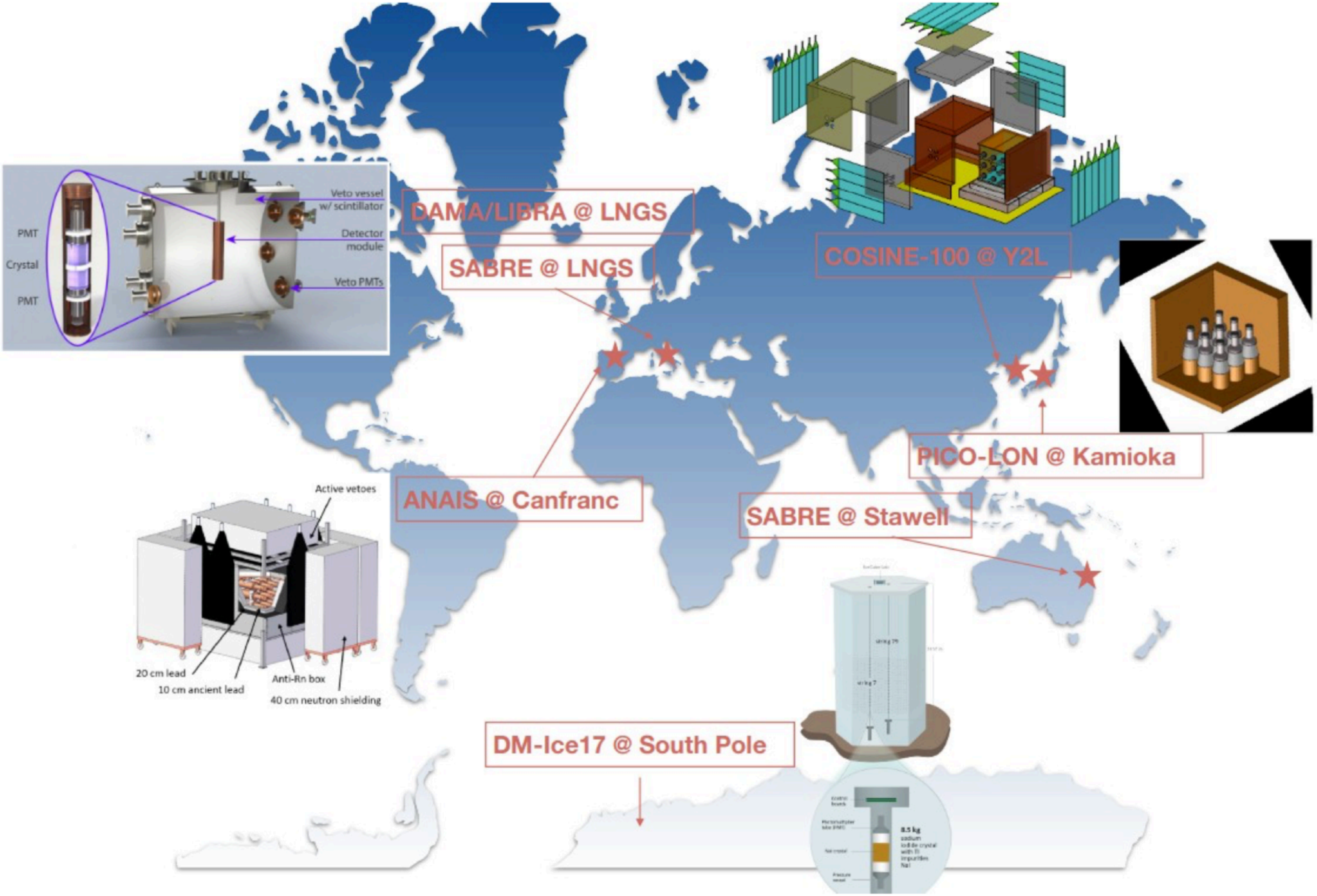


Consider the 70 days with the largest signal



DAMA/LIBRA modulated spectrum as would be seen in XENON100 (for axial-vector WIMP-e⁻ scattering)

Other NaI detectors



DAMA/LIBRA @ LNGS

SABRE @ LNGS

COSINE-100 @ Y2L

PICO-LON @ Kamioka

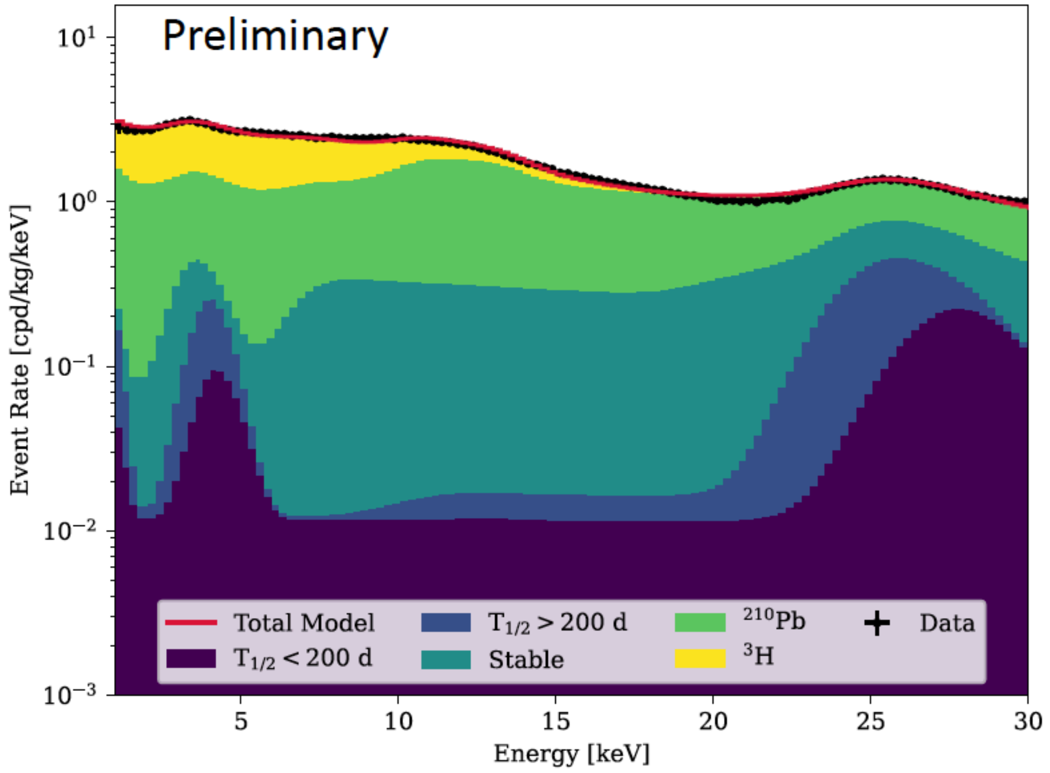
ANAIS @ Canfranc

SABRE @ Stawell

DM-Ice17 @ South Pole

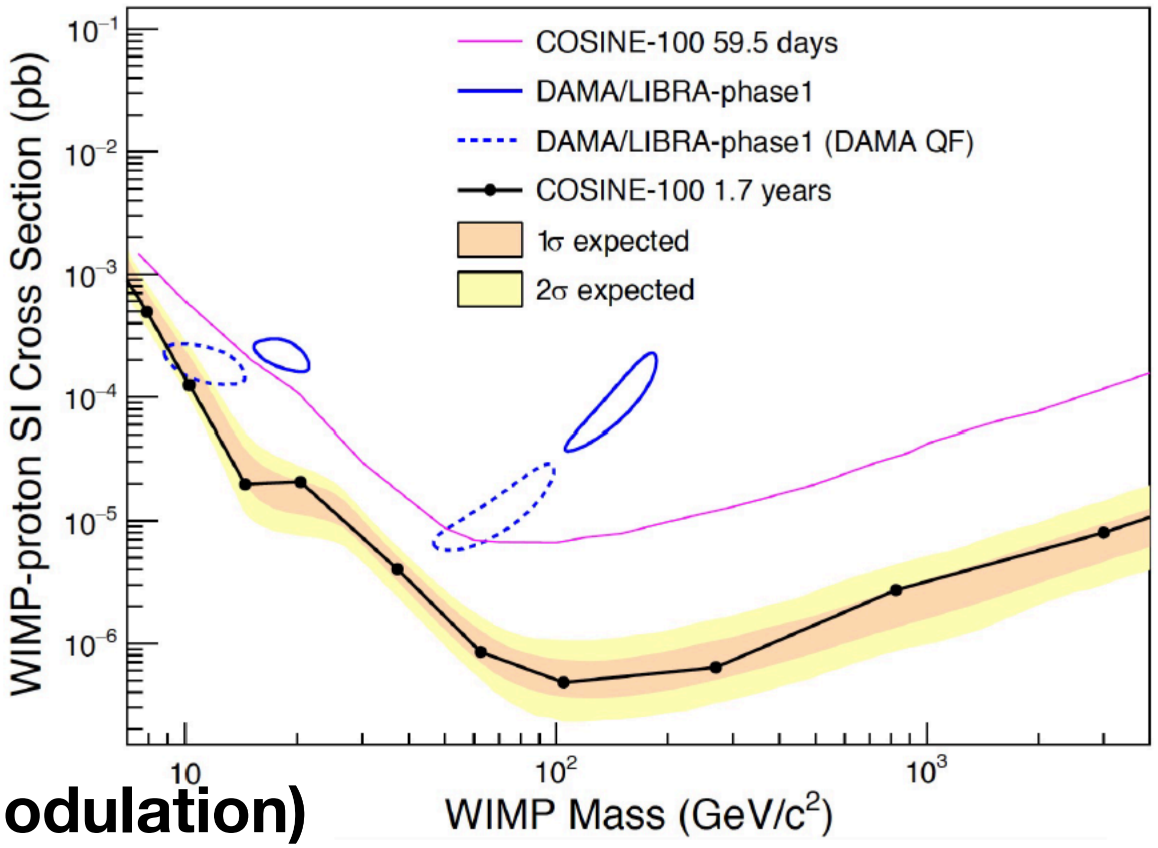
Other NaI detectors: COSINE-100

First approach: model dependent vs background

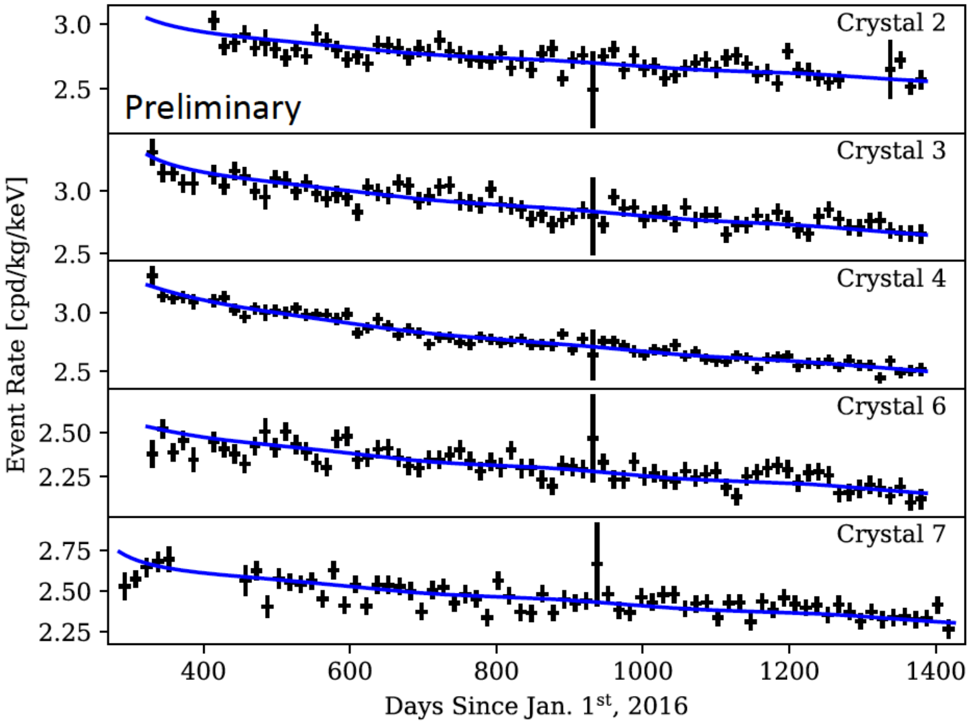


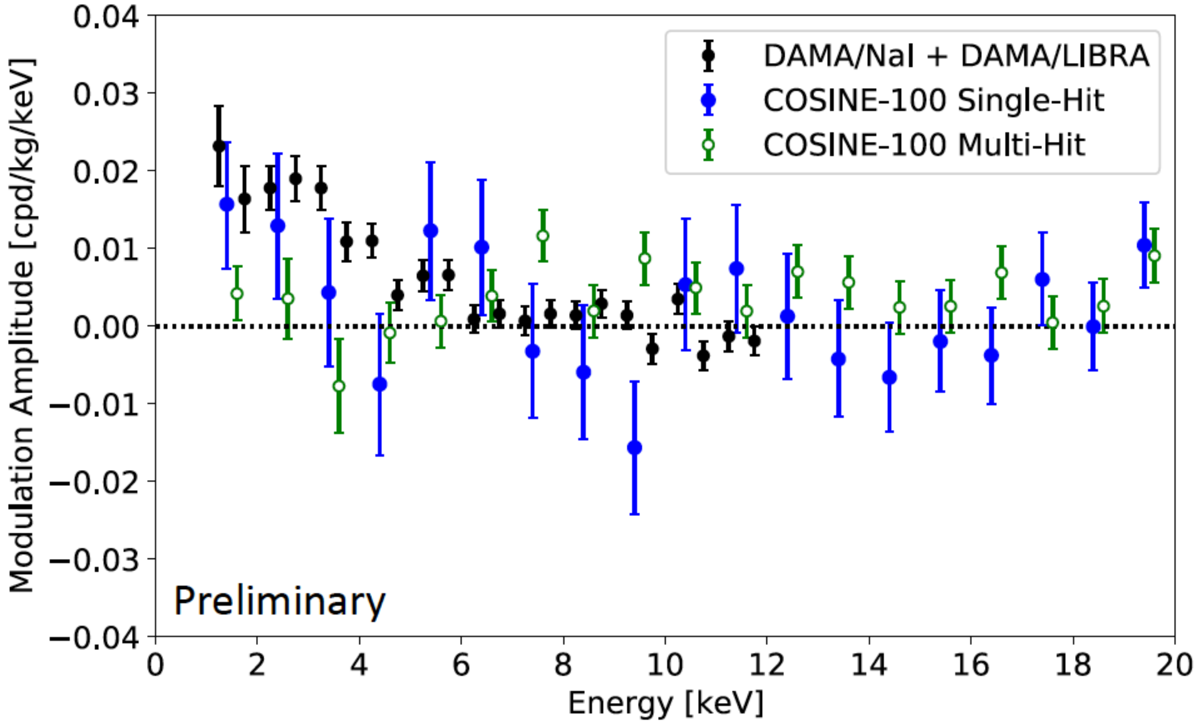
arXiv:2104:03537

New data release: 1.7y vs 59days



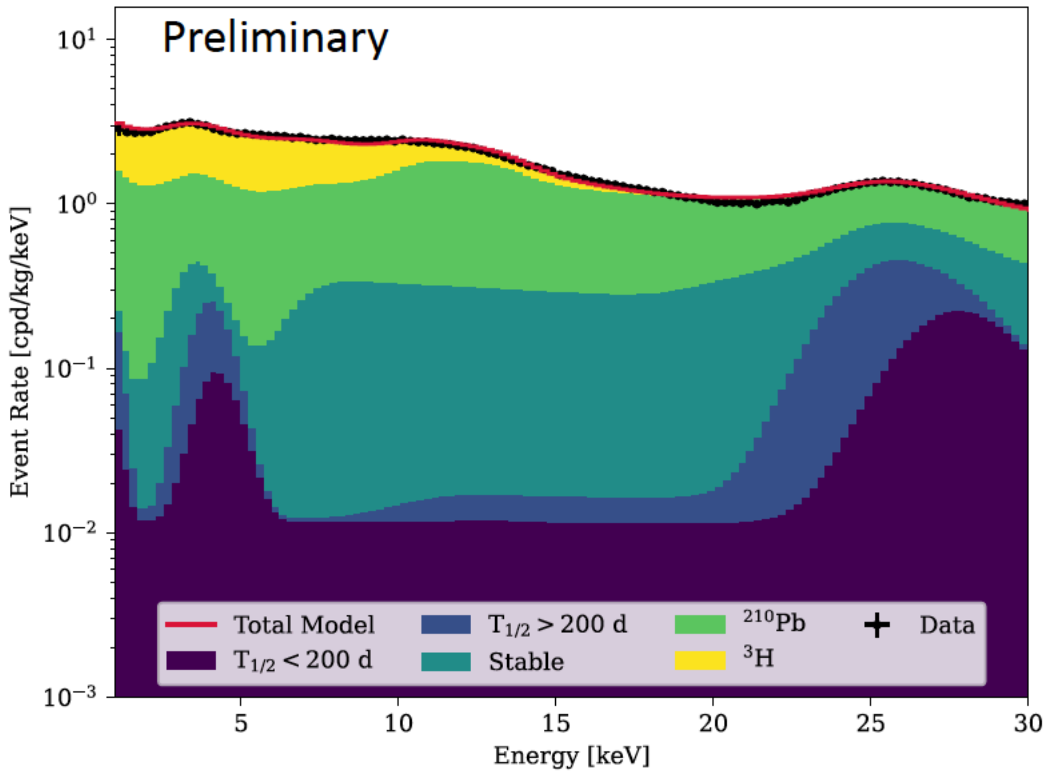
2nd approach: model independent (annual modulation)





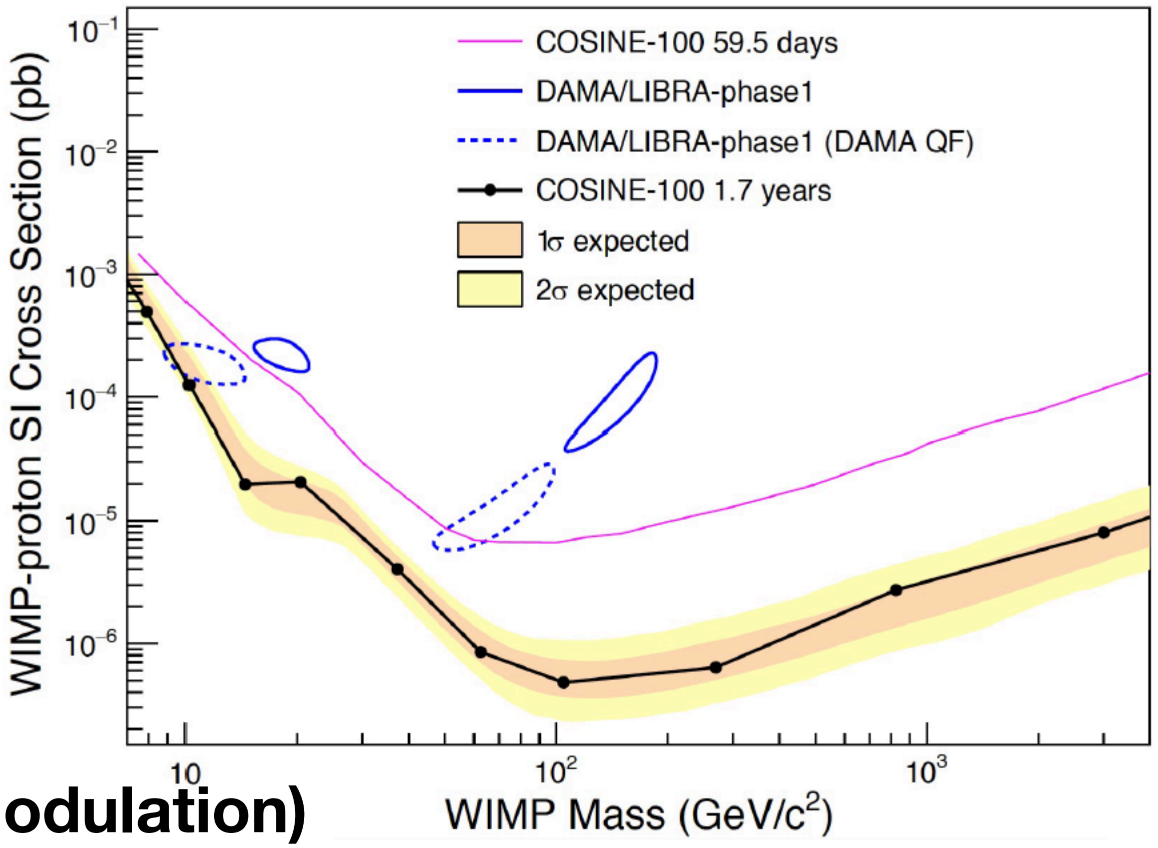
Other NaI detectors: COSINE-100

First approach: model dependent vs background

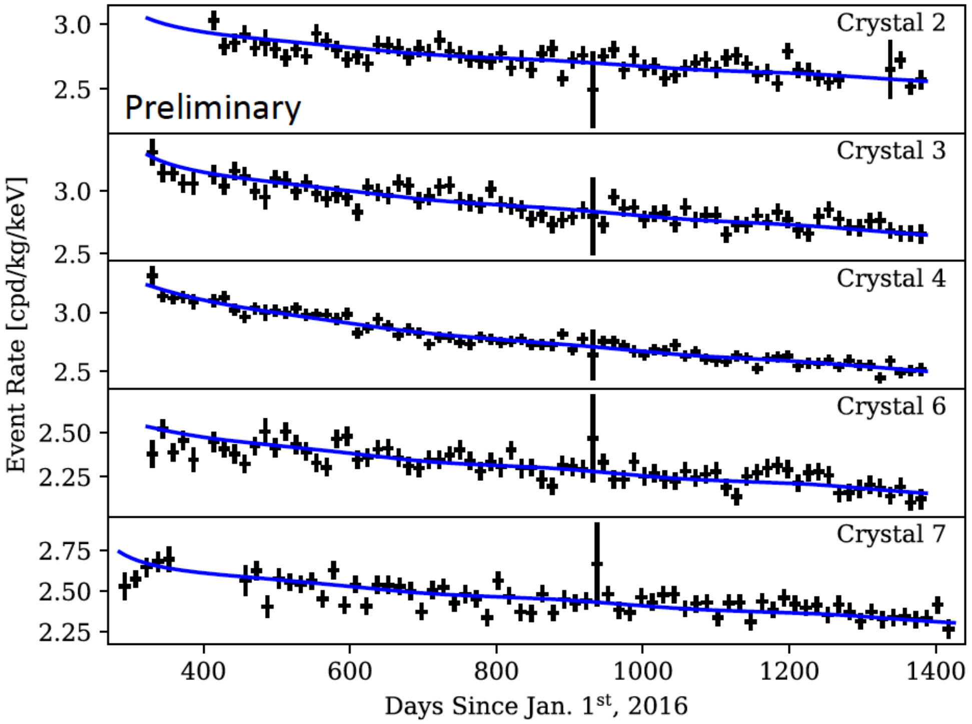


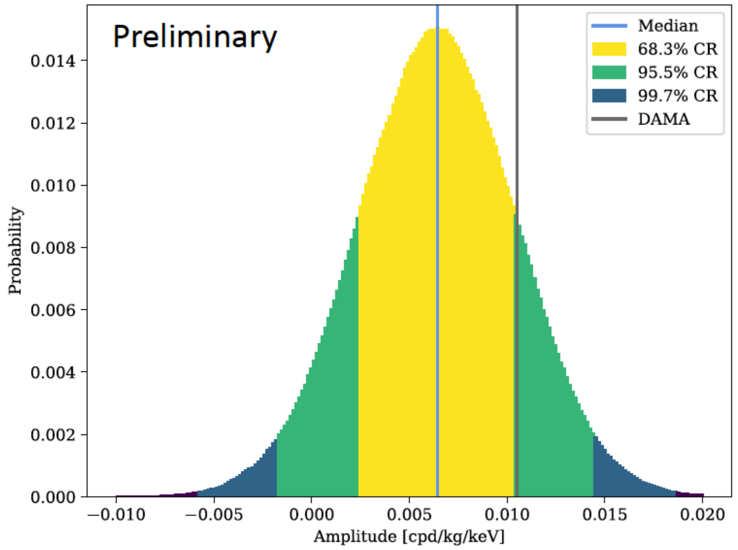
arXiv:2104:03537

New data release: 1.7y vs 59days



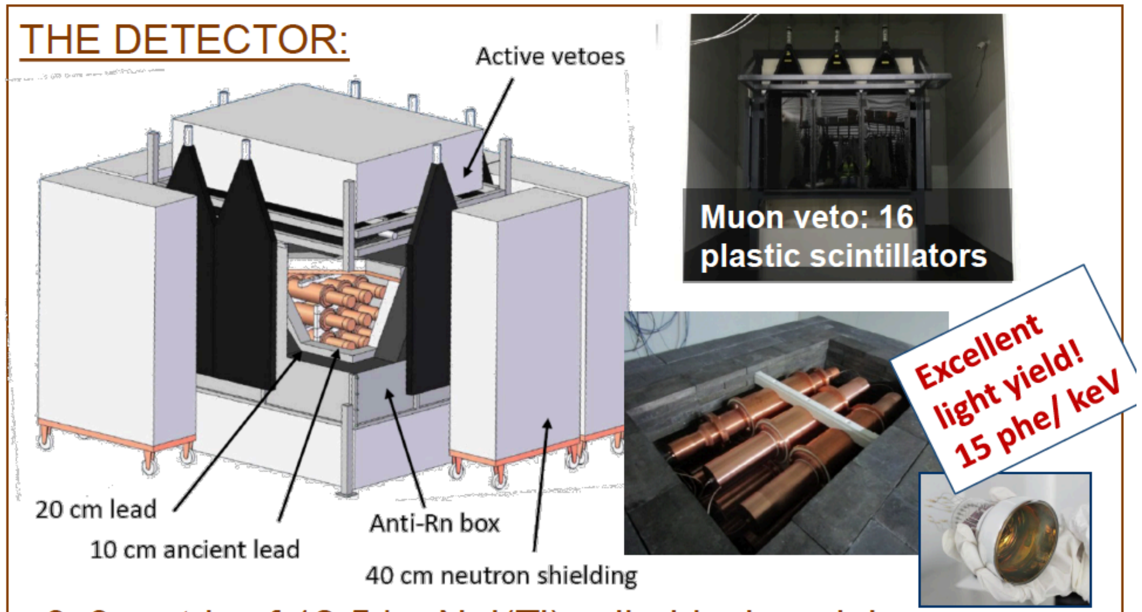
2nd approach: model independent (annual modulation)





Best-fit modulation amplitude of 0.0064 ± 0.0040 cpd/kg/keV at 1-6 keV

Other NaI detectors: ANAIS-112



3x3 matrix of 12.5 kg NaI(Tl) cylindrical modules (**112.5 kg** active mass), each coupled to 2 HQE PMT

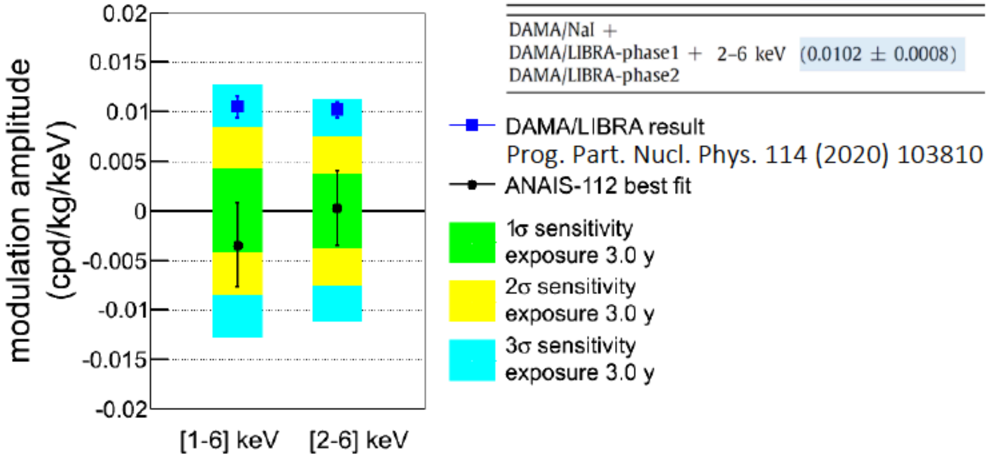
taking data since August 2017

>400 kg × y exposure by now

3

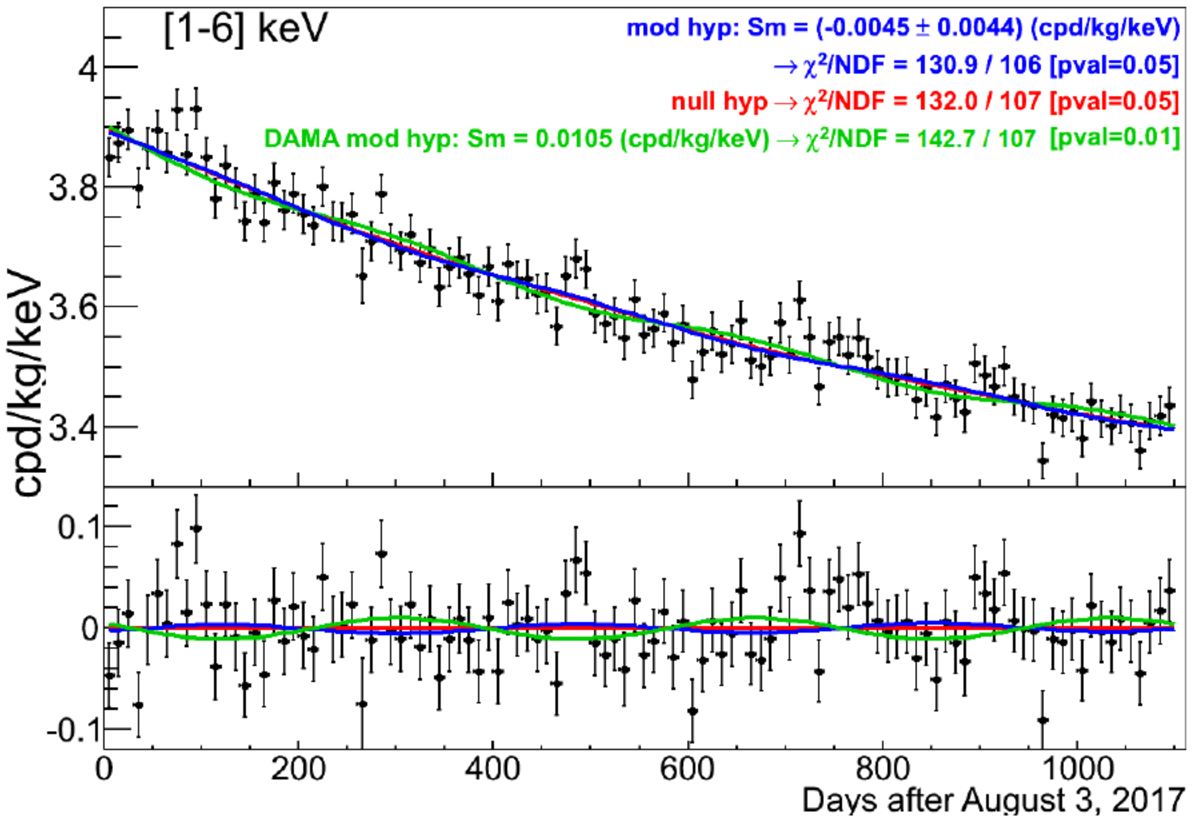
presented at IDM2022

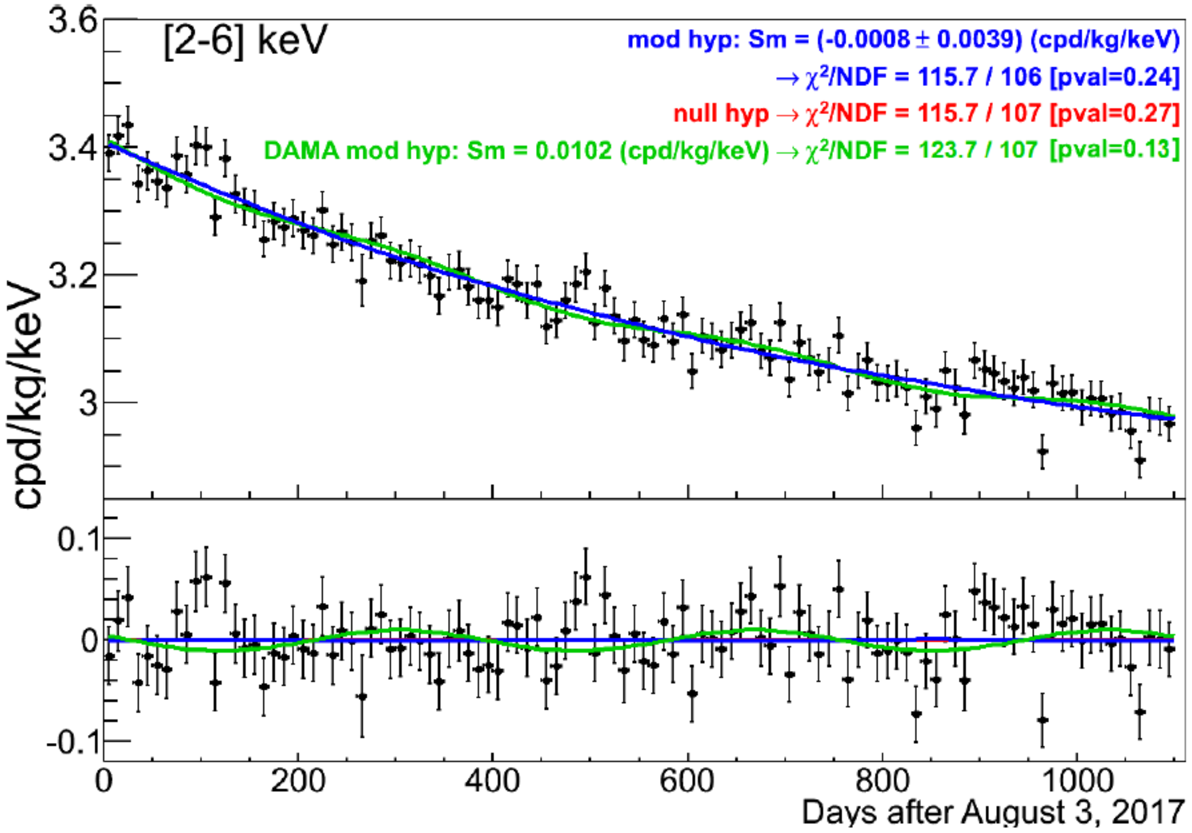
		A (cpd/kg/keV)
DAMA/LIBRA-phase2	1–6 keV	(0.0105 ± 0.0011)
DAMA/NaI + DAMA/LIBRA-phase1 + DAMA/LIBRA-phase2	2–6 keV	(0.0102 ± 0.0008)



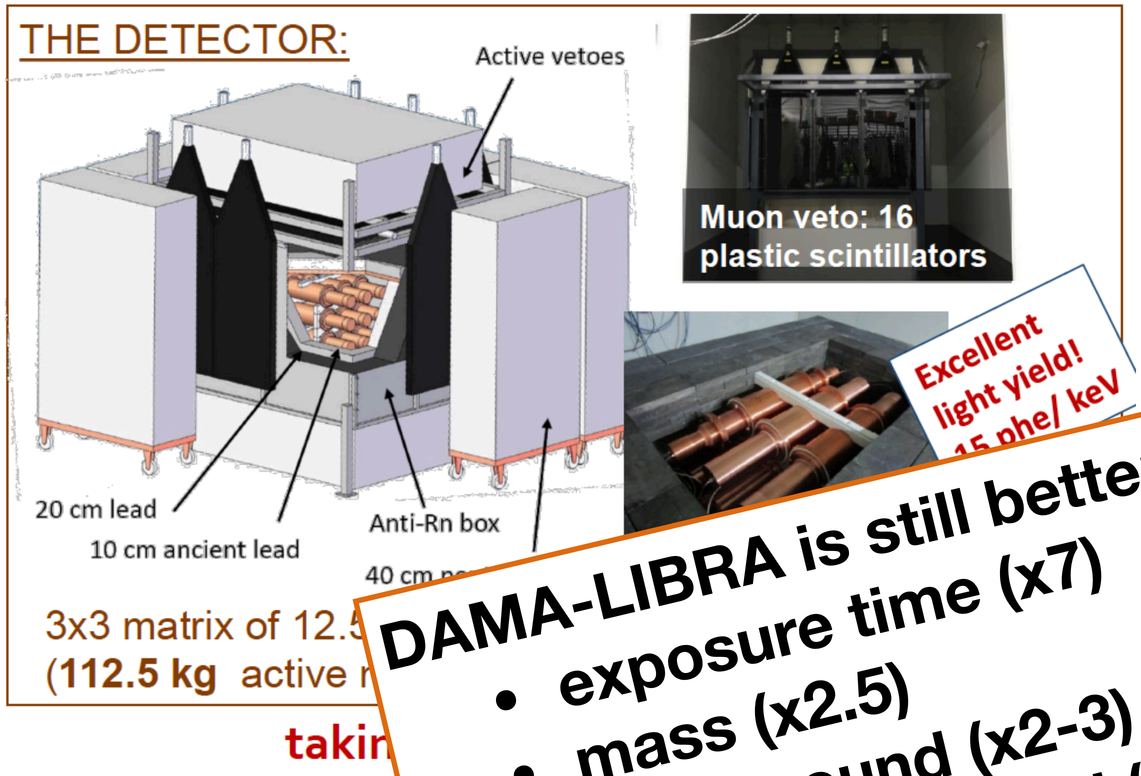
Current sensitivity: 2.5σ [1–6] keV
2.7σ [2–6] keV

12

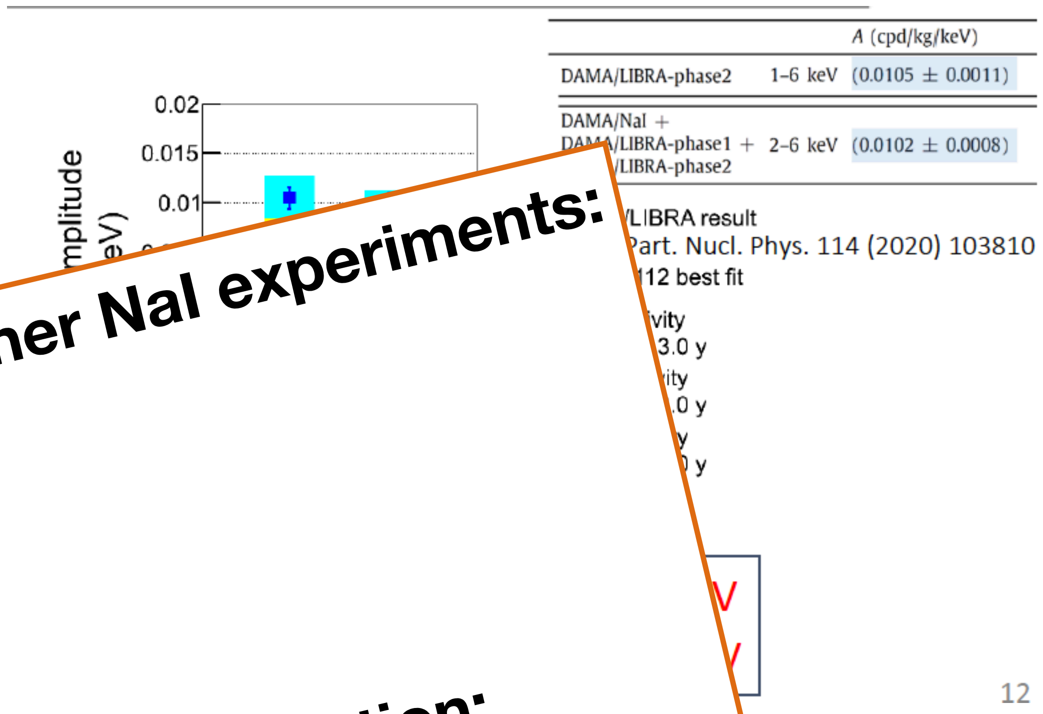




Other NaI detectors: ANAIS-112



presented at IDM2022

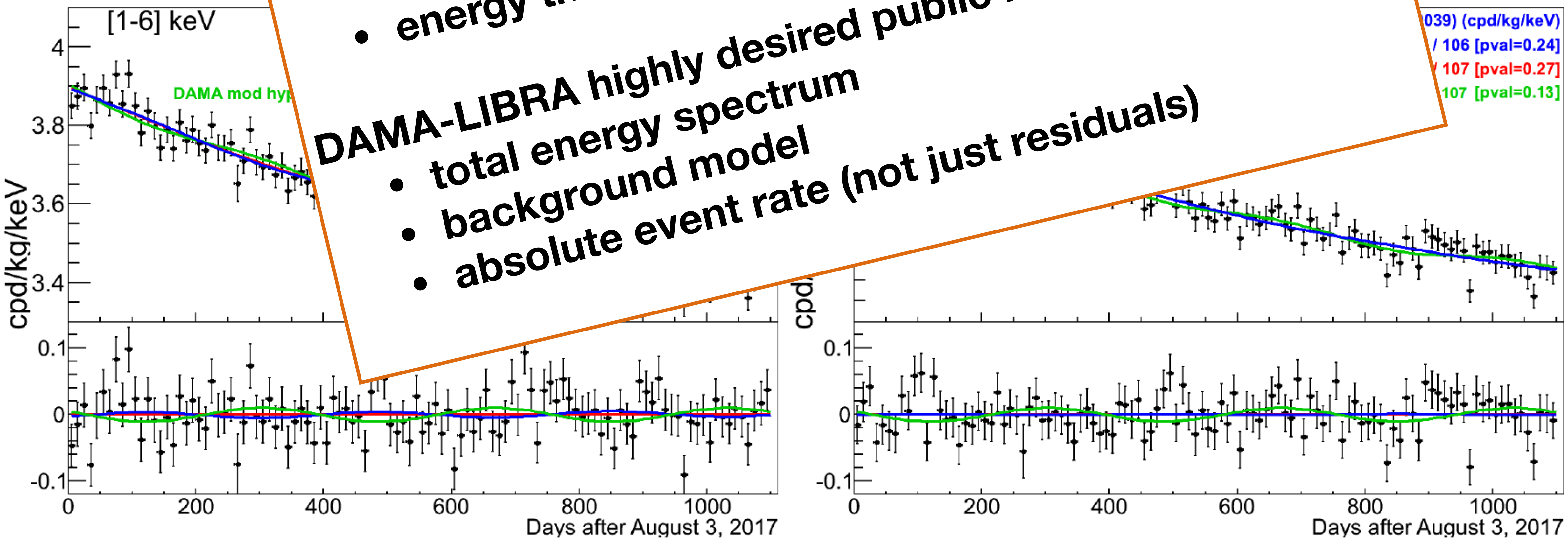


DAMA-LIBRA is still better than other NaI experiments:

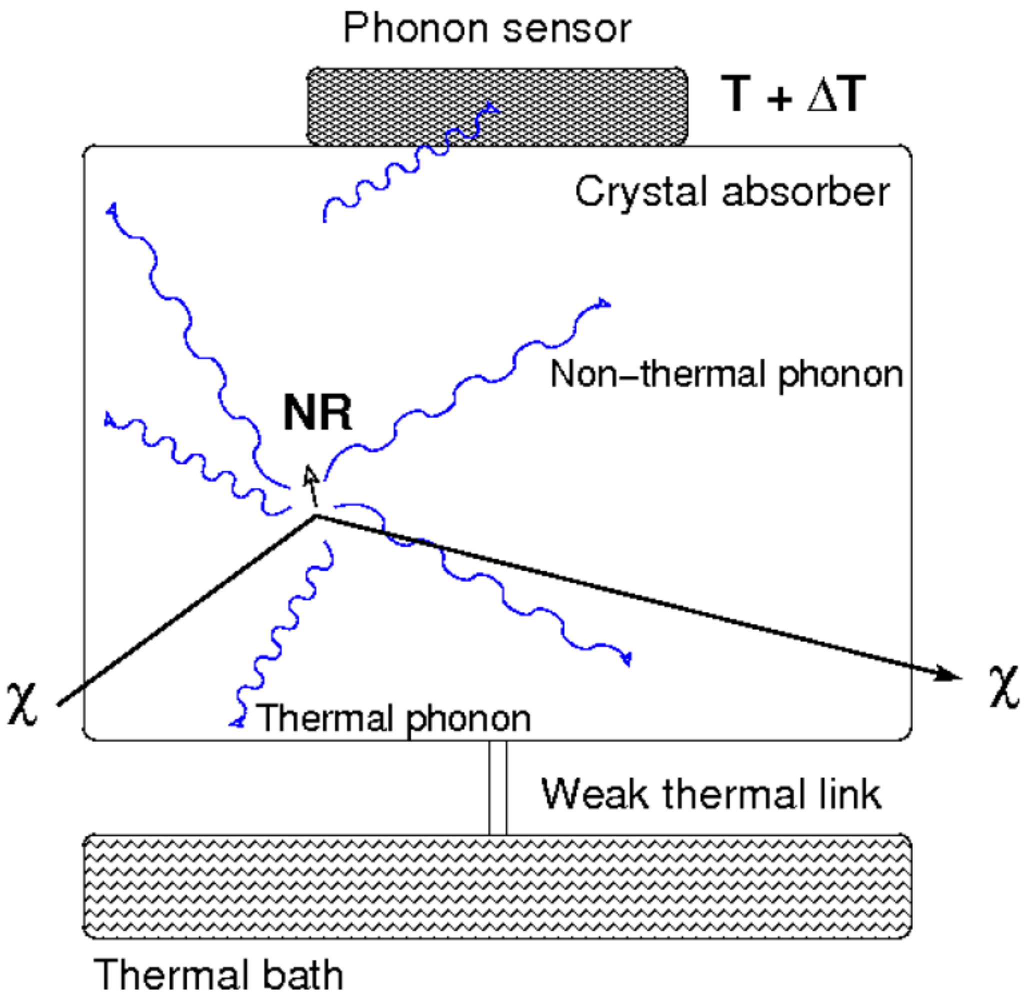
- **exposure time (x7)**
- **mass (x2.5)**
- **background (x2-3)**
- **energy threshold (x1.x)**

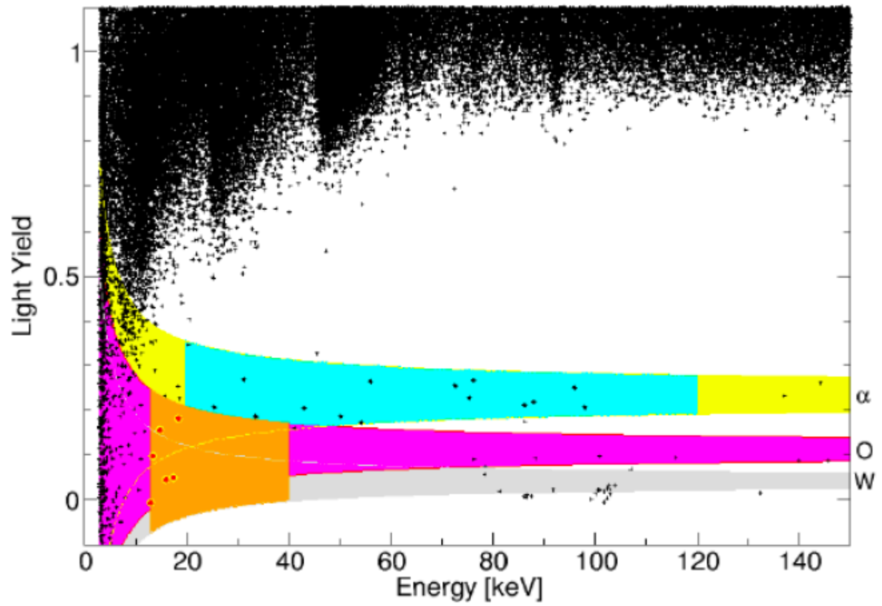
DAMA-LIBRA highly desired public information:

- **total energy spectrum**
- **background model**
- **absolute event rate (not just residuals)**



Cryogenic bolometers





- Crystals at $(10 - 100)$ mK
- Temperature rise:

  $\Delta T = E/C(T)$

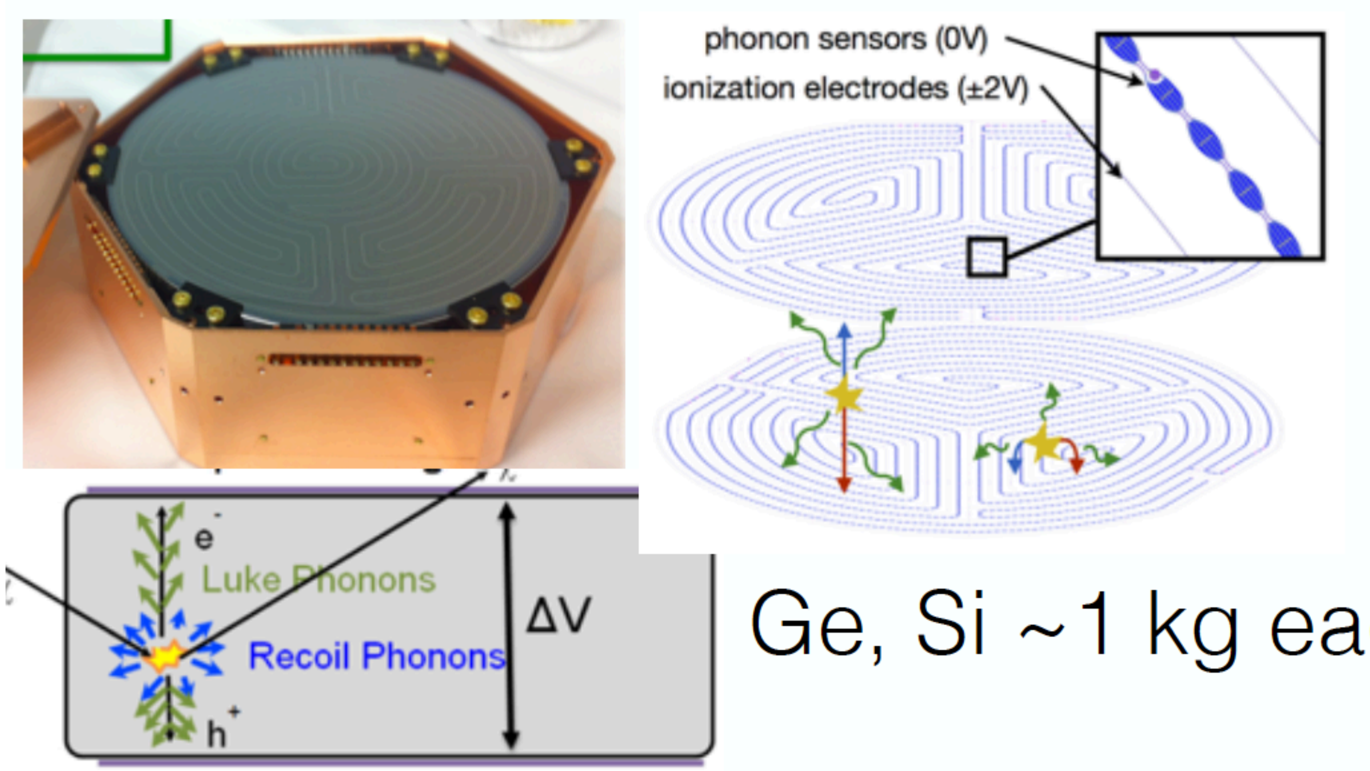
  E.g. Ge at 20 mK, $\Delta T = 20\ \mu$K for few keV recoil
- Measurements of ΔT

  NTD: neutron transmutation-doped Ge sensors

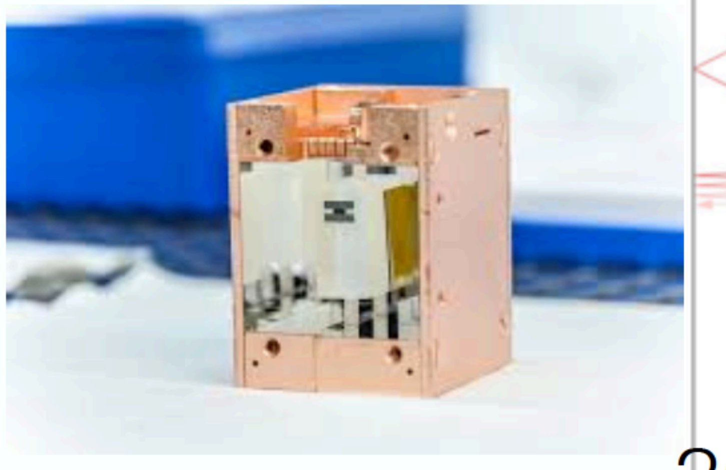
  TES: Transition edge sensors
- Discrimination: combination with light or charge read-out
- Large separation of electronic and nuclear recoil bands

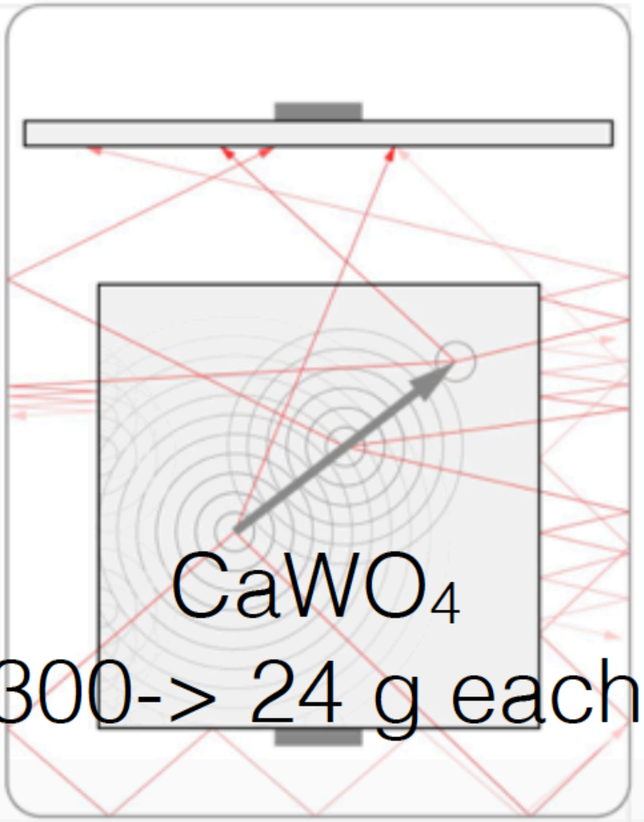
Example from CRESST, EPJC 72 (2012) 1971

Cryogenic bolometers



Ge, Si ~1 kg each



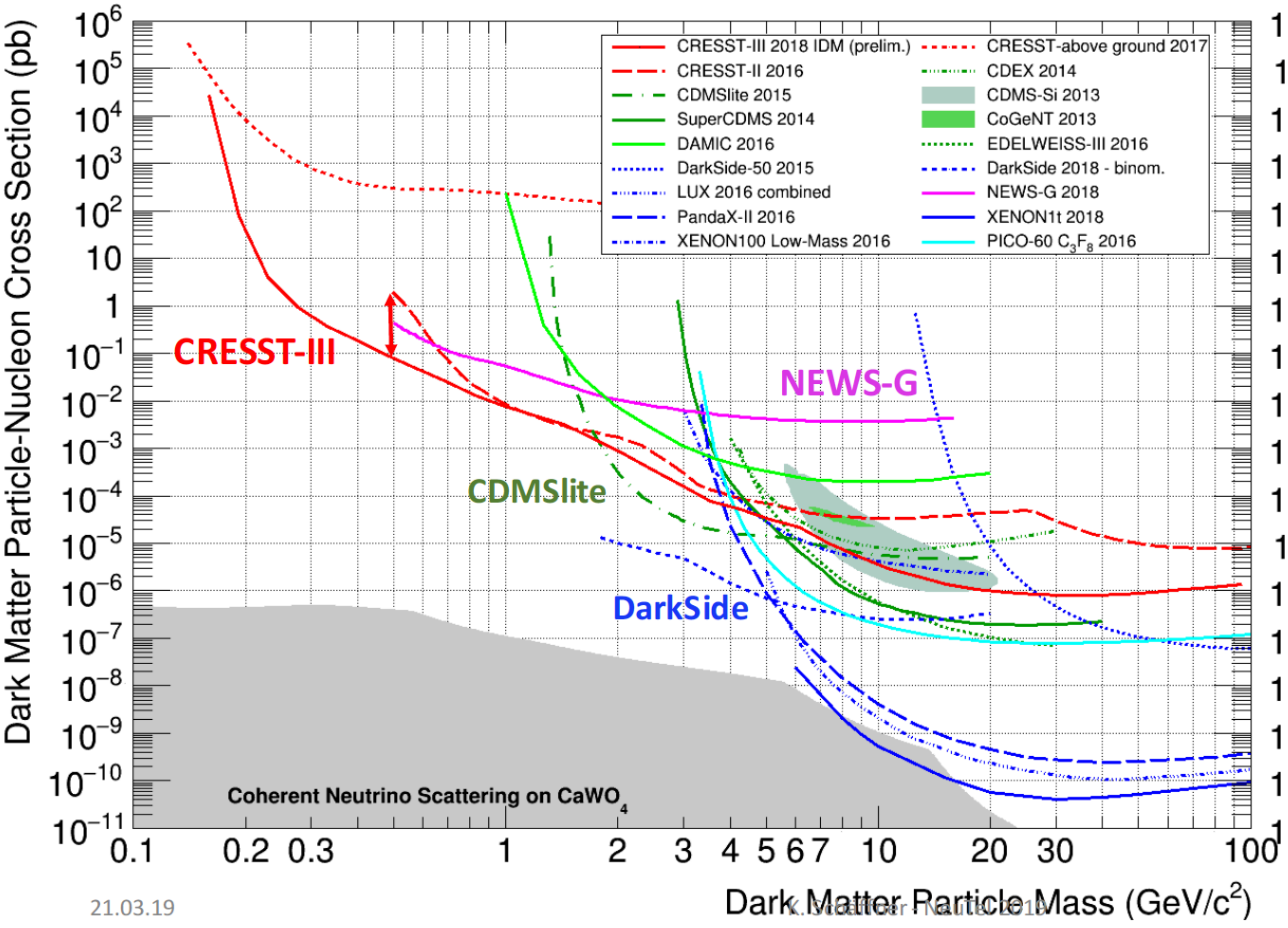


$CaWO_4$

300-> 24 g each

- SuperCDMS/EDELWEISS 2 techniques
  - HV (CDMSlite): Luke phonons: low threshold, but no discrimination
  - iZIP/FID: ionization and phonon signals with interleaved sensors discriminate against electronic recoils and surface events
- CRESST
  - $CaWO_4$ crystals for phonons and scintillation
- DAMIC
  - Si CCD

Summary of low mass Dark Matter searches



21.03.19

K. Schaffner - Neutel 2019

Liquid Noble Detectors

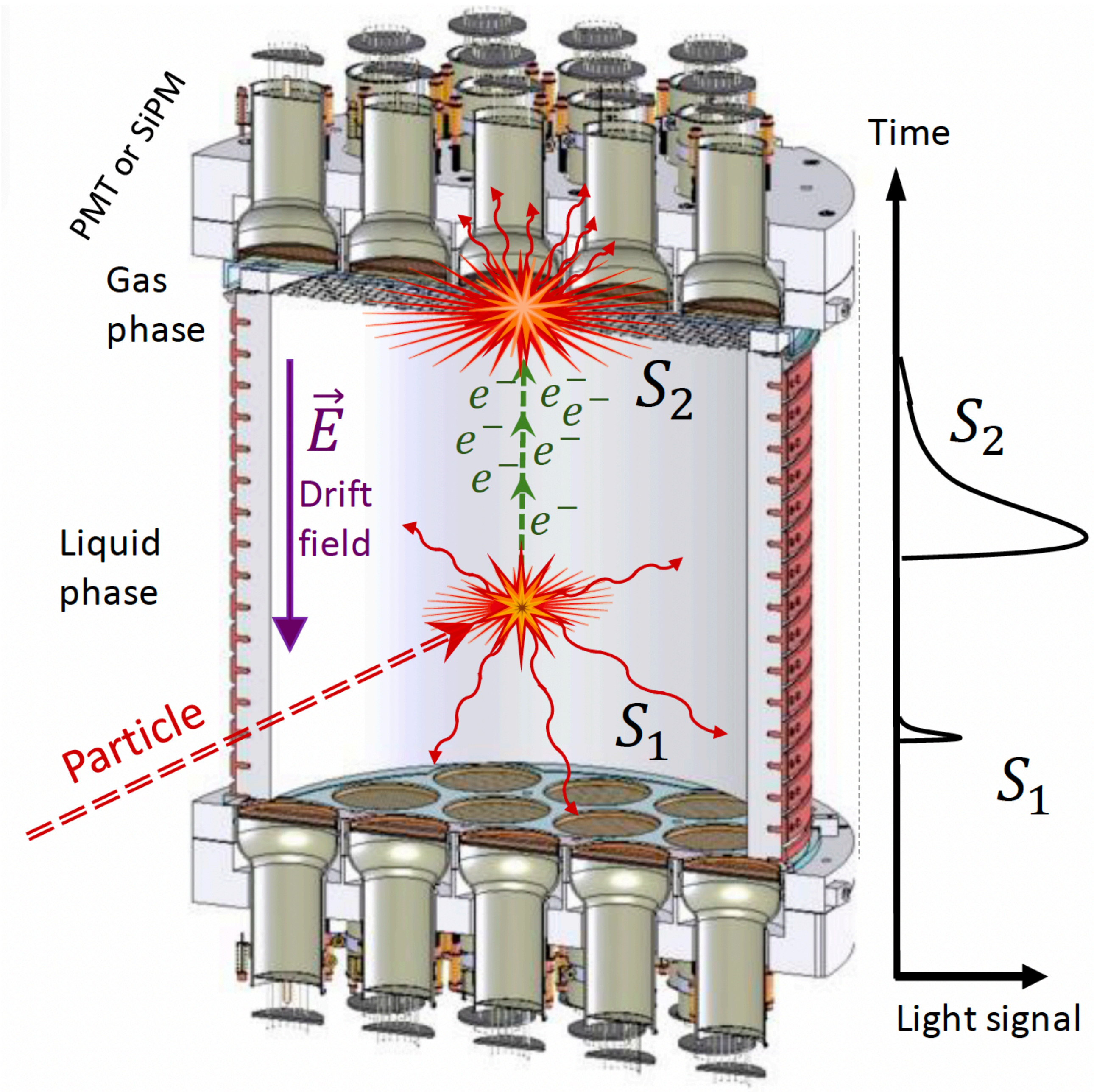
- Large masses and homegeneous targets (LNe, LAr & LXe)

  Two detector concepts: single & double phase
- 3D position reconstruction → fiducialization
- Transparent to their own scintillation light

	LNe	LAr	LXe
Z (A)	10 (20)	18 (40)	54 (131)
Density [g/cm^3]	1.2	1.4	3.0
Scintillation λ	78 nm	125 nm	178 nm
BP [K] at 1 atm	27	87	165
Ionization [e$^-$/keV]*	46	42	64
Scintillation [γ/keV]*	7	40	46

* for electronic recoils

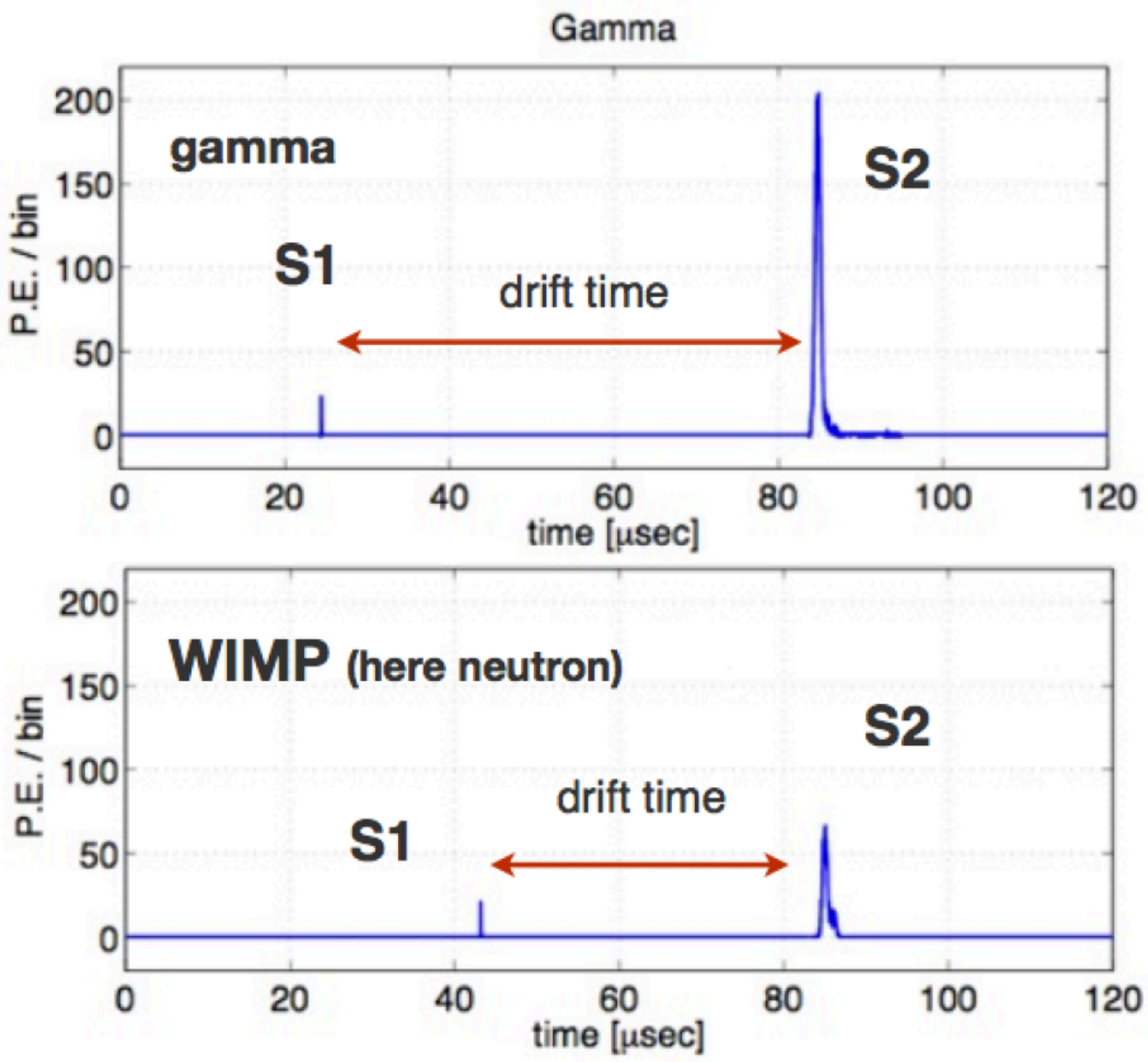
Liquid Noble Detectors: Double Phase TPC



- Drift field
- Electronegative purity
- Position resolution

- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)

→ Electron- /nuclear recoil discrimination



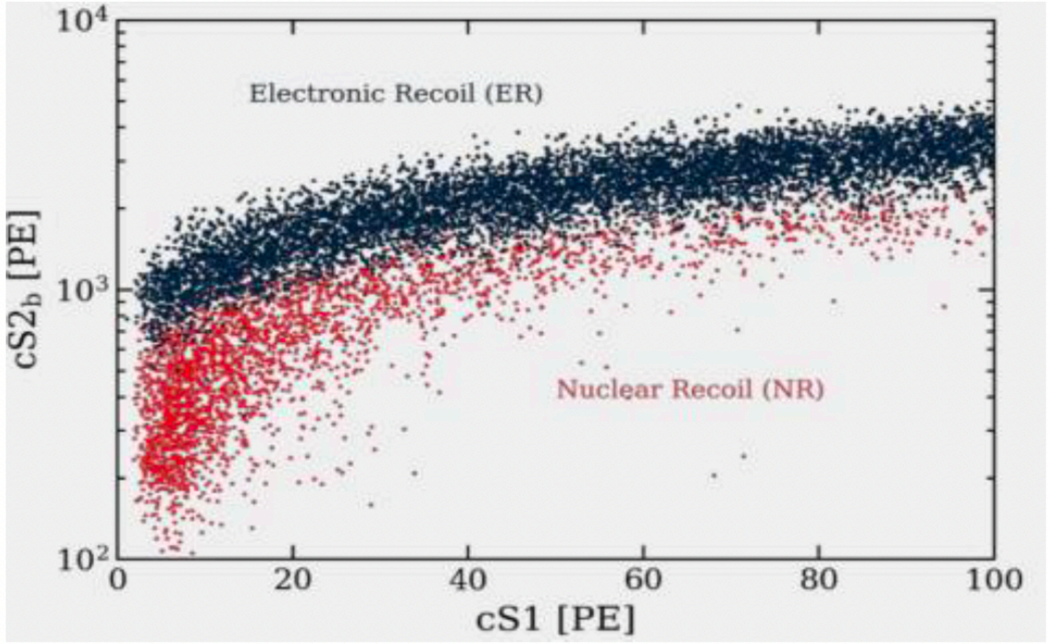
Liquid Noble Detectors: Double Phase TPC

Nuclear recoils VS electron recoils

XENON: S2/S1

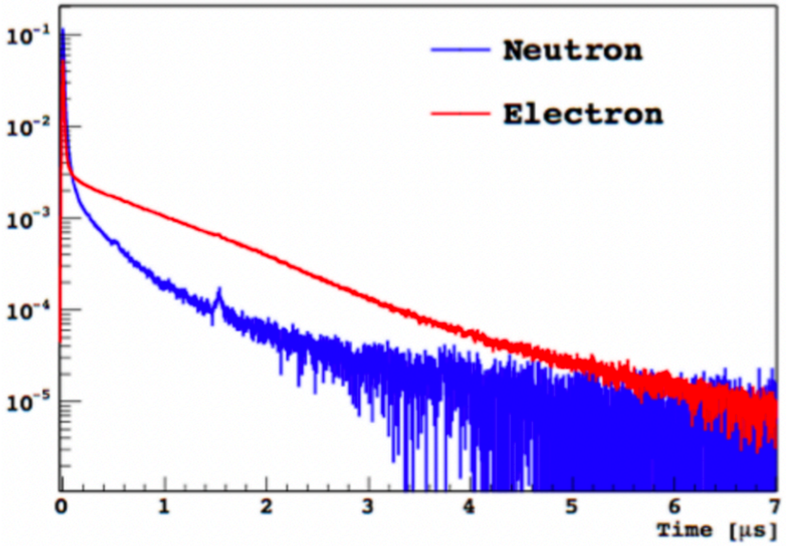
With the separation achieved by XENON100, it is found that a **99.5% Electronic Recoil discrimination** corresponds to a **50% acceptance of Nuclear Recoil events**, while 99.75% ER discrimination gives 40% Nuclear Recoil acceptance.

➢ XENONnT In the discrimination space ($cS2/cS1$ vs $cS1$), >99.7% ER rejection powerin NR reference region achieved.



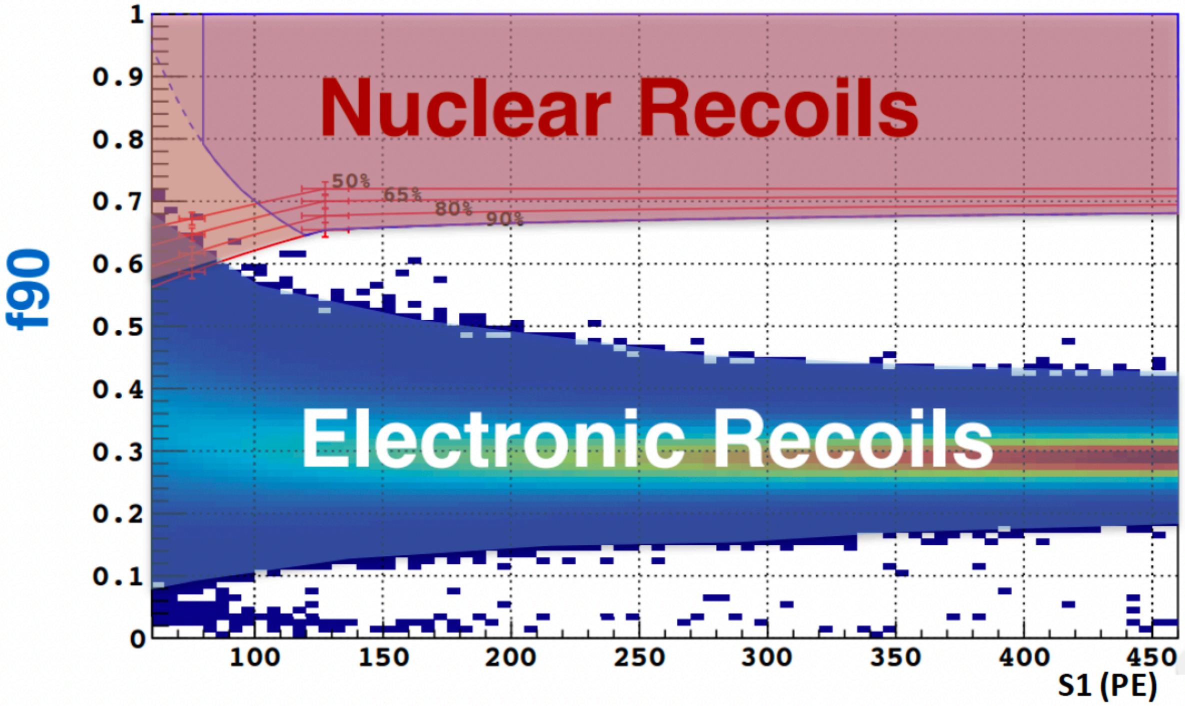
ARGON: S1 Pulse Shape Discrimination (PSD)

Argon has a fast component with a 7 ns decay time (NR), or a slower component with 1.6 µs decay time (ER) depending on the nature of incident particle.



In DarkSide-50, the discrimination parameter f90, defined for each scintillation event as the fraction of primary scintillation light (S1) collected in the first 90 ns of the pulse.

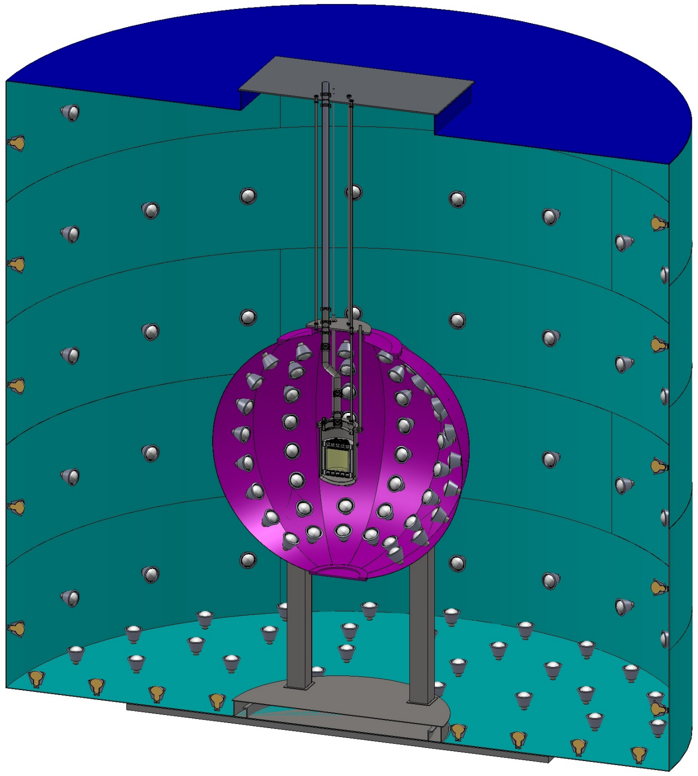
Rejection power $>10^7$



DarkSide-50 and -20k

- **DarkSide-20k**
  - Scheduled for 2024-25?
  - Utilizing underground argon
  - Atmospheric LAr veto, DUNE style cryostat possible
  - Background free
- Global Argon Dark Matter Collaboration

DarkSide-50



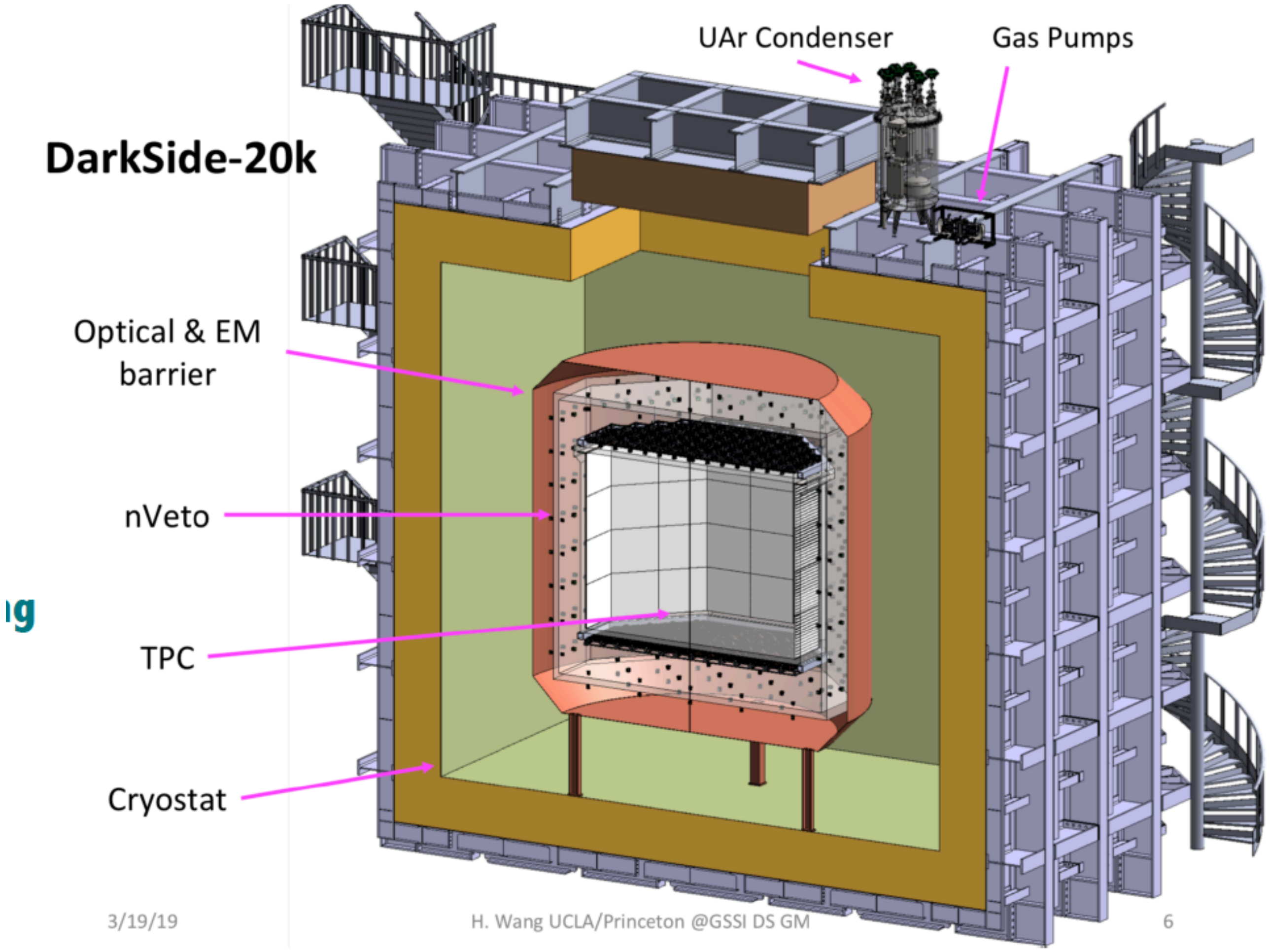
- Detector inside Borexino counting facility at LNGS (Italy)
- 50 kg depleted argon from underground sources

  > 1000 reduction in ^{39}Ar level
- Pulse shape & charge/light ratio for particle discrimination

  Pulse-shape separation > 10^7
- Hamamatsu R11065 as photosensor

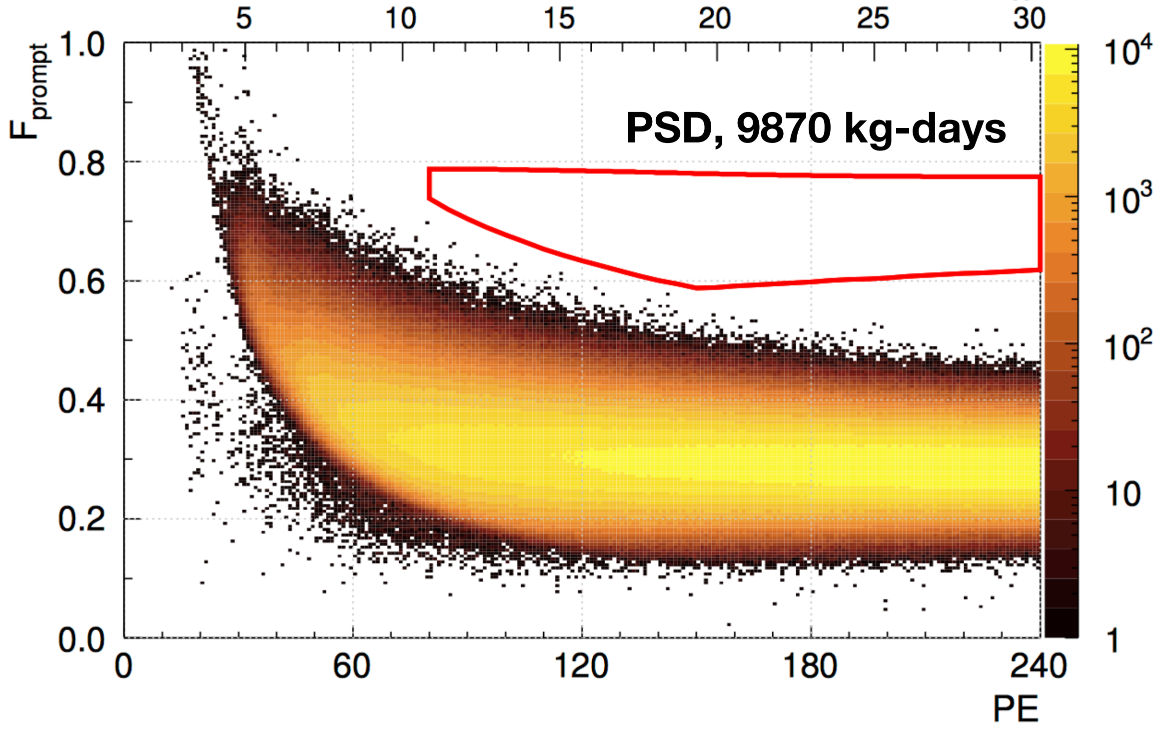
  Challenge: operation of PMTs at LAr temperatures

  → plan to use SiPMs in the next generation detector

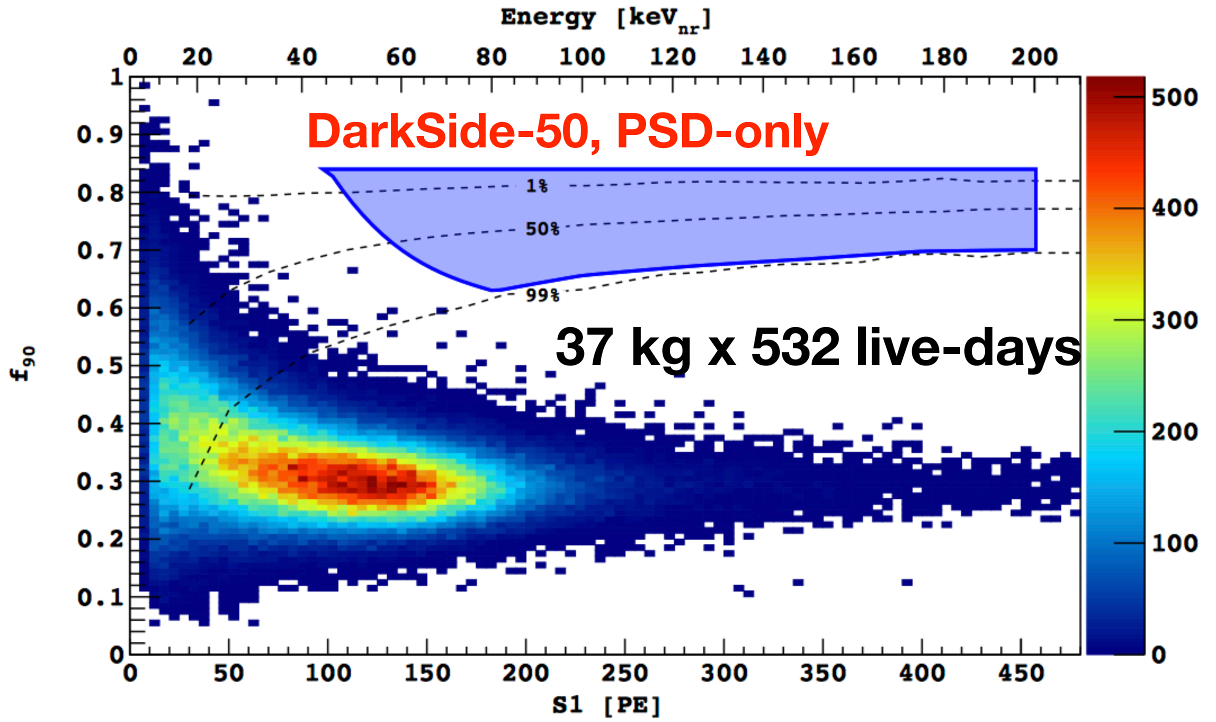


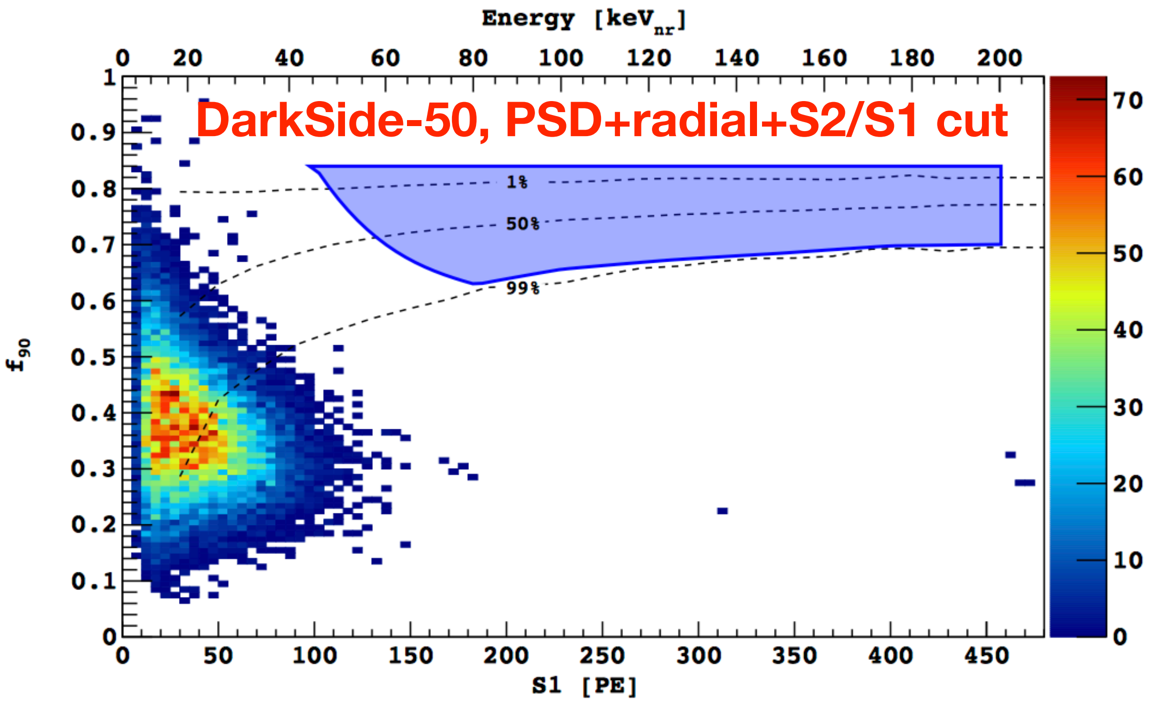
Liquid Argon results: DarkSide-50 & DEAP-3600

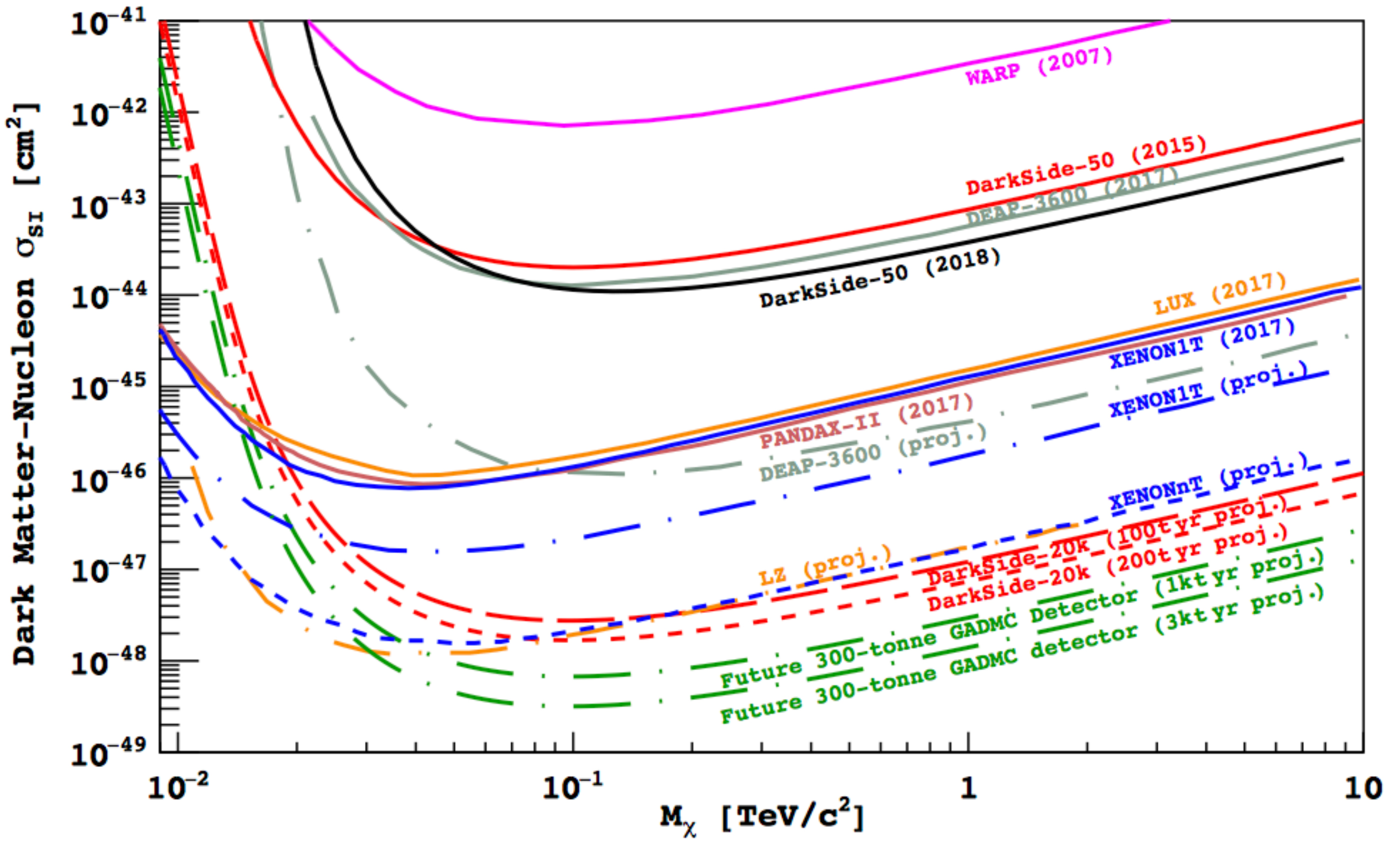
DEAP-3600, arXiv:1707.08042



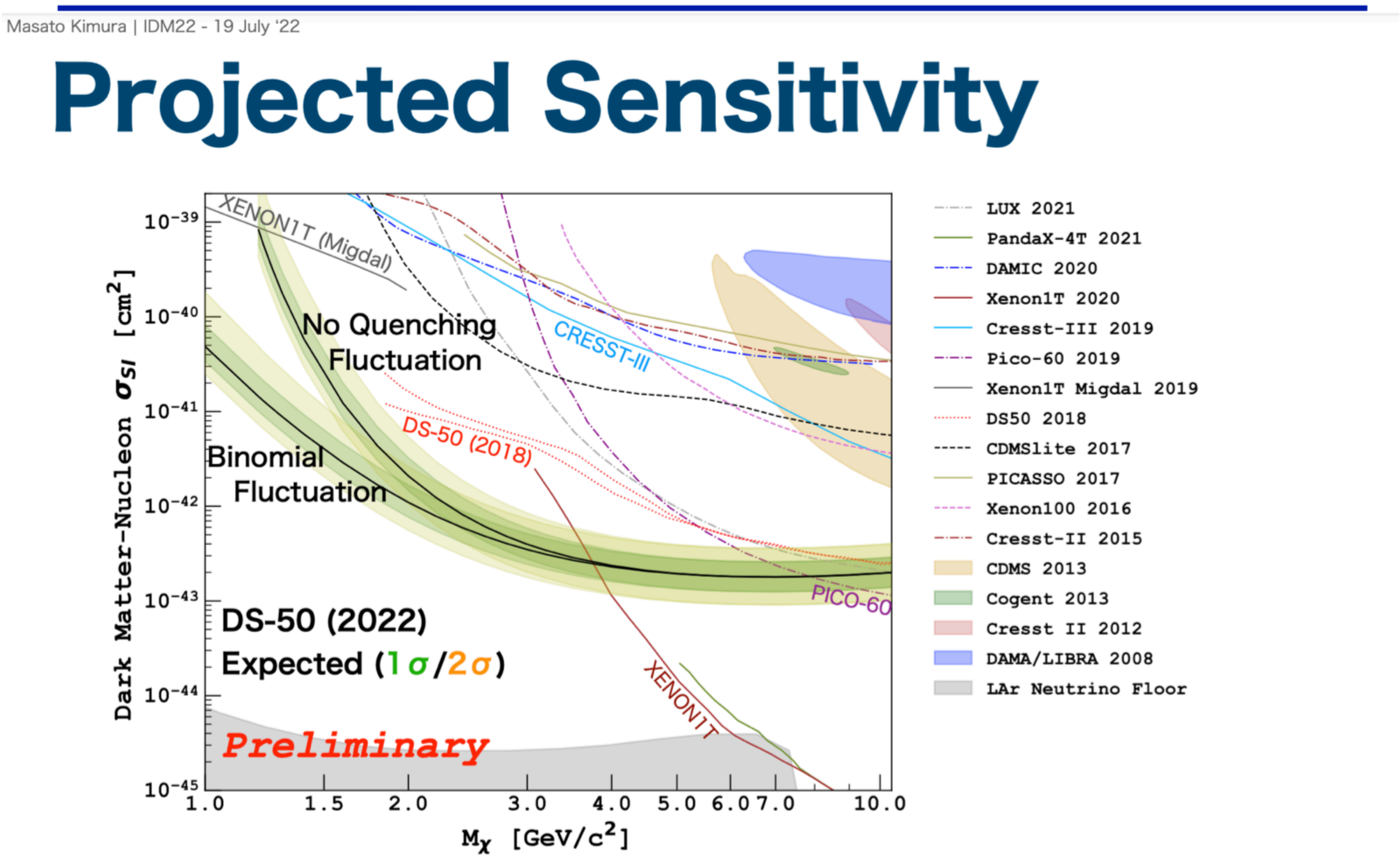
DarkSide-50, arXiv:1802.07198







Liquid Argon: DarkSide-50 S2-only result

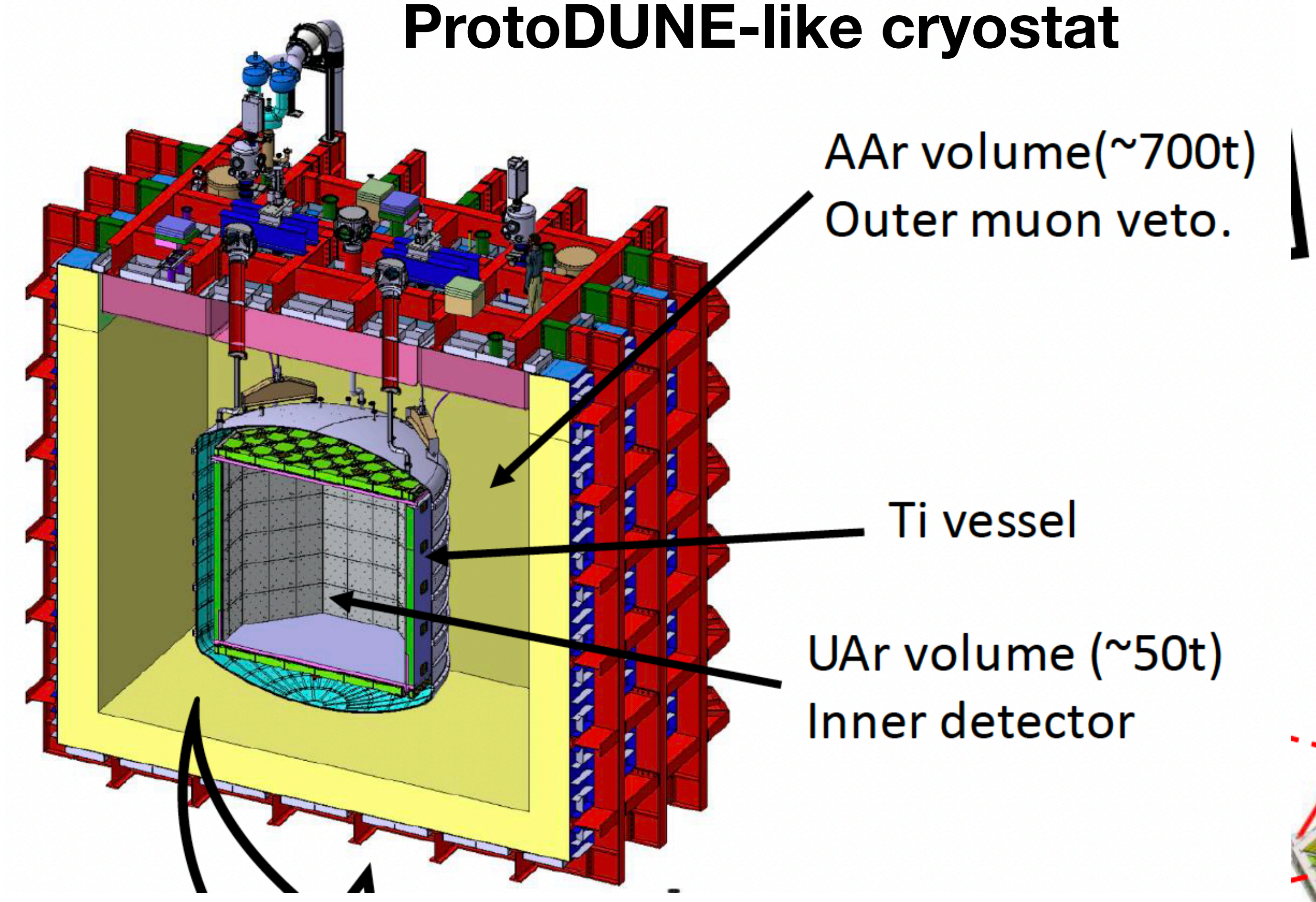


Masato Kimura | IDM22 - 19 July '22

Projected Sensitivity

The future LAr TPC: DarkSide-20k

ProtoDUNE-like cryostat



TPC with 28 m² of PhotoDetectors (SiPM)

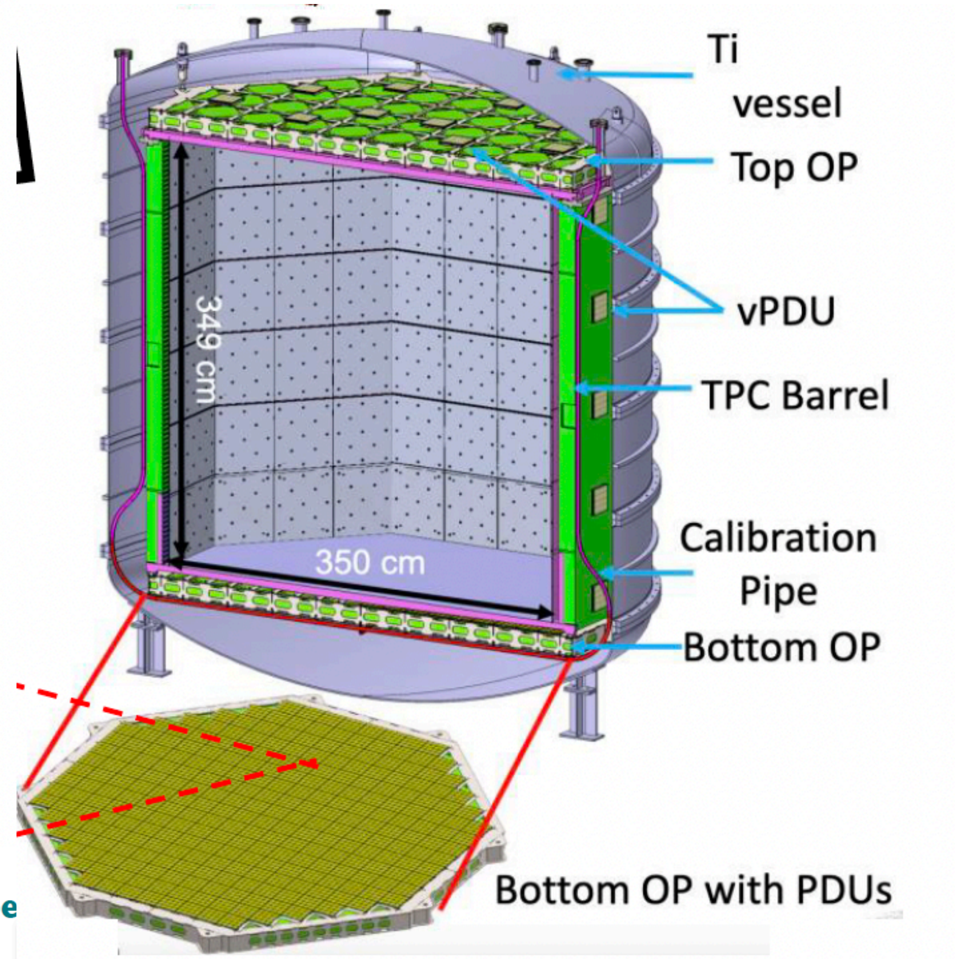
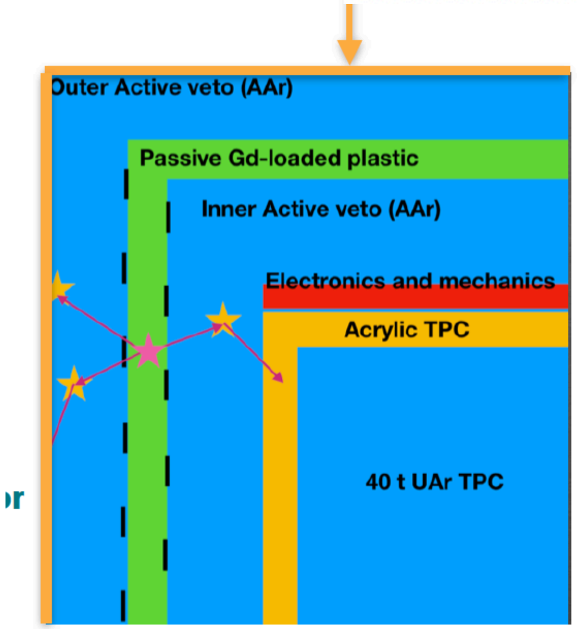
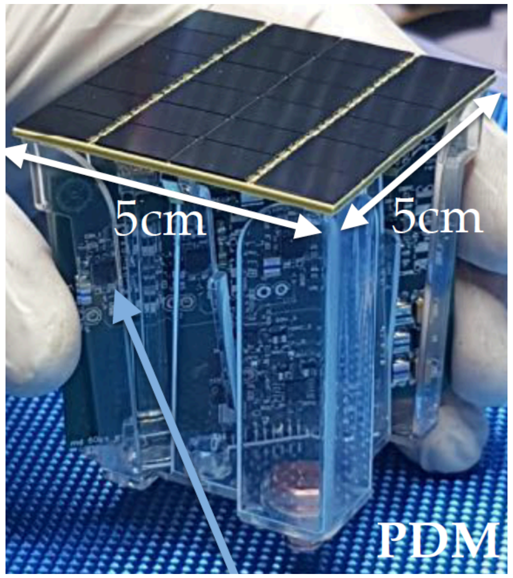


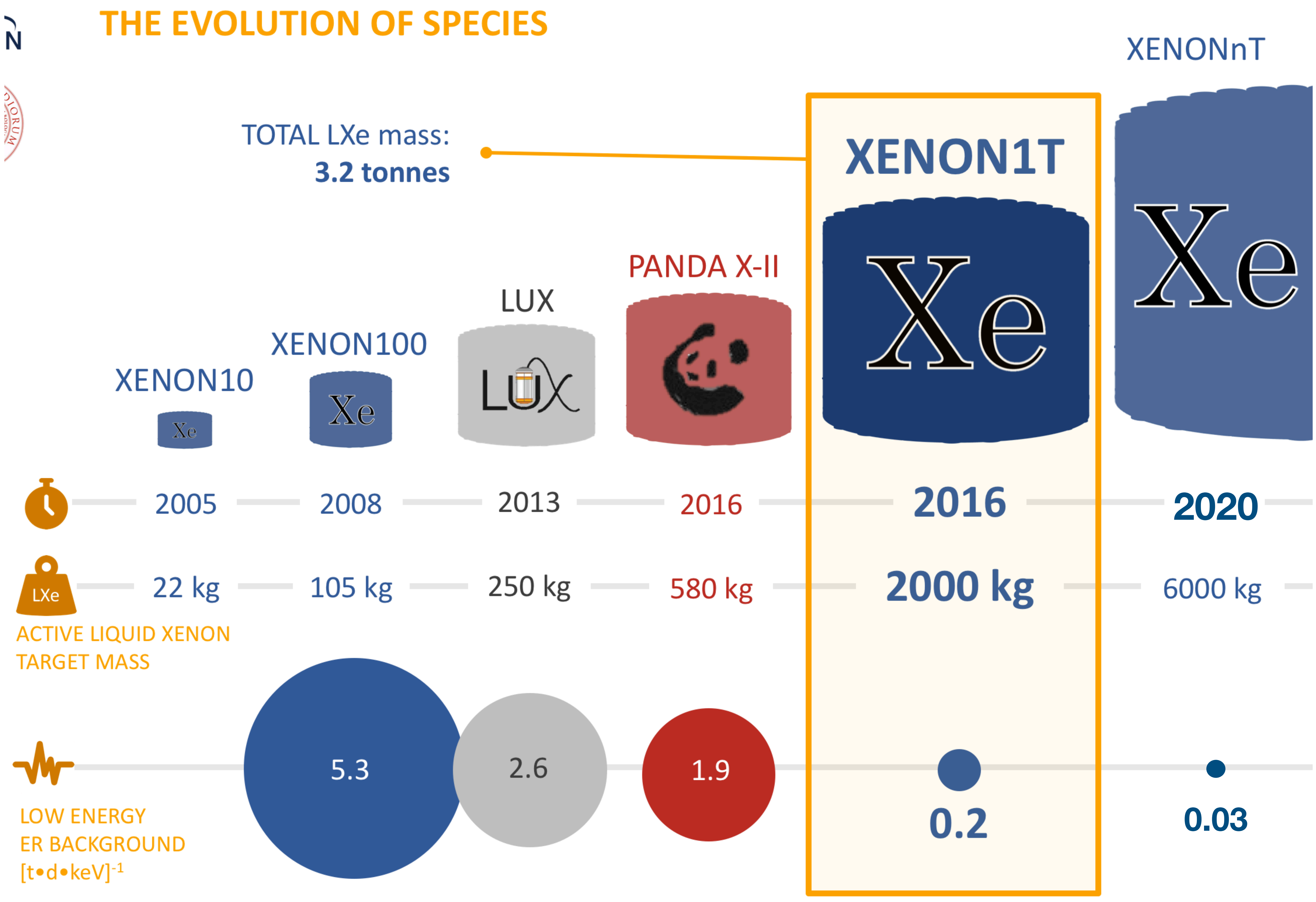

Foto Hall C, Agosto 2023





LAr filling expected in 2026

Evolution of LXeTPC detectors

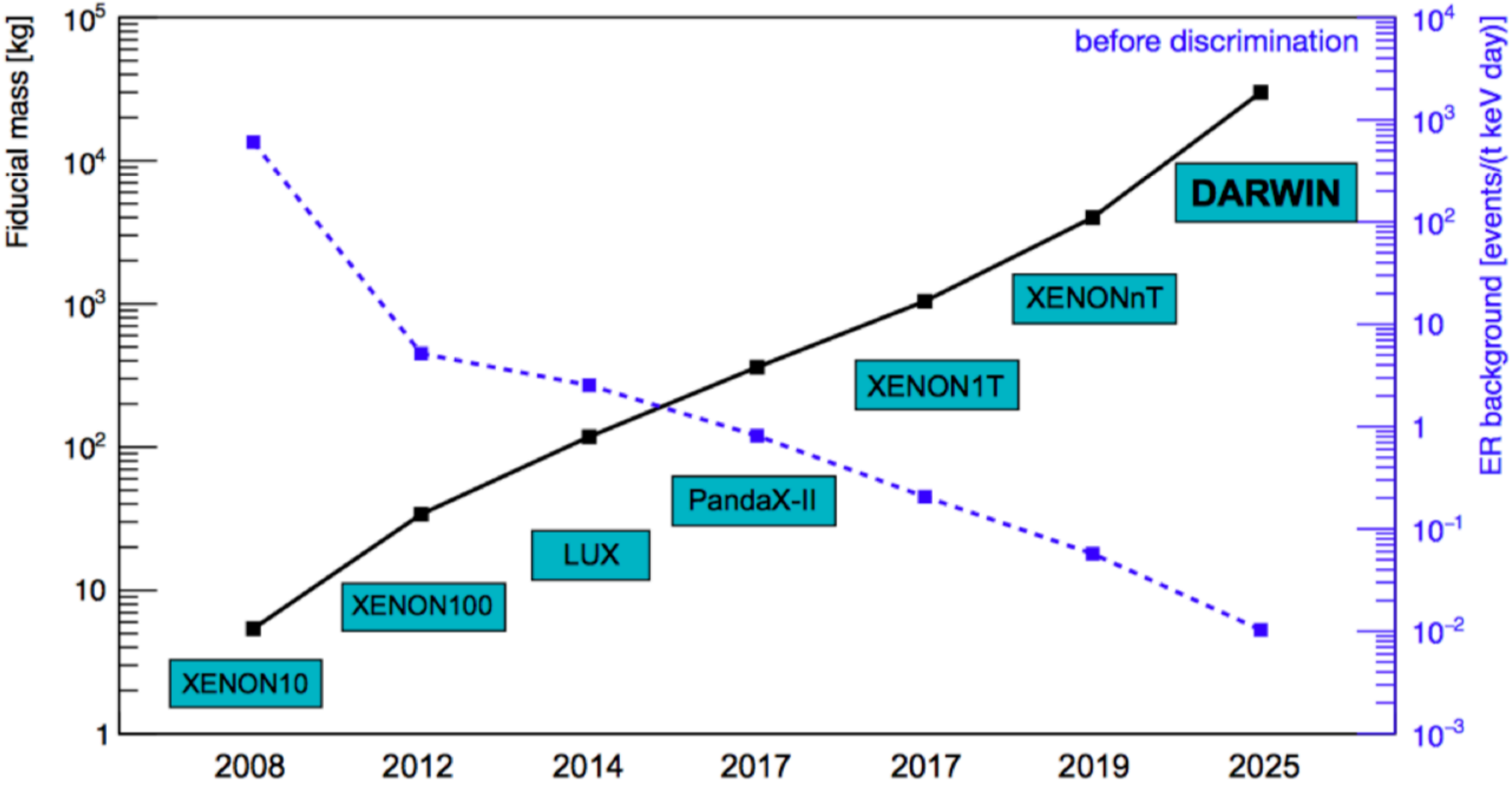


THE EVOLUTION OF SPECIES

TOTAL LXe mass:
3.2 tonnes

	XENON10	XENON100	LUX	PANDA X-II	**XENON1T**	XENONnT
	2005	2008	2013	2016	**2016**	**2020**
ACTIVE LIQUID XENON TARGET MASS	22 kg	105 kg	250 kg	580 kg	**2000 kg**	6000 kg
LOW ENERGY ER BACKGROUND [t•d•keV]$^{-1}$		5.3	2.6	1.9	**0.2**	**0.03**

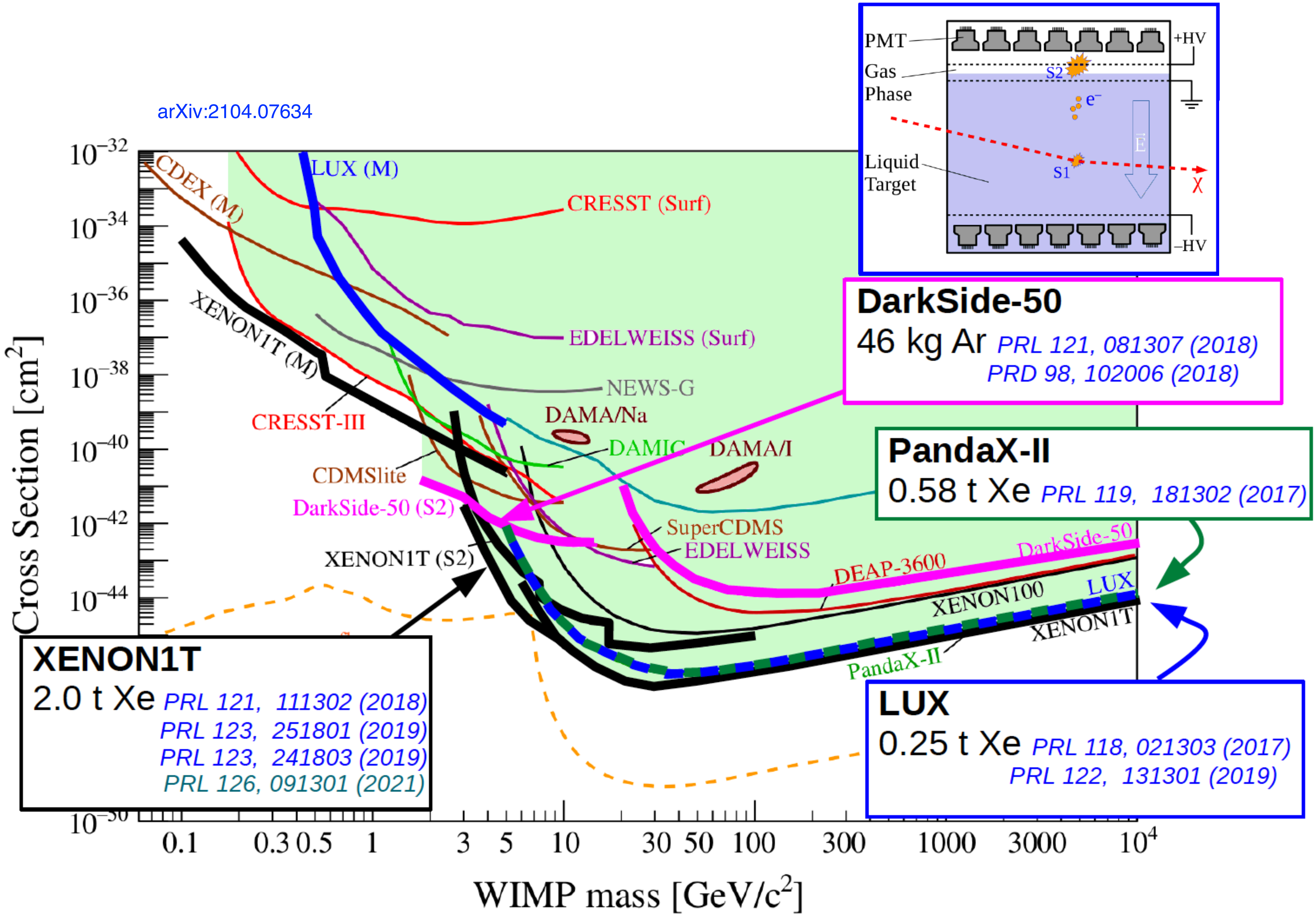
Evolution of LXeTPC detectors



(from T. Marrodan)

Summary of prev-gen Noble Liquid results

arXiv:2104.07634



DarkSide-50

46 kg Ar *PRL 121, 081307 (2018)*
PRD 98, 102006 (2018)

PandaX-II

0.58 t Xe *PRL 119, 181302 (2017)*

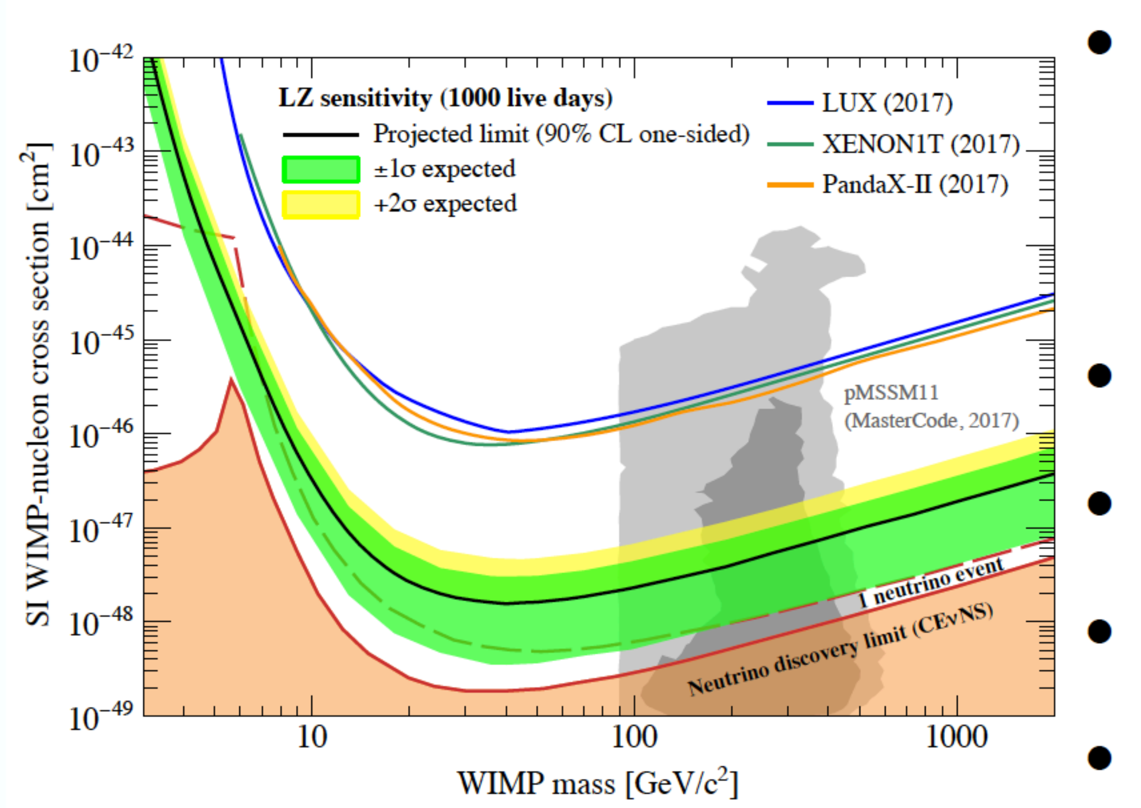
XENON1T

2.0 t Xe *PRL 121, 111302 (2018)*
PRL 123, 251801 (2019)
PRL 123, 241803 (2019)
PRL 126, 091301 (2021)

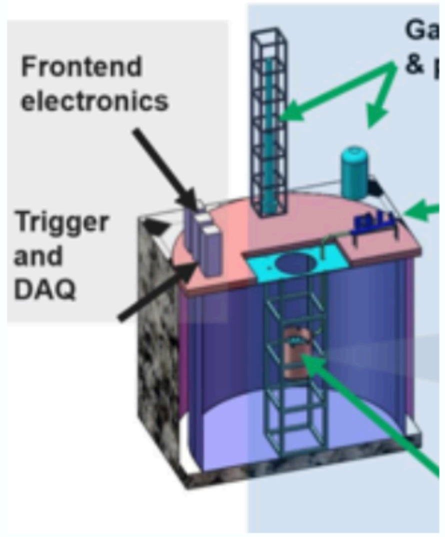
LUX

0.25 t Xe *PRL 118, 021303 (2017)*
PRL 122, 131301 (2019)

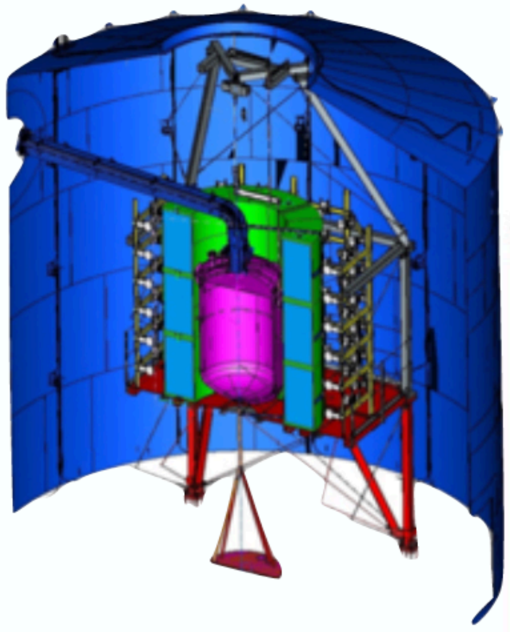
Current and next steps: LXe TPCs



- Results from running experiments and secondary results from completed ones
- XENONnT: 2019 8t, 4t fiducial
- PandaX-4T: 2020 4t
- LZ:2020 10t, 5.6t fiducial
- DARWIN:2024 50t

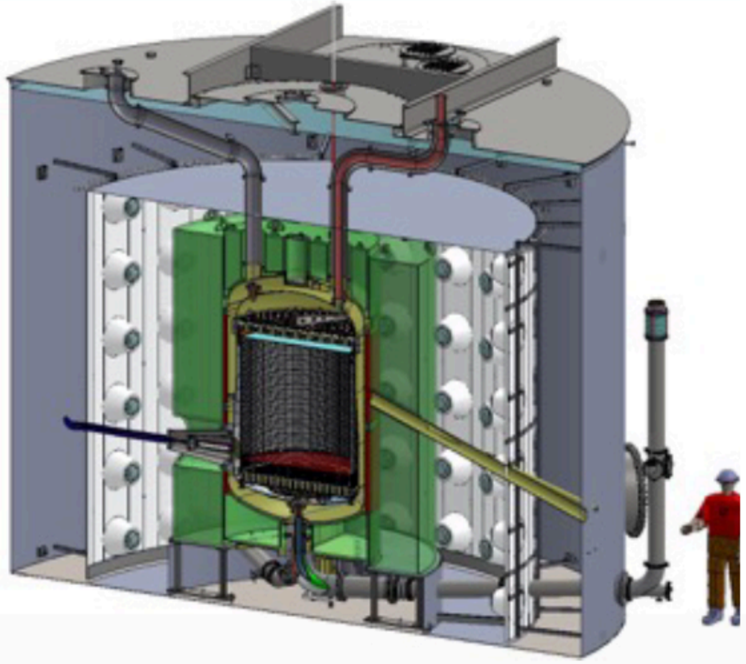


PandaX-4T

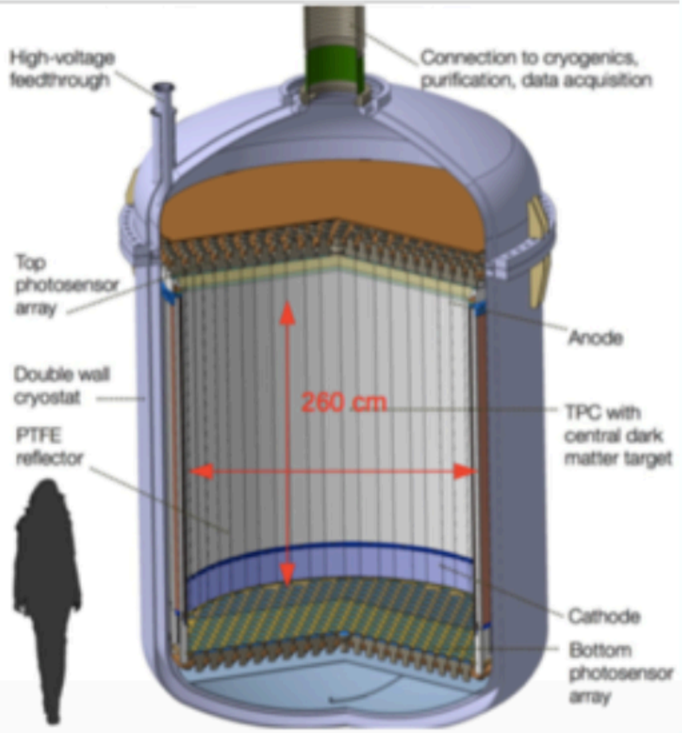


XENONnT

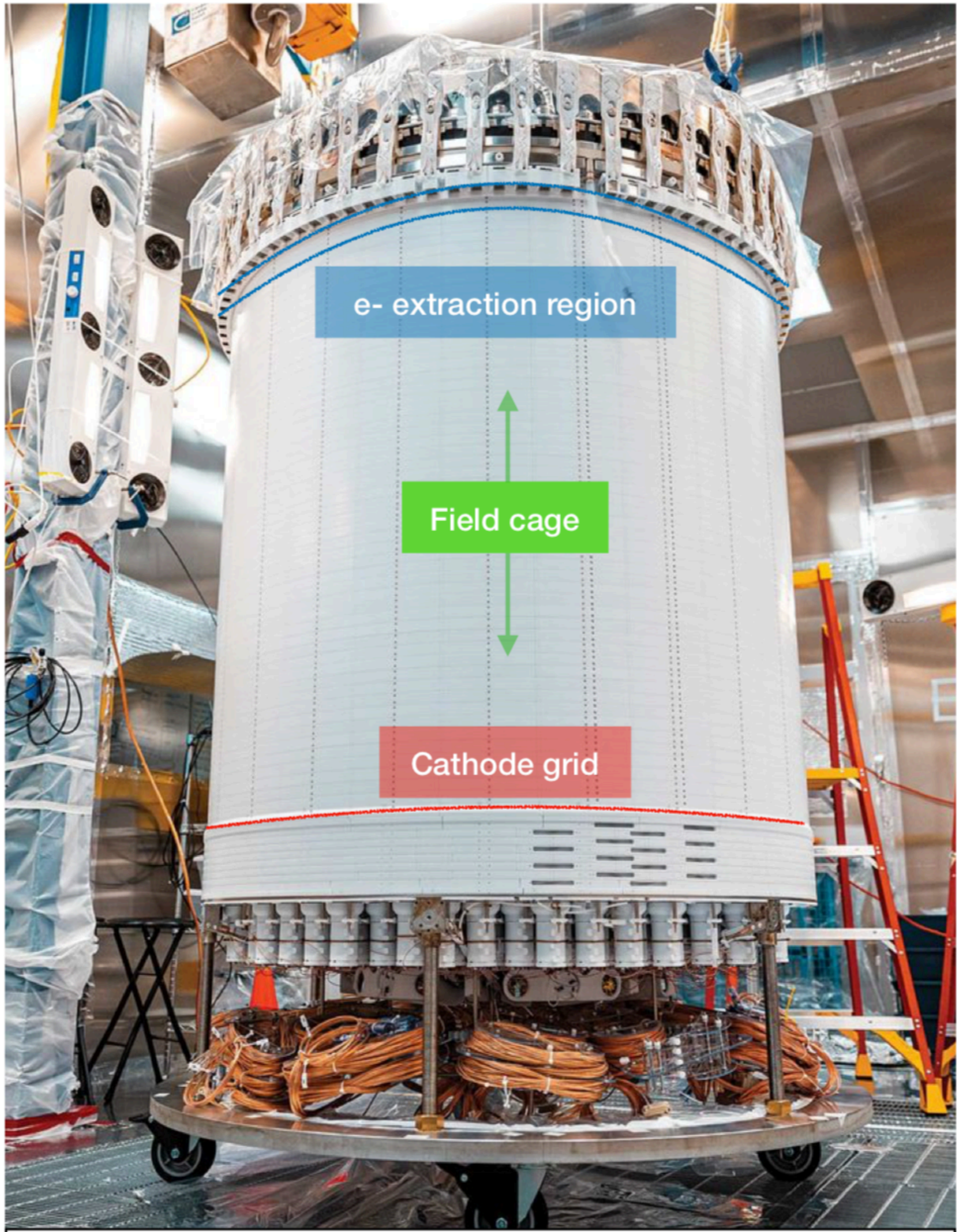
LZ



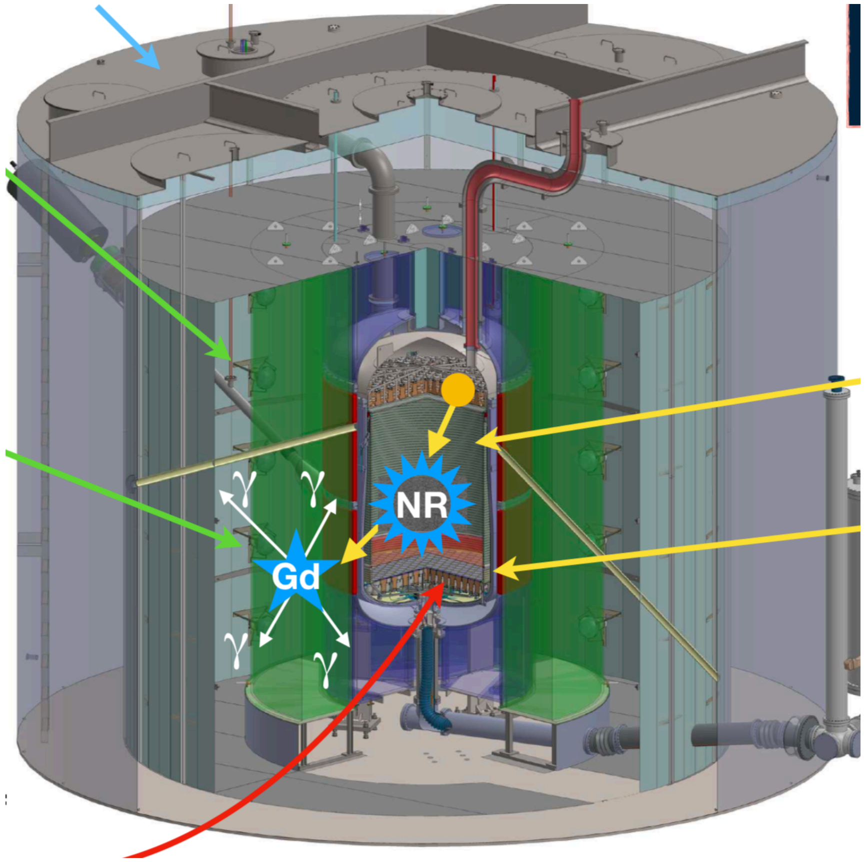
DARWIN



LUX-ZEPLIN



Construction in radon reduced clean room at surface assembly lab completed in 2019



- PTFE field cage maximizes light collection efficiency.
- 494 3” PMTs in total - Hamamatsu R11410-22.
- Woven electrode grids to generate electric-field in the active xenon region (7 tonnes of LXe)
- Nominal cathode voltage of -50 kV (drift field ~ 300 V/cm)
- ~ 2 tonne instrumented skin region between the outside of the TPC and the inner wall of the cryostat vessel.
- First (not blinded) results presented in July ‘22

LUX-ZEPLIN results (July 2022)

Rn level:

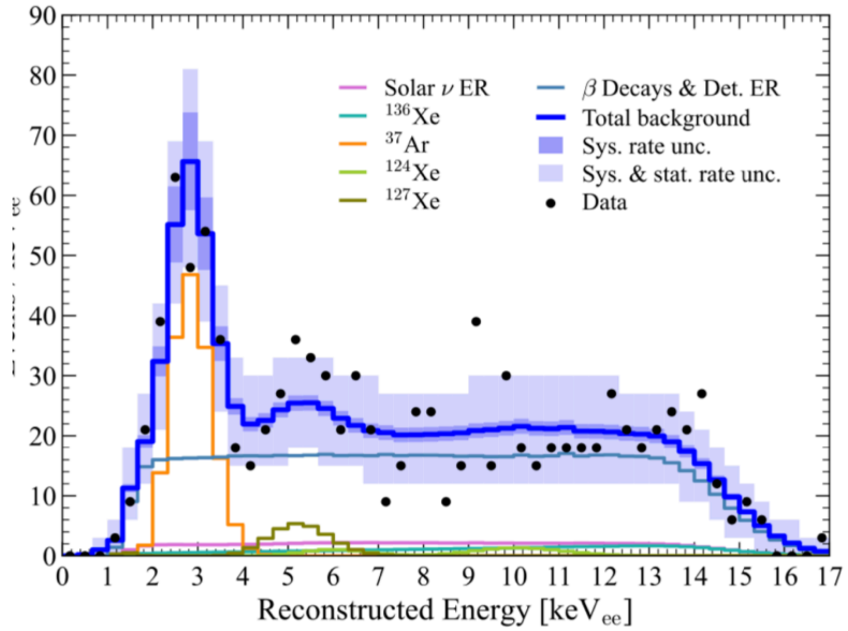
Rn222 (μBq/kg)	Pb214 (μBq/kg)	Po214 (μBq/kg)
4.37 ± 0.31 (stat)	**3.26 ± 0.13(stat) ± 0.57(sys)**	2.56 ± 0.21 (stat)

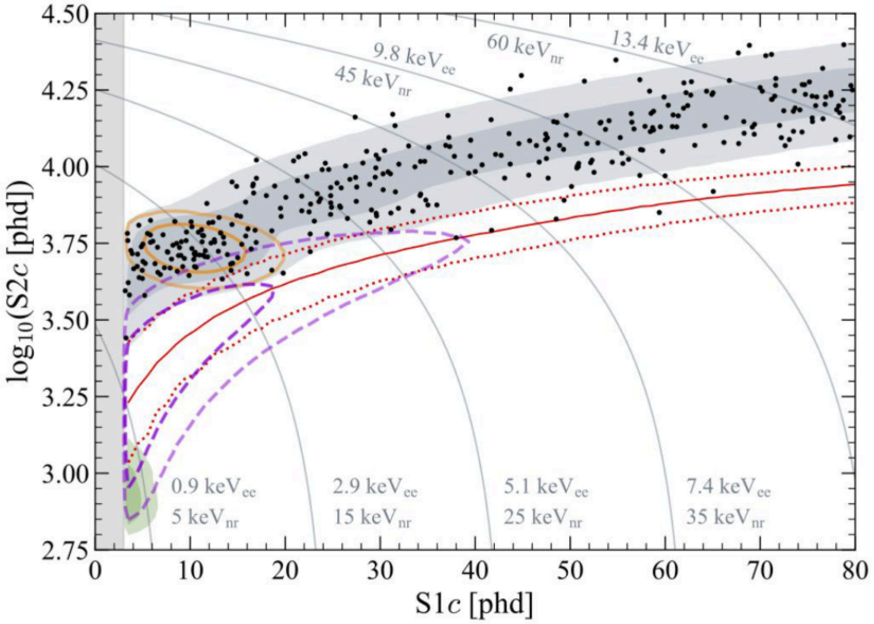
nVeto performances:

- OD neutron tag settings:
  - ≥ 200 keV
  - Δt ≤ 1200 μs
- Single-scatter neutron tagging efficiency [measured]: 88.5±0.7%
- Livetime hit: 5%

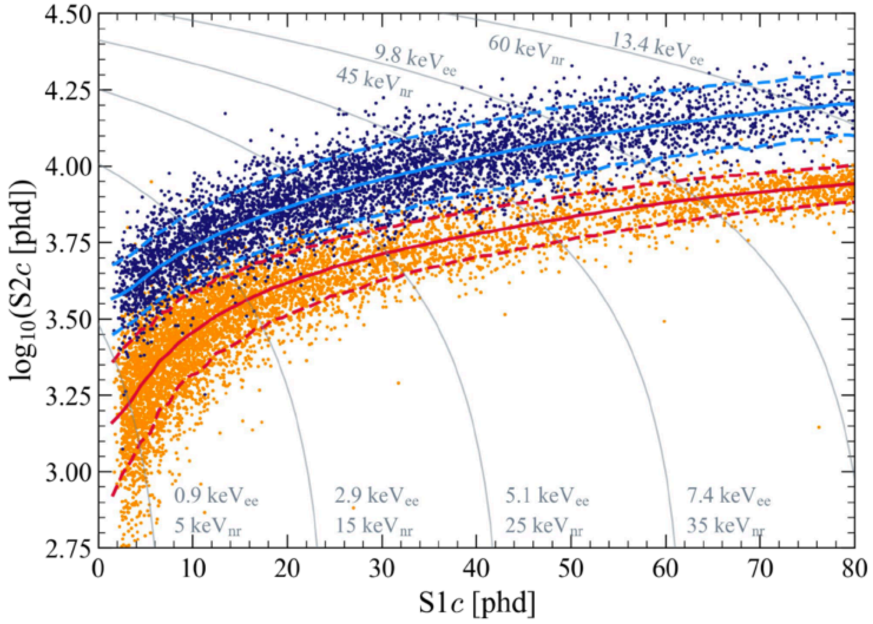
- Science Run 1 - ~3.5 month run, exposure is 60 live days x 5.5 tonnes fiducial
  - (7t active in TPC+2t Xe skin+17t Gd-loaded LS)

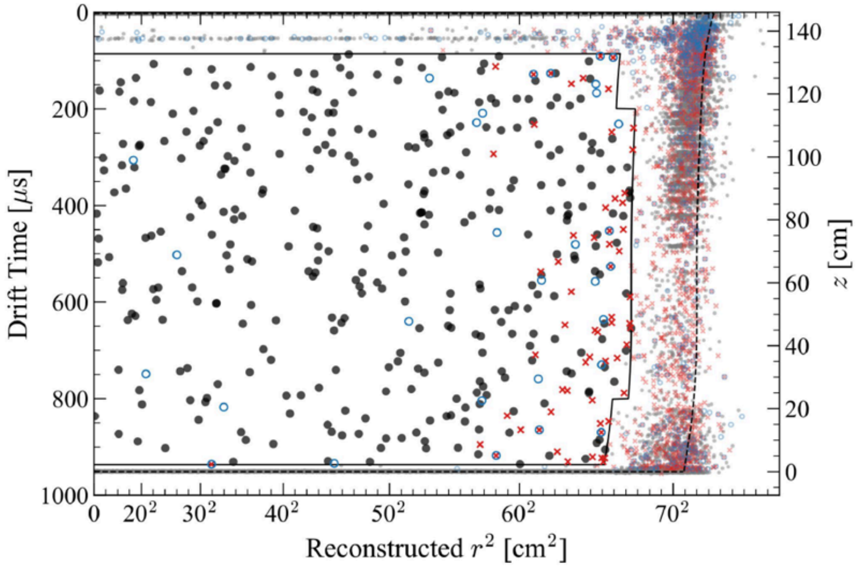
arXiv:2207.03764

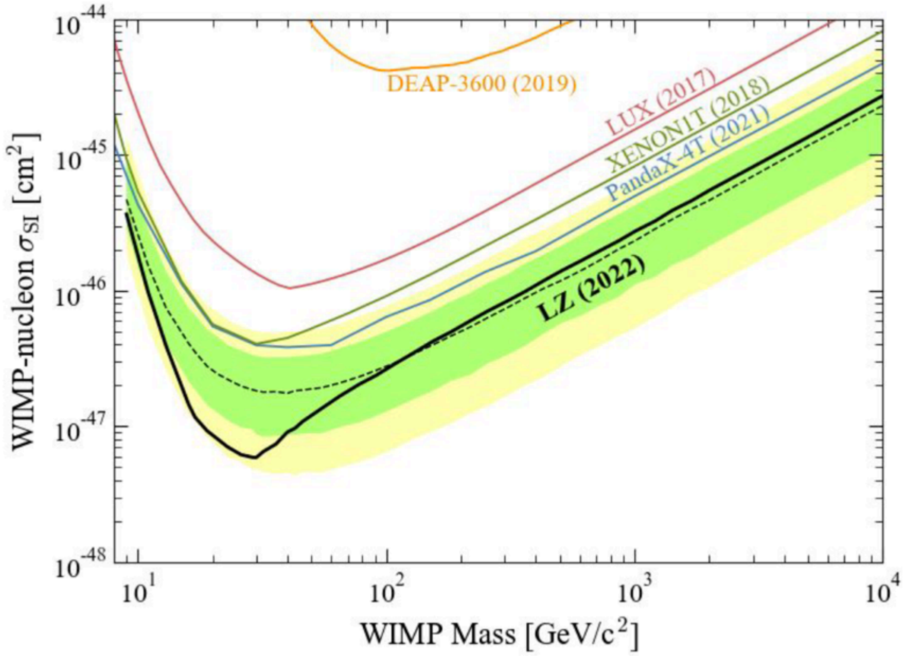




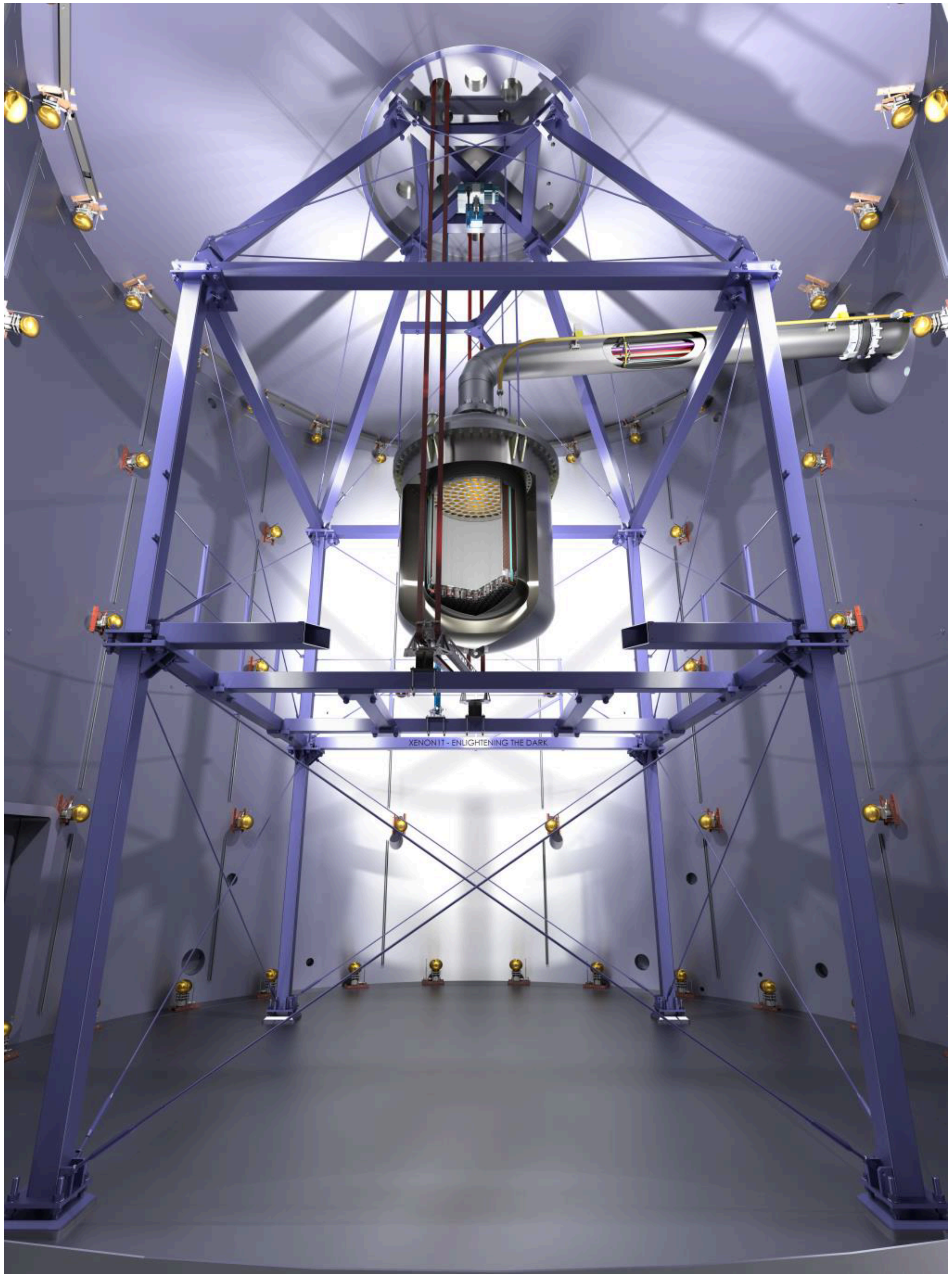
ER and NR calibrations:





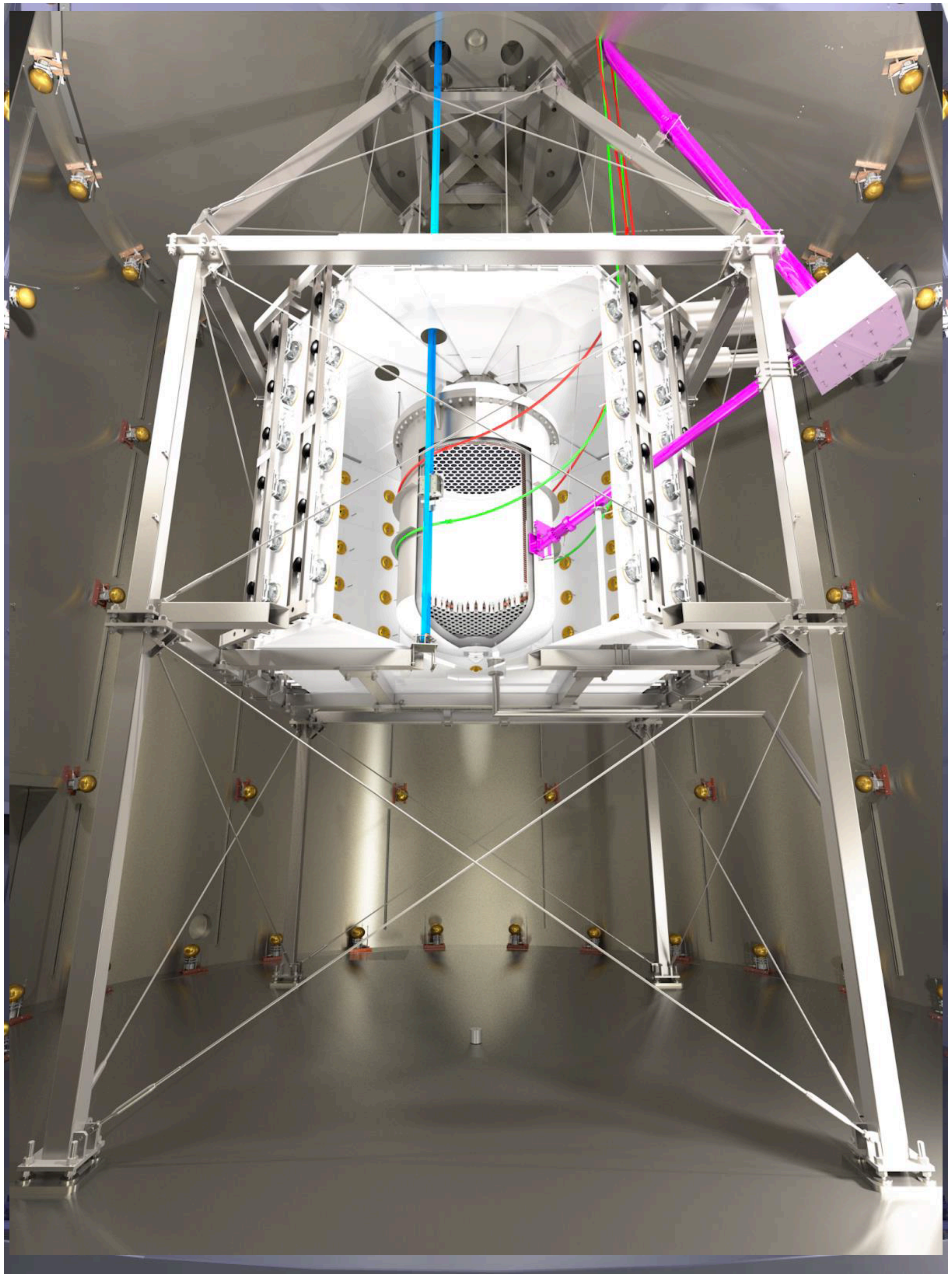


From XENON1T



Water Cerenkov Muon Veto

to XENONnT

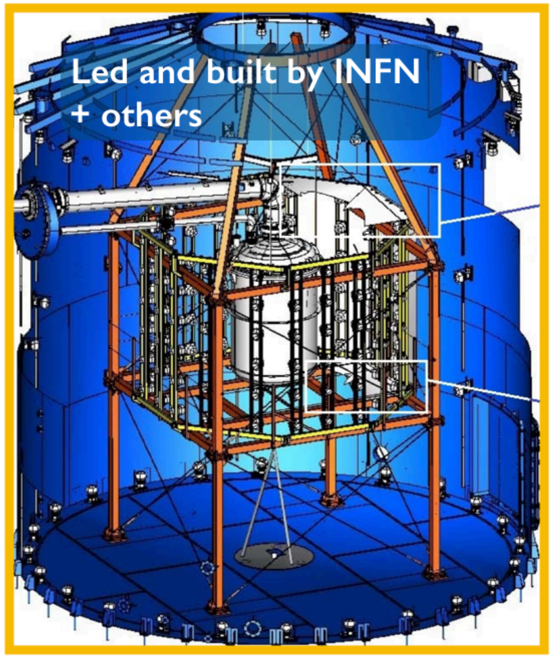


Gd-loaded
Water Cerenkov
Neutron Veto

XENONnT

Larger TPC

- Total 8.4 t LXe
- 5.9 t in TPC
- ~ 4 t fiducial
- 248 → 494 PMTs

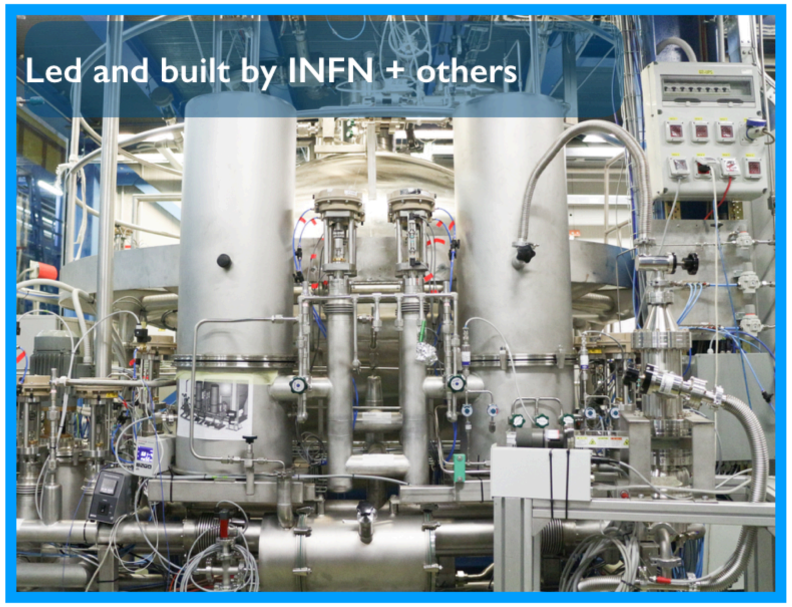


Neutron veto

- Inner region of existing muon veto
- optically separate
- 120 additional PMTs
- Gd in the water tank
- 0.5 % $Gd_2(SO_4)_3$

^{222}Rn distillation

- Reduce Rn (^{214}Pb) from pipes, cables, cryogenic system
- New system, PoP in XENON1T



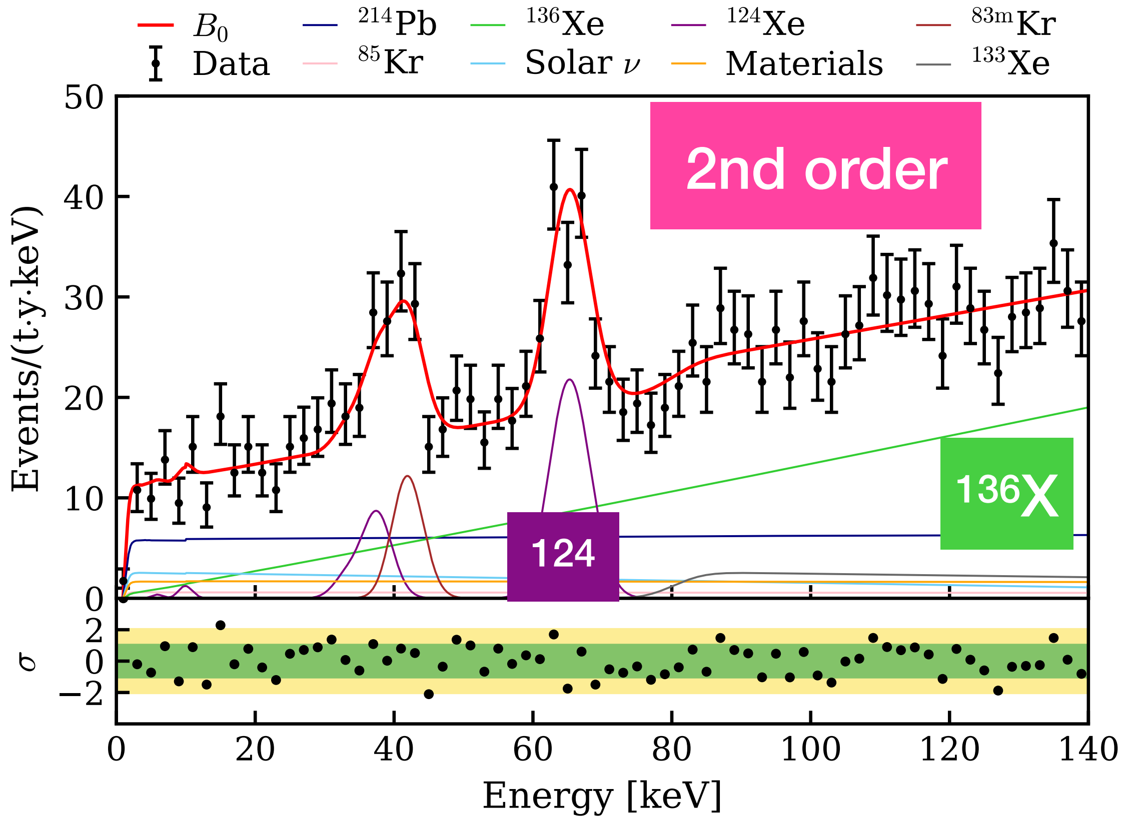
LXe purification

- Faster xenon cleaning
- 5 L/min LXe (2500 slpm)
- XENON1T ~ 100 slpm

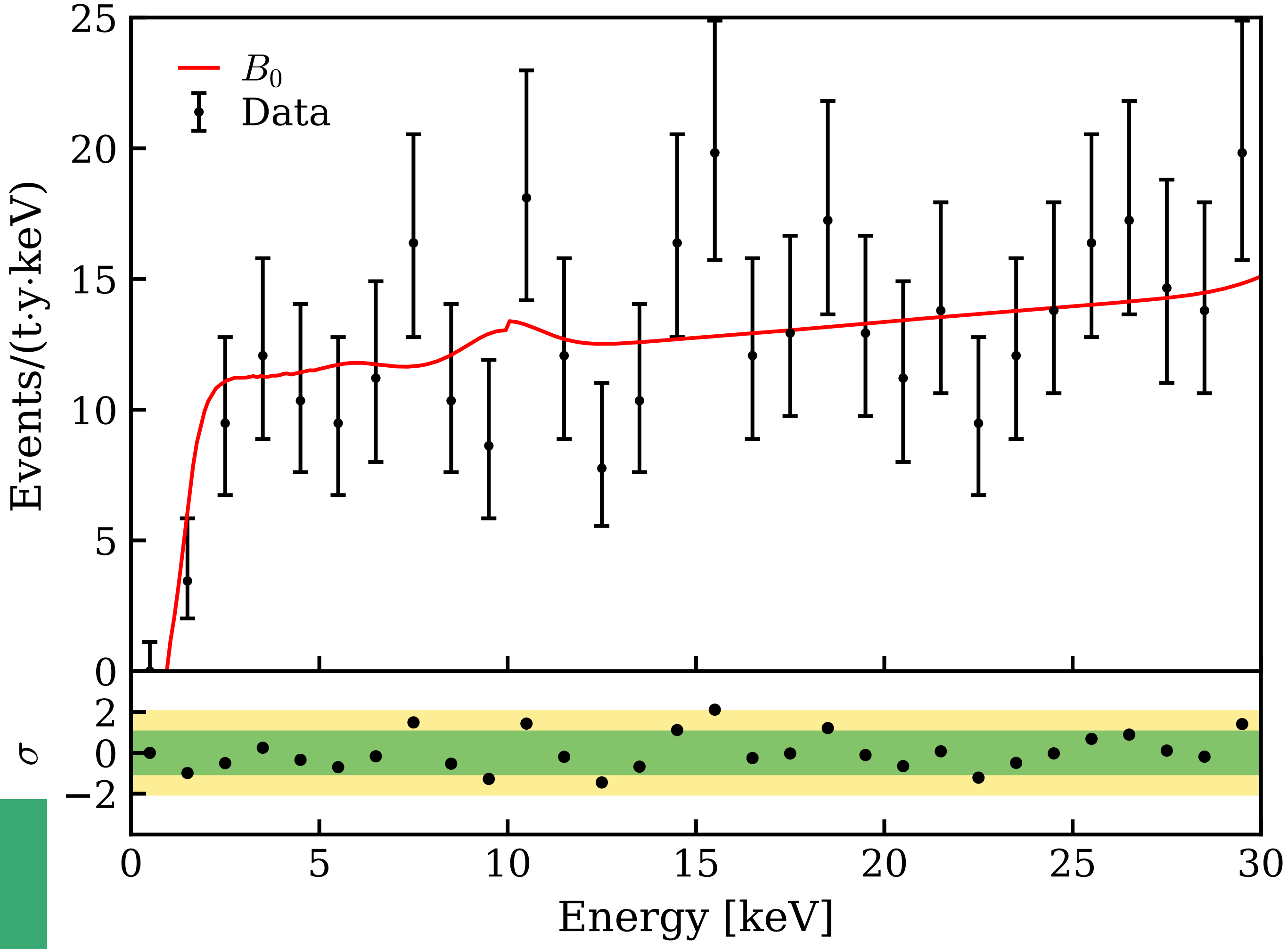
- Completed construction in 2020
- Commissioning in first half of 2021
- Currently in Science Run

XENONnT ER results (July 2022)

Energy spectrum dominated by 2nd-order weak processes



Zoom in the low-energy region: no discrepancy from the bkg model



XENONnT key performances in SR0:
> 10 ms **electron lifetime,**
1.77 ± 0.01 μBq/kg **radon concentration**

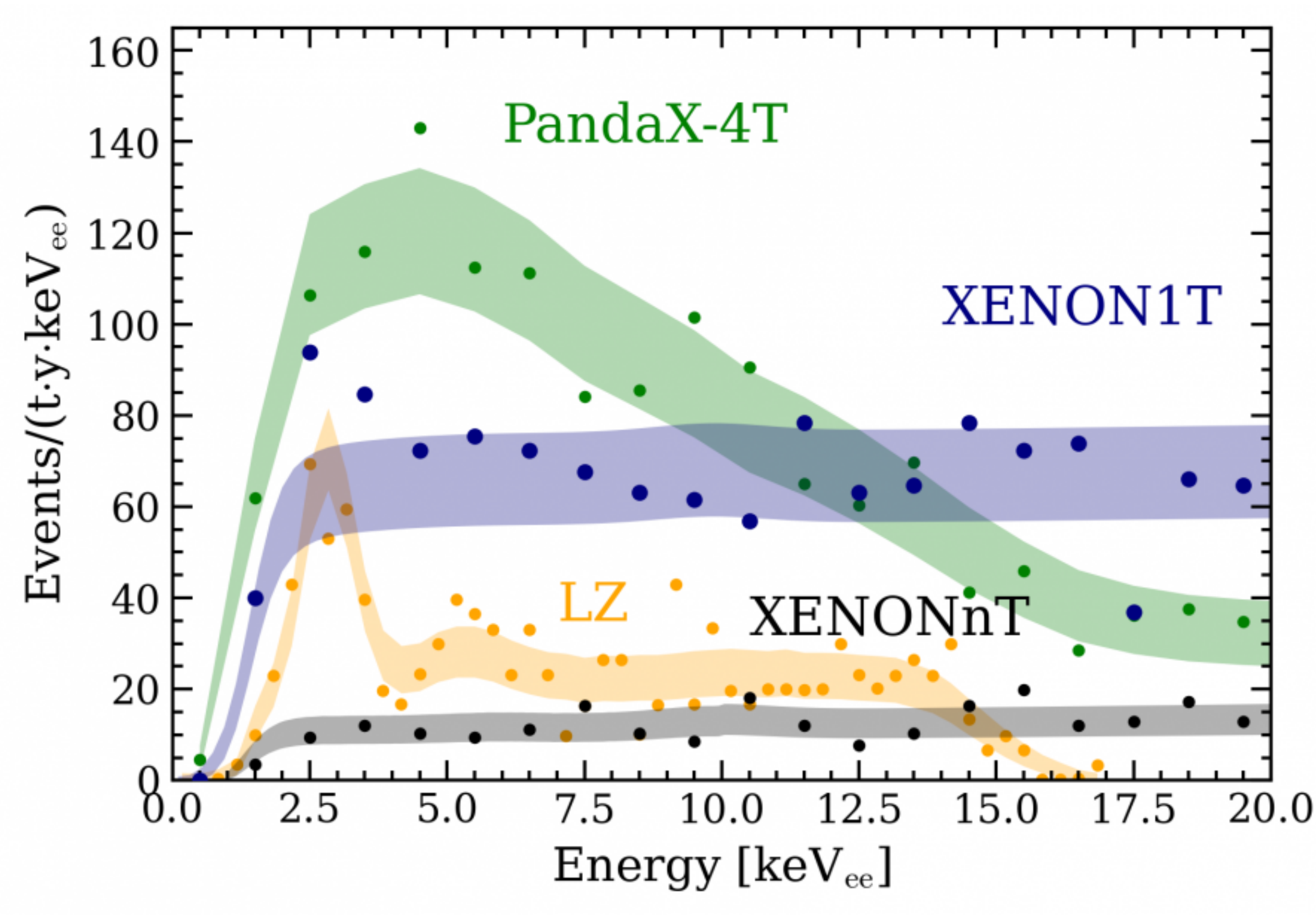
Excellent agreement with our background model.
Lowest ER background ever achieved in a DM experiment:
(16.1 ± 0.3) events/(t × yr × keV)

No trace of ^{3}H, even in the Tritium-enhanced run

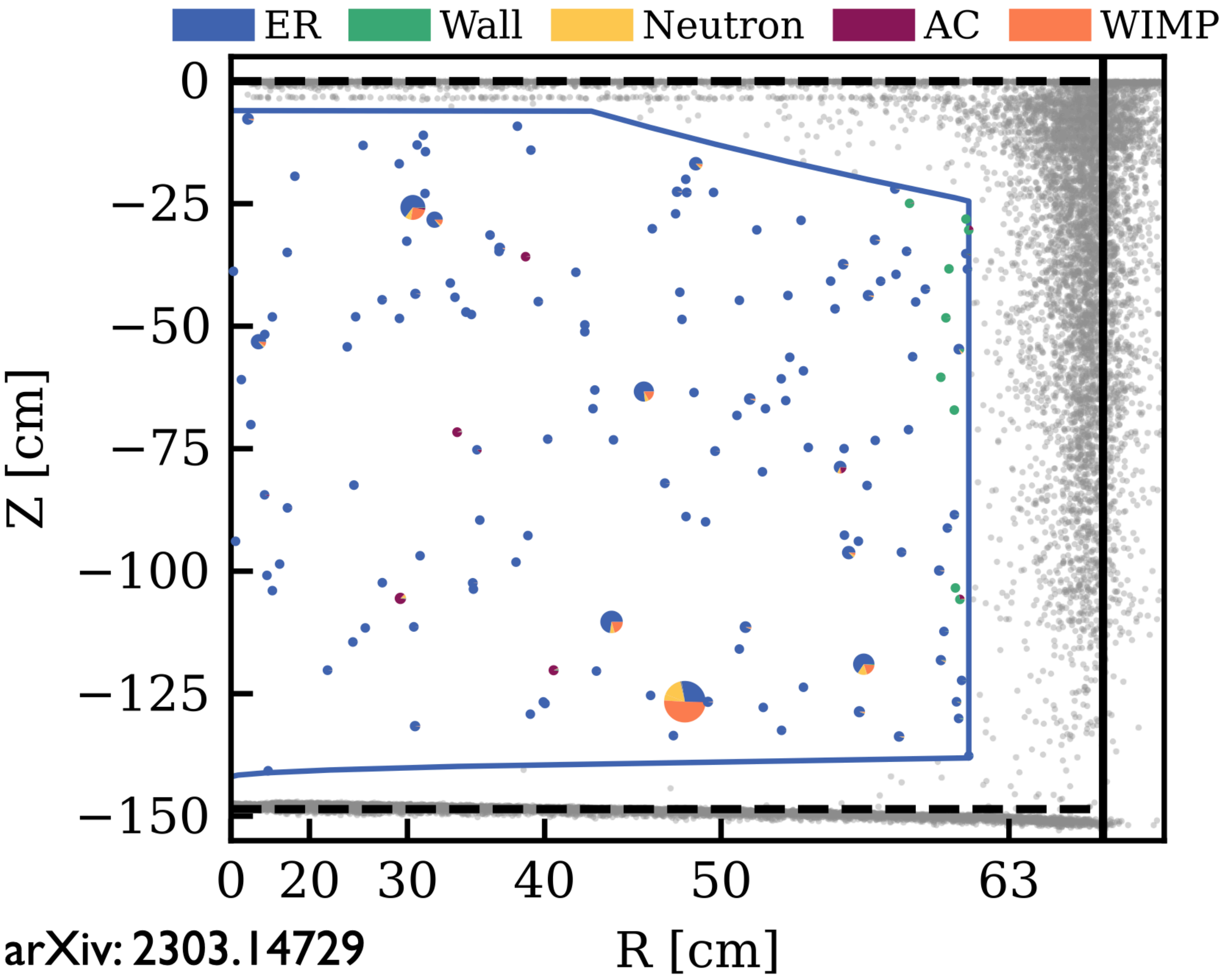
Set new best limits on Solar Axions, ν magnetic moment, ALPs, …

Search of new physics with ER data in XENONnT: PRL 129, 161805 (2022)

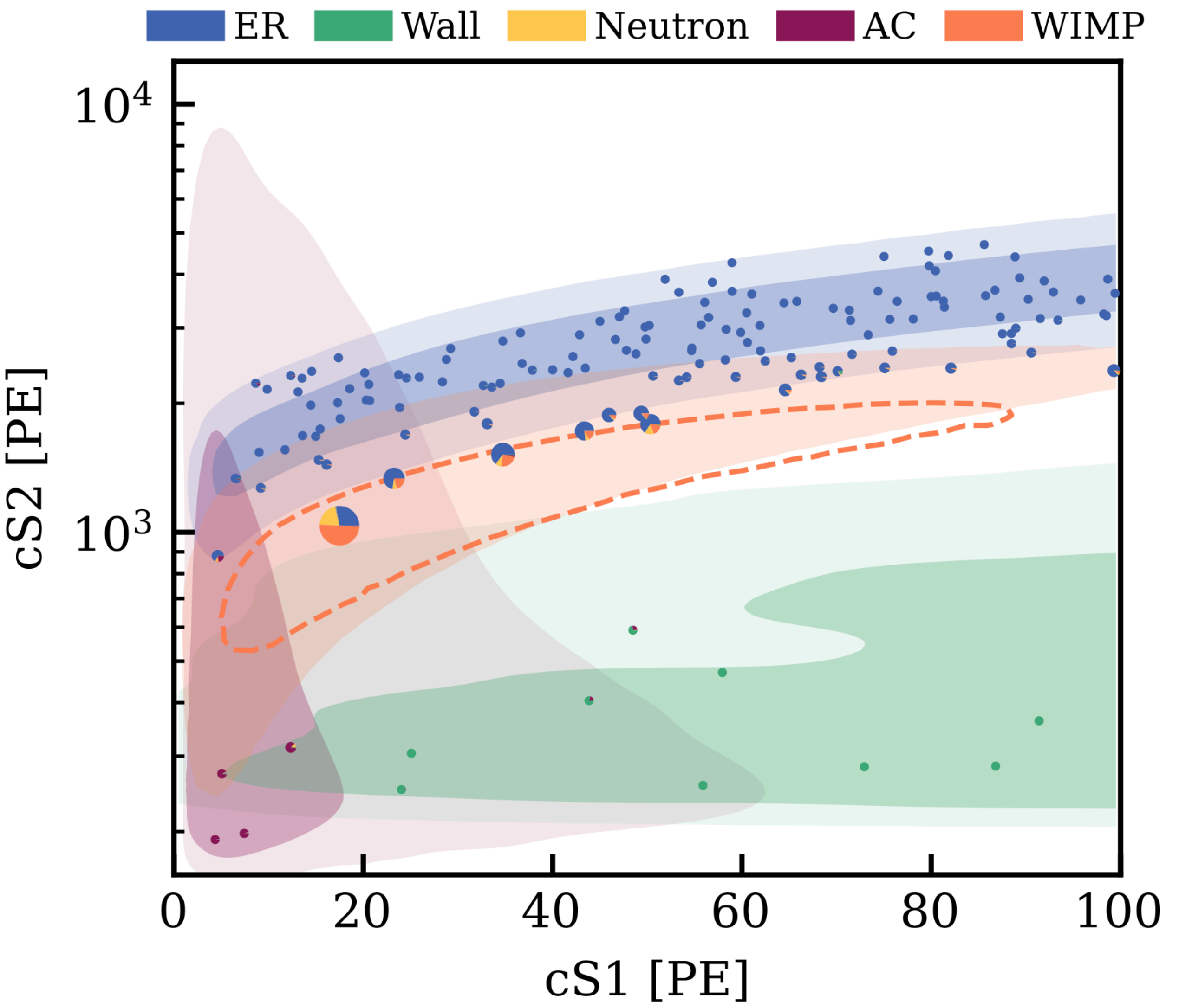
Comparison of the ER bkg in LXe detector



XENONnT NR results (March 2023)



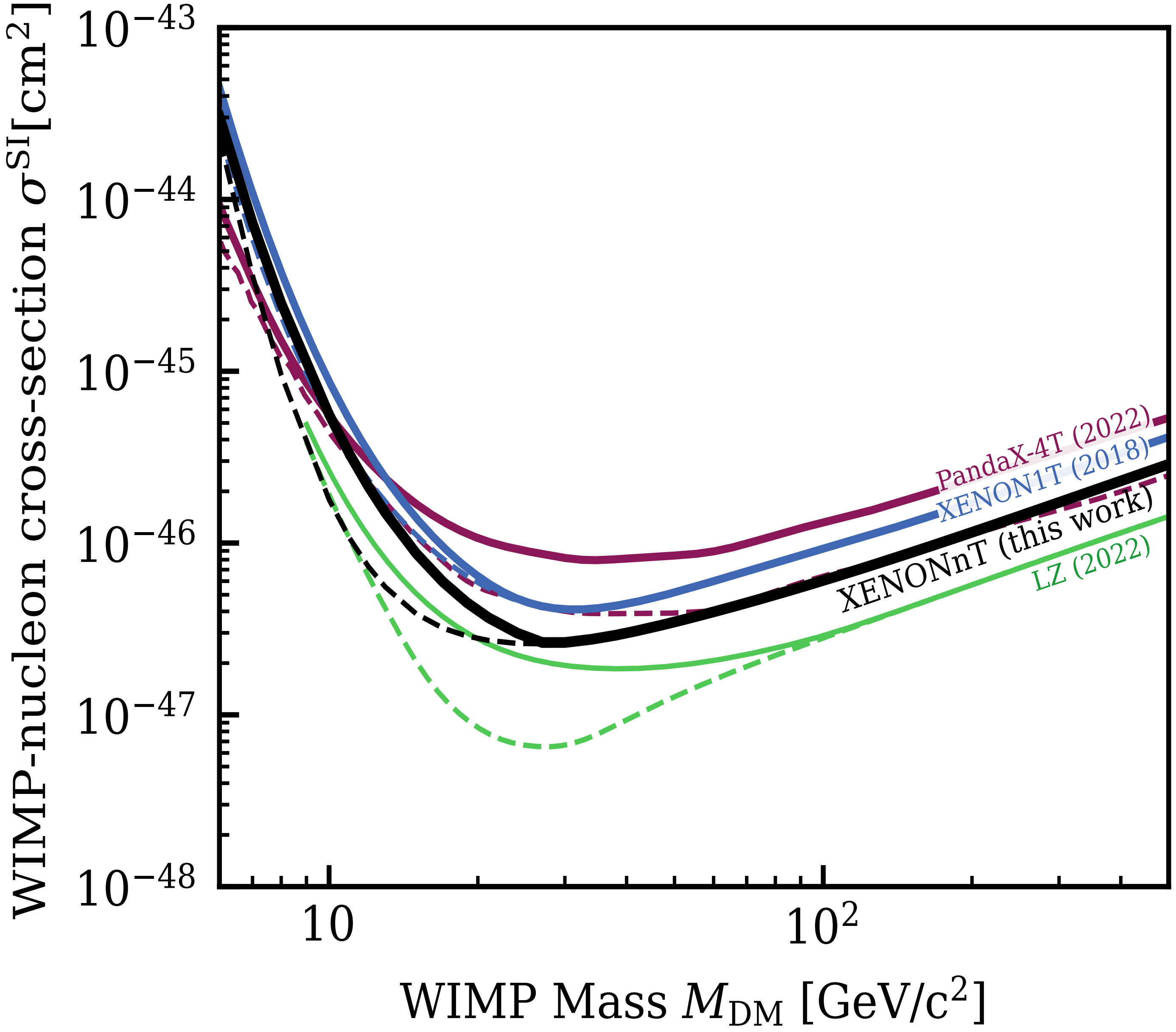
arXiv: 2303.14729



*) Assuming a 200 GeV WIMP and a best-fit σ = 2.5 × 10^{-47} cm^2

XENONnT NR results (March 2023)

PCL rejection power
threshold of 50% [median sens.]



Comparison
with other results from
non-blind analyses

PandaX-4T, PRL 127, 261802 (2021)
XENON1T, PRL 121, 111302 (2018)
LZ, PRL 131, 041002 (2023), arXiv:2207.03764
XENONnT, PRL 131, 041003 (2023), 2303.14729

SYNOPSIS

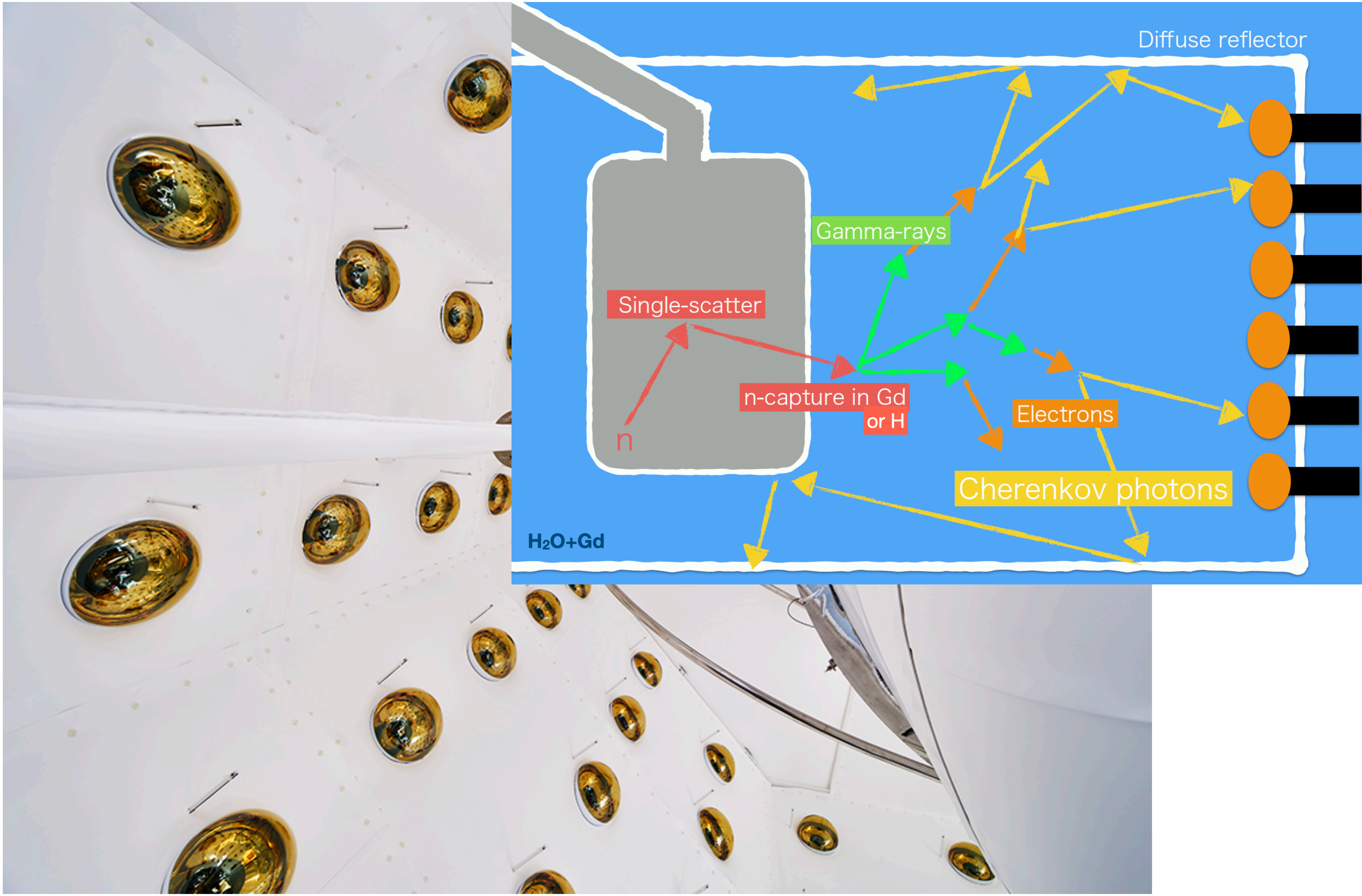
The Search for WIMPs Continues

July 28, 2023 • *Physics* 16, s106

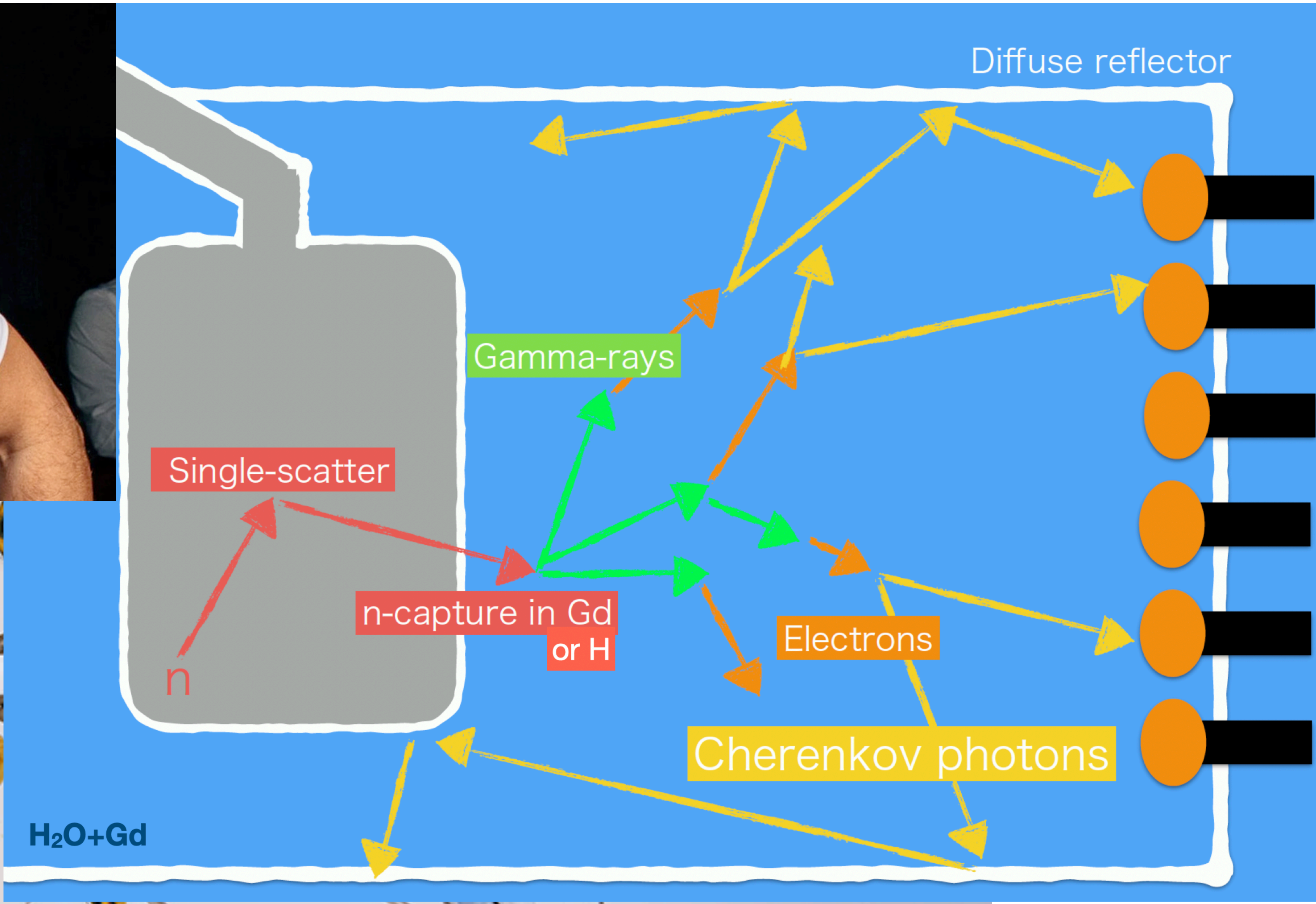
Two mammoth underground detectors have delivered more stringent upper limits on how strongly a putative dark matter candidate interacts with normal matter.

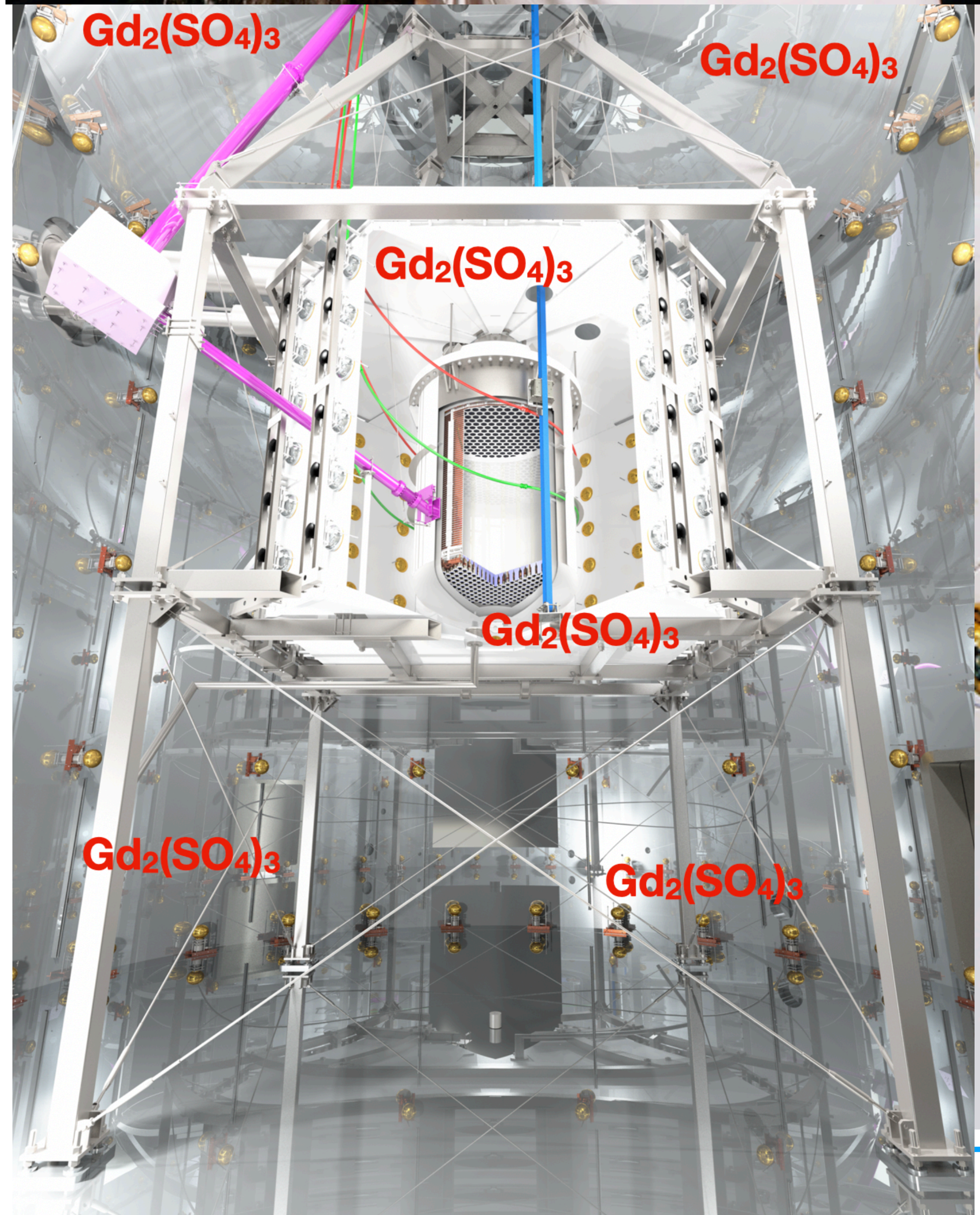
XENONnT Neutron Veto

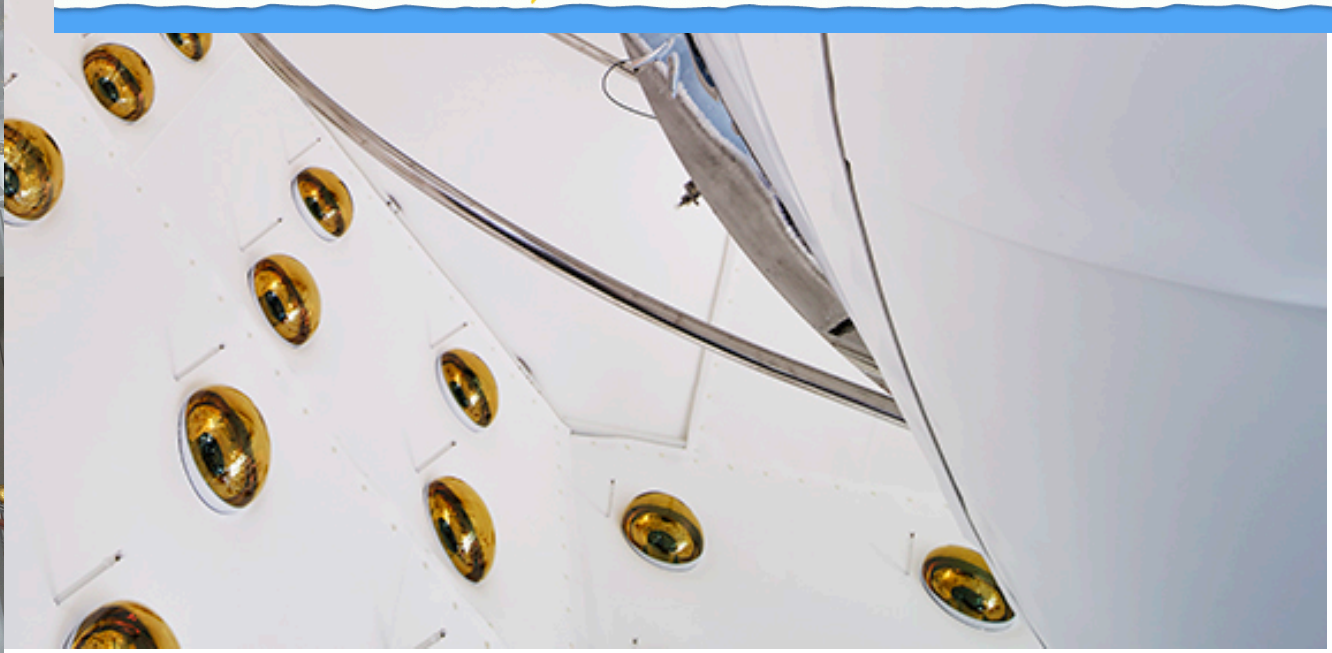
XENONnT Neutron Veto



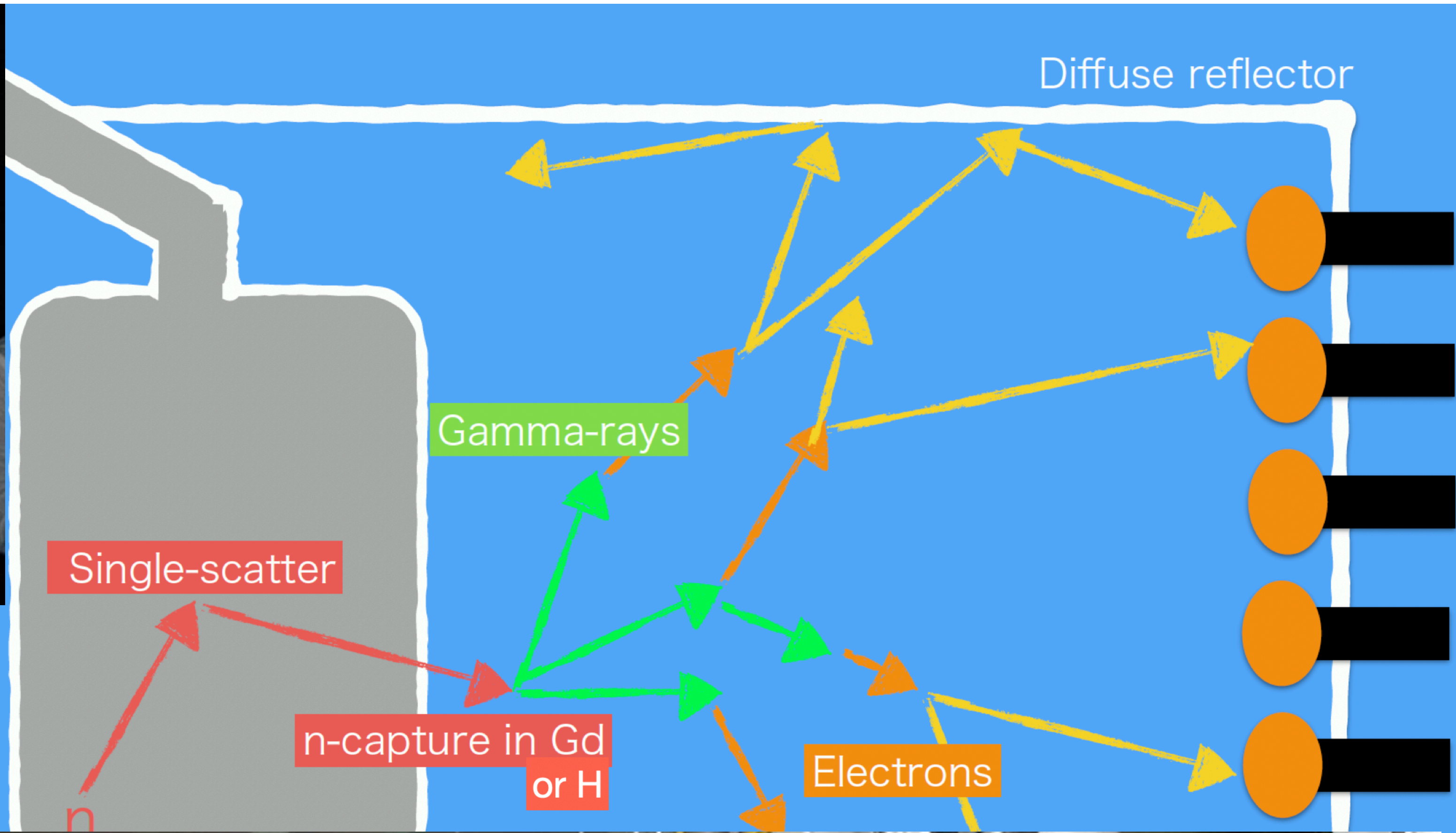
XENONnT Neutron Veto

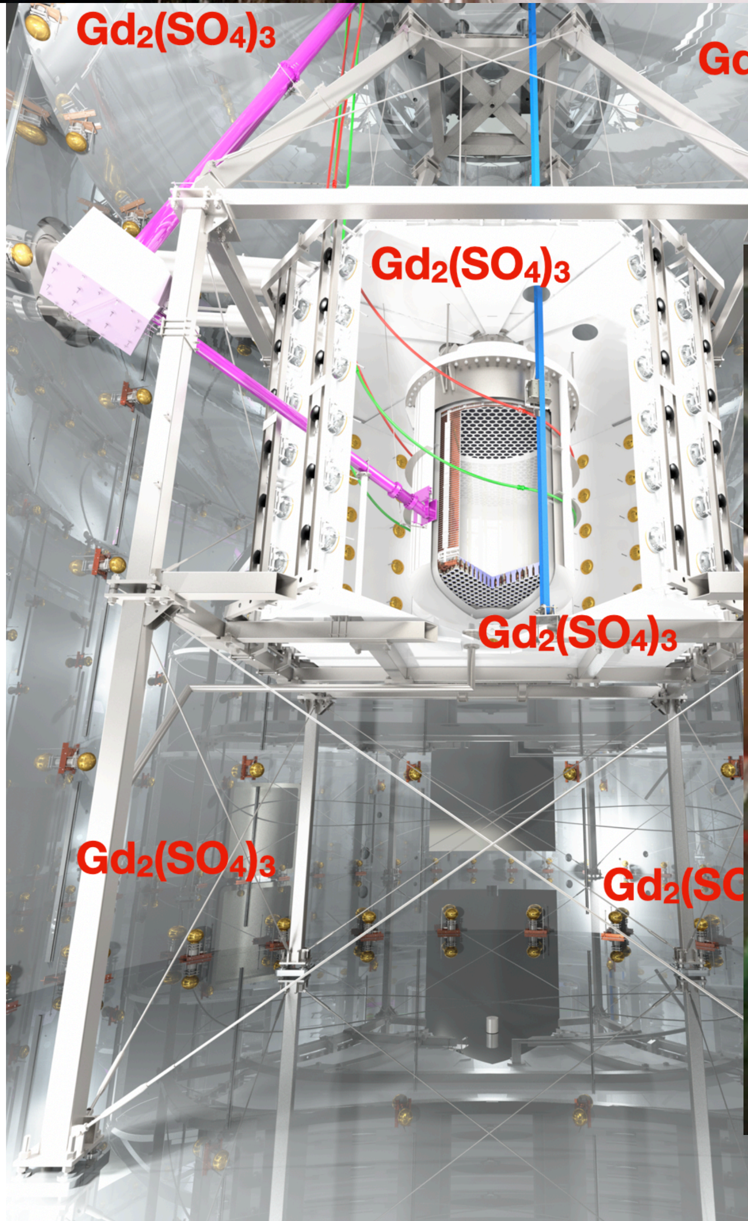


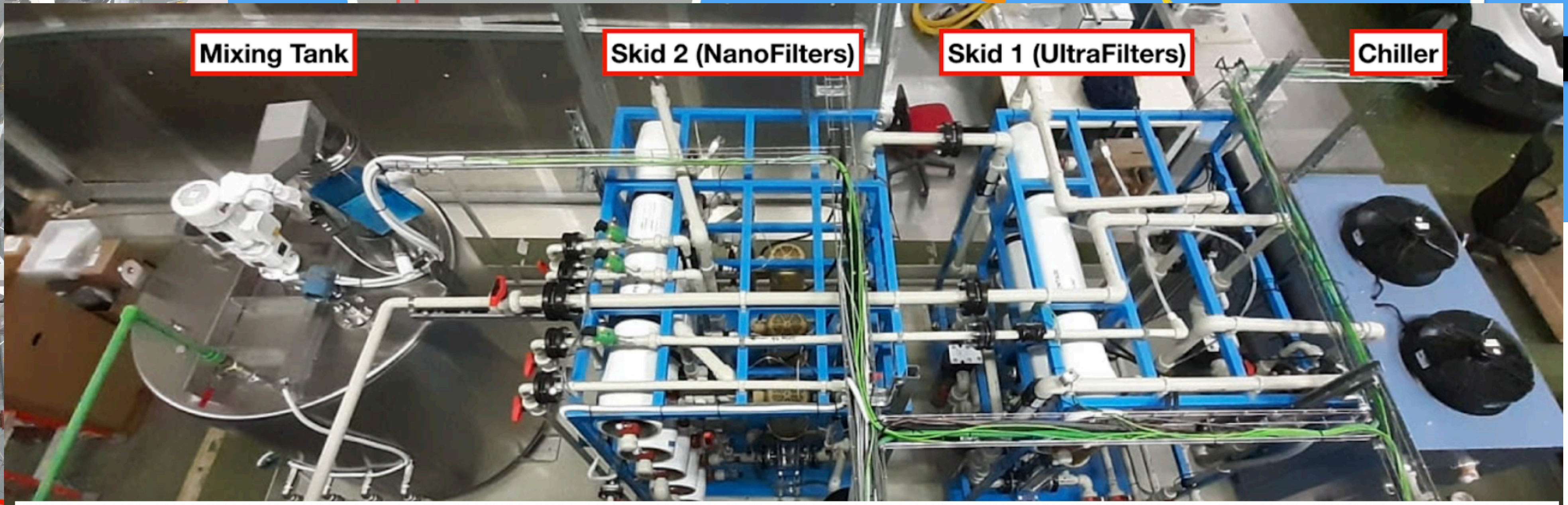


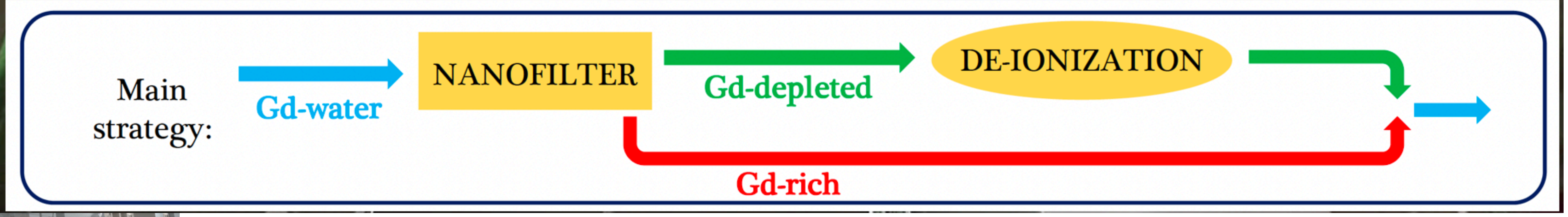


XENONnT Neutron Veto

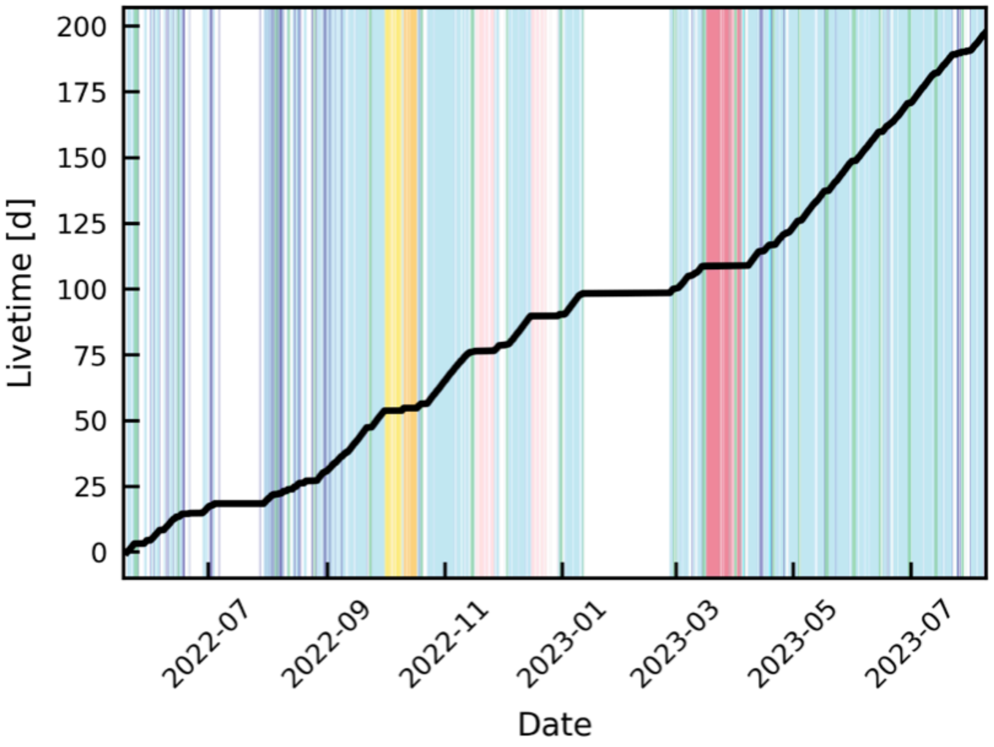




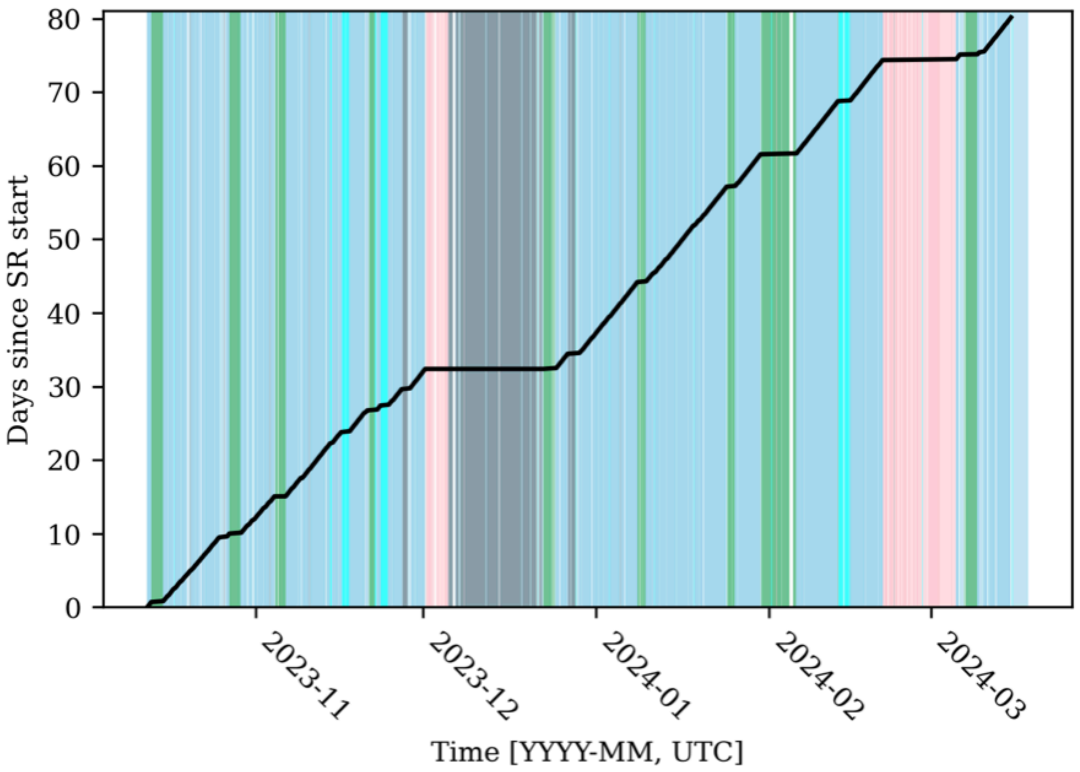




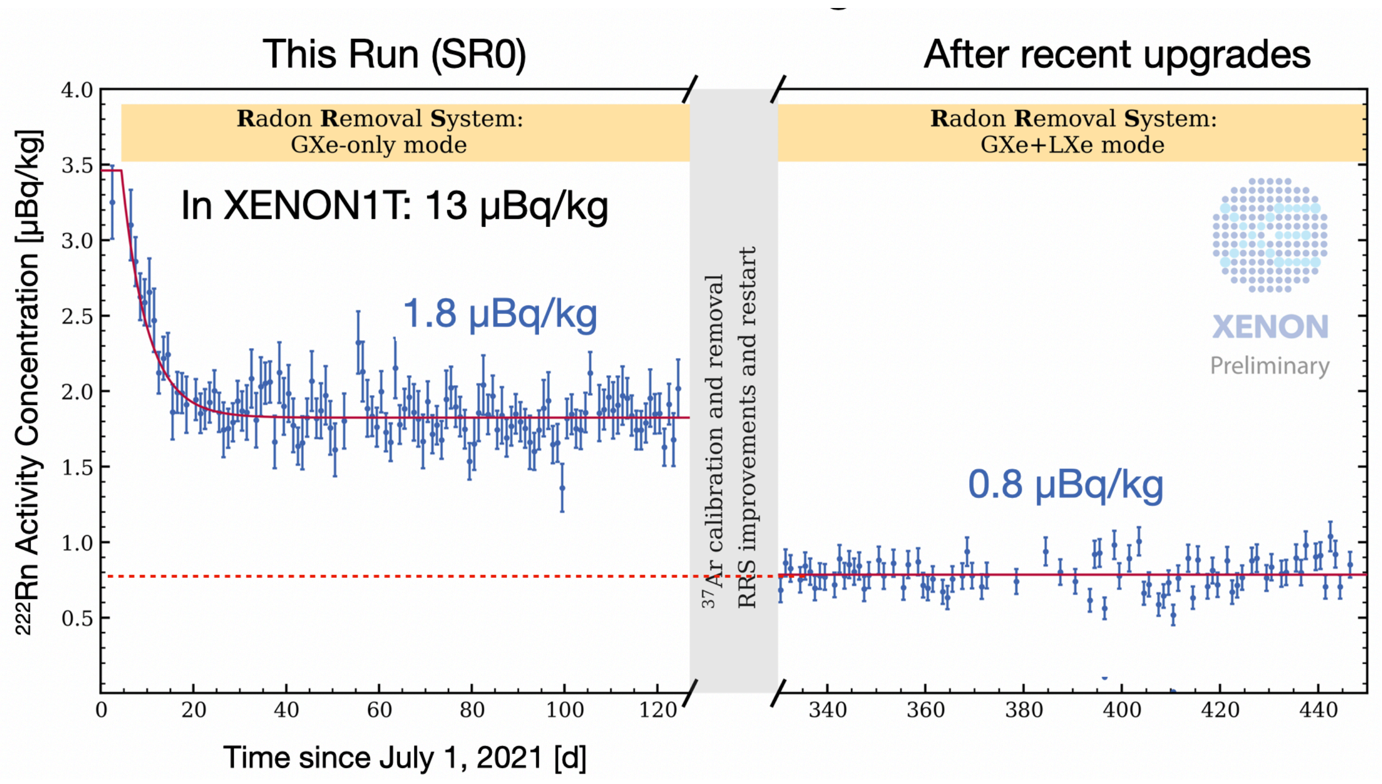
XENONnT recent improvements

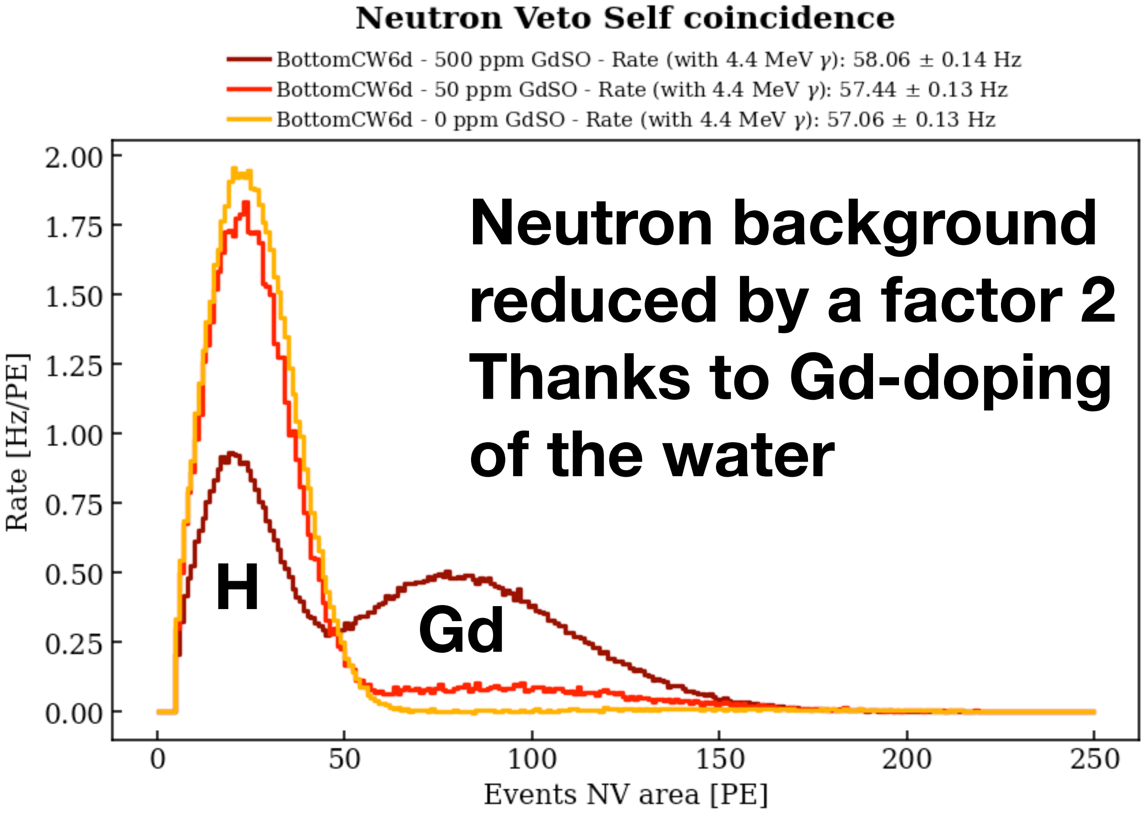


SR1: 200 days with reduced Rn (ER)



SR2: 100 days (so far!) with reduced n-background (NR)





Neutron background reduced by a factor 2 Thanks to Gd-doping of the water

Panda-X4T recent results (May 2024)

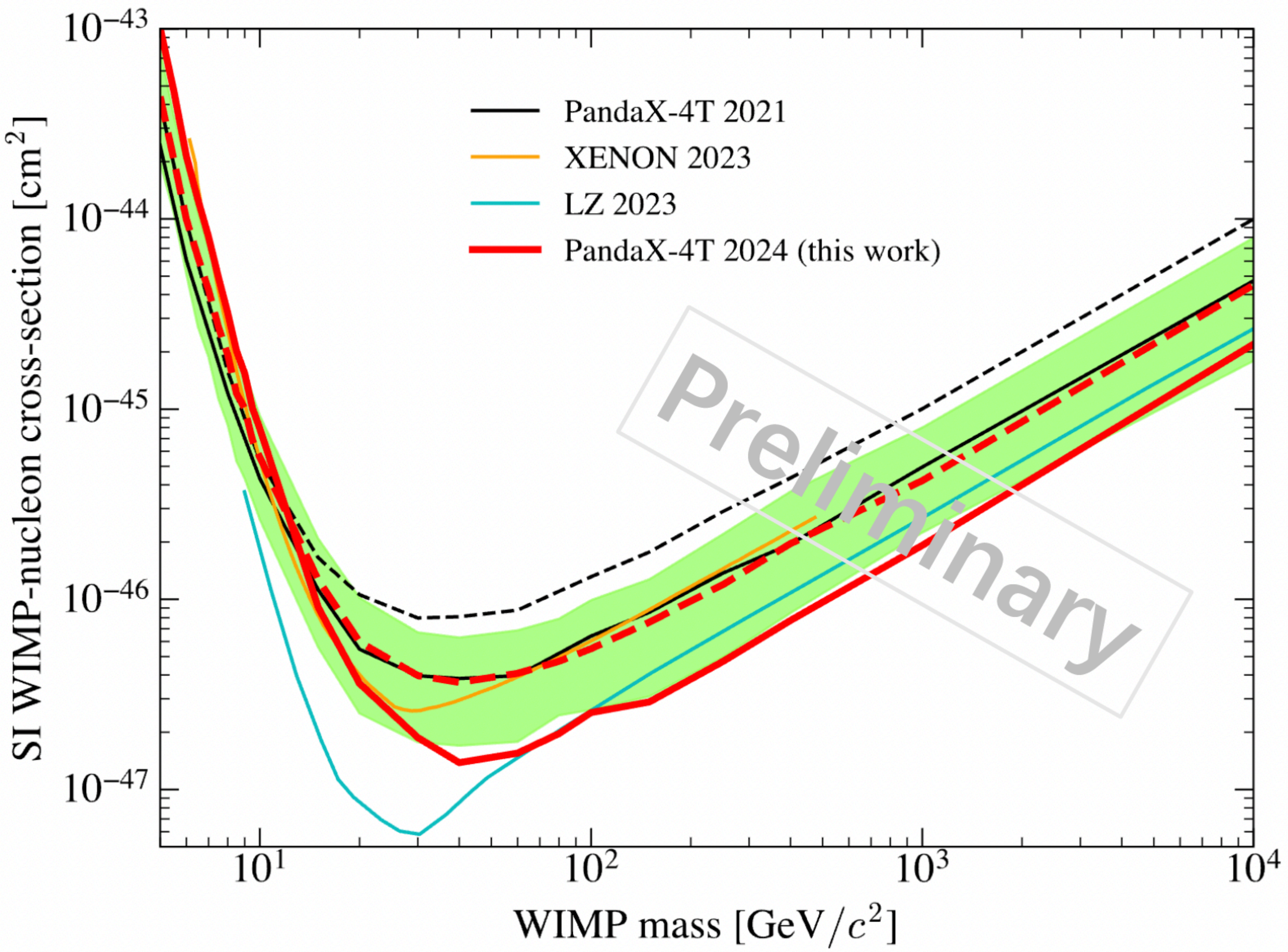
Fully blind analysis Run0+Run1:

- ➢ **Scanning WIMP mass from 5 to 10000 GeV/c^2**
- ➢ **→ No significant excess!**
- **+1σ upward fluctuation: < 8GeV/c^2**

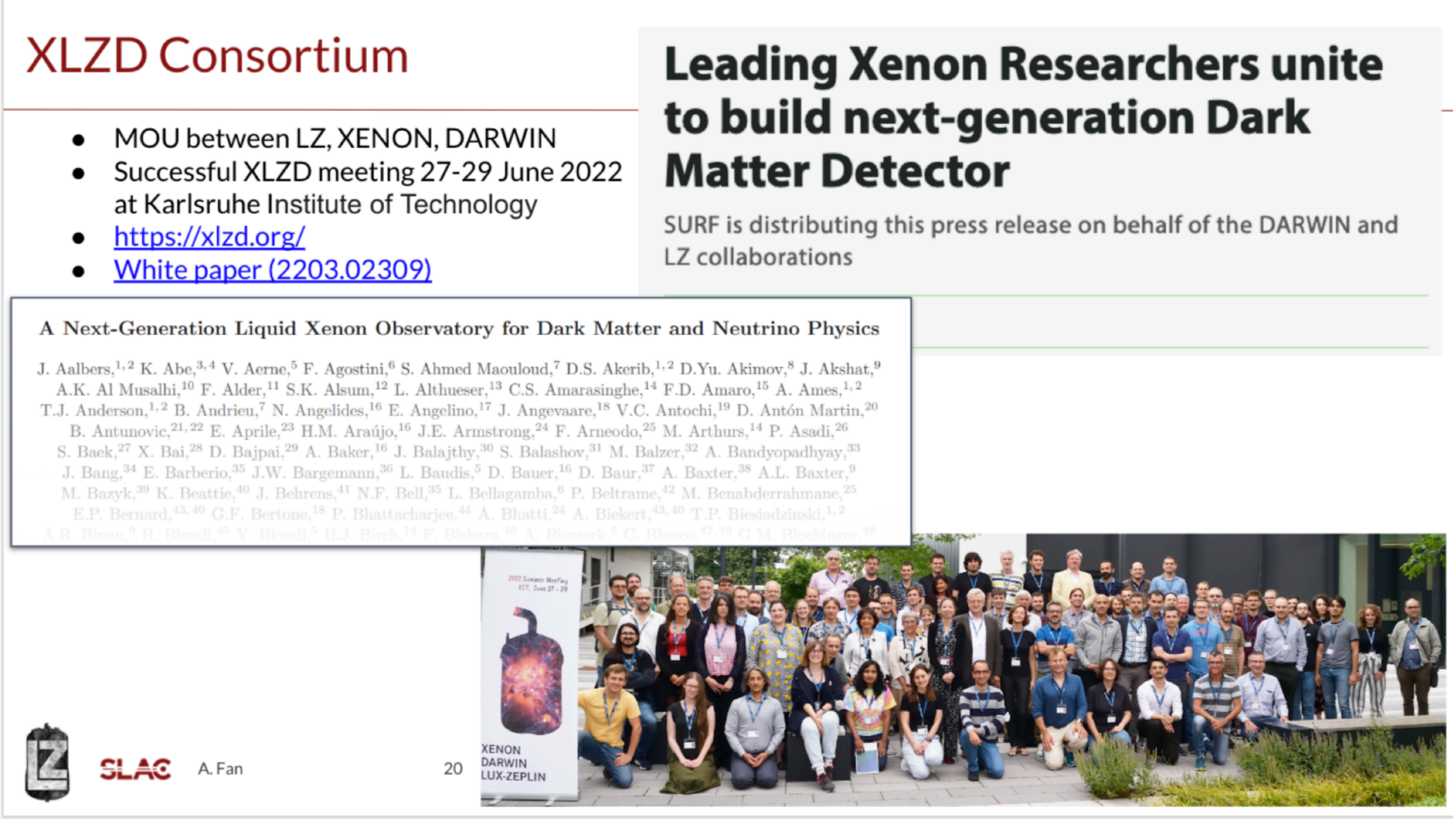
Global significance (after LEE correction):

$$Z^{\text{global}} = 1.17$$

- **State-of-the-art: >100 GeV/c^2**
- **Lowest upper limit: 1.7×10^{-47} cm^2** at **40 GeV/c^2** after -1σ power-constraint



XLZD -> next-gen LXe detector



XLZD Consortium

- MOU between LZ, XENON, DARWIN
- Successful XLZD meeting 27-29 June 2022 at Karlsruhe Institute of Technology
- https://xlzd.org/
- White paper (2203.02309)

Leading Xenon Researchers unite to build next-generation Dark Matter Detector

SURF is distributing this press release on behalf of the DARWIN and LZ collaborations

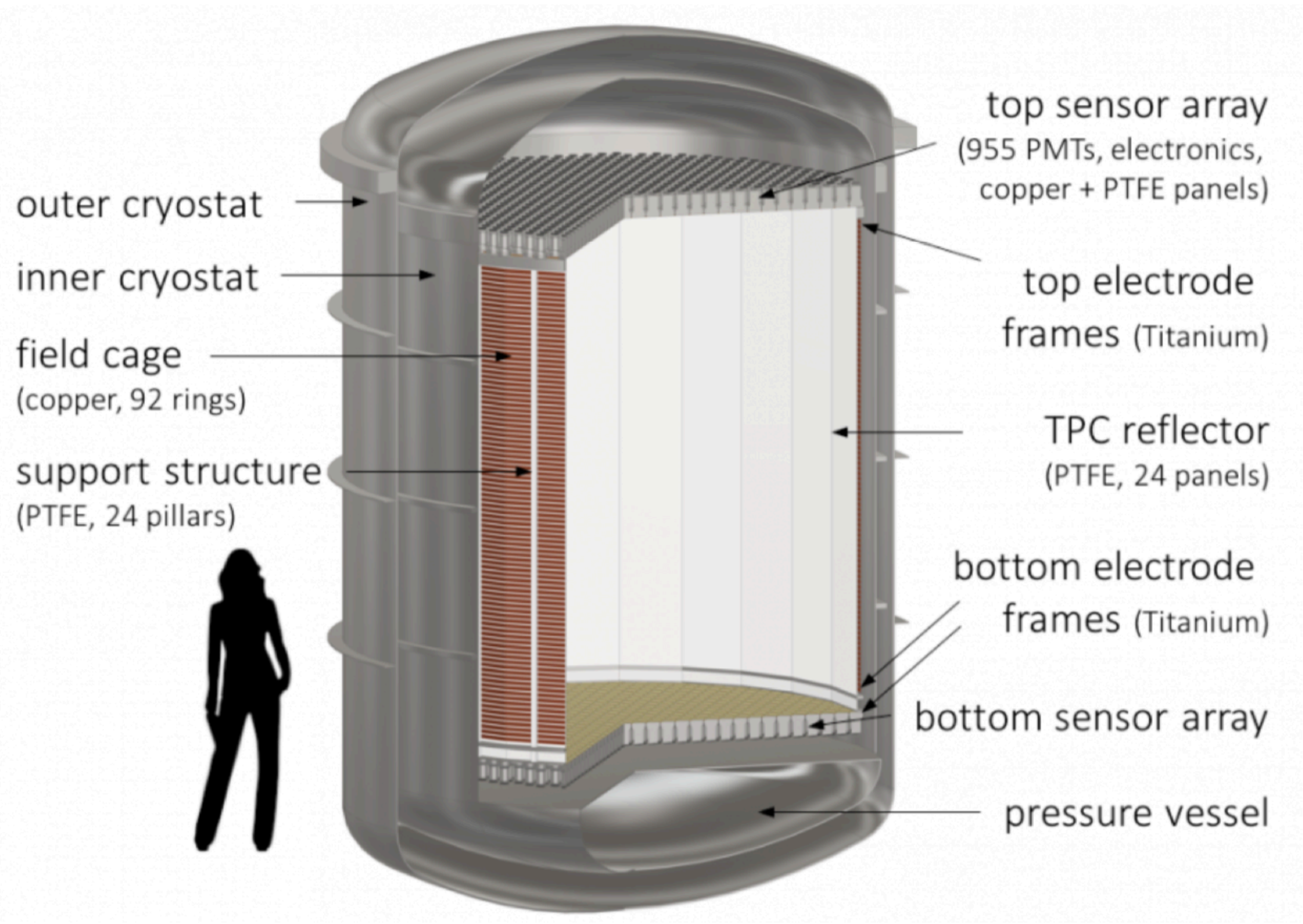
A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

J. Aalbers,[1,2] K. Abe,[3,4] V. Aerne,[5] F. Agostini,[6] S. Ahmed Maouloud,[7] D.S. Akerib,[1,2] D.Yu. Akimov,[8] J. Akshat,[9] A.K. Al Musalhi,[10] F. Alder,[11] S.K. Alsum,[12] L. Althueser,[13] C.S. Amarasinghe,[14] F.D. Amaro,[15] A. Ames,[1,2] T.J. Anderson,[1,2] B. Andrieu,[7] N. Angelides,[16] E. Angelino,[17] J. Angevaare,[18] V.C. Antochi,[19] D. Antón Martin,[20] B. Antunovic,[21,22] E. Aprile,[23] H.M. Araújo,[16] J.E. Armstrong,[24] F. Arneodo,[25] M. Arthurs,[14] P. Asadi,[26] S. Baek,[27] X. Bai,[28] D. Bajpai,[29] A. Baker,[16] J. Balajthy,[30] S. Balashov,[31] M. Balzer,[32] A. Bandyopadhyay,[33] J. Bang,[34] E. Barberio,[35] J.W. Bargemann,[36] L. Baudis,[5] D. Bauer,[16] D. Baur,[37] A. Baxter,[38] A.L. Baxter,[9] M. Bazyk,[39] K. Beattie,[40] J. Behrens,[41] N.F. Bell,[35] L. Bellagamba,[6] P. Beltrame,[42] M. Benabderrahmane,[25] E.P. Bernard,[43,40] G.F. Bertone,[18] P. Bhattacharjee,[44] A. Bhatti,[24] A. Biekert,[43,40] T.P. Biesiadzinski,[1,2] A.R. Binau,[9] R. Biondi,[45] Y. Biondi,[5] H.J. Birch,[14] F. Bishara,[46] A. Bismark,[5] C. Blanco,[47,19] G.M. Blockinger,[48]

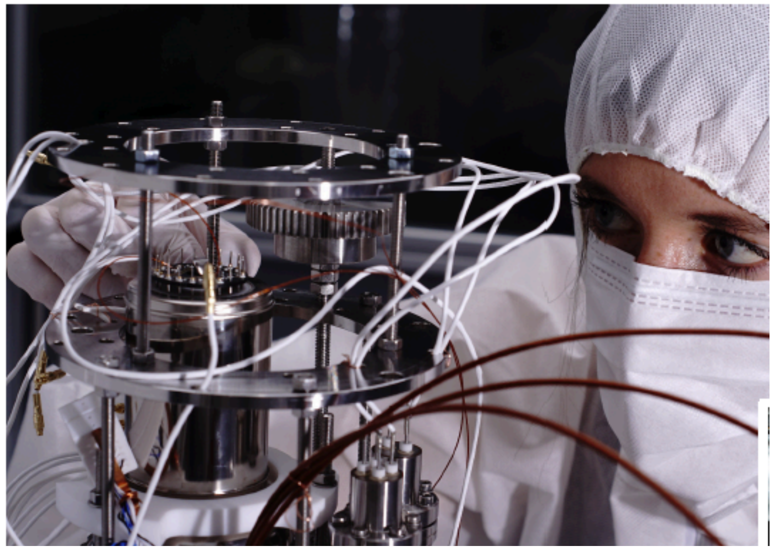
SLAC A. Fan 20

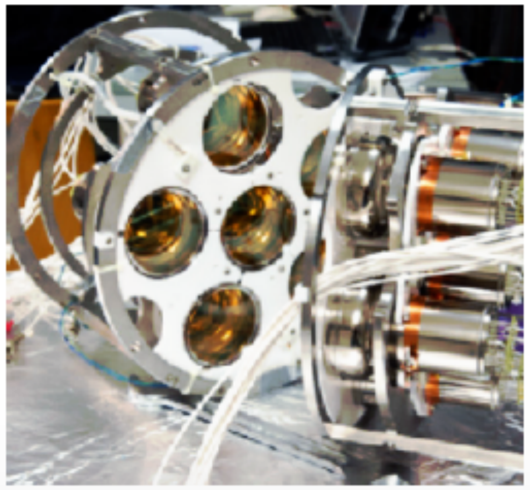
XLZD -> next-gen LXe detector

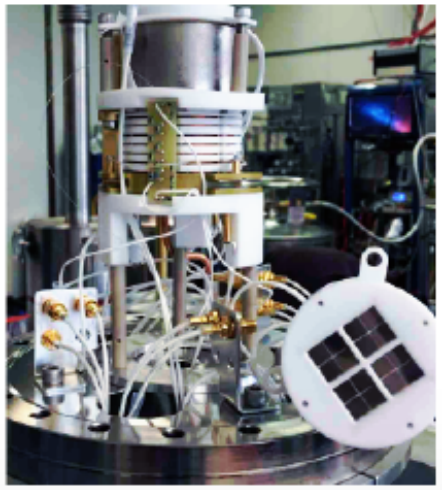
Various ongoing R&D on Rn, photosensors, electrodes

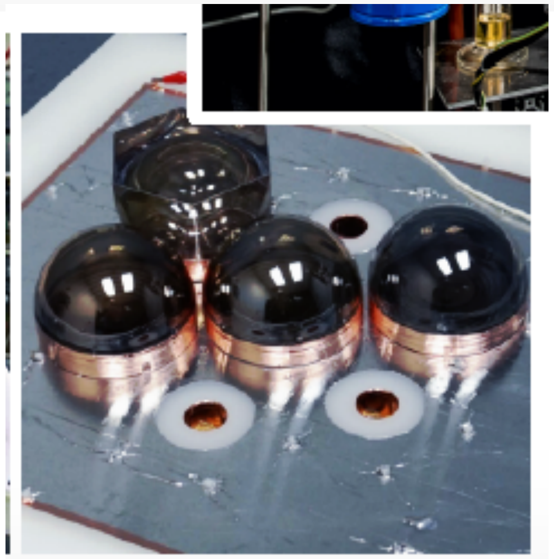


http://darwin-observatory.org/



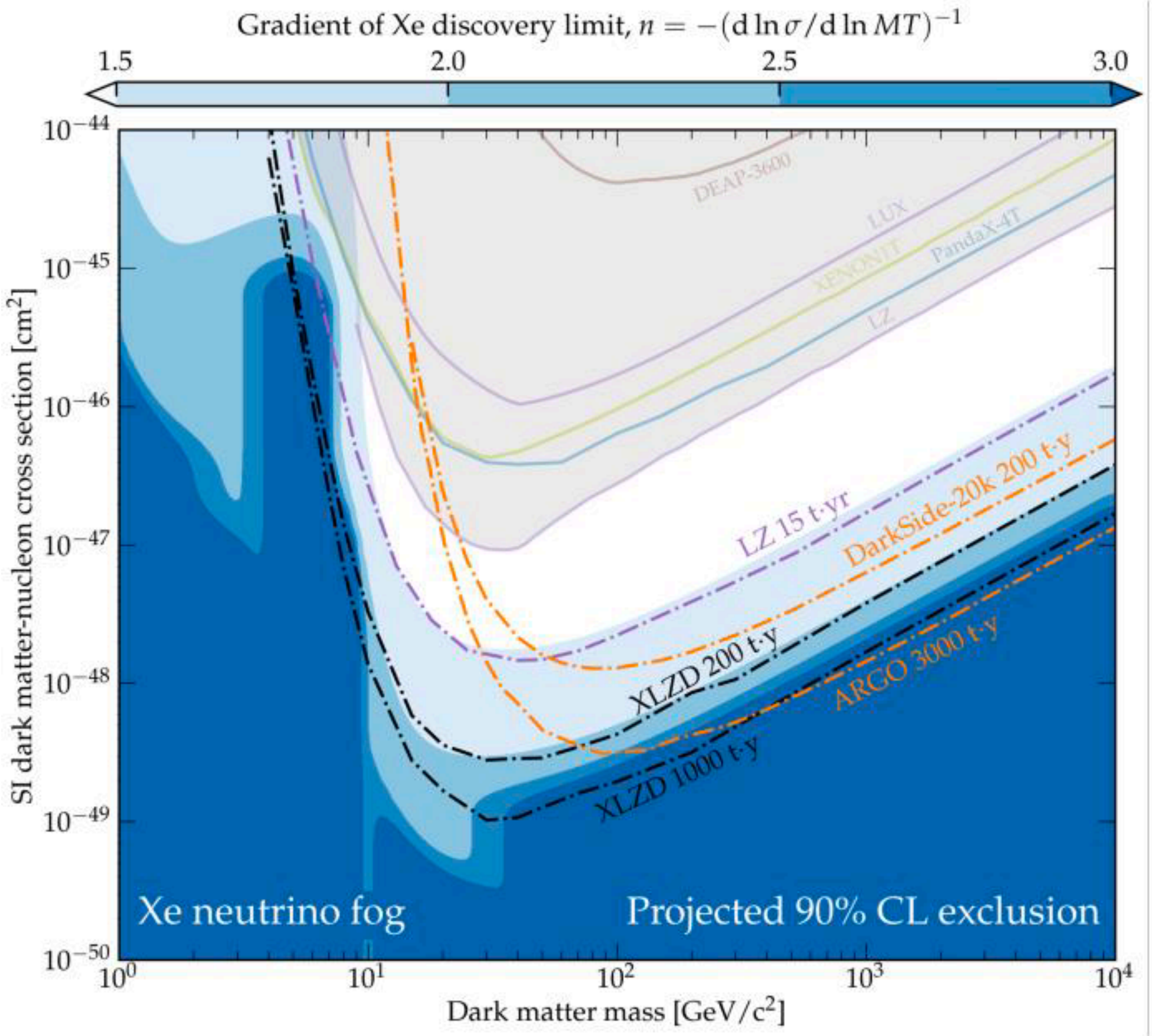






- Baseline design for a large liquid xenon dark matter detector
- TPC of about 3.0 m ⌀ & 3.0 m drift length
- 80 t LXe total mass (60 t inside the TPC)

Direct Detection of WIMPs by 2030?



nT, LZ projections

DarkSide-20k

XLZD / ARGO

Thanks !

Recent Results in Direct Dark Matter Detection

Marco Selvi
INFN Bologna

Invisibles24, 2 July 2024, Bologna

Thanks !

Recent Results in Direct Dark Matter Detection

Marco Selvi
INFN Bologna

Invisibles24, 2 July 2024, Bologna

Backup

Future in NaI detectors: new COSINE-100 results

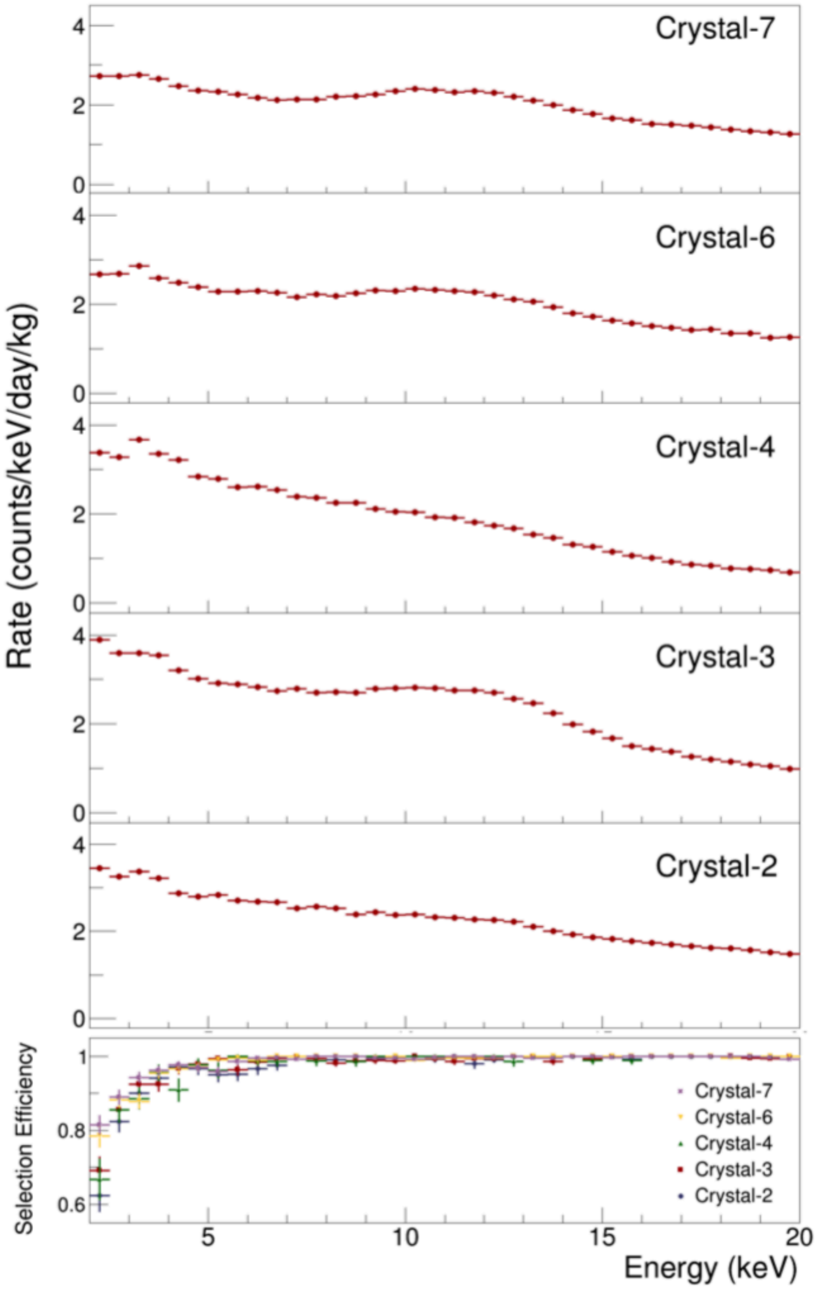


FIG. 2. Efficiency-corrected and time-integrated energy spectra for the five crystals used in this analysis between 2–20 keV (top panels) and signal selection efficiency evaluated using ^{60}Co calibration data (bottom panel). The efficiencies at 2 keV are $>60\%$ for all crystals. The primary sources of background in the crystals are ^{210}Pb and ^{40}K, which are lower for Crystal-6 and Crystal-7. These spectra are obtained using the full data set considered in this analysis.

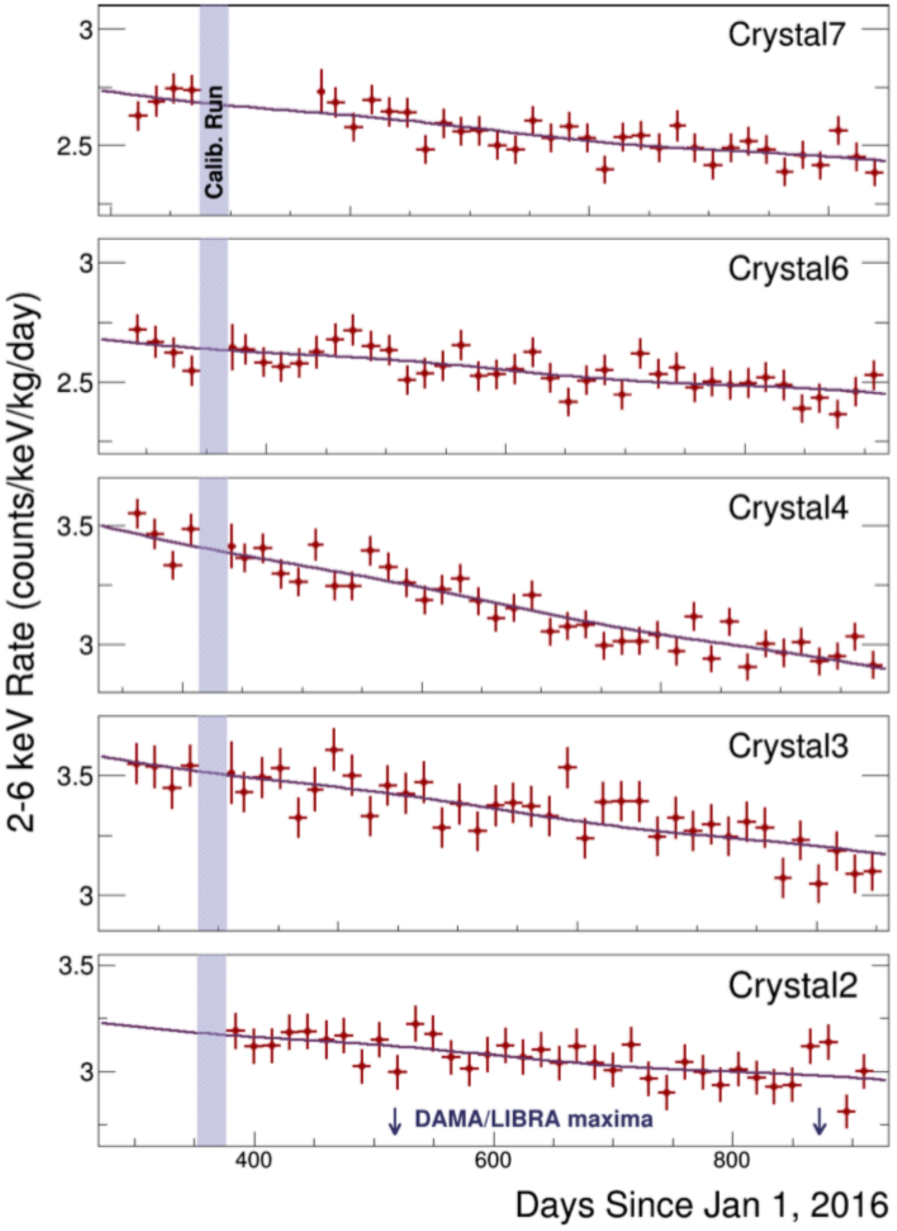
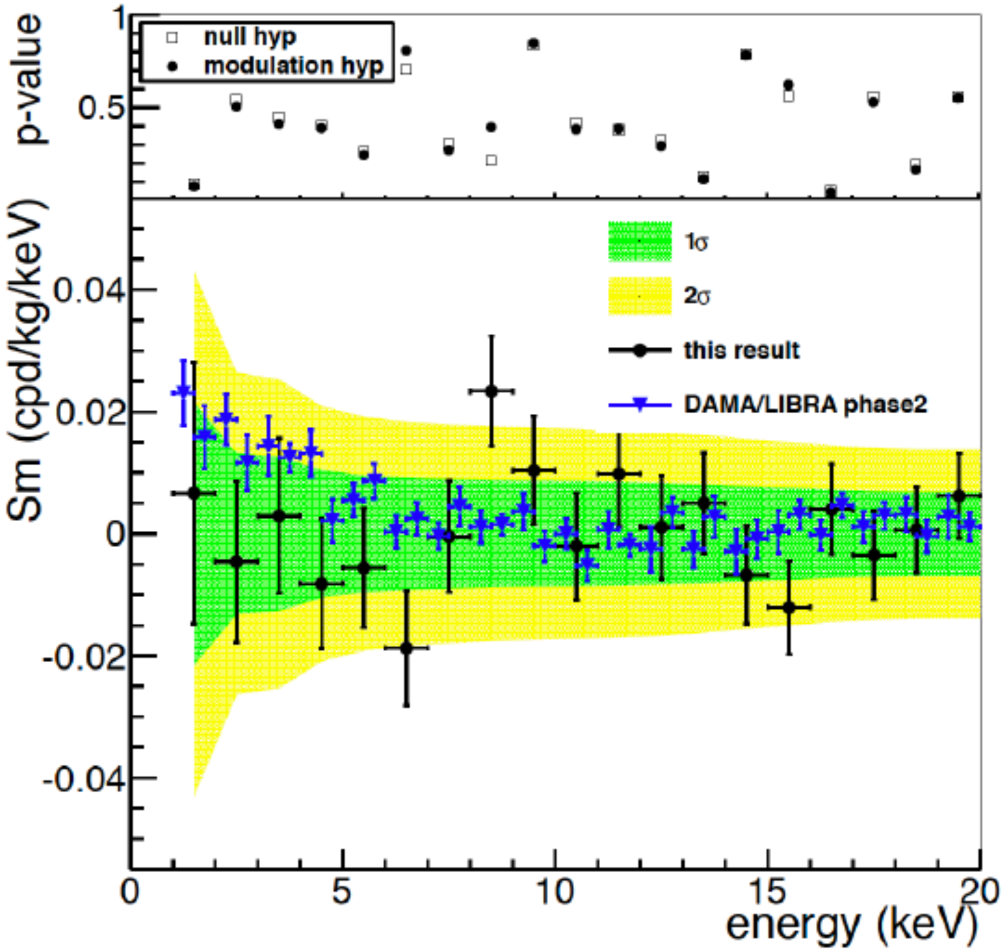


FIG. 3. Rate vs. time for Crystals 2, 3, 4, 6, & 7 from October 21, 2016 to July 18, 2018 for energies between the 2–6 keV energy bin in 15-day intervals. The histograms show the result of the fit described in the text. Solid blue arrows indicate the peak date in the modulation as reported by DAMA/LIBRA [12]. Data taking was suspended for calibrations at the end of 2016 as indicated by the shaded region.

ANAIS

NEW

ANAIS-112



arXiv:1903.03973

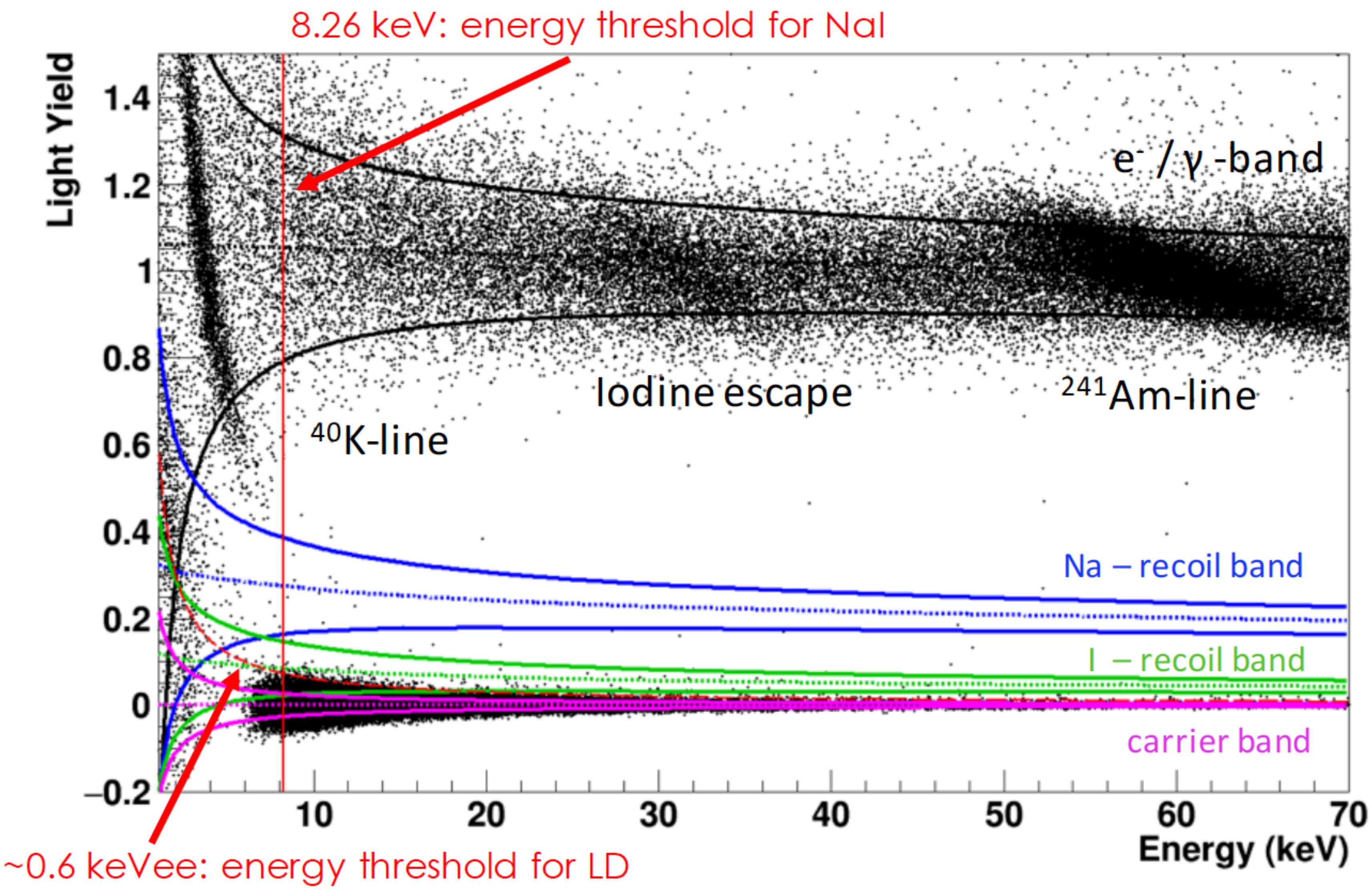
time: 1.5 years of data

exposure: 157.55 kg year

best fits are consistent with the absence of modulation

COSINUS

COSINUS PROTOTYPE DETECTOR



- NaI energy threshold is (8.26 ± 0.02 (stat.))keV
- width of the ^{241}Am peak is (4.508 ± 0.064 (stat.)) keV
- carrier events identified by pulse shape

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

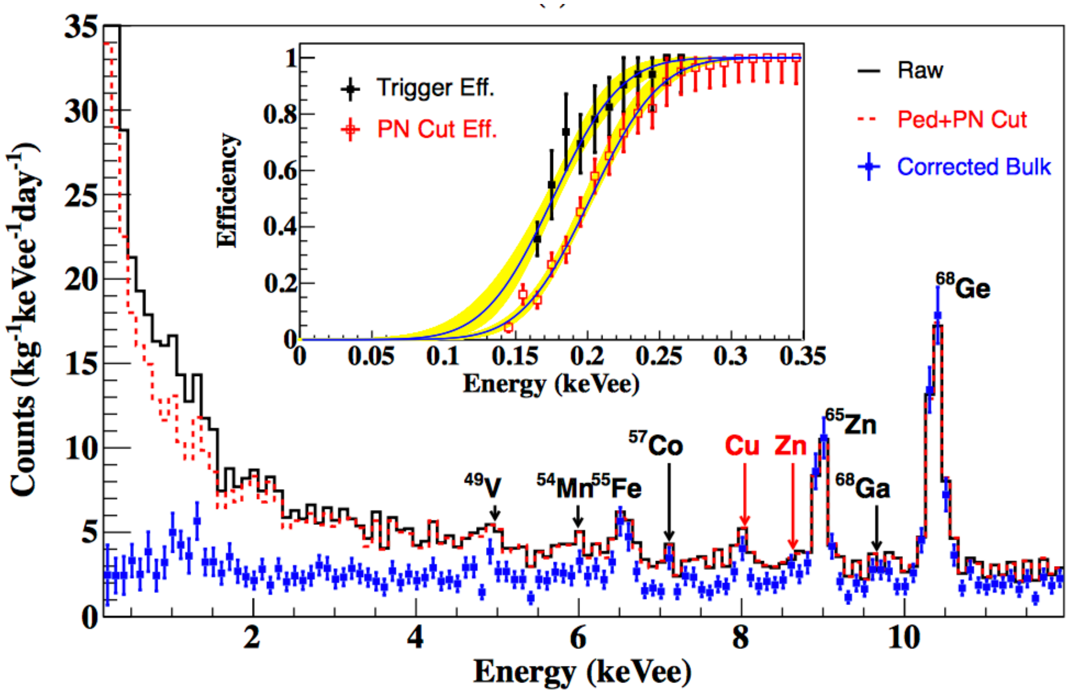
Low-mass (1-10 GeV) dark matter: low-threshold counting

battle between low-threshold and low-background

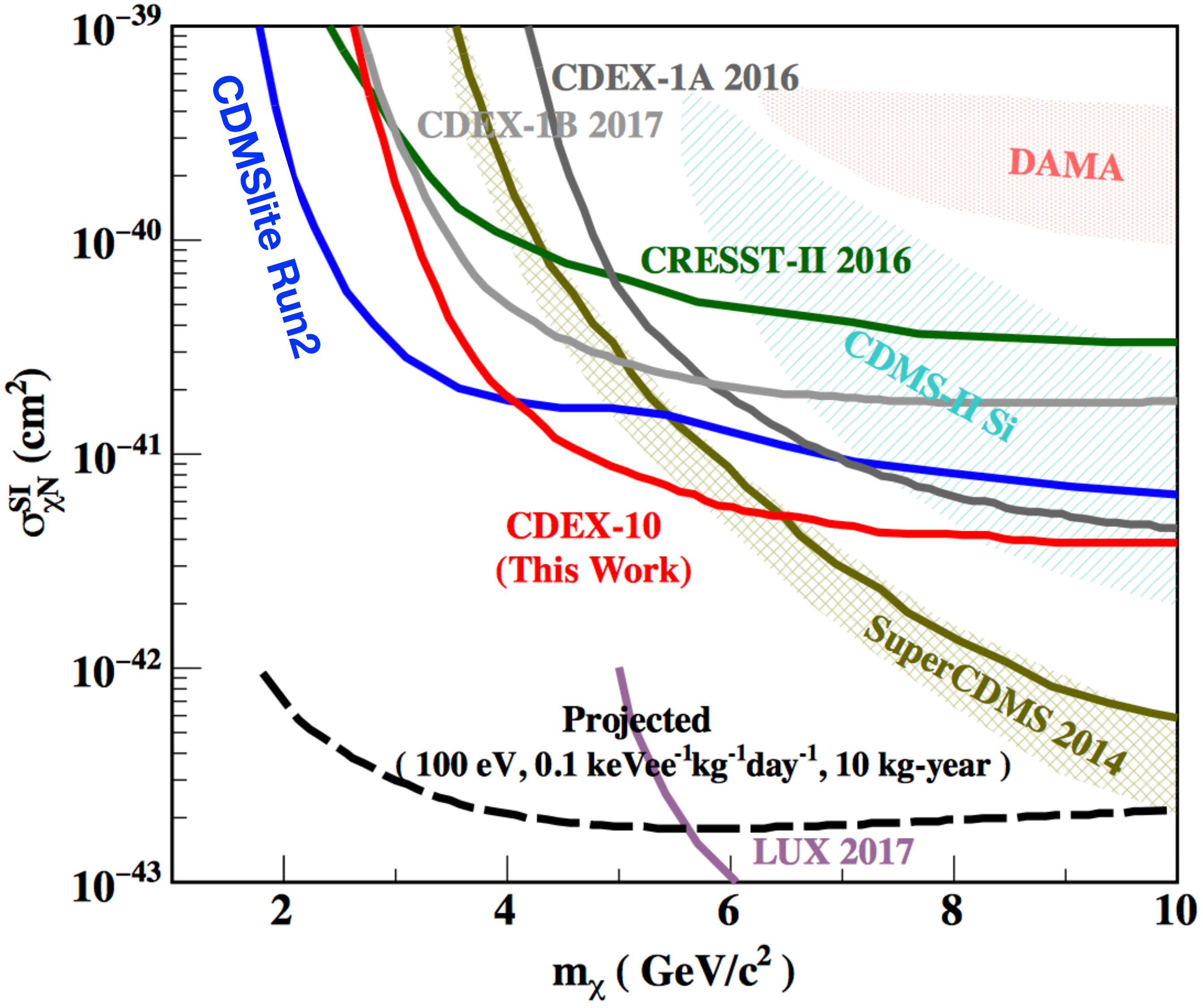
CoGeNT, CDEX: Ge Point Contact detector, low capacitance

CDEX-10 at CJPL

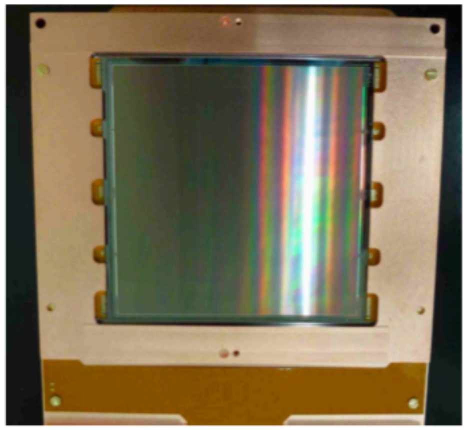
- 10kg Ge detector in liquid nitrogen
- 102.8 kg-days exposure
- analysis threshold: 160 eVee
- residual bkg rate: ~2.5 evt/keVee/kg/day
- improved SI & SD-n limits at 5 GeV/c^2



CDEX, arXiv:1802.09016

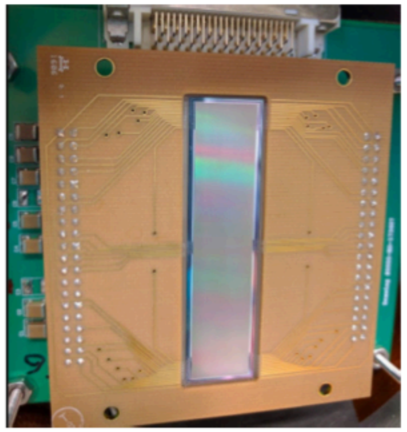


Sub-GeV Dark Matter searches



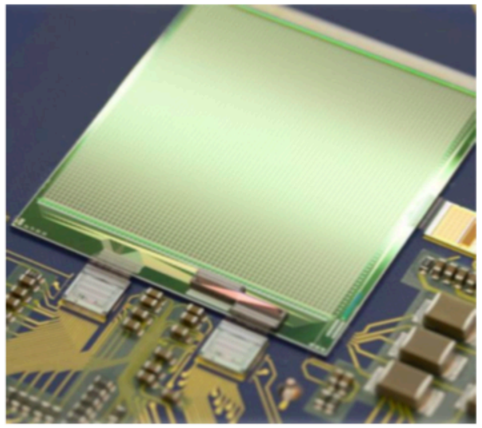
DAMIC

PRL 118 (2017) 141803



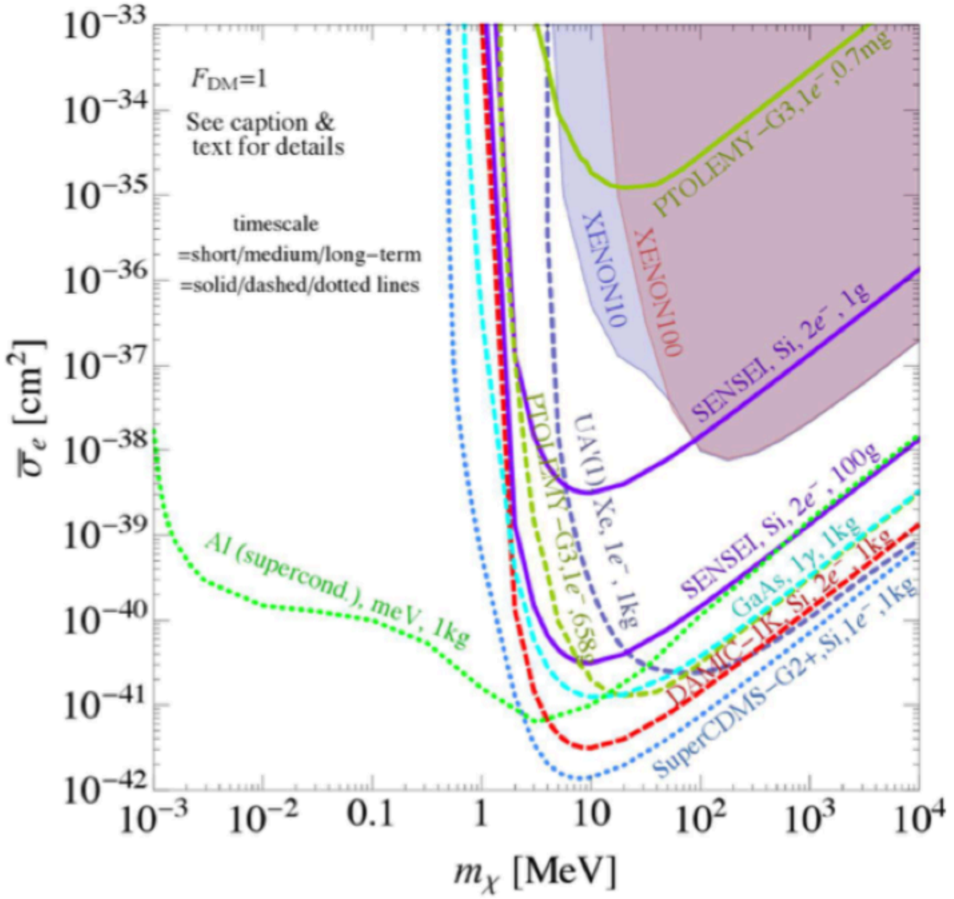
SENSEI

PRL 121 (2018) 061803



DANAE

EPJC 77 (2017) 12, 905



- Test of DM-electron scattering down to 1 MeV DM mass
- Silicon detector with E_{th} = 50 eV$_{ee}$
- CCD technology being used

Figure from 'New Ideas in Dark Matter 2017', arXiv:1707.04591

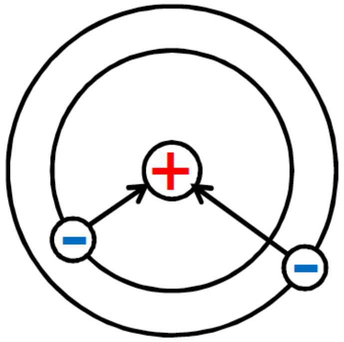
Low energy ER calibration in XENON1T

^{37}Ar decay:
Electron capture

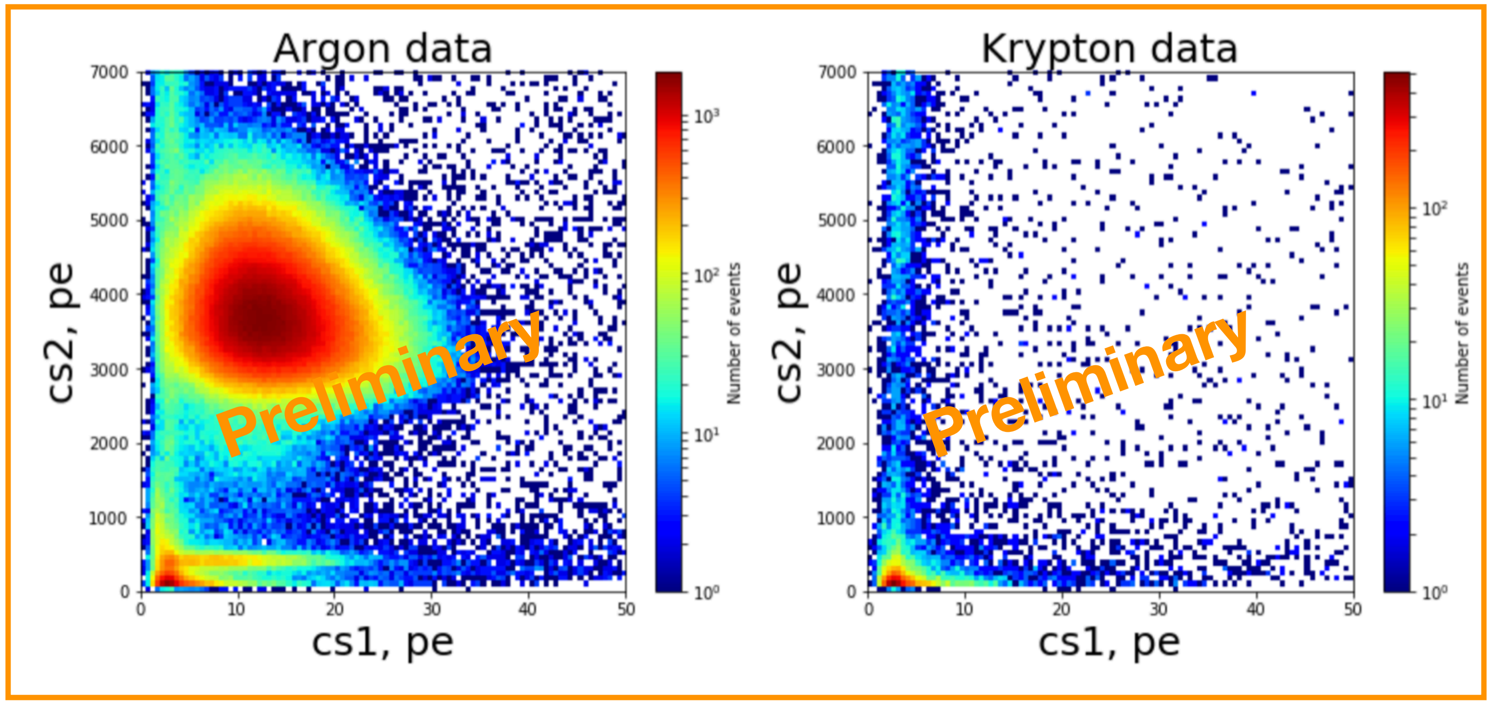
$T_{1/2} = 35$d

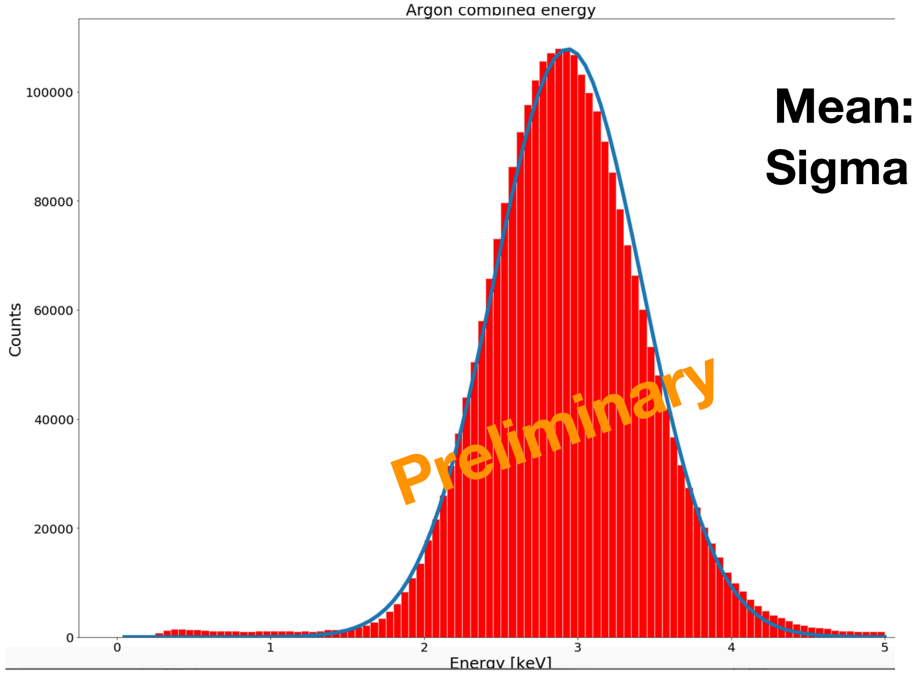
Why use ^{37}Ar:

- Internal source (diluted in xenon): avoid self-shielding of xenon
- Very low-energy line source: 2.82 keV

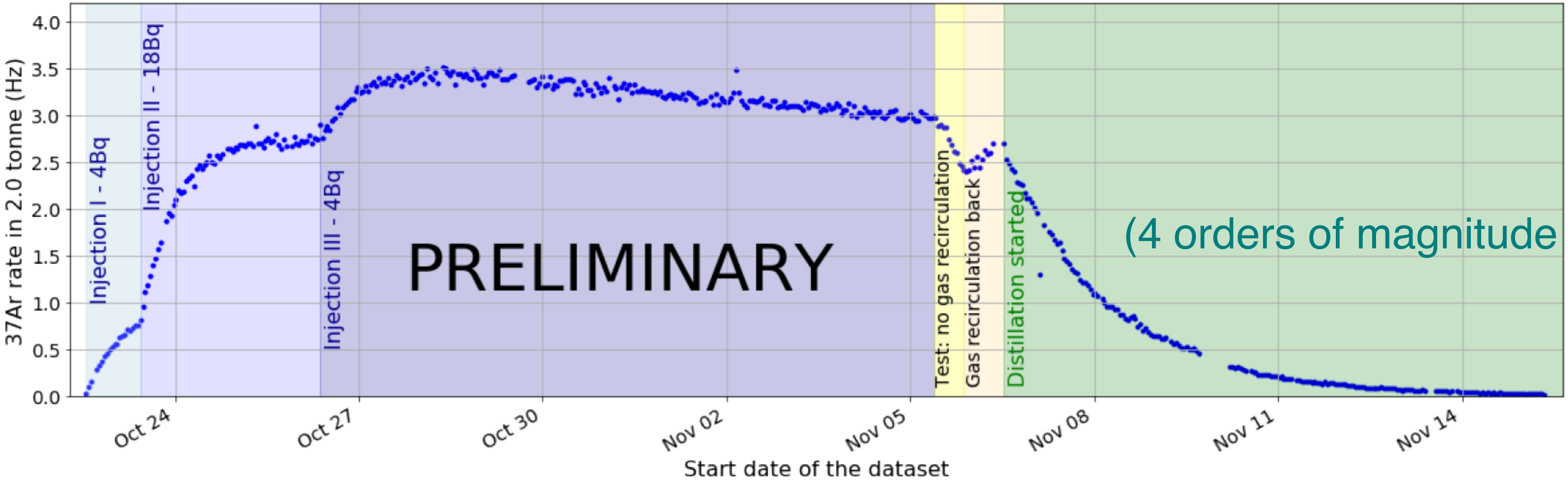


	K-Shell	L-Shell
Energy:	2.82 keV	0.27 keV
Branching ratio:	90%	9%



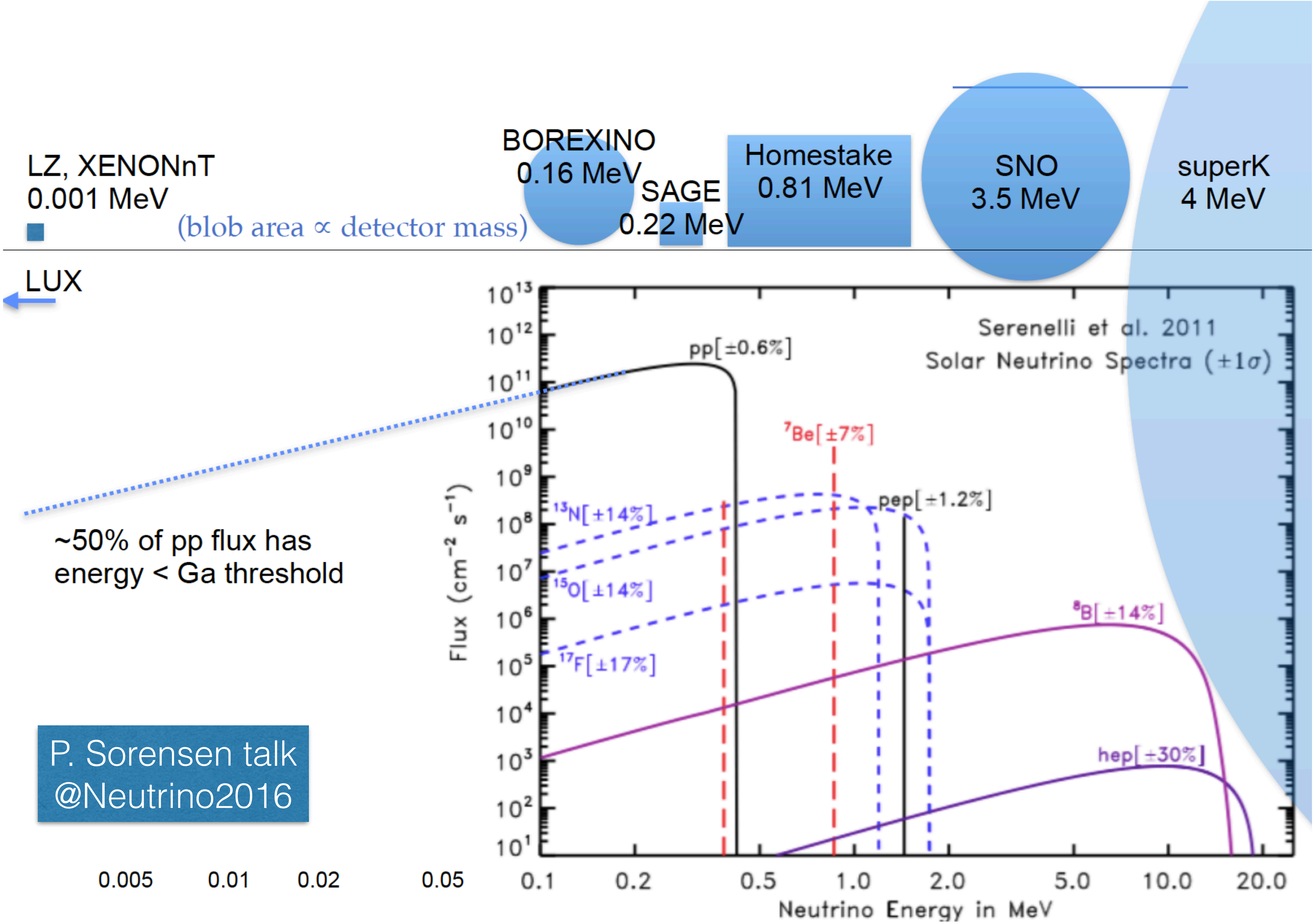


Mean: 2.9 keV
Sigma: 0.5 keV



(4 orders of magnitude in 16 days)

Solar neutrino & detectors

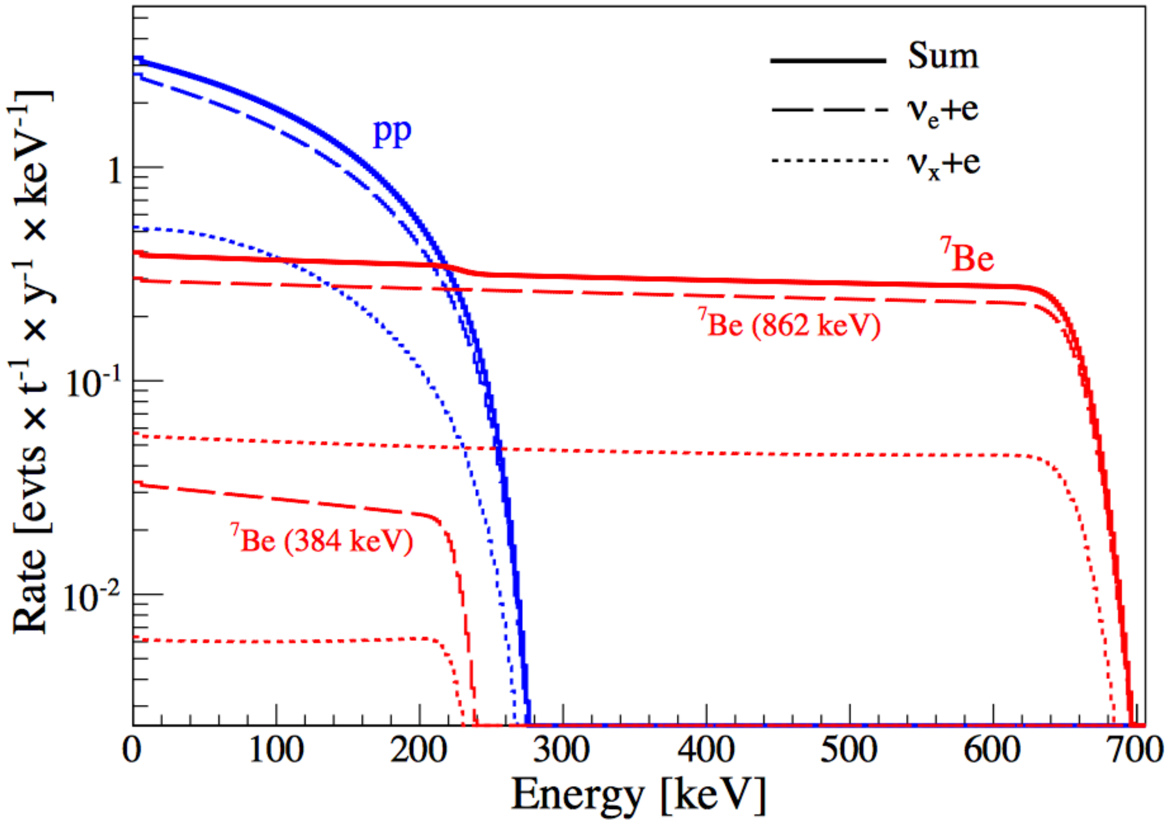


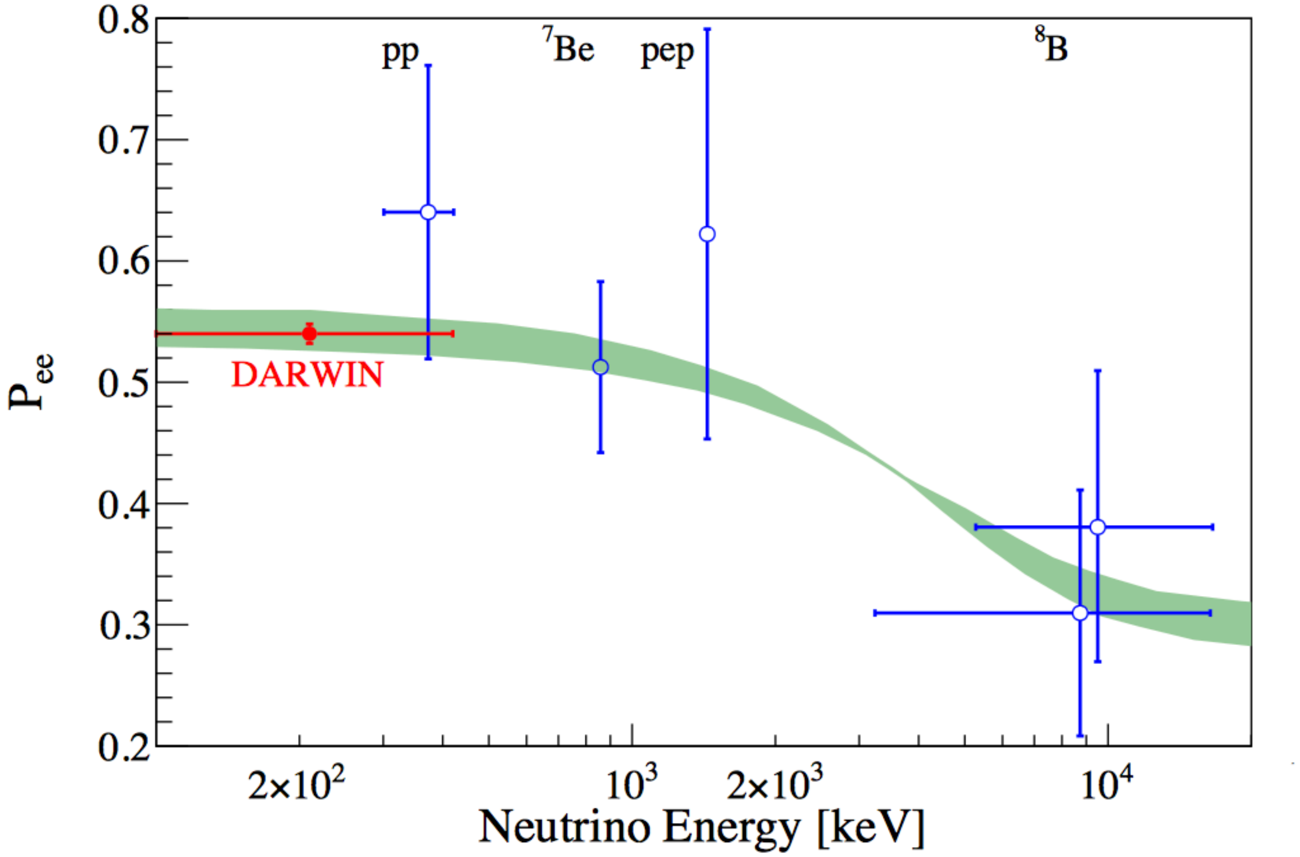
~50% of pp flux has energy < Ga threshold

P. Sorensen talk @Neutrino2016

Measuring pp neutrinos

JCAP 1611 (2016) no.11, 017





- XENONnT/LZ could reduce the uncertainty on the pp flux to 2.2% (currently Borexino is @10%)
- DARWIN (50t LXe) could bring this down further, to ~1%
- Need to reduce Rn by a factor >10

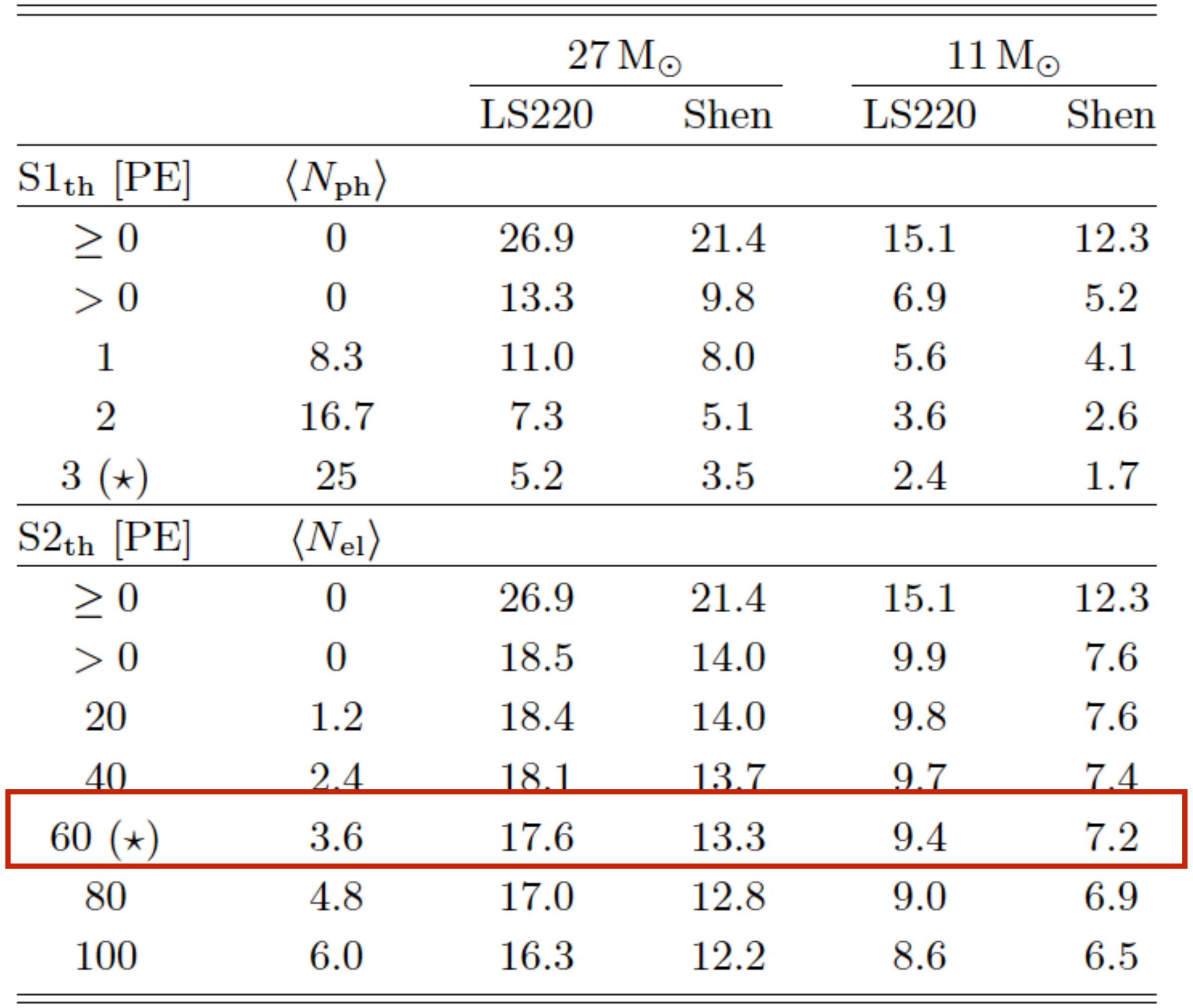
Neutrinos from SN

R. Lang, C. McCabe, S. Reichard, M.S., I. Tamborra,
"Supernova neutrino physics with xenon dark matter detectors", Phys. Rev. D 94 (2016) no.10, 103009.

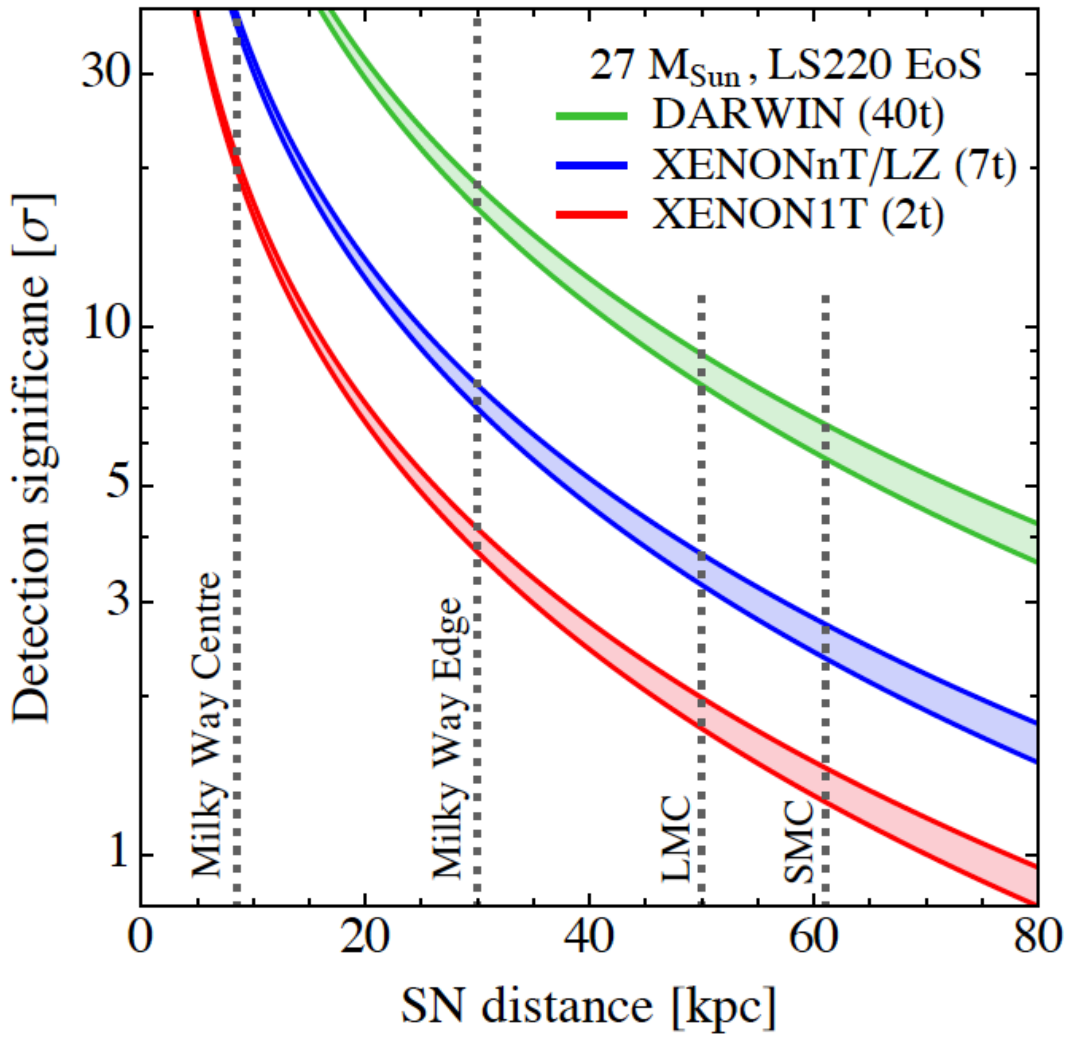
CEvNS with xenon nuclei: not affected by neutrino oscillation

- Low energy events -> S2-only analysis
- (in the few s burst duration the background rate is small enough: 0.02 / (t s))

Events per ton of Xe

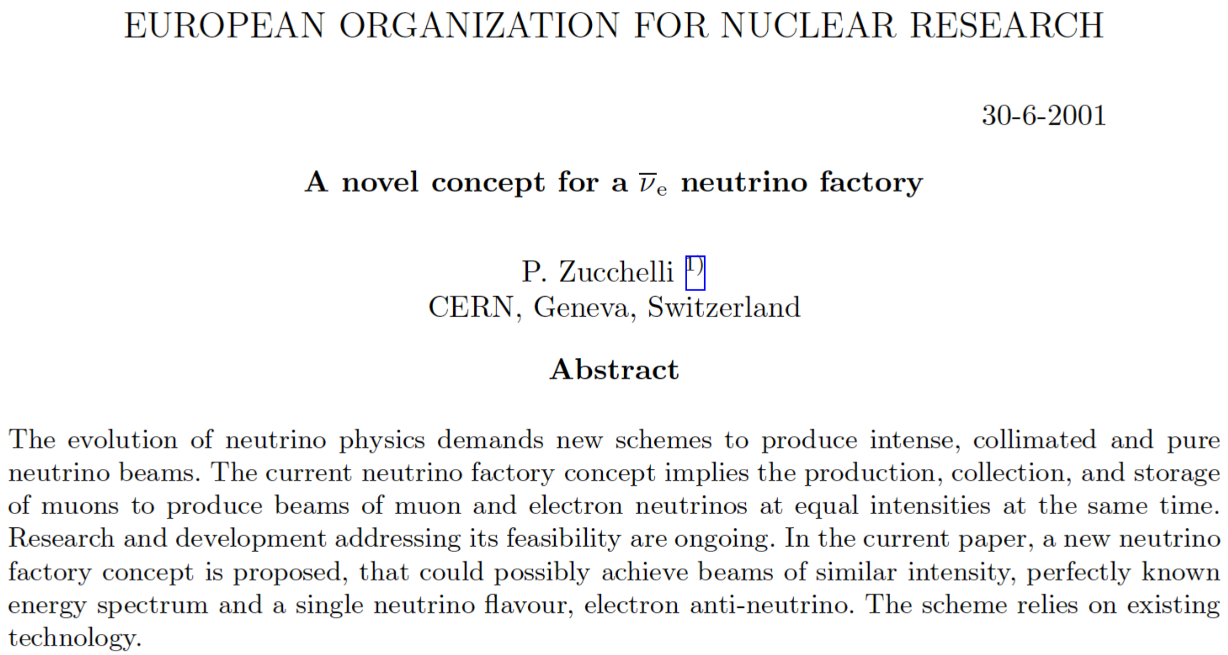


		27 $M_\odot$		11 $M_\odot$	
		LS220	Shen	LS220	Shen
$S1_{th}$ [PE]	$\langle N_{ph} \rangle$				
≥ 0	0	26.9	21.4	15.1	12.3
> 0	0	13.3	9.8	6.9	5.2
1	8.3	11.0	8.0	5.6	4.1
2	16.7	7.3	5.1	3.6	2.6
3 ($\star$)	25	5.2	3.5	2.4	1.7
$S2_{th}$ [PE]	$\langle N_{el} \rangle$				
≥ 0	0	26.9	21.4	15.1	12.3
> 0	0	18.5	14.0	9.9	7.6
20	1.2	18.4	14.0	9.8	7.6
40	2.4	18.1	13.7	9.7	7.4
60 ($\star$)	3.6	17.6	13.3	9.4	7.2
80	4.8	17.0	12.8	9.0	6.9
100	6.0	16.3	12.2	8.6	6.5



Neutrinos as NR calibration

- An O(10 MeV) beta-beam -> CNNS NR



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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A novel concept for a $\overline{\nu}_e$ neutrino factory

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Abstract

The evolution of neutrino physics demands new schemes to produce intense, collimated and pure neutrino beams. The current neutrino factory concept implies the production, collection, and storage of muons to produce beams of muon and electron neutrinos at equal intensities at the same time. Research and development addressing its feasibility are ongoing. In the current paper, a new neutrino factory concept is proposed, that could possibly achieve beams of similar intensity, perfectly known energy spectrum and a single neutrino flavour, electron anti-neutrino. The scheme relies on existing technology.

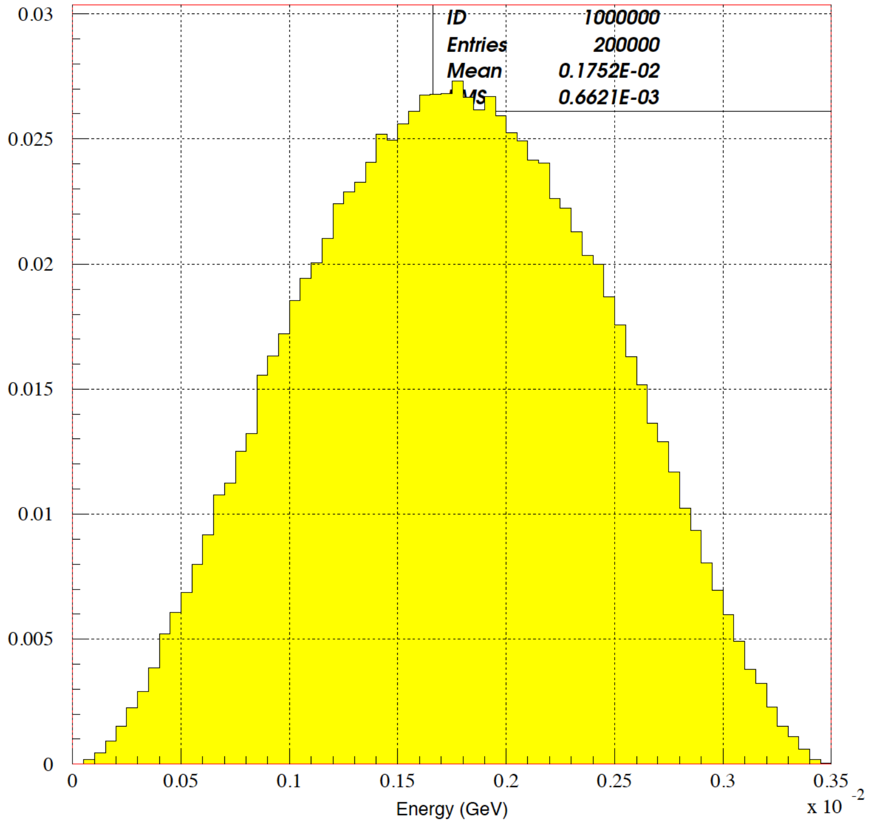

Figure 1: Neutrino energy spectrum in the centre-of-mass frame for a ^{6}He decay.

Accelerate an ^{6}He nucleus (end point at rest: 3.5 MeV) up to gamma = 10 (end point 70 MeV)

CNNS produce a *"few keV->tens of keV"* NR, uniformly distributed in the detector, with very well know energy spectrum.