Dark Matter at the GeV Scale and Below

with cryogenic detectors

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TECHNISCHE UNIVERSITÄT MÜNCHEN

Cryogenic Dark Matter Detectors

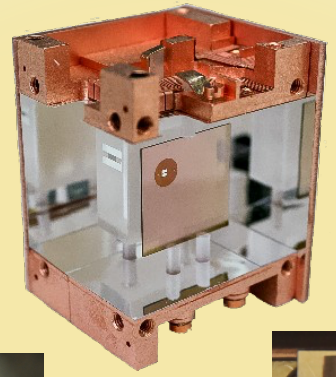
They are **beautiful** ❤

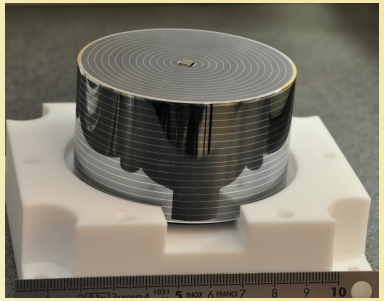
They are **diverse** 

They are **clever**

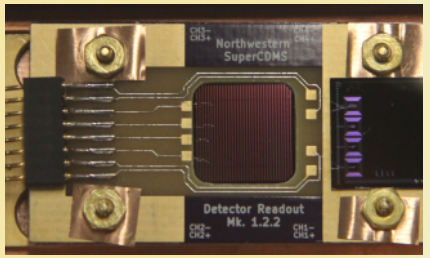
They are **low threshold**

CRESST-III

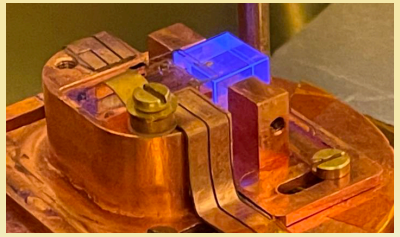




EDELWEISS FID800



SuperCDMS HVeV



Cosinus NaI

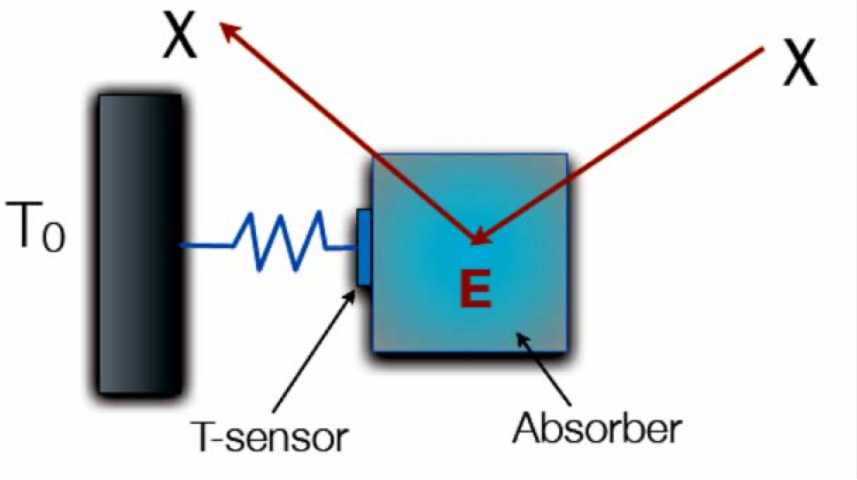
They are **small**

They are **big**

They are **multi-target**

They are (sometimes) **a pain** 😓

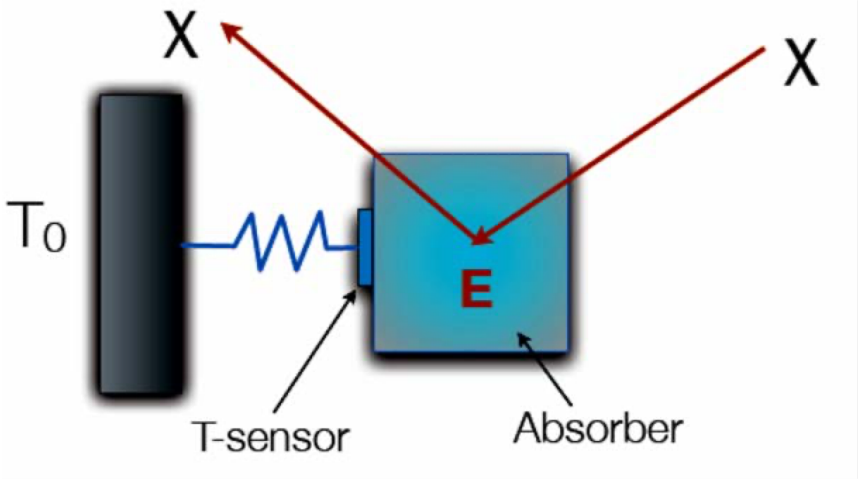
Cryogenic Detectors



$$C(T) = \frac{\Delta E}{\Delta T} \propto T^3$$

Need small heat capacity!
Need small temperature (mK)

Cryogenic Detectors



$$C(T) = \frac{\Delta E}{\Delta T} \propto T^3$$

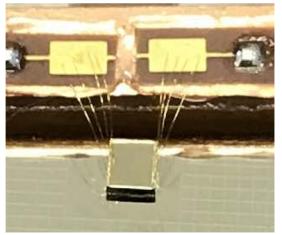
Need small heat capacity!
Need small temperature (mK)

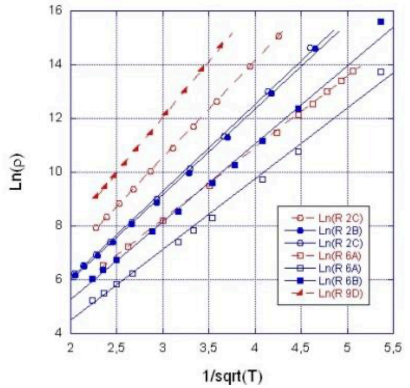
Sensor types:

EDELWEISS

Neutron-transmutation-doped (NTD) sensors

- Ge wafers with strong T-R dependence
- High linearity
- Sensitive to thermal phonons

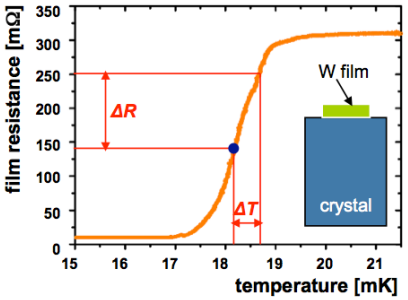




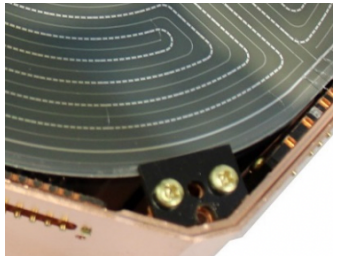
CRESST, SuperCDMS, COSINUS, EDELWEISS NEW

Transition-Edge-Sensor (TES)

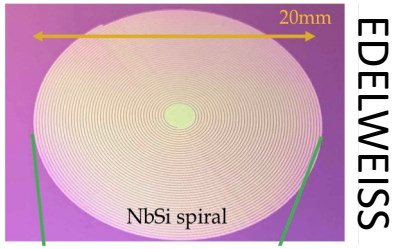
- Thin-film deposited on crystals
- Strong R-T dependence at superconducting transition
- Sensitive to athermal phonons



CRESST



SuperCDMS



EDELWEISS

The EXCESS background

success

"Threshold*inos*"

Scalability

Technological Breakthrough

Background rejection

time

A new community was born

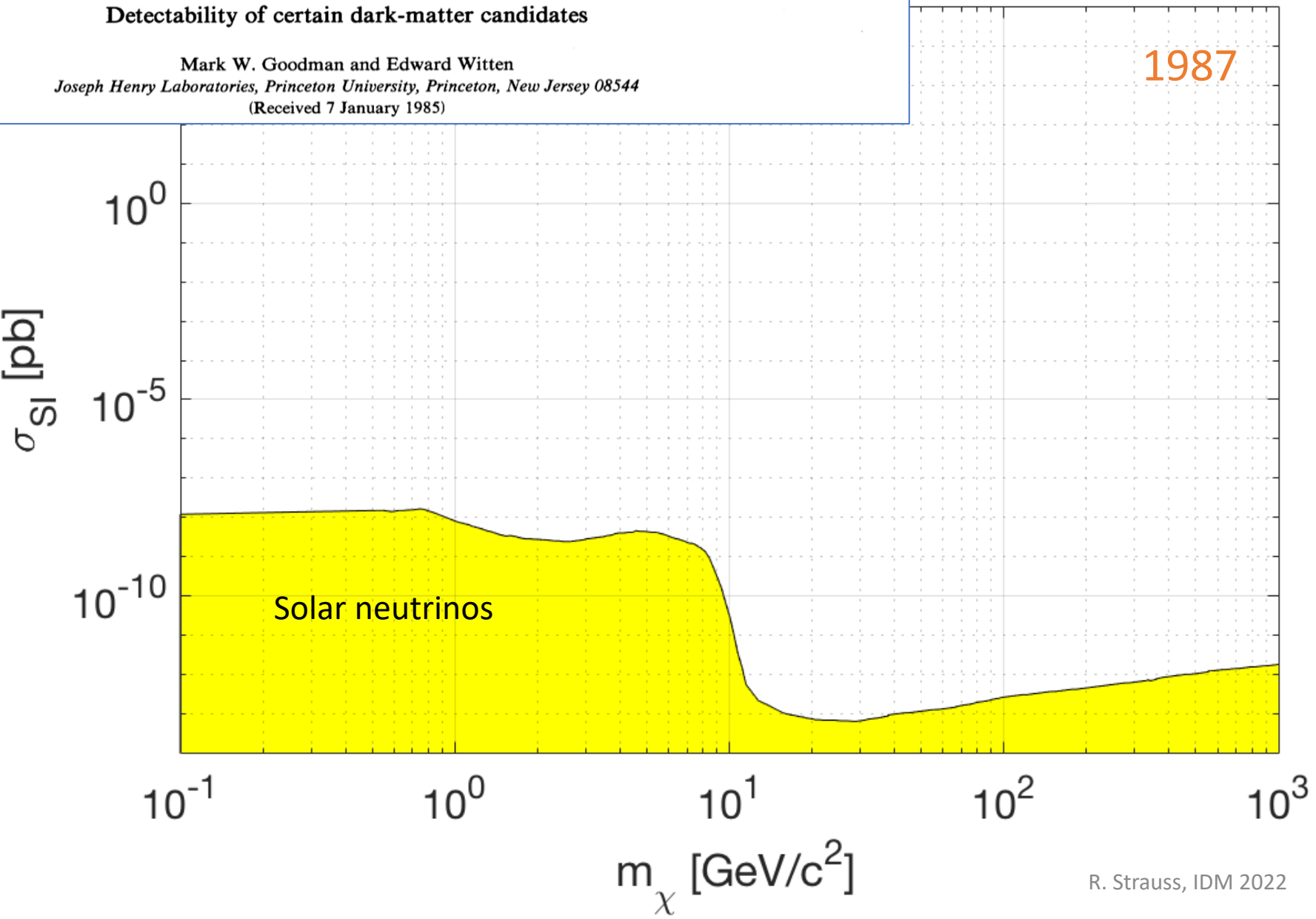
LTD-1 near Munich, 1987

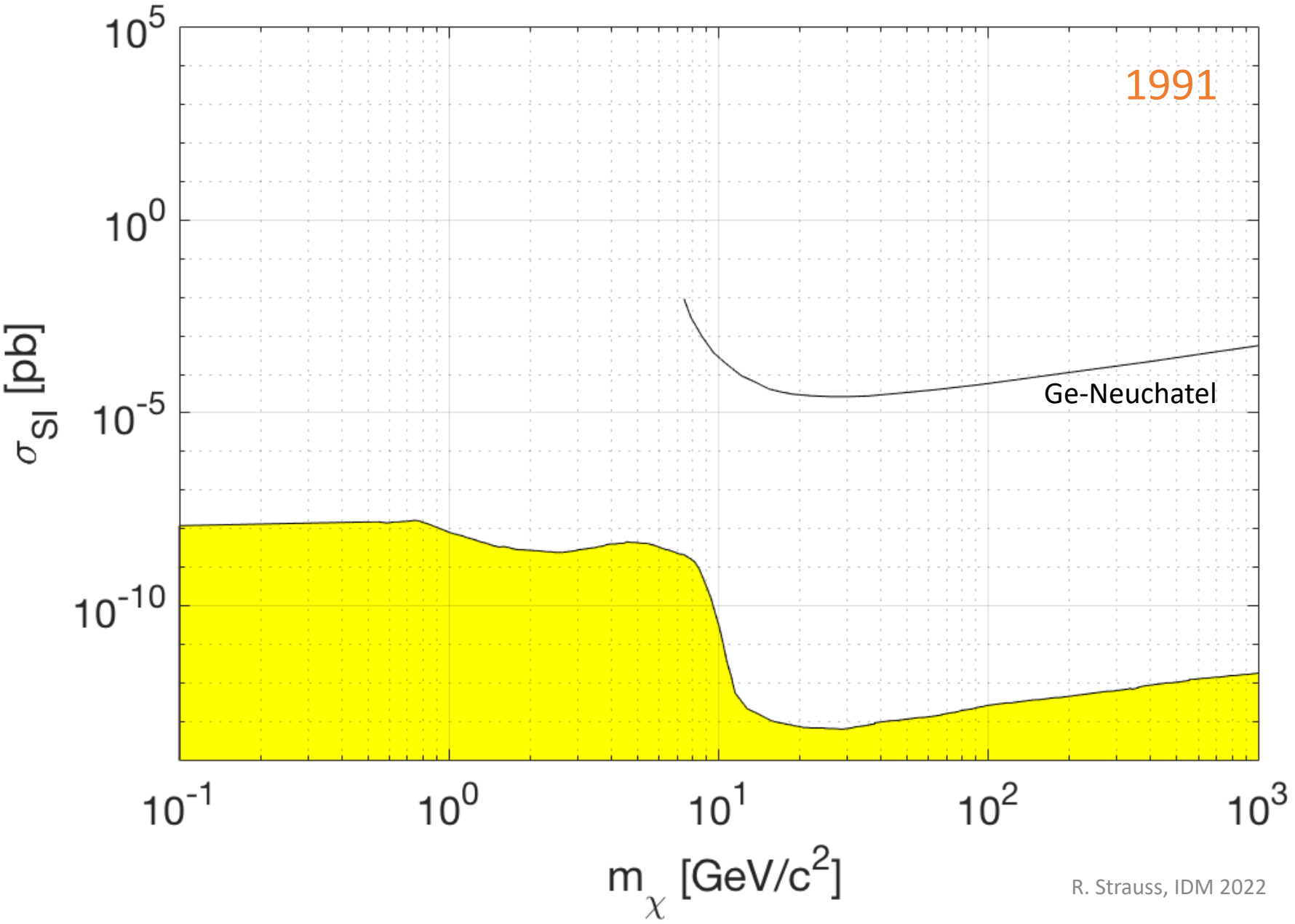
PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

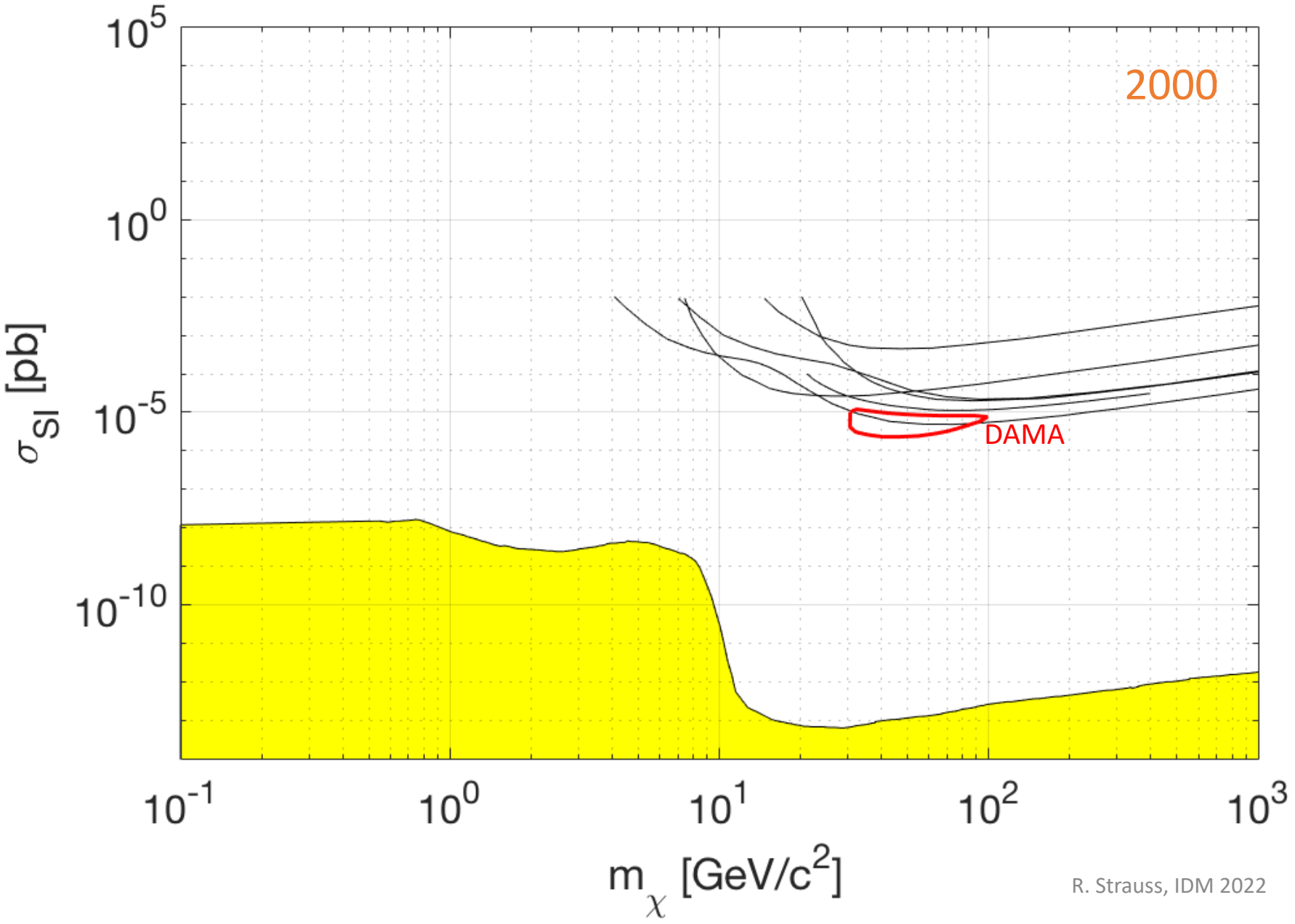
Detectability of certain dark-matter candidates

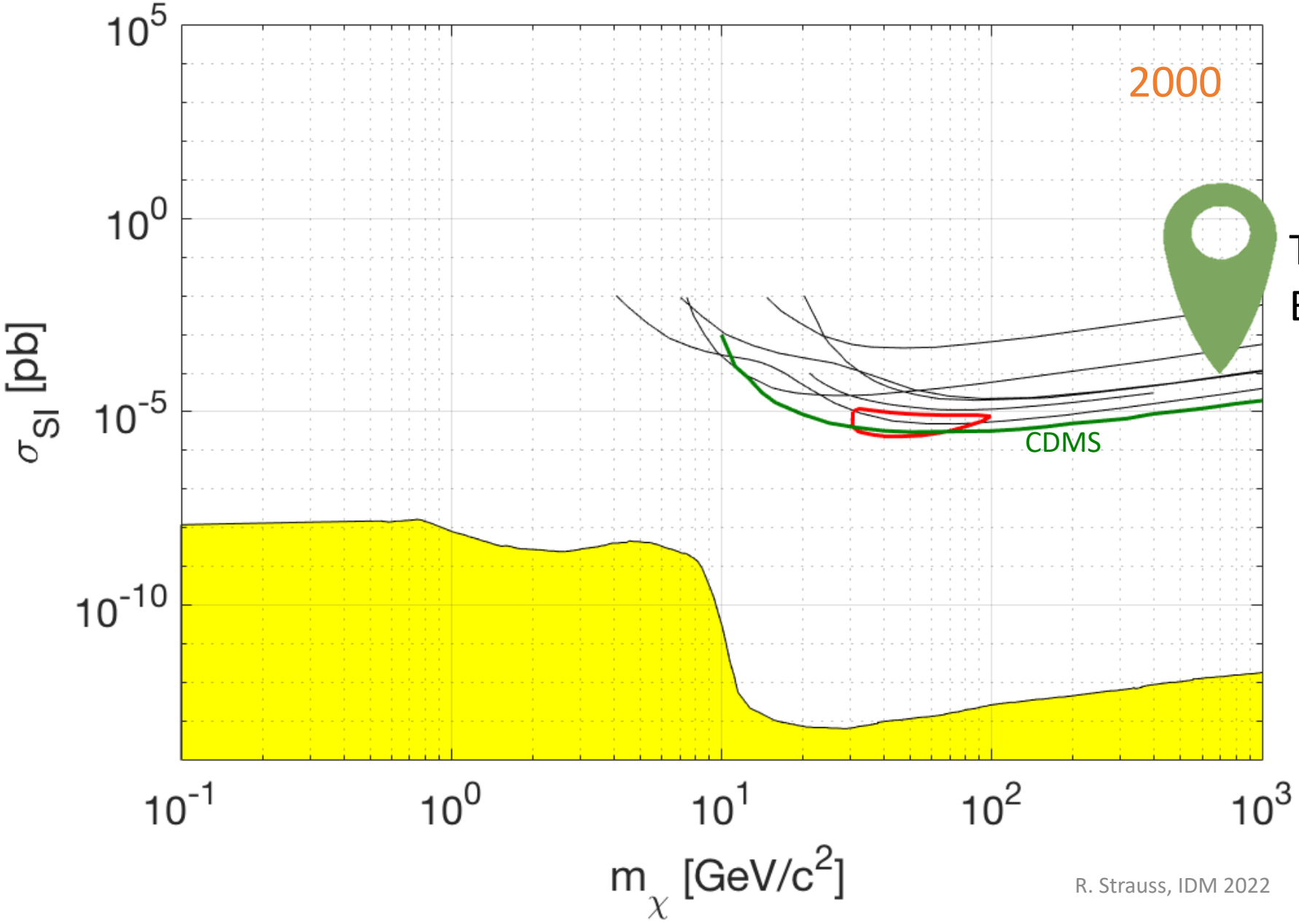
Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

1987

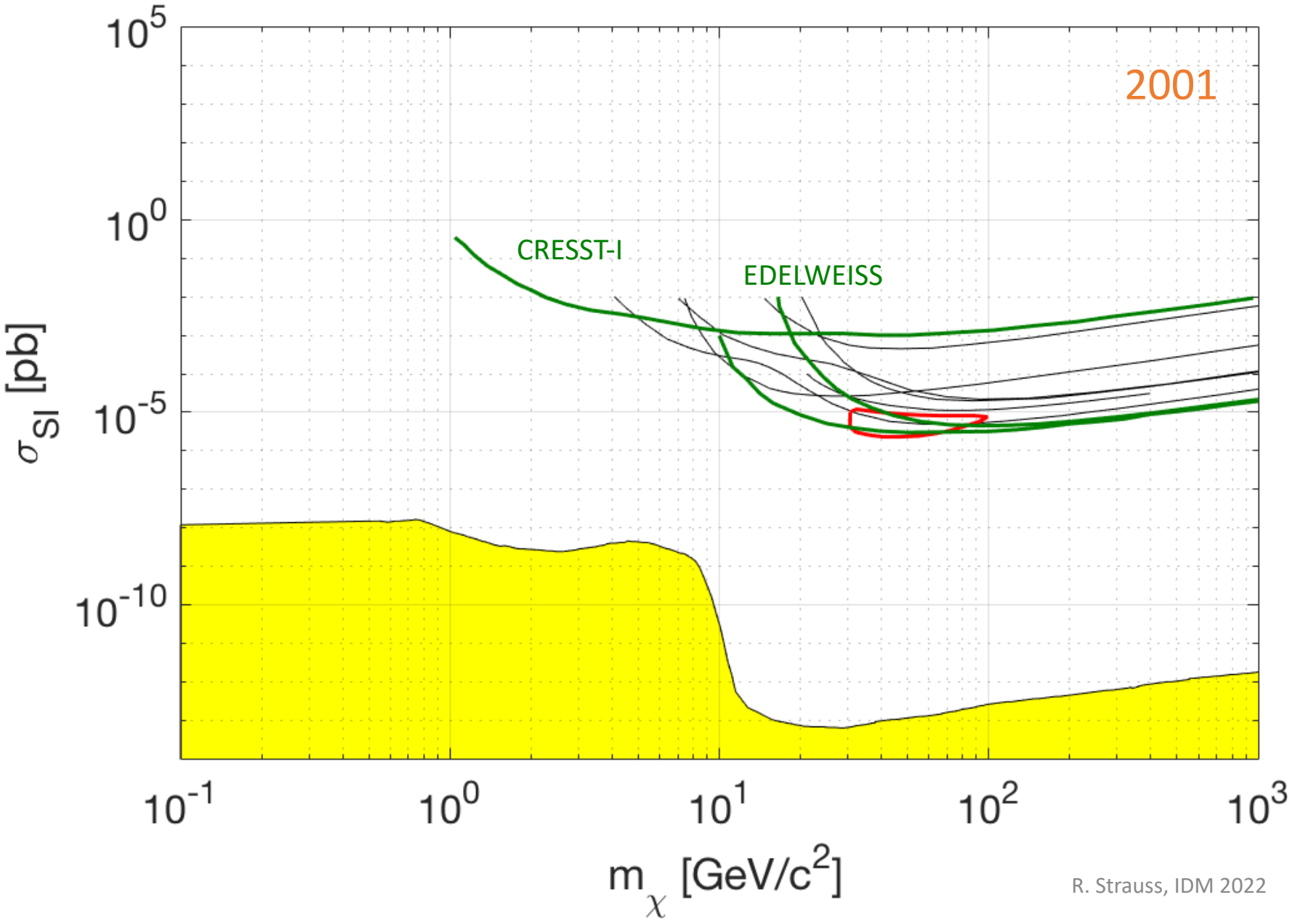


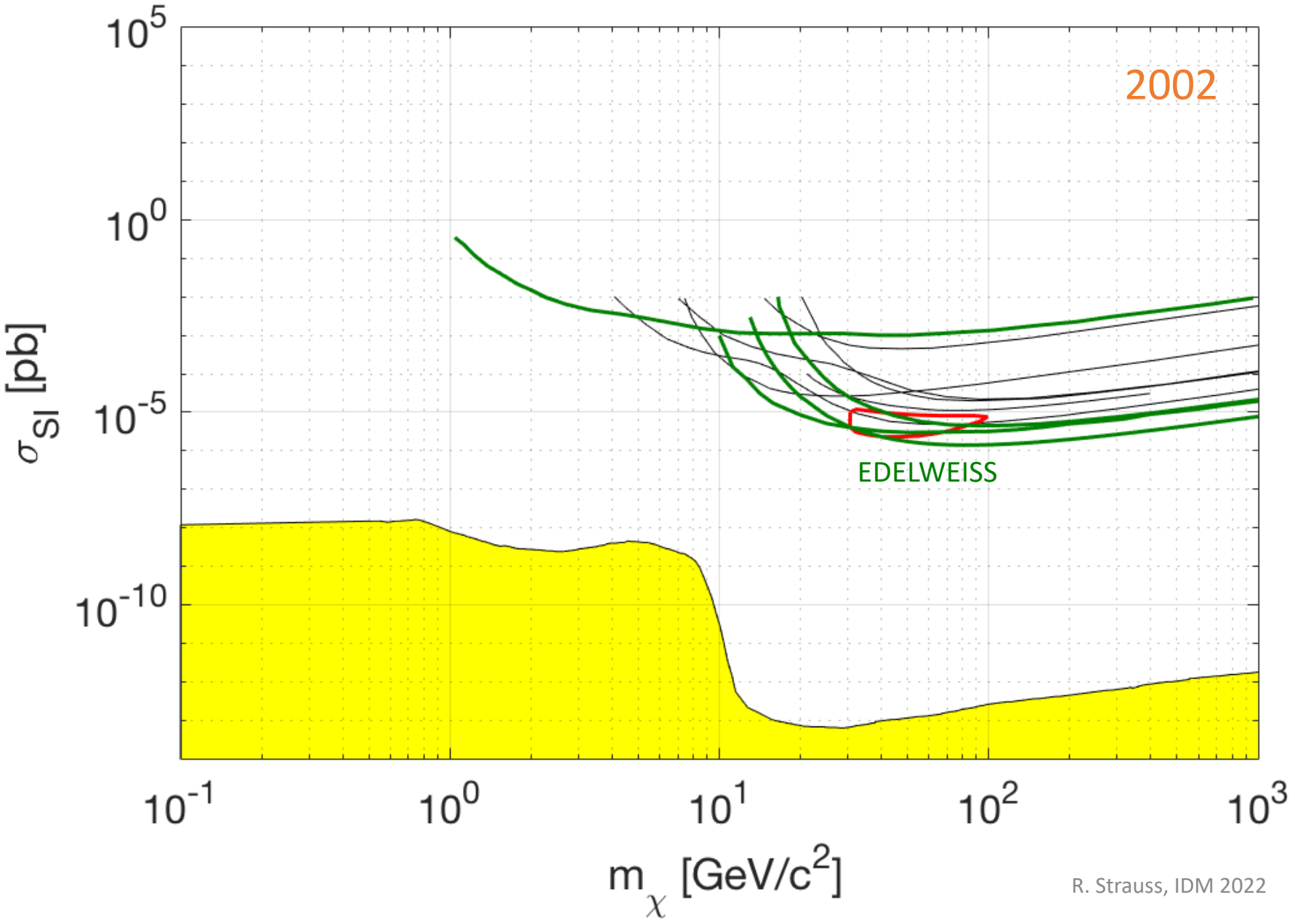

1991
Ge-Neuchatel
10^5
10^0
10^{-5}
10^{-10}
σ_{SI} [pb]
10^{-1}
10^0
10^1
10^2
10^3
m_χ [GeV/c^2]

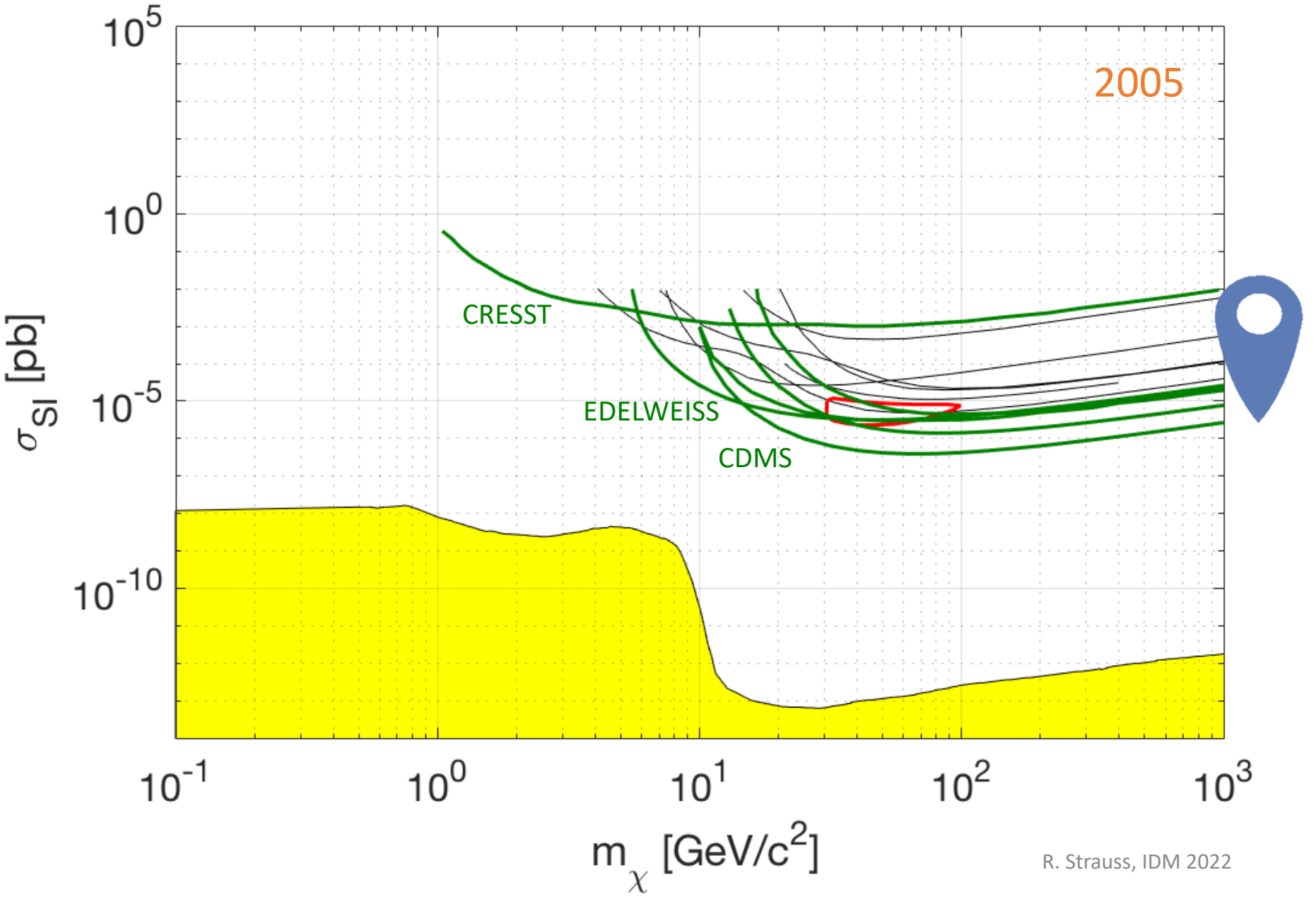

2000
DAMA
10^5
10^0
10^{-5}
10^{-10}
σ_{SI} [pb]
10^{-1}
10^0
10^1
10^2
10^3
m_χ [GeV/c^2]



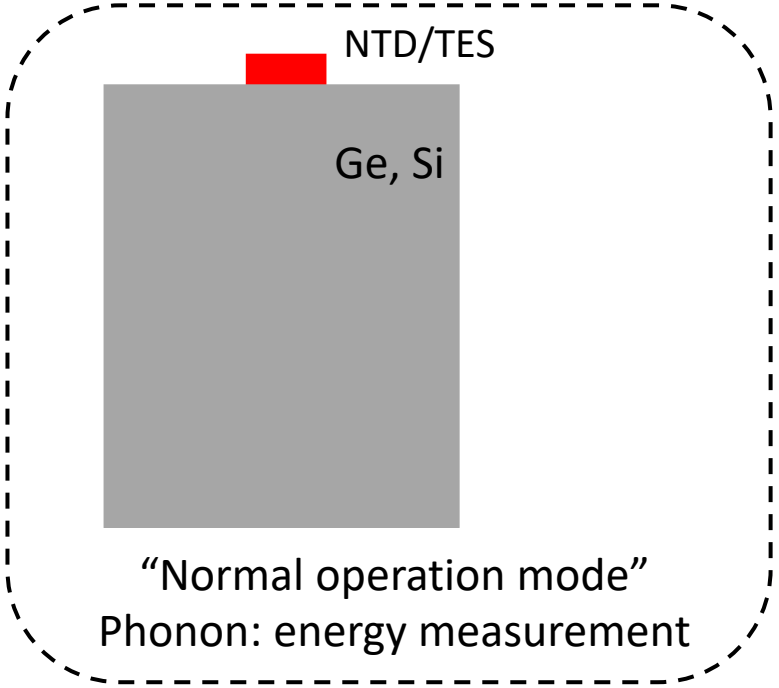
Technological Breakthrough


2001
CRESST-I
EDELWEISS
10^5
10^0
10^{-5}
10^{-10}
σ_{SI} [pb]
10^{-1}
10^0
10^1
10^2
10^3
m_χ [GeV/c^2]

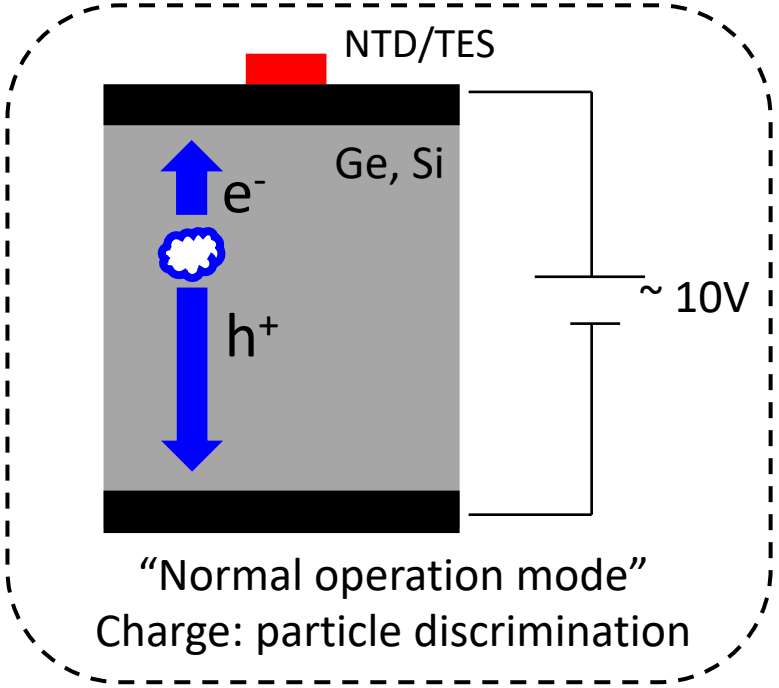

2002
EDELWEISS
10^5
10^0
10^{-5}
10^{-10}
σ_{SI} [pb]
10^{-1}
10^0
10^1
10^2
10^3
m_χ [GeV/c^2]



Background Rejection

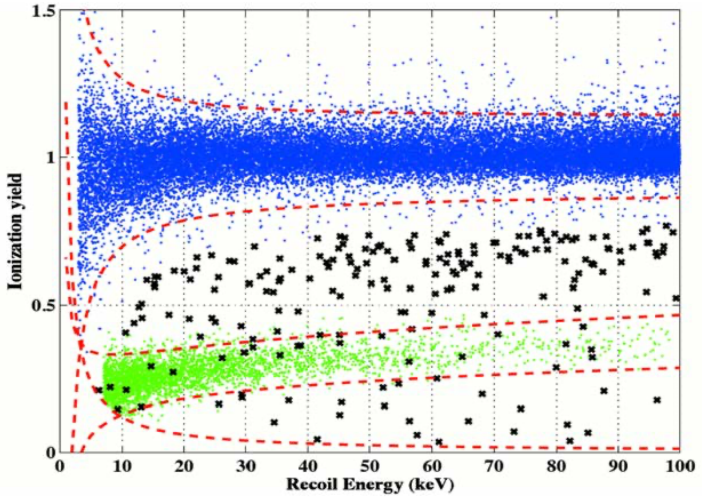


Background Rejection

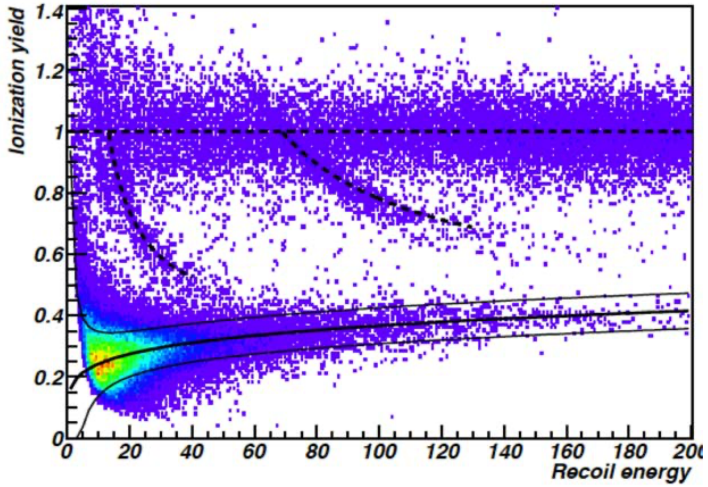


"Normal operation mode"
Charge: particle discrimination

Background Rejection

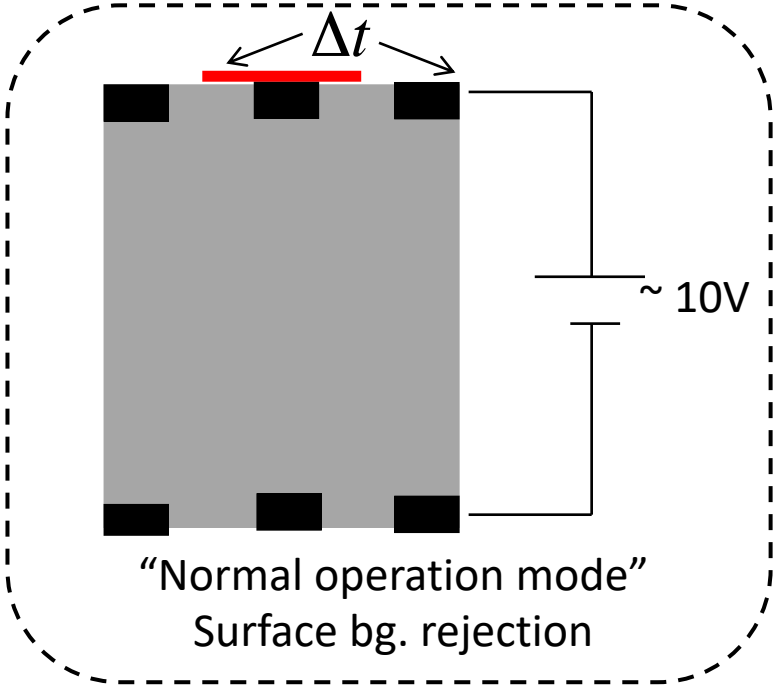


SuperCDMS

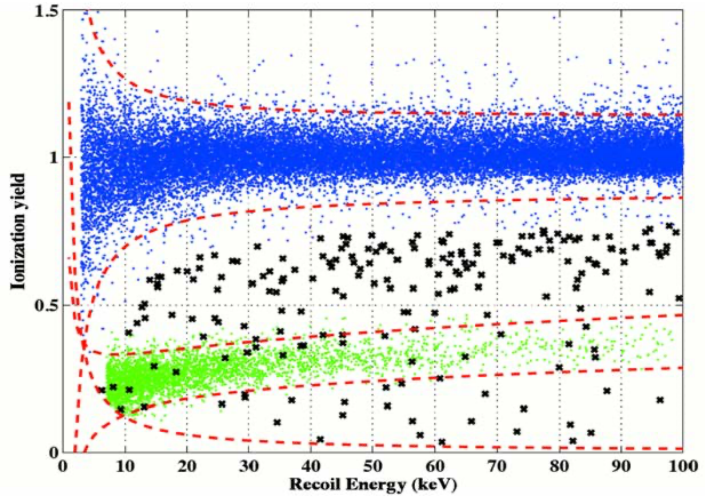


EDELWEISS

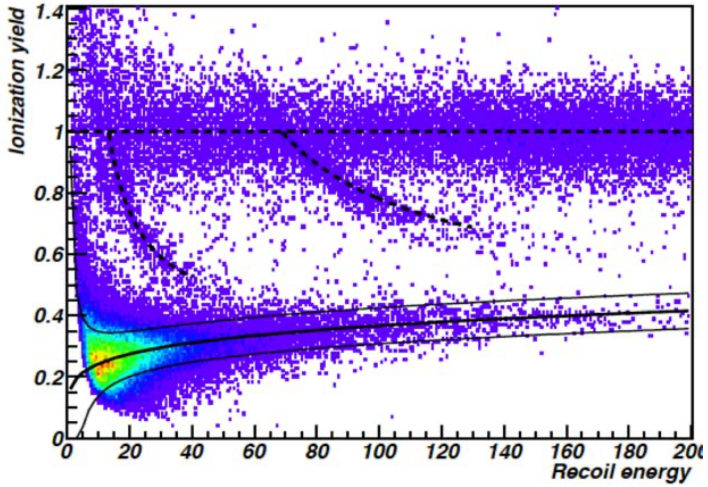
Background Rejection



"Normal operation mode"
Surface bg. rejection



SuperCDMS



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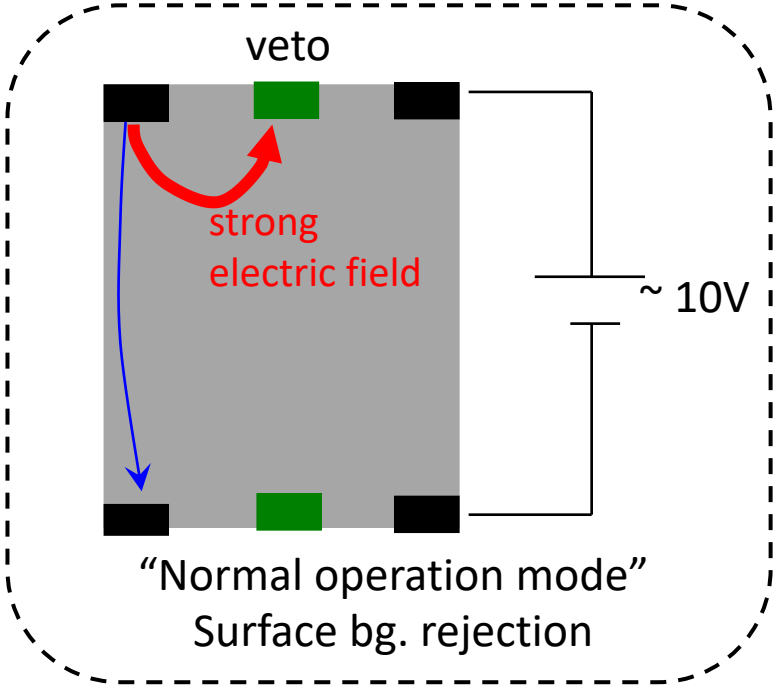

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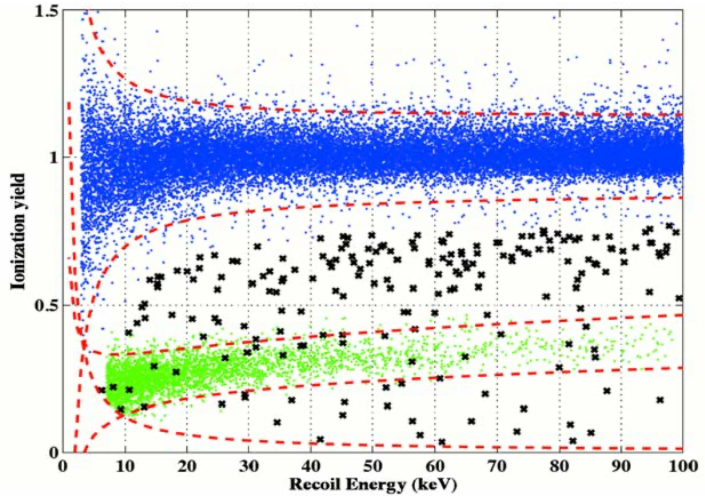
Surface bg. rejection



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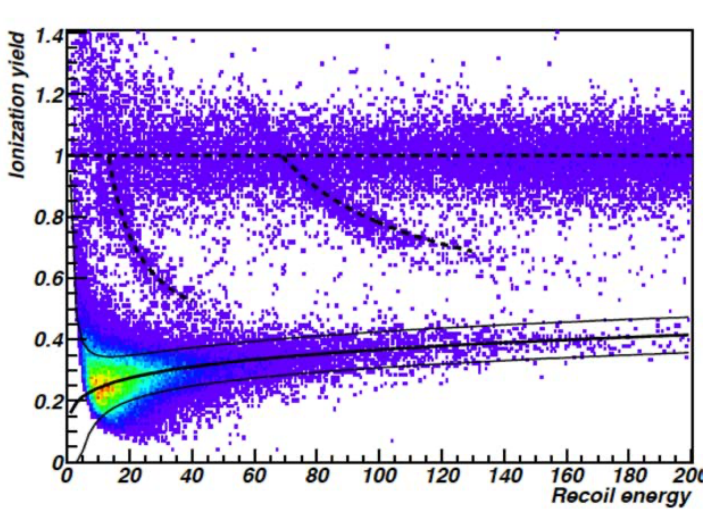

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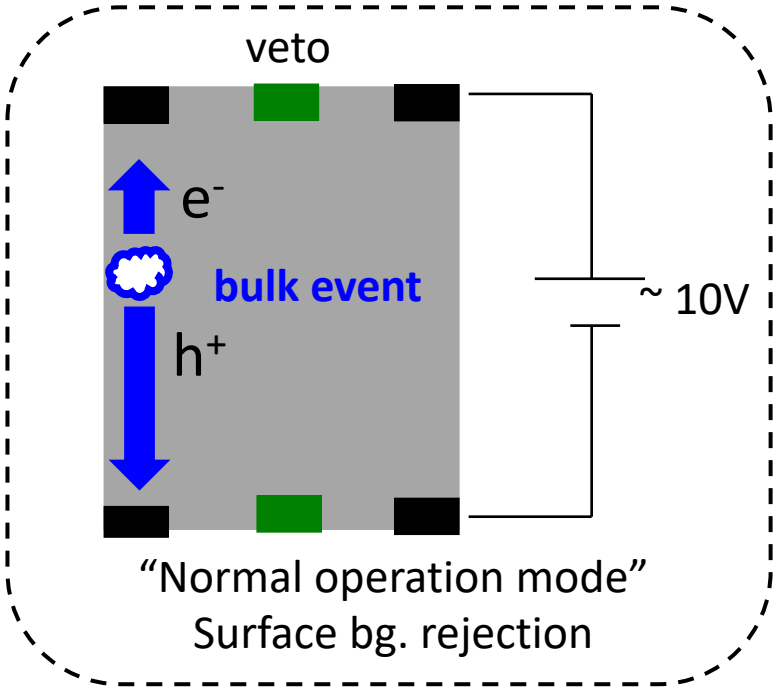

"Normal operation mode"
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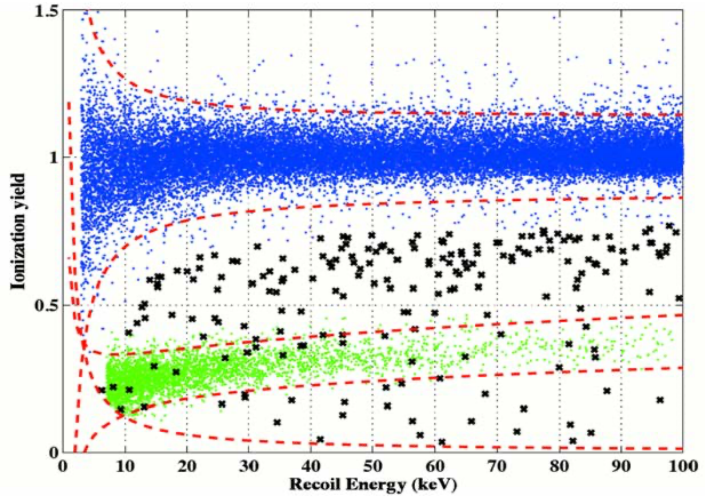

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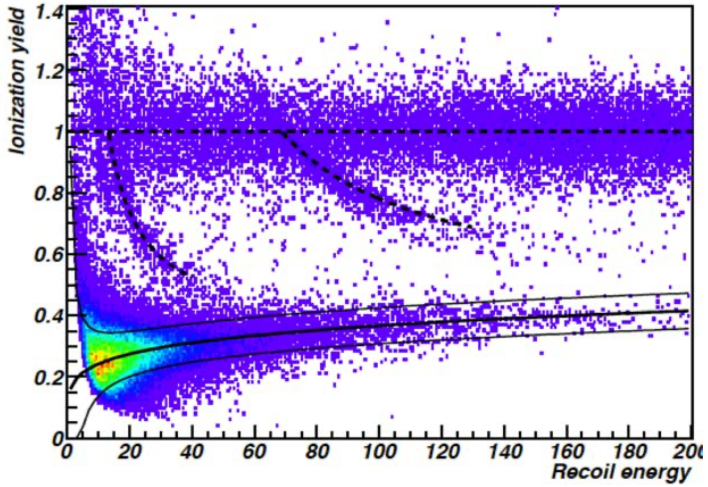

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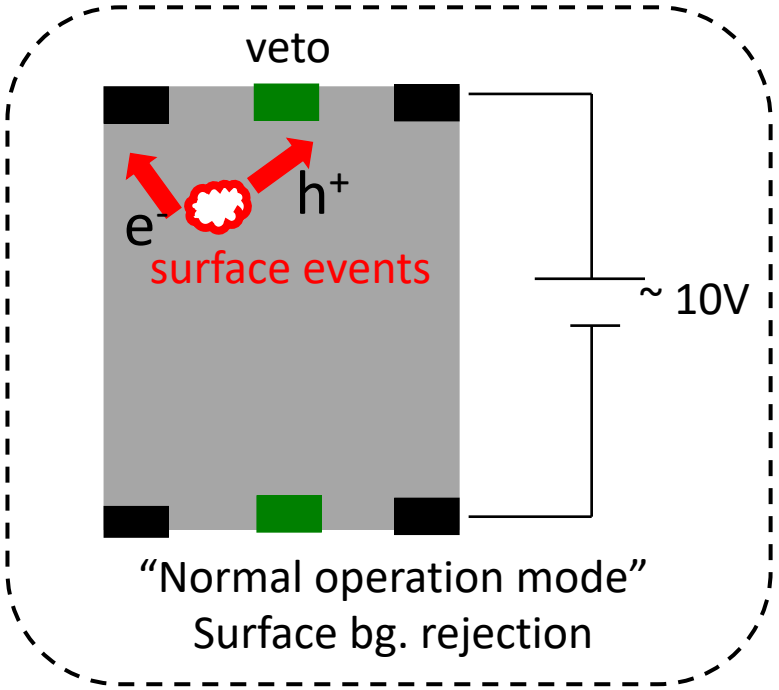
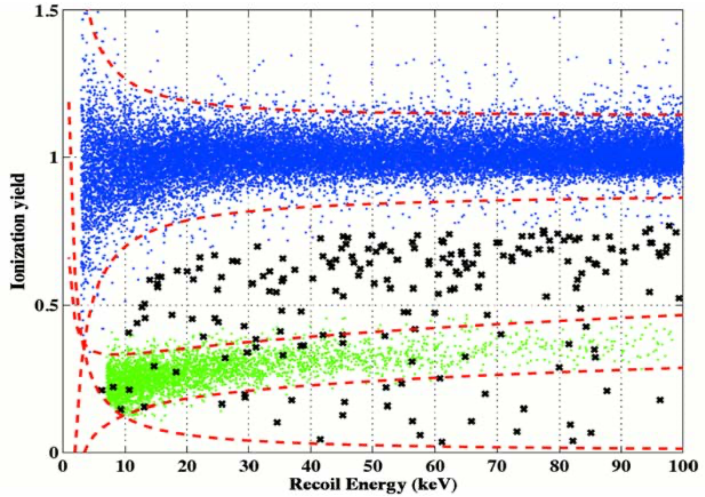
Background Rejection



"Normal operation mode"
Surface bg. rejection



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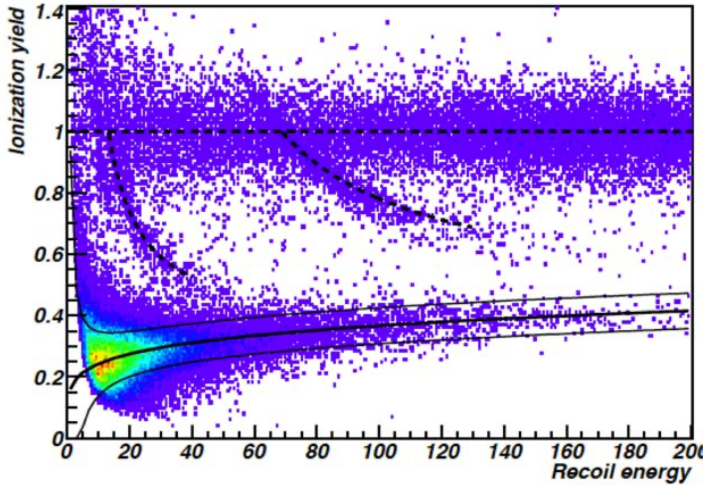

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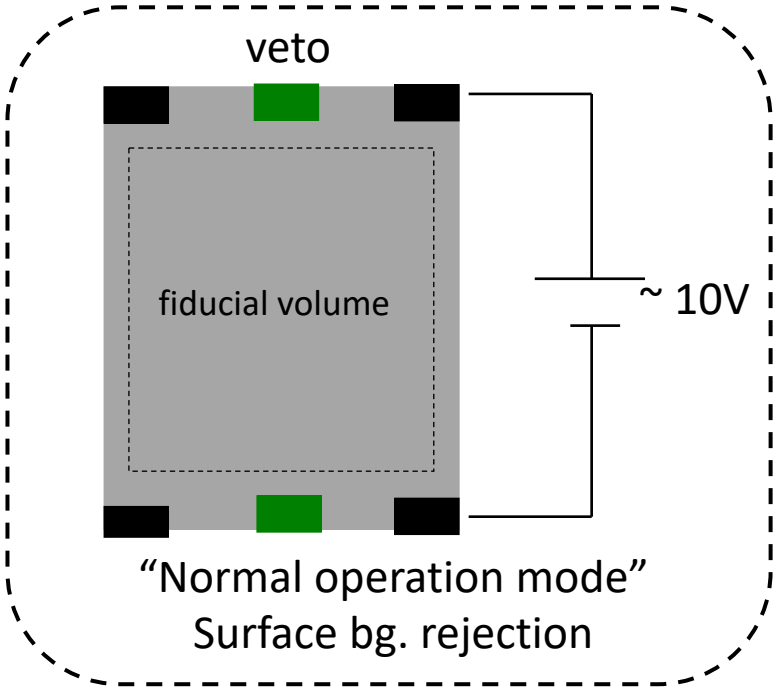

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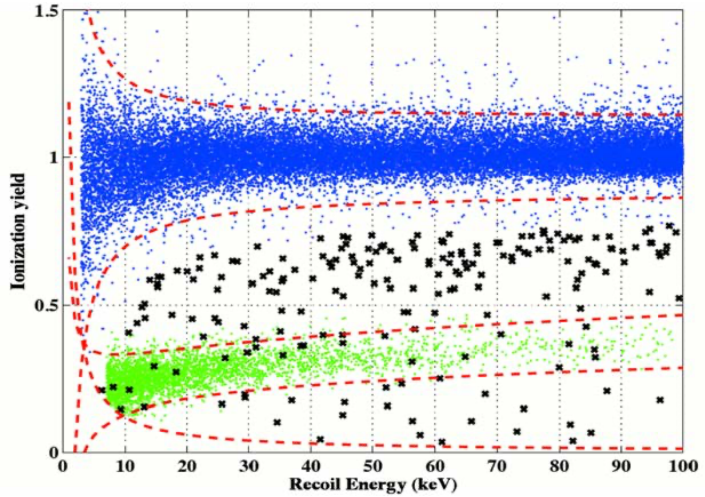
Surface bg. rejection



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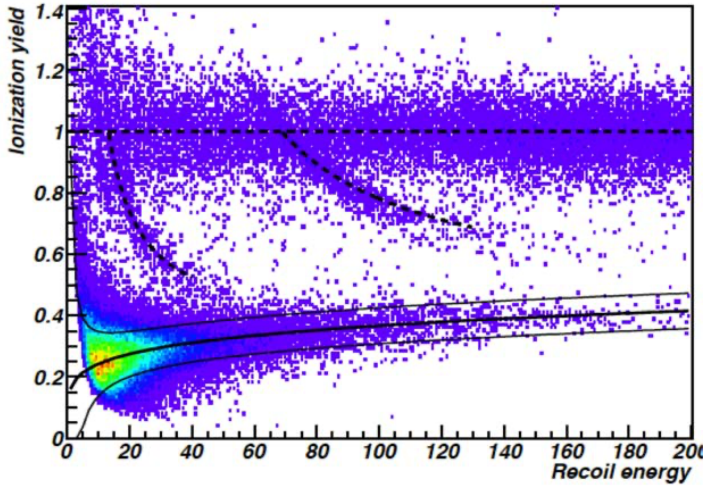
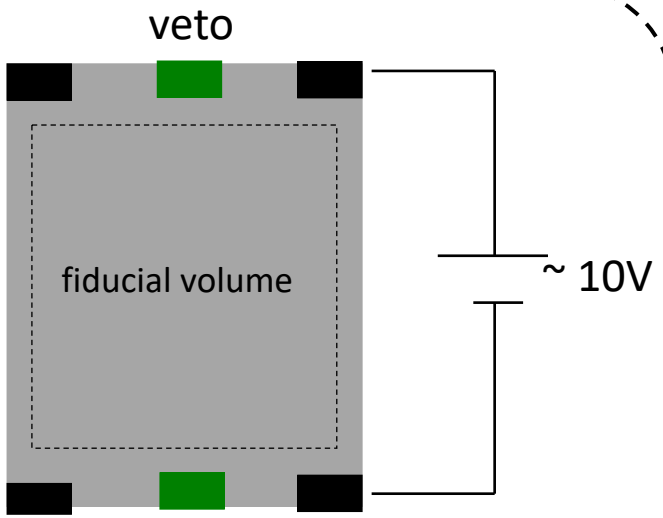
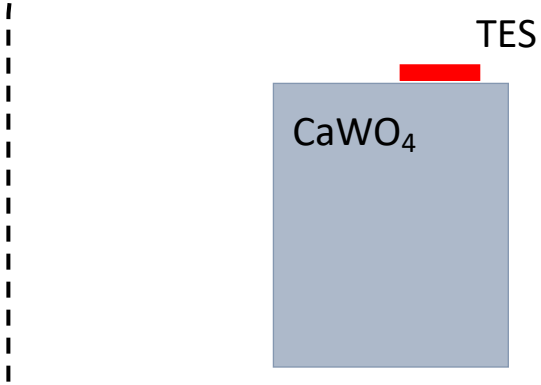


EDELWEISS

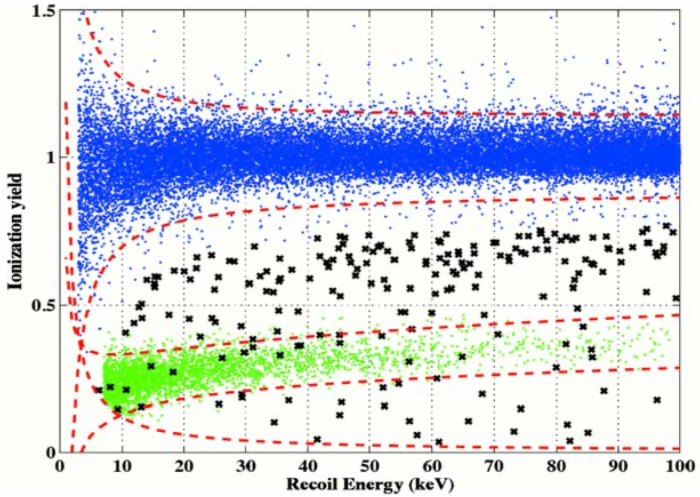
Background Rejection



"Normal operation mode"
Surface bg. rejection



Phonon: energy measurement



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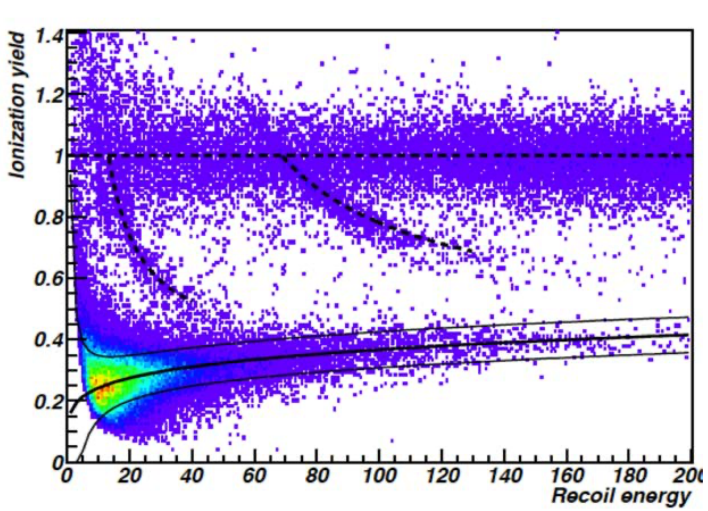

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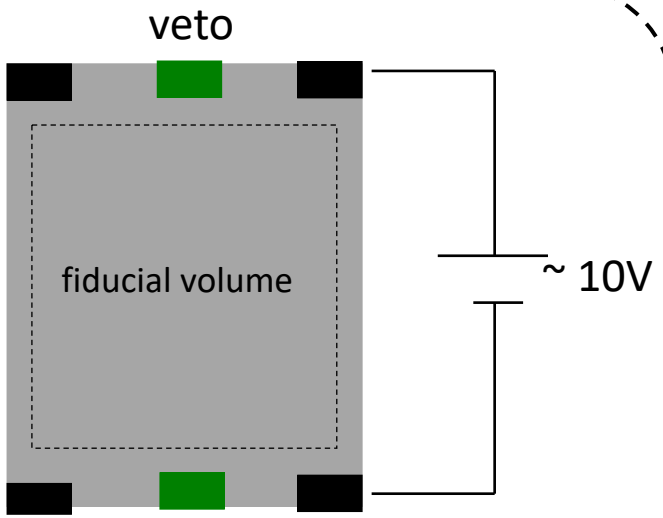
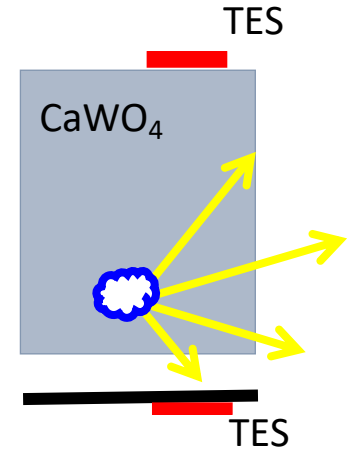
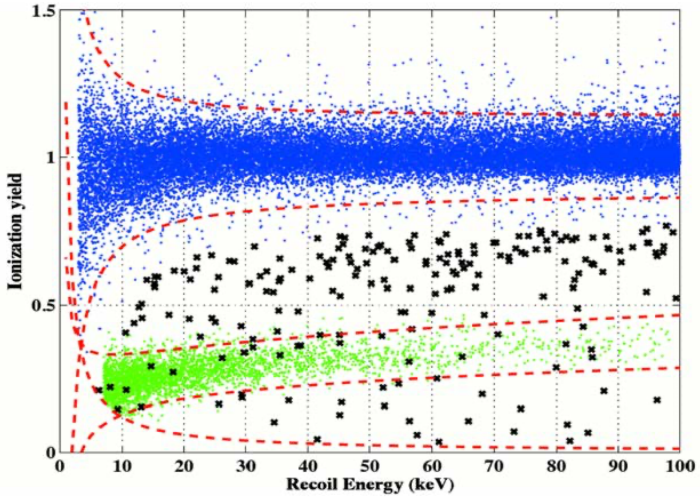


"Normal operation mode"
Surface bg. rejection



Light: particle discrimination



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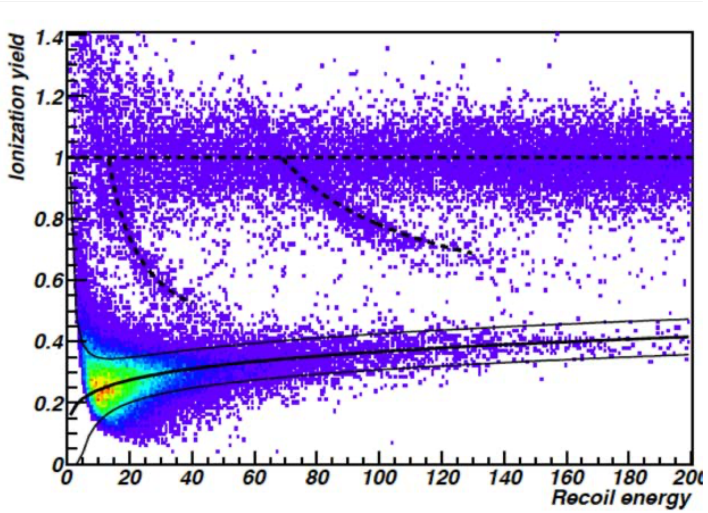
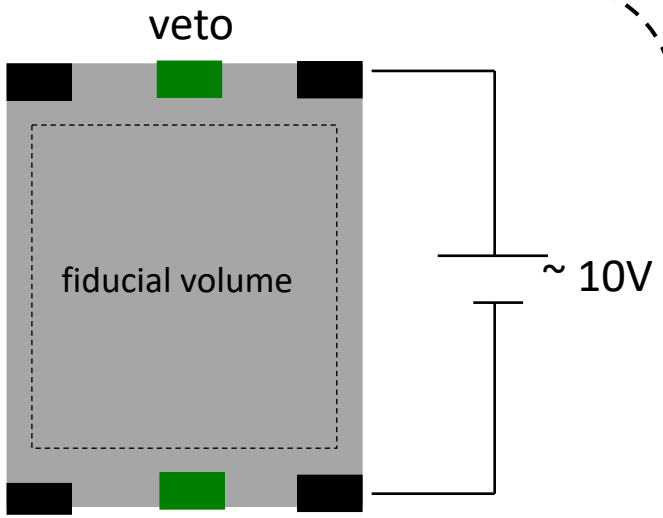
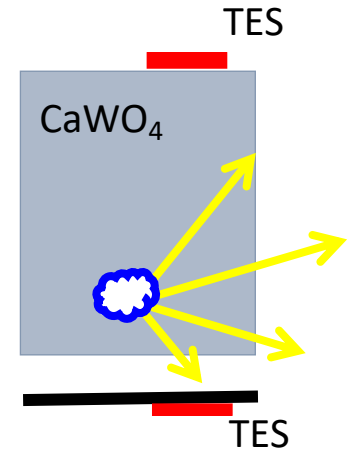


EDELWEISS

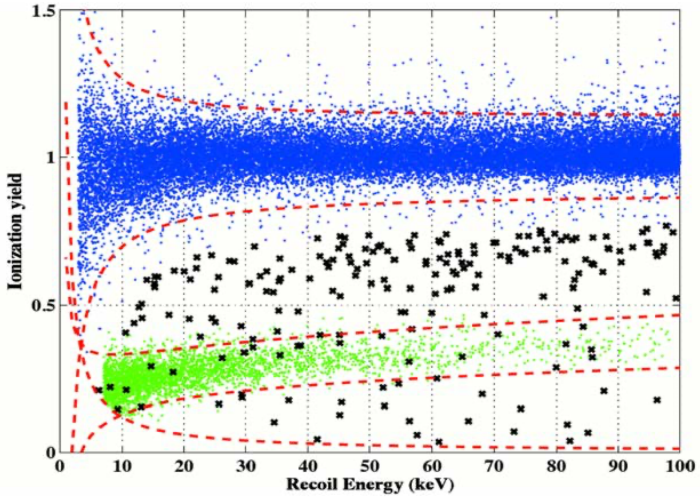
Background Rejection



"Normal operation mode"
Surface bg. rejection



Light: particle discrimination



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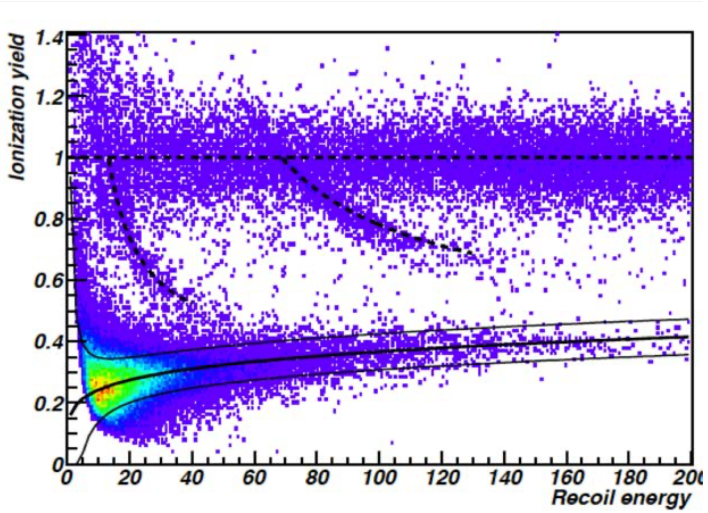
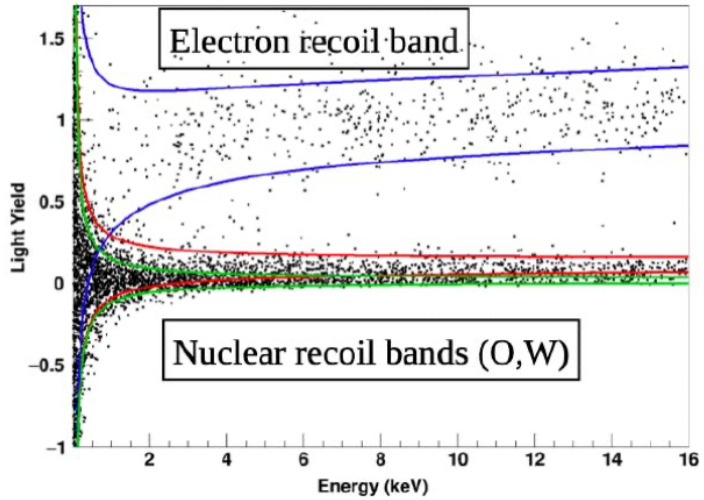
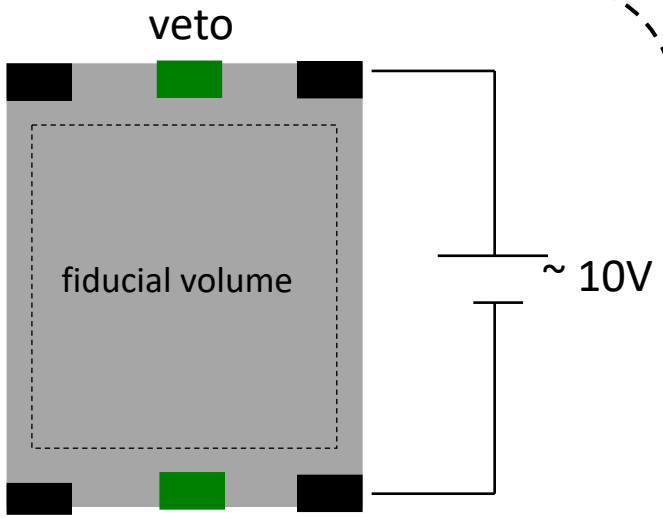


EDELWEISS

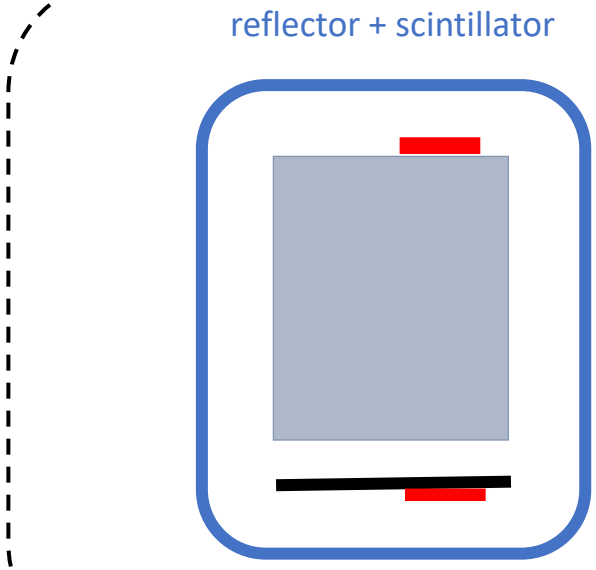


CRESST-II

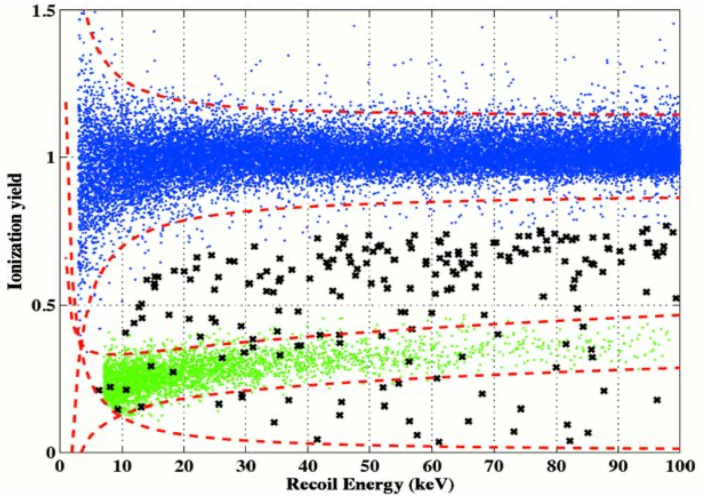
Background Rejection



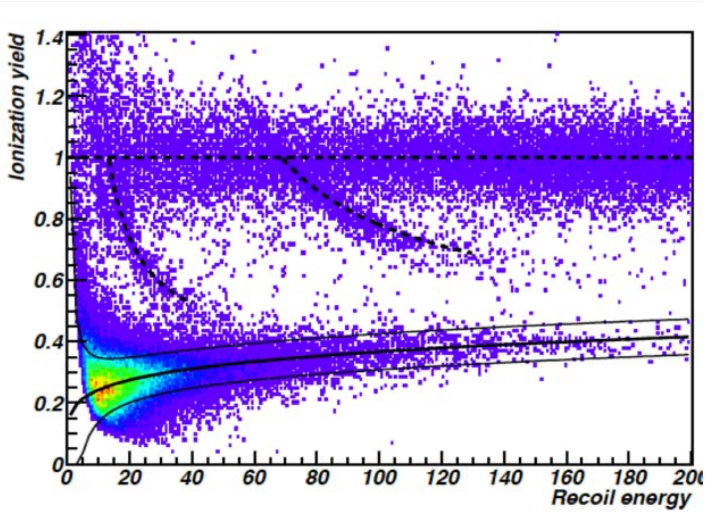
"Normal operation mode"
Surface bg. rejection



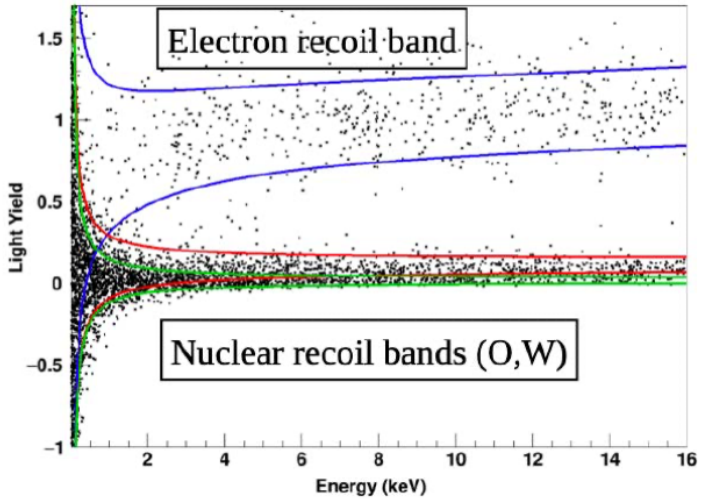
rejection of surface-alpha bg.



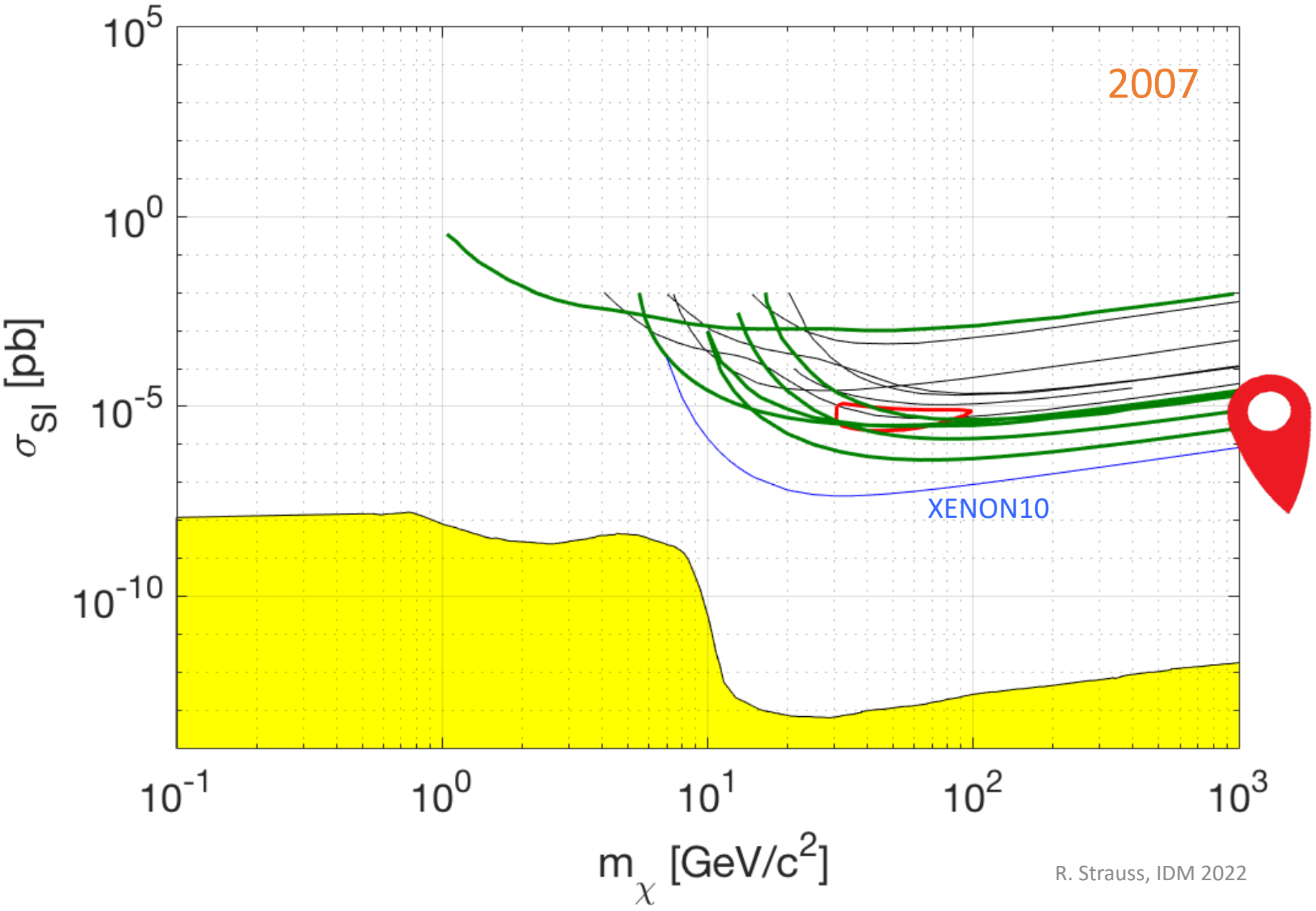
SuperCDMS



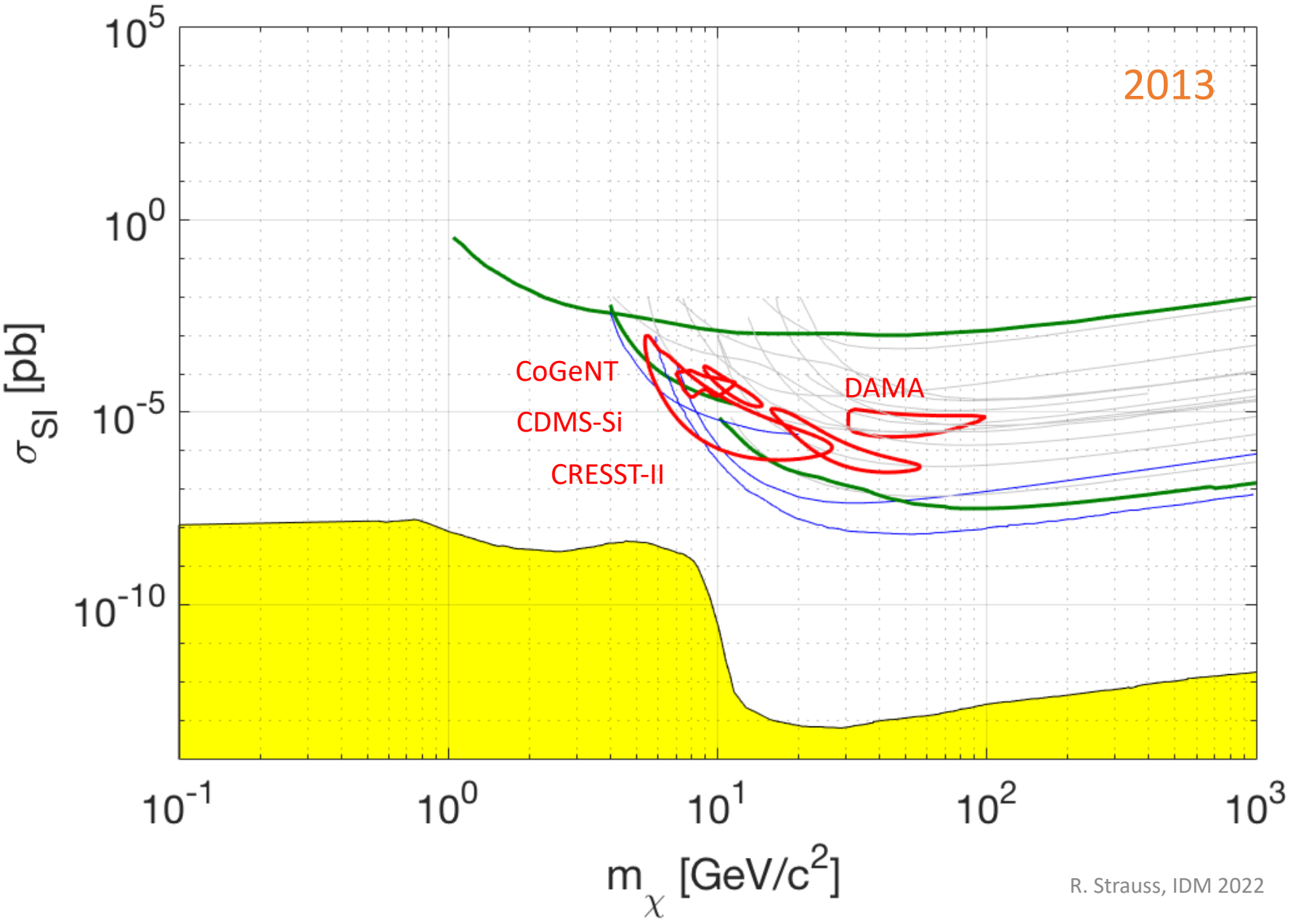
EDELWEISS

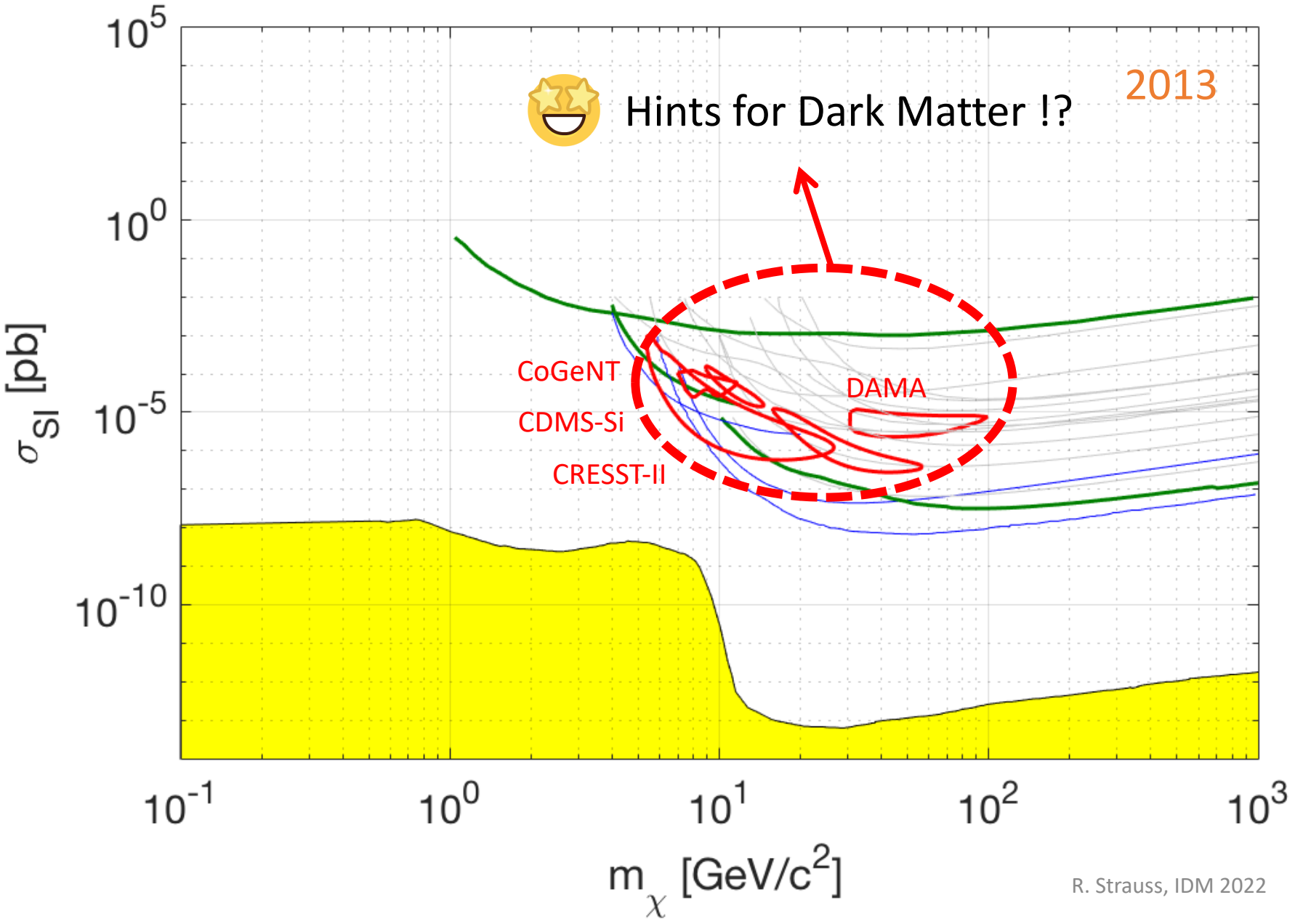


CRESST-II



Scalability


2013
CoGeNT
CDMS-Si
CRESST-II
DAMA
σ_{SI} [pb]
m_χ [GeV/c^2]
10^5
10^0
10^{-5}
10^{-10}
10^{-1}
10^0
10^1
10^2
10^3


Hints for Dark Matter !?
2013
CoGeNT
CDMS-Si
CRESST-II
DAMA
σ_{SI} [pb]
m_χ [GeV/c^2]
10^5
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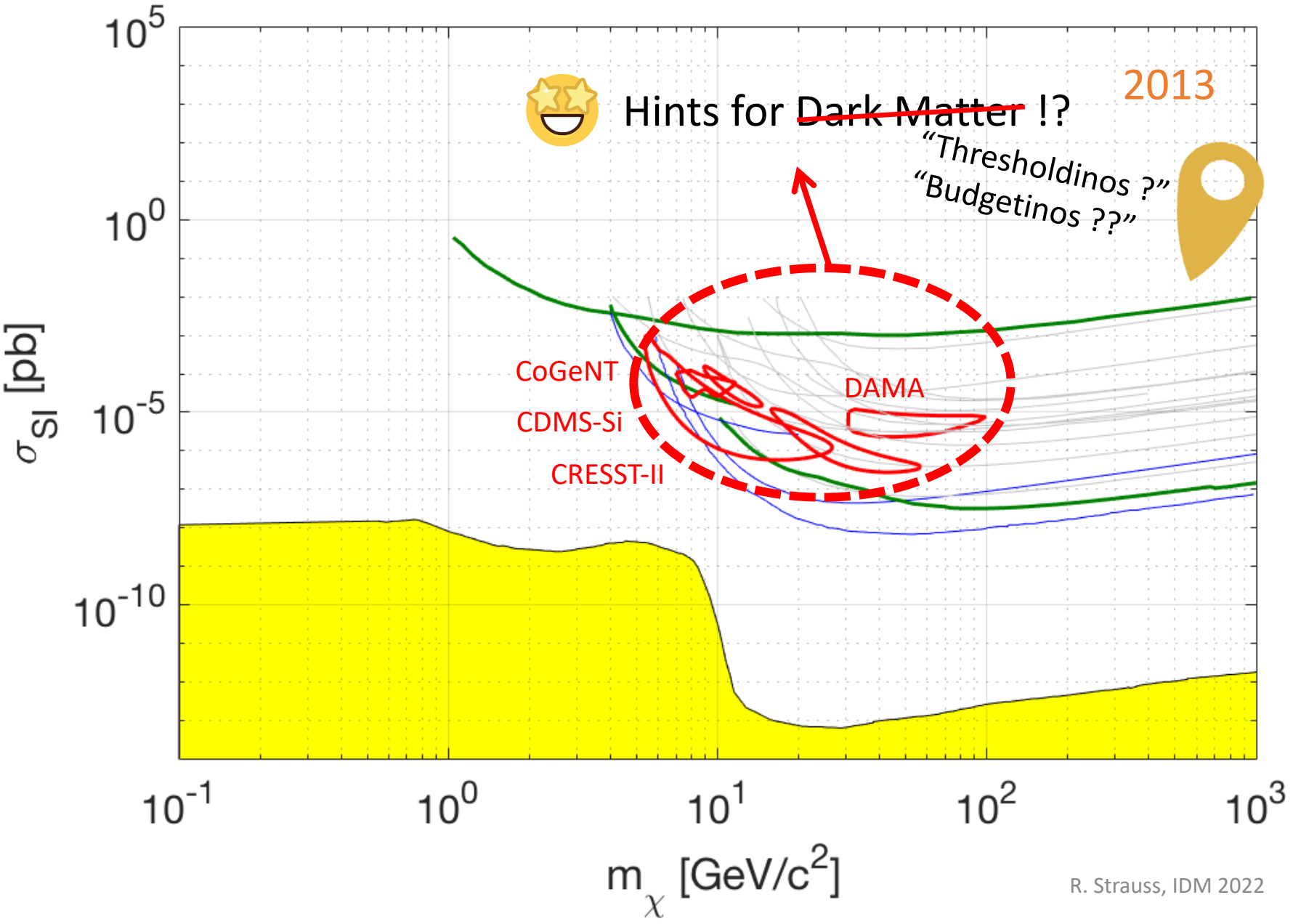
Hints for ~~Dark Matter~~ !?
2013
"Thresholdinos ?"
"Budgetinos ??"
CoGeNT
CDMS-Si
CRESST-II
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σ_{SI} [pb]
m_χ [GeV/c^2]
10^5
10^0
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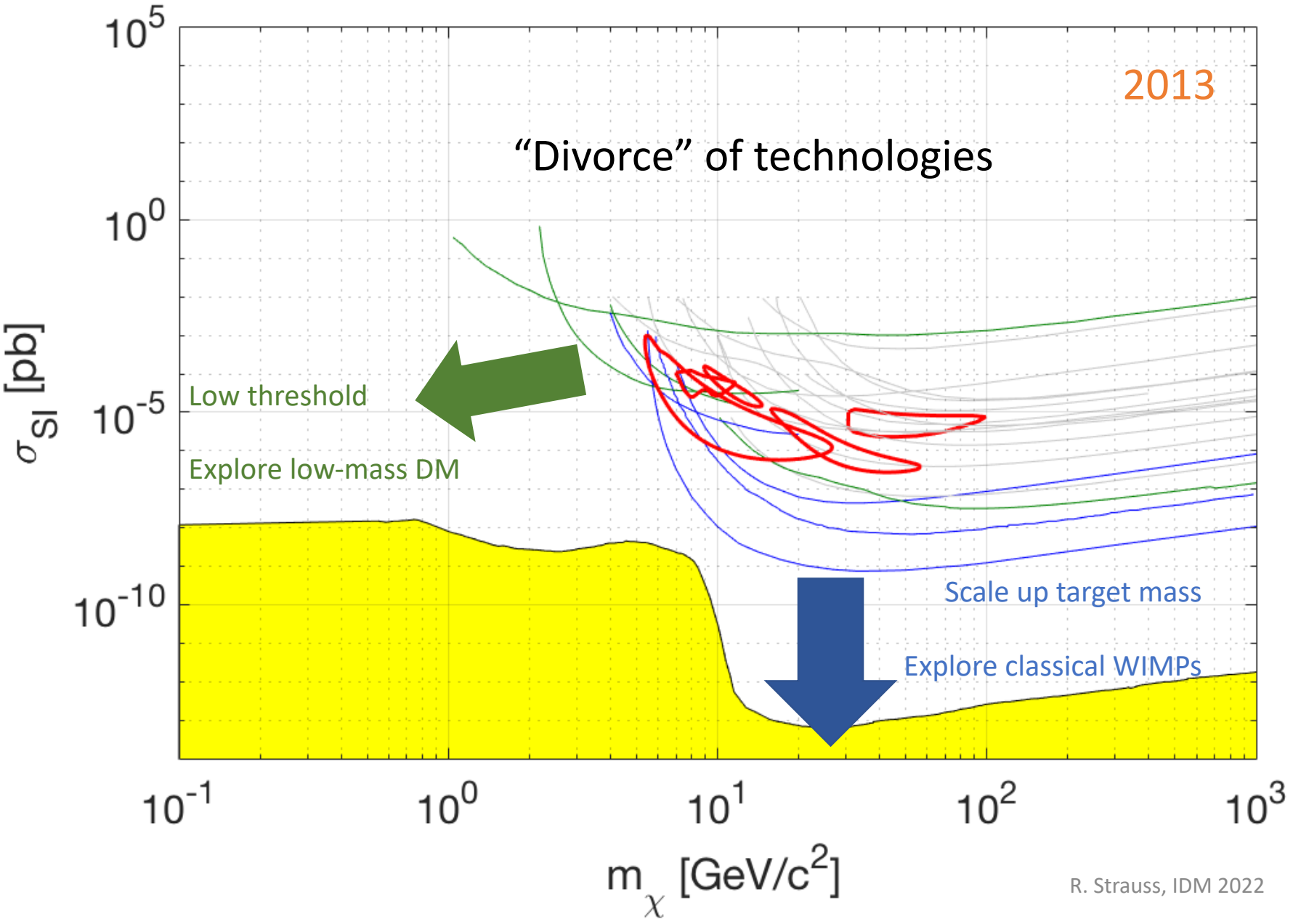
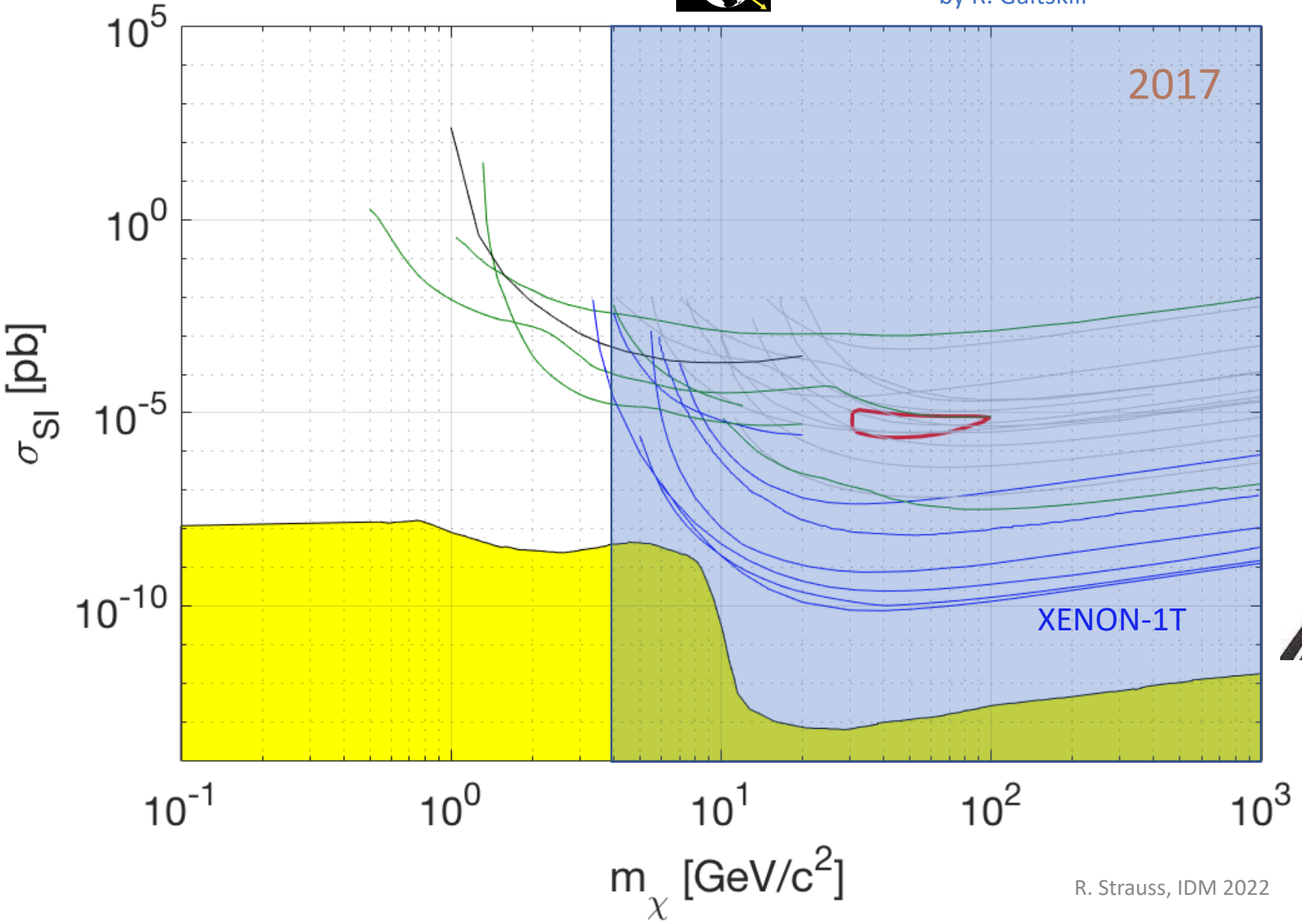
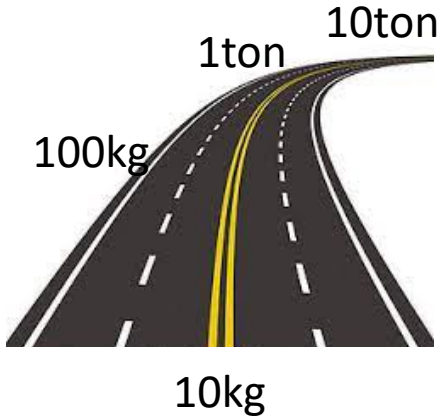

2013
"Divorce" of technologies
Low threshold
Explore low-mass DM
Scale up target mass
Explore classical WIMPs
σ_{SI} [pb]
m_χ [GeV/c^2]
10^5
10^0
10^{-5}
10^{-10}
10^{-1}
10^0
10^1
10^2
10^3

Dark Matter at the WIMP scale

by R. Gaitskill



LZ @SURF

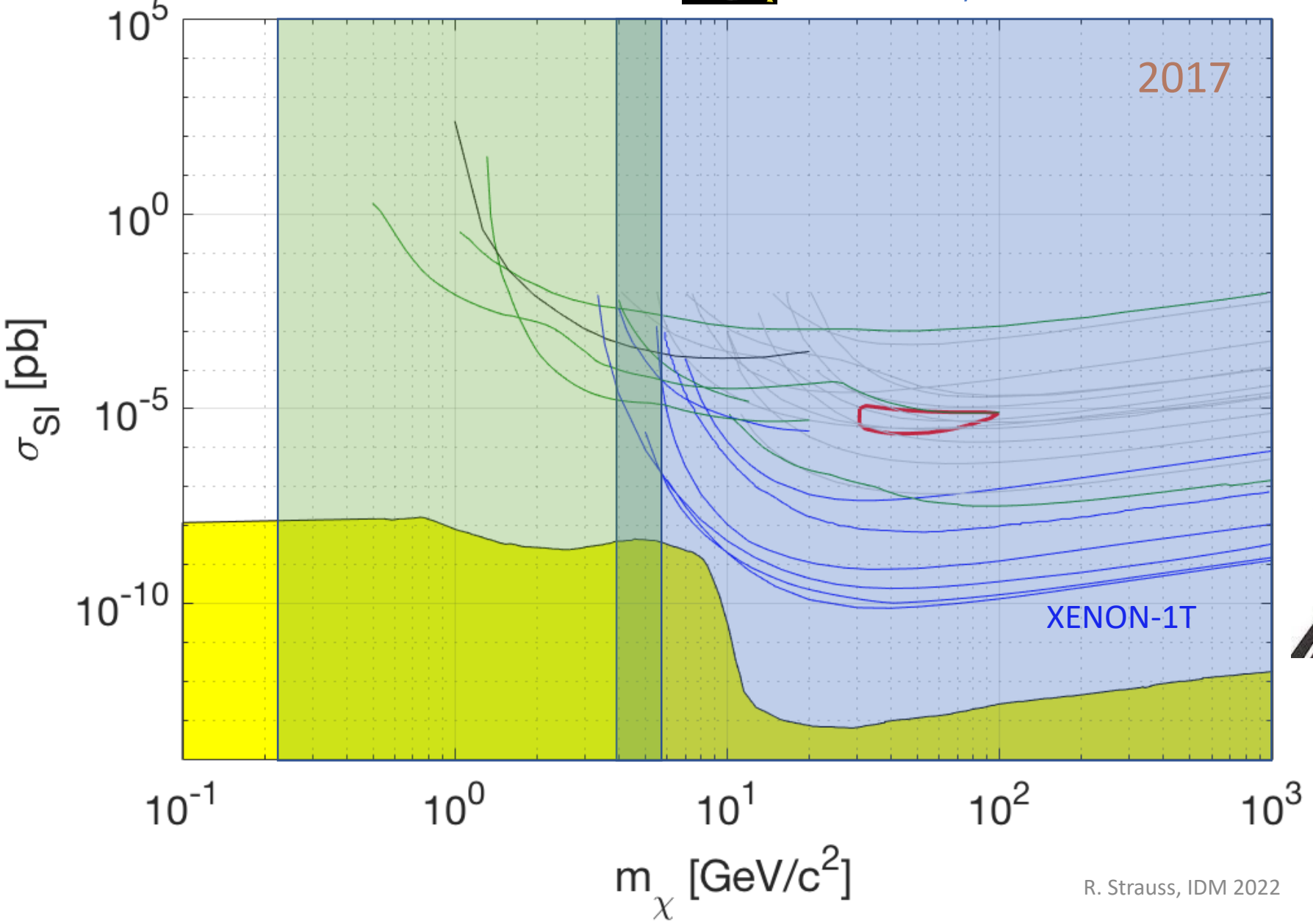


GeV scale and below

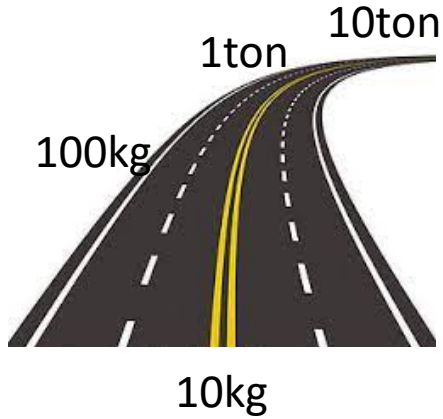
This talk

Dark Matter at the WIMP scale

by R. Gaitskill



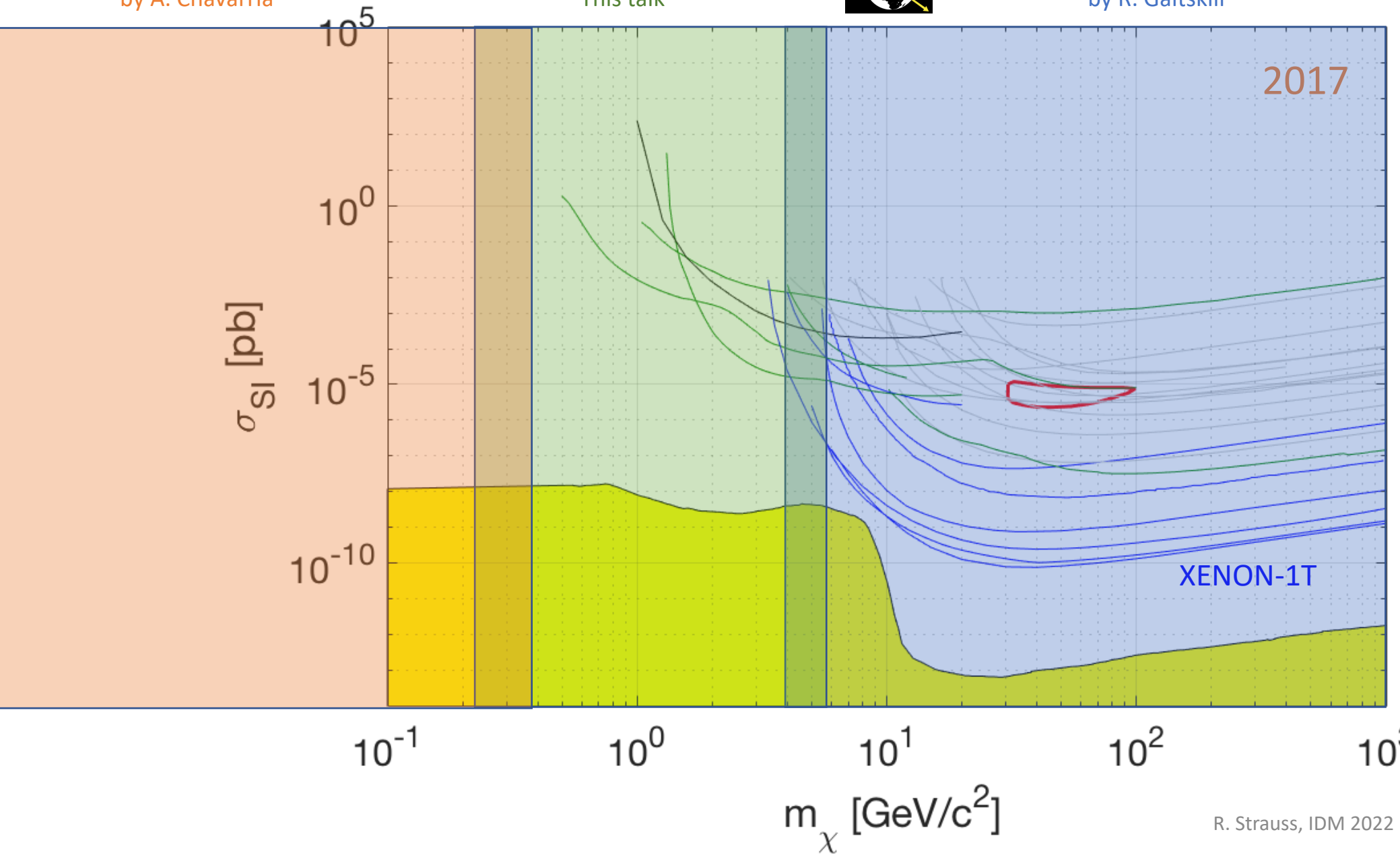
LZ @SURF



Even lighter Dark Matter
by A. Chavarria

GeV scale and below
This talk

Dark Matter at the WIMP scale
by R. Gaitskill



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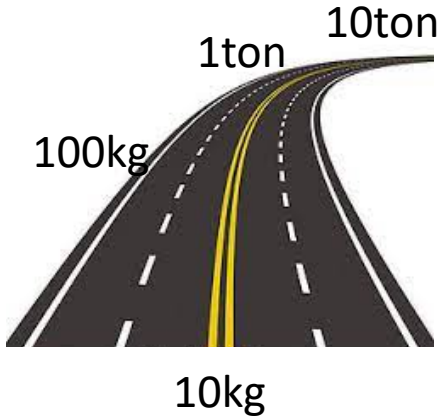

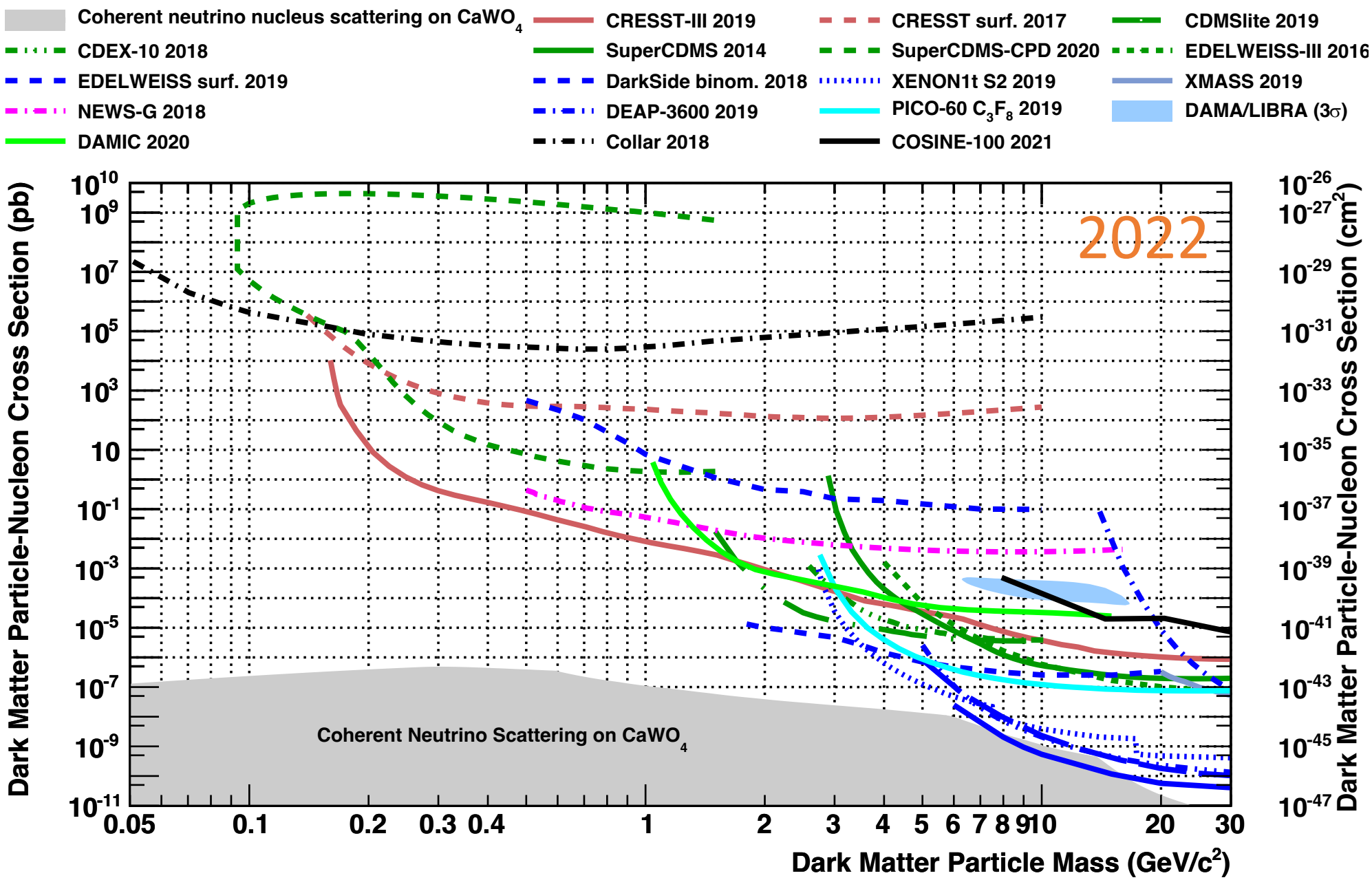
Coherent neutrino nucleus scattering on $CaWO_4$
CDEX-10 2018
EDELWEISS surf. 2019
NEWS-G 2018
DAMIC 2020
CRESST-III 2019
SuperCDMS 2014
DarkSide binom. 2018
DEAP-3600 2019
Collar 2018
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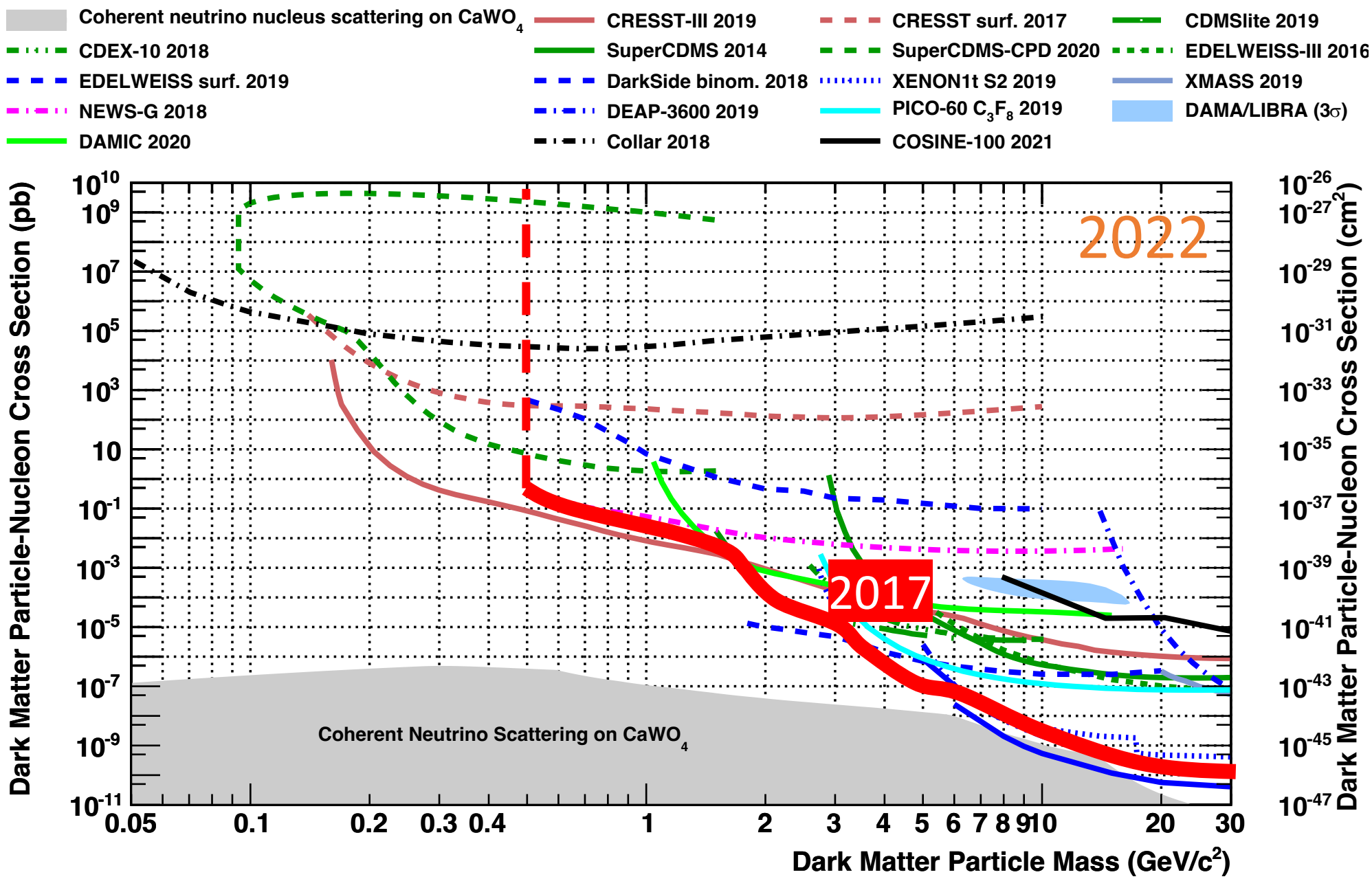
SuperCDMS-CPD 2020
XENON1t S2 2019
PICO-60 C_3F_8 2019
COSINE-100 2021
CDMSlite 2019
EDELWEISS-III 2016
XMASS 2019
DAMA/LIBRA (3σ)
2022
Coherent Neutrino Scattering on $CaWO_4$
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm^2)
Dark Matter Particle Mass (GeV/c^2)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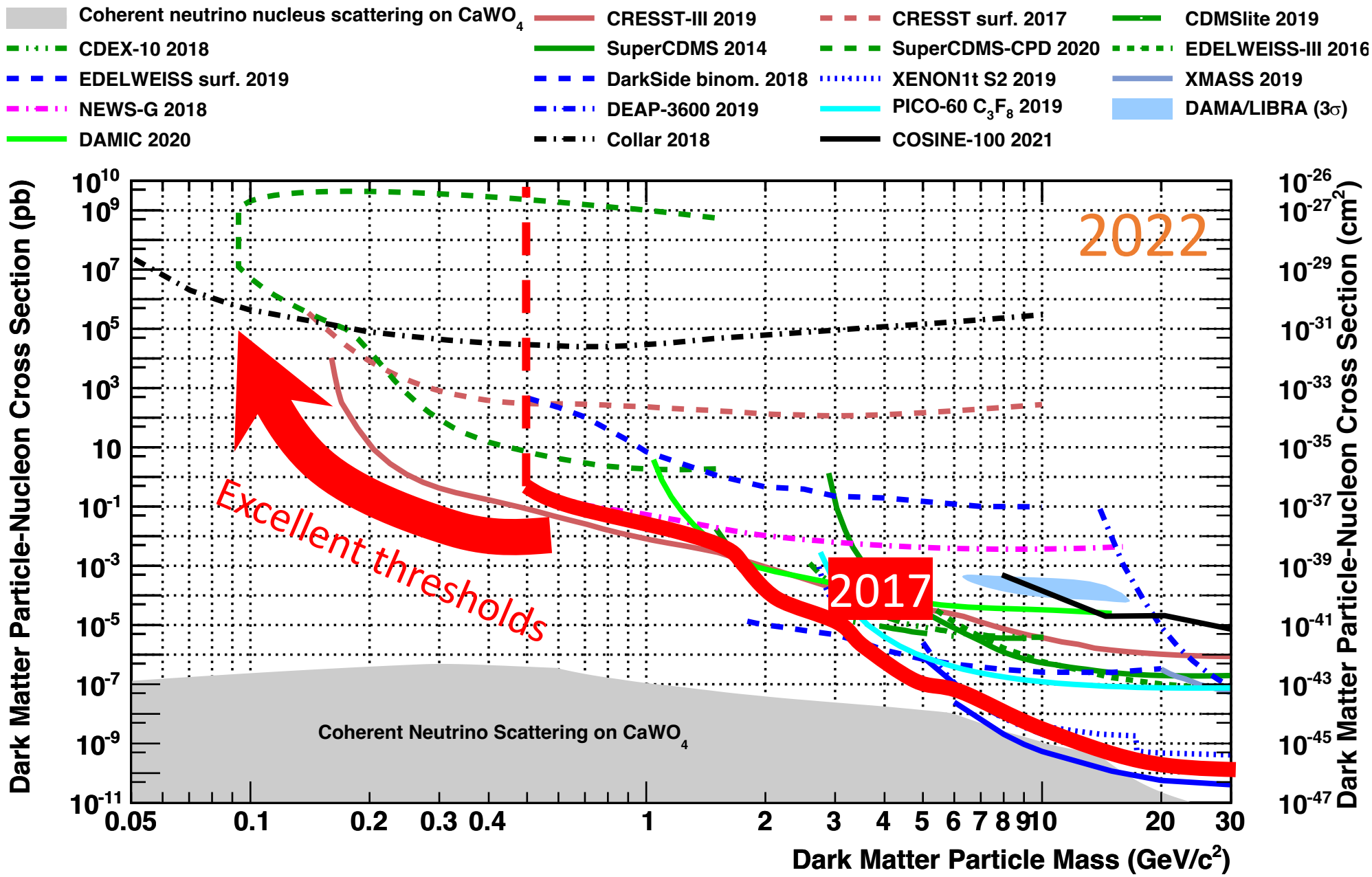
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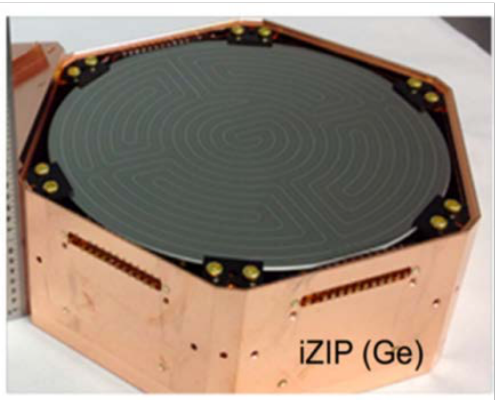
2022
2017
Excellent thresholds
Coherent Neutrino Scattering on CaWO4
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm2)
Dark Matter Particle Mass (GeV/c2)

arXiv:2203.08463

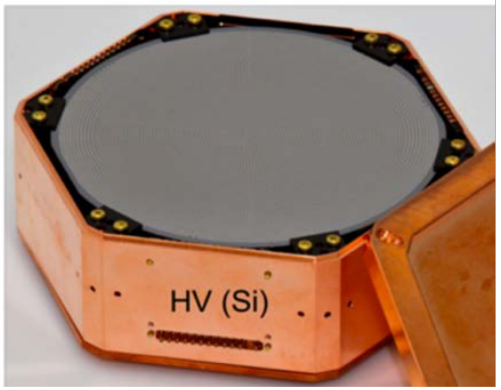
Excellent thresholds achieved….

… and R&D is running full steam!

SuperCDMS @ SNOLAB

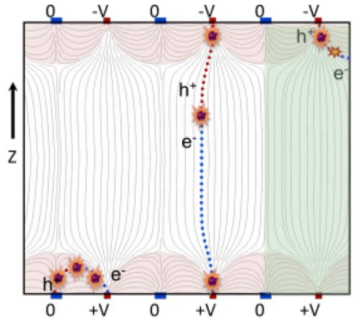


1.4kg Ge



0.6kg Si

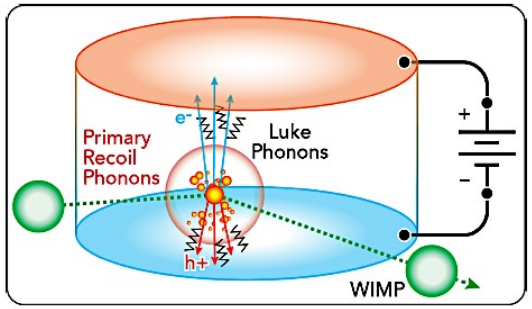
Interleaved phonon and charge readout



→ Particle discrimination

→ **E_{th} ~ 150 eV_{nr}**

High voltage applied to electrodes

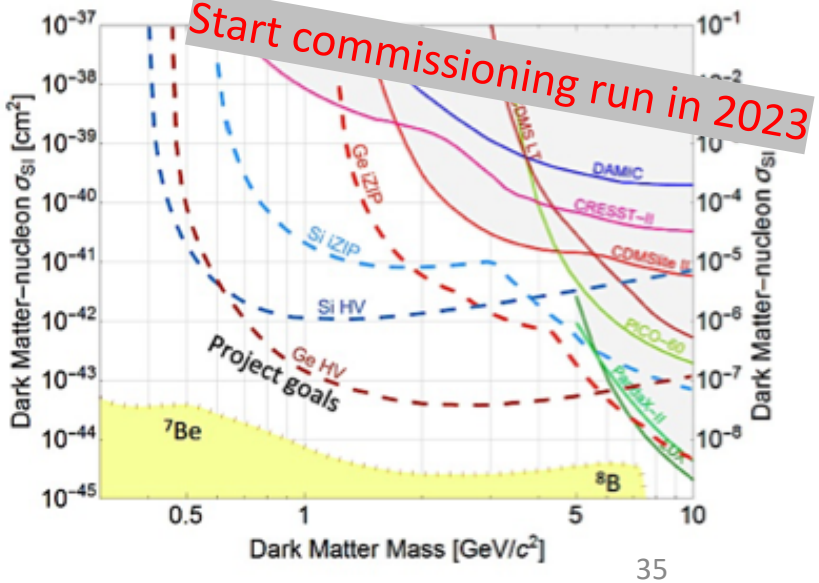


→ Low Threshold

→ **E_{th} ~ 60eV_{nr}**

	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8
Phonon resolution [eV]	33	19	34	13
Ionization resolution [eV_{ee}]	160	180	–	–
Voltage Bias ($V_+ - V_-$) [V]	6	8	100	100

Start commissioning run in 2023



arXiv:2203.08463

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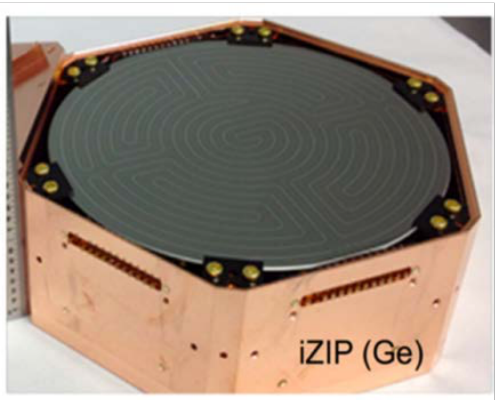
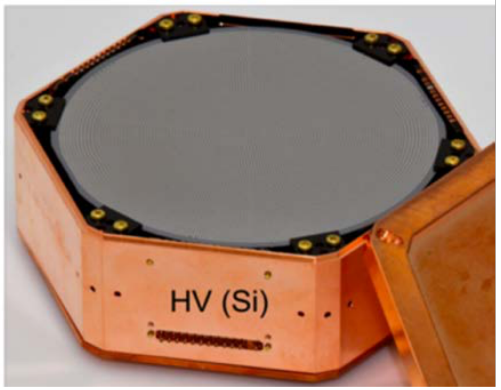
SuperCDMS @ SNOLAB

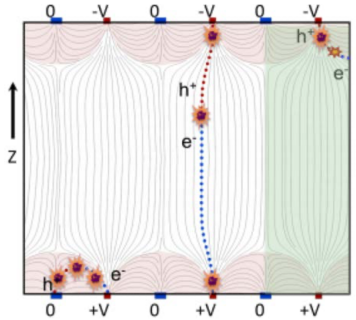


1.4kg Ge



0.6kg Si

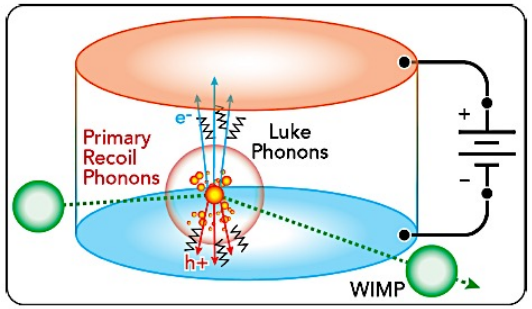
Interleaved phonon and charge readout



→ Particle discrimination

→ **E_{th} ~ 150 eV_{nr}**

High voltage applied to electrodes



→ Low Thres

→ **E_{th} ~ 60e**

	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8
Phonon resolution [eV]	33	19	34	13
Ionization resolution [eV_{ee}]	160	180	–	–
Voltage Bias ($V_+ - V_-$) [V]	6	8	100	100

Start commissioning run in 2023

Overview of the SuperCDMS SNOLAB Experiment
M. J. Wilson, Mo 16:50

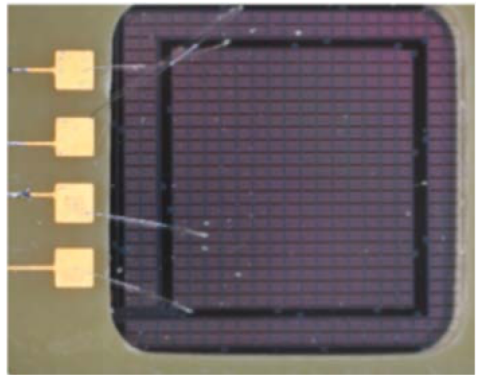
Calibration of SuperCDMS HVeV detector
Valentina Novati, Mo 15:20

SuperCDMS: novel active veto
Hao Chen, Mo 15:20

Excellent thresholds achieved….

… and R&D is running full steam!

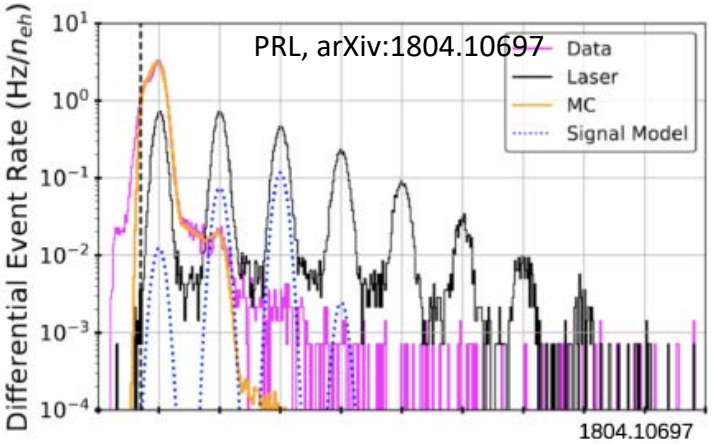
SuperCDMS @ Surface



HVeV detector

1cm^2 x 4mm Si wafer

→ Single e-h resolution
E_{th} = 9.2 eV_{nr}



ER background in the peaks!

NR between the peaks!

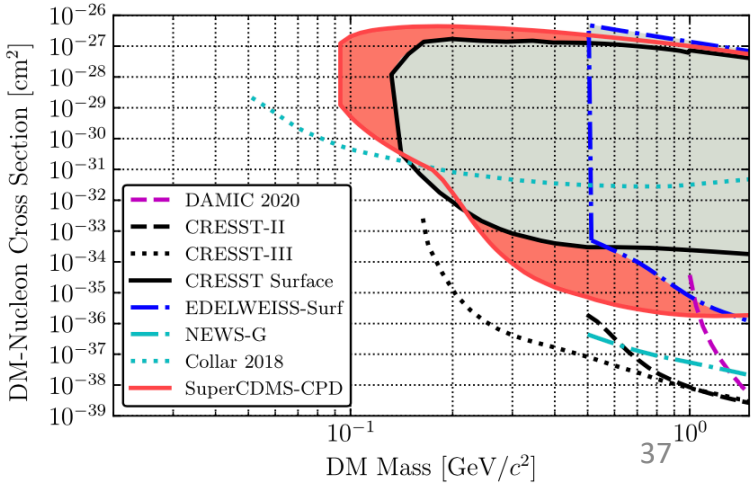
CPD detector

1mm thick Si wafer
10.6g

E_{th} = 16.3eV_{nr}

→ Sensitivity to
100MeV particles

PRL, arXiv:2007.14289



Excellent thresholds achieved….

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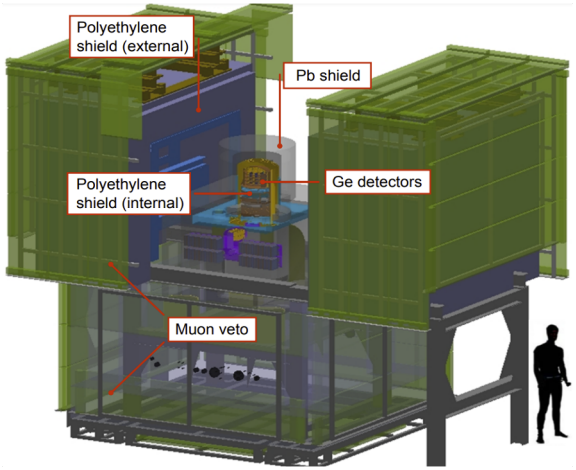
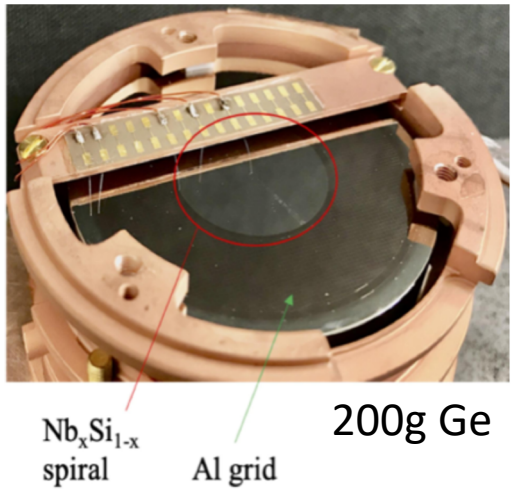
EDELWEISS @ LSM



High voltage mode + NbSi TES

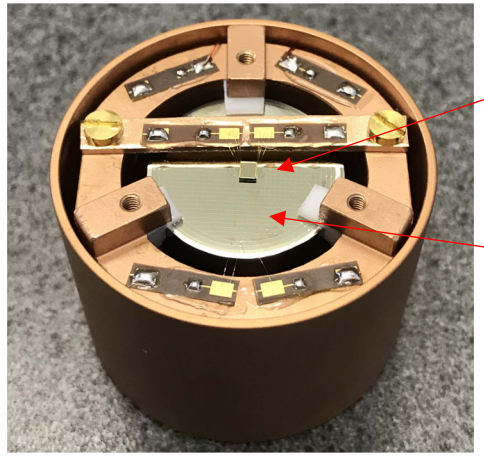


200g Ge

E_{th} = 400eV$_{nr}$
E_{th} = 20eV$_{ee}$ (HV)

→ Ideal for Migdal searches

EDELWEISS @ Surface



E_{th} = 60eV$_{nr}$

33g Ge

Recent results:

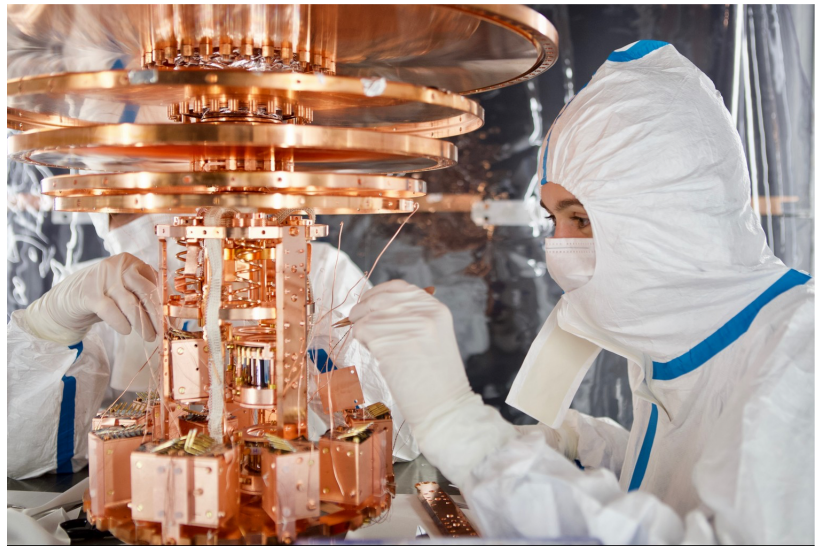
EDELWEISS-Surf [PRD 99 082013 (2019)]
33 g Ge bolometer.
Electron-DM results [PRL 125, 141401 (2020)]
HV 33 g Ge bolometer.
Migdal with NbSi TES [arXiv:2203.03993

Sub-GeV Dark Matter Searches with EDELWEISS: New results and prospects, H. Lattaud, Mo 16:30

Excellent thresholds achieved….

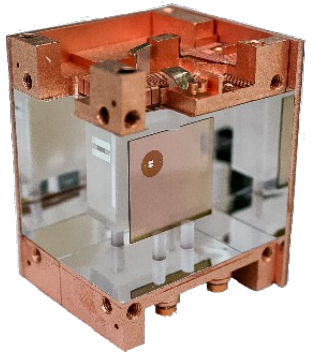
… and R&D is running full steam!

CRESST-III @ LNGS



Detector A – 23.6 g $CaWO_4$

data taking period	Oct 2016 – Jan 2018
exposure	5.698 kg · days
baseline resolution	4.6 eV
nuclear recoil threshold	30.1 eV



E_{th} = 30.1eV$_{nr}$

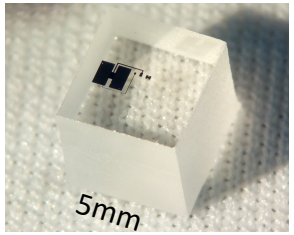
→ **Leading SI limit at 150MeV to 2GeV**

→ **Spin dependent ^{17}O**

First results from CRESST-III *Phys. Rev. D 100, 102002, arXiv:1904.00498*

MeV-scale dark mattter *EPJ C volume 77, 637 (2017) arXiv:1707.06749*

CRESST @ Surface

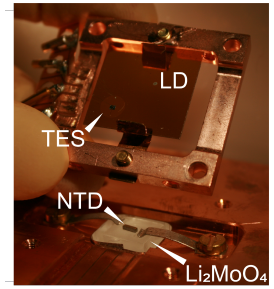


0.5g Al_2O_3

E_{th} =19.7 eV$_{nr}$

→ Explored new SI parameter space in 2017

→ Earth scattering limits



2.7g Li_2MoO_4

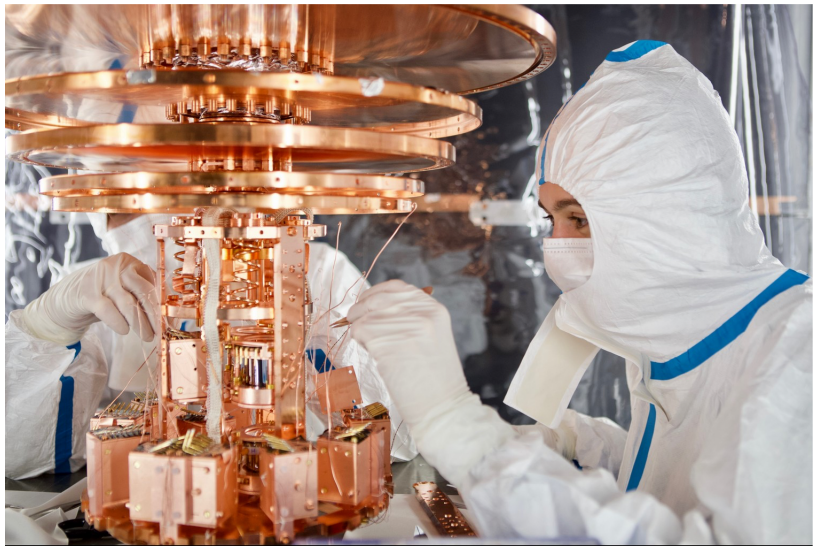
E_{th} =930 eV$_{nr}$

→ Pathfinder for SD searches

Excellent thresholds achieved….

… and R&D is running full steam!

CRESST-III @ LNGS



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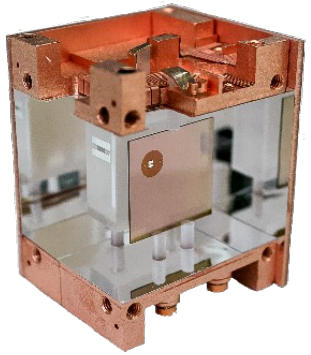

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→ **Leading SI limit at 150MeV t**

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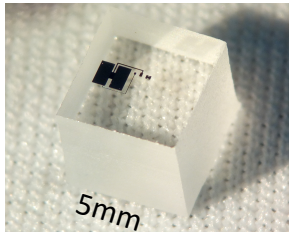

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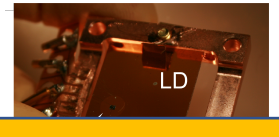


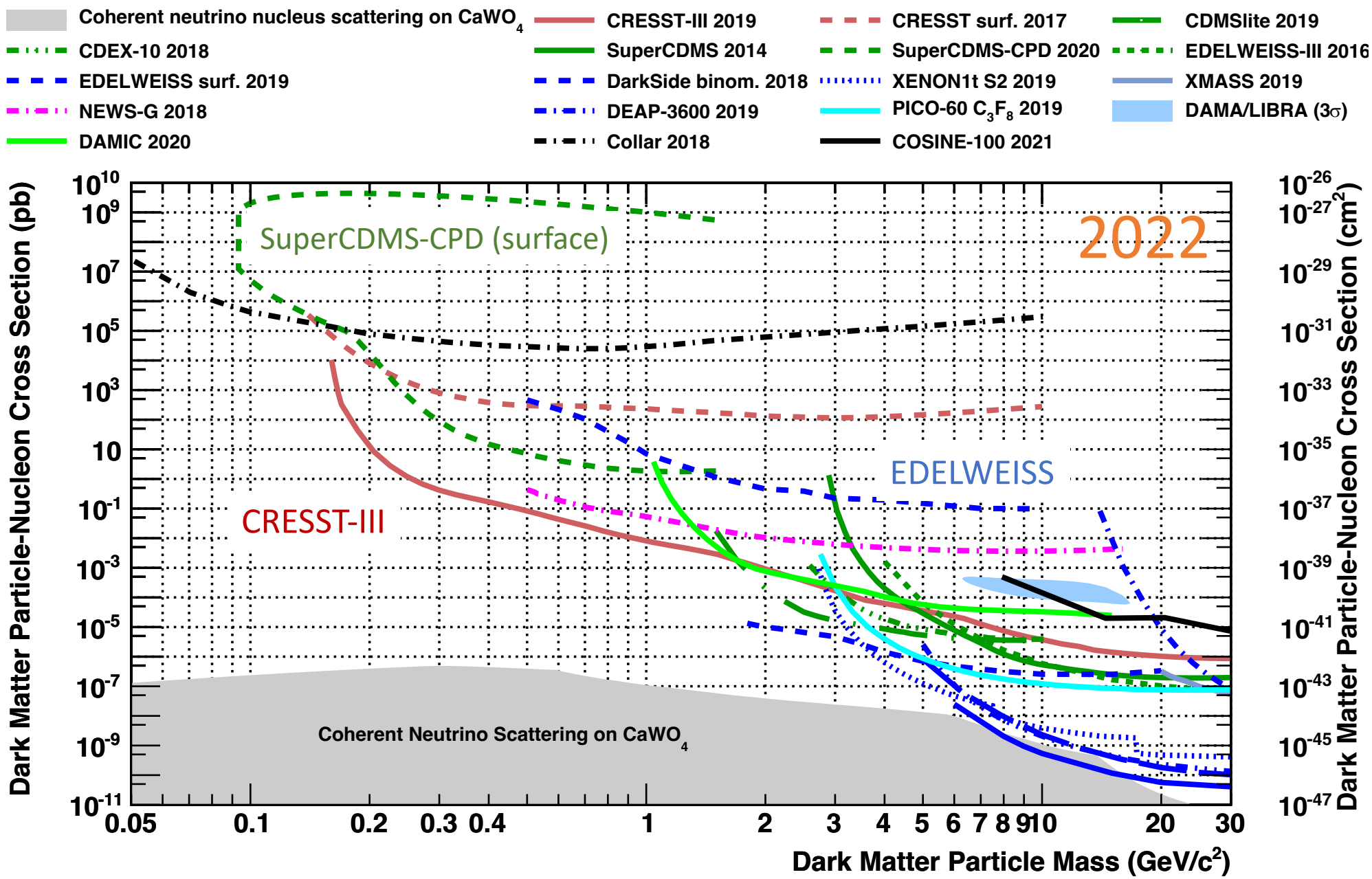
2.7g Li_2MoO_4

The CRESST-III Dark Matter Search: Status and Outlook, C. Strandhagen, Mo 16:30

Probing Lithium targets in CRESST-III, S. Gupta , Mo 17:30

Characterization of a Low Background CaWO4 Crystal for CRESST-III, A. Kinast, Thu 14:40

Stay tuned: New results (SI, SD, thresholds!) @IDM2022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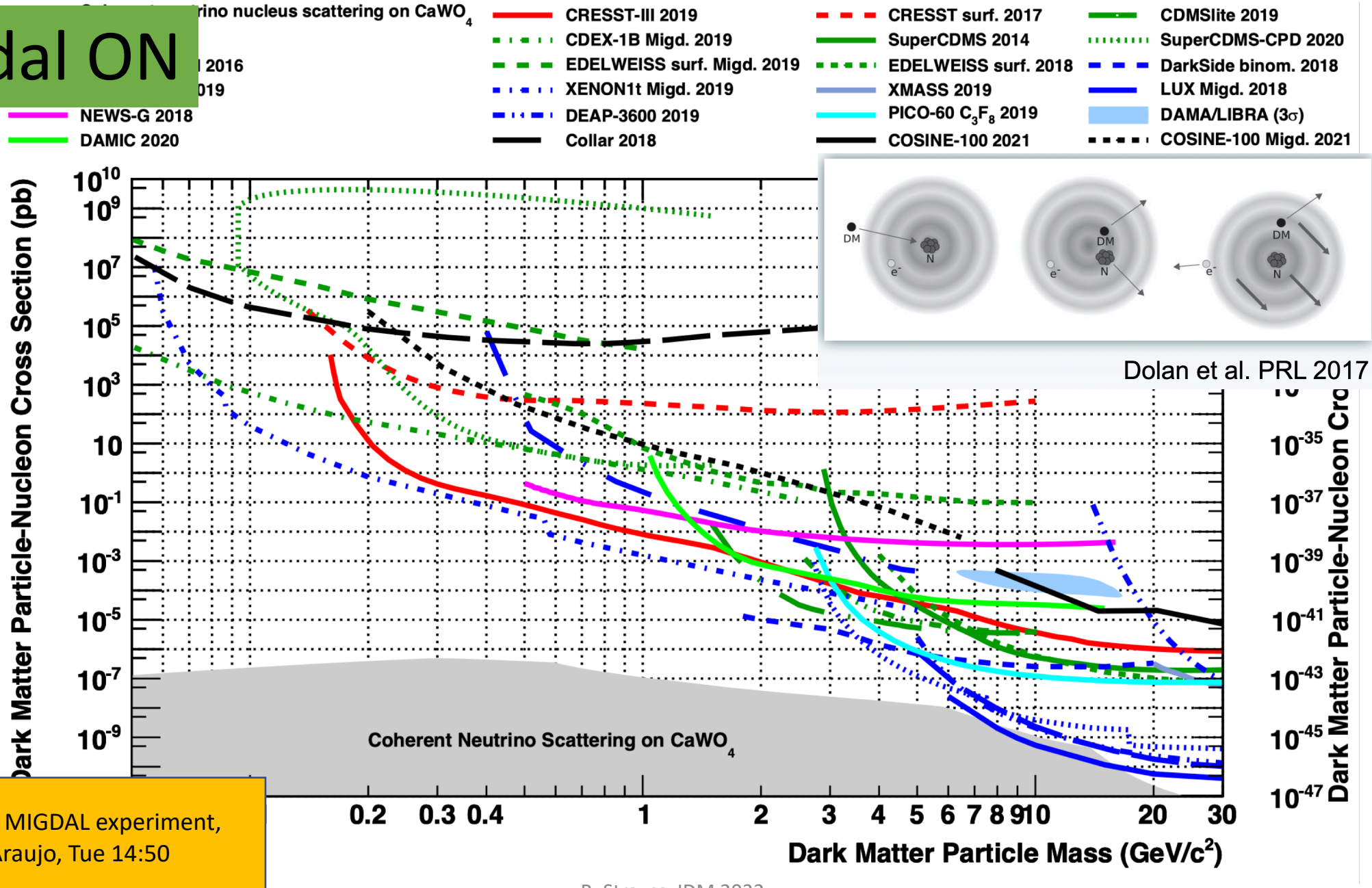
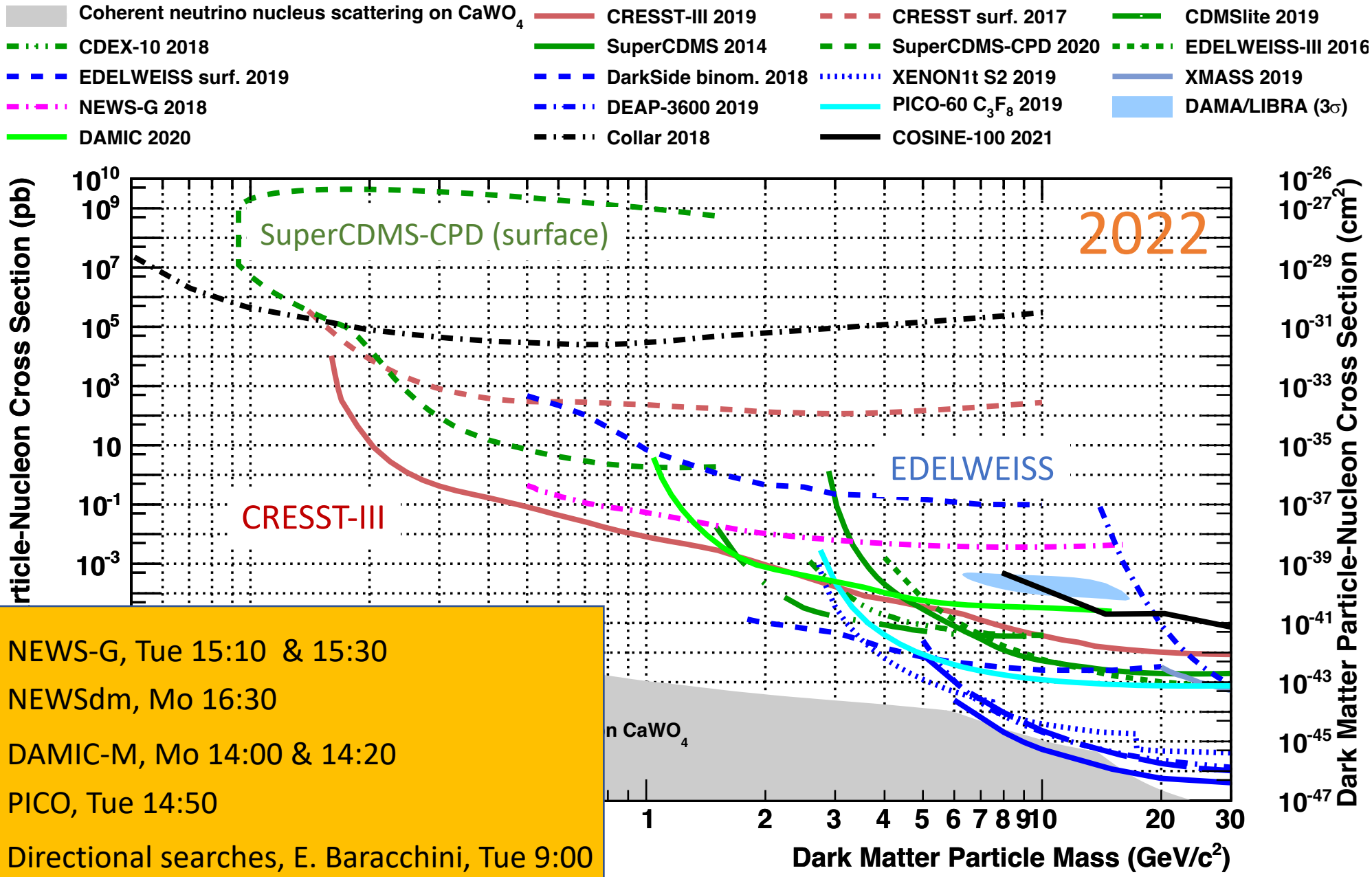
CRESST-III
Coherent Neutrino Scattering on CaWO4
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm2)
Dark Matter Particle Mass (GeV/c2)

Migdal ON



Dolan et al. PRL 2017

The MIGDAL experiment,
H. Araujo, Tue 14:50



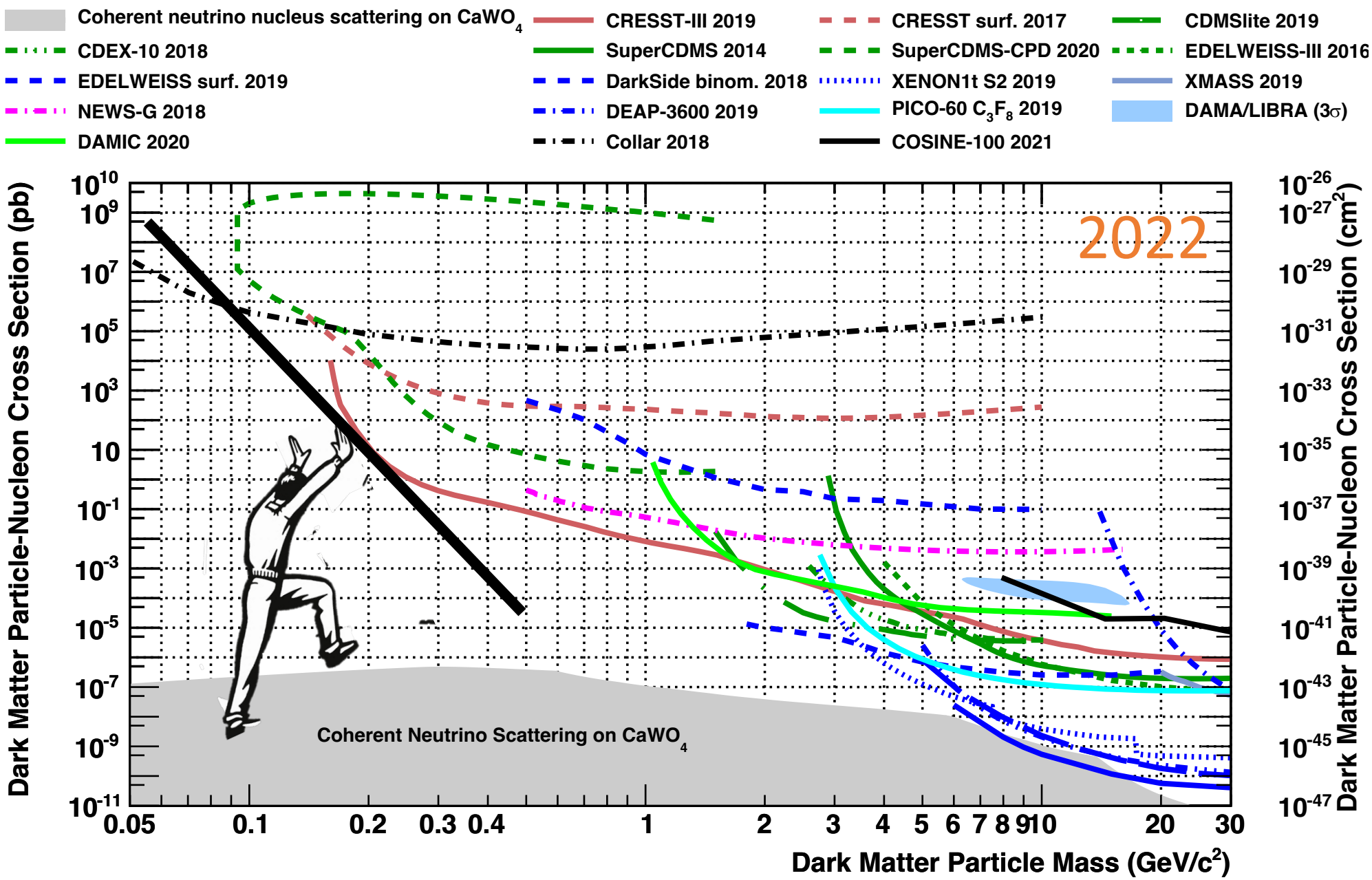
NEWS-G, Tue 15:10 & 15:30

NEWSdm, Mo 16:30

DAMIC-M, Mo 14:00 & 14:20

PICO, Tue 14:50

Directional searches, E. Baracchini, Tue 9:00

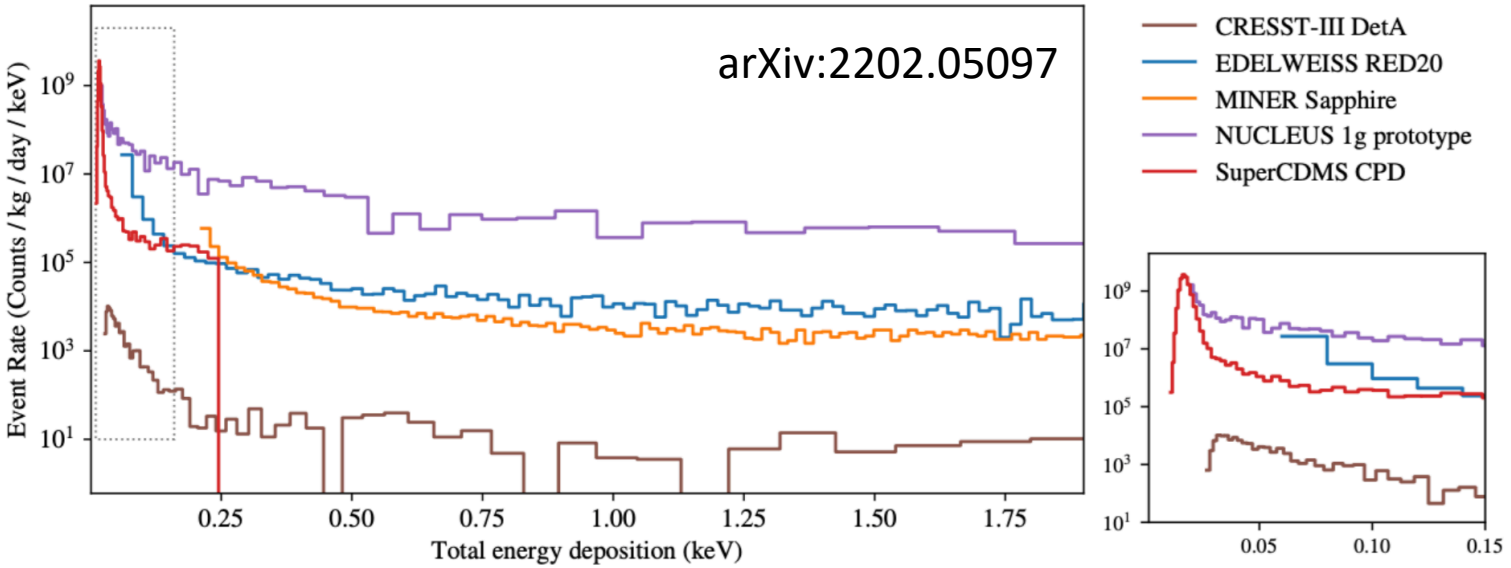

Coherent neutrino nucleus scattering on CaWO4
CDEX-10 2018
EDELWEISS surf. 2019
NEWS-G 2018
DAMIC 2020
CRESST-III 2019
SuperCDMS 2014
DarkSide binom. 2018
DEAP-3600 2019
Collar 2018
CRESST surf. 2017
SuperCDMS-CPD 2020
XENON1t S2 2019
PICO-60 C3F8 2019
COSINE-100 2021
CDMSlite 2019
EDELWEISS-III 2016
XMASS 2019
DAMA/LIBRA (3σ)
2022
Coherent Neutrino Scattering on CaWO4
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm2)
Dark Matter Particle Mass (GeV/c2)

The low energy EXCESS background

Workshop series
- June 2021
- Feb 2022
- July 2022 @IDM

>300 participants(!)

Exponentially rising background towards lower energies

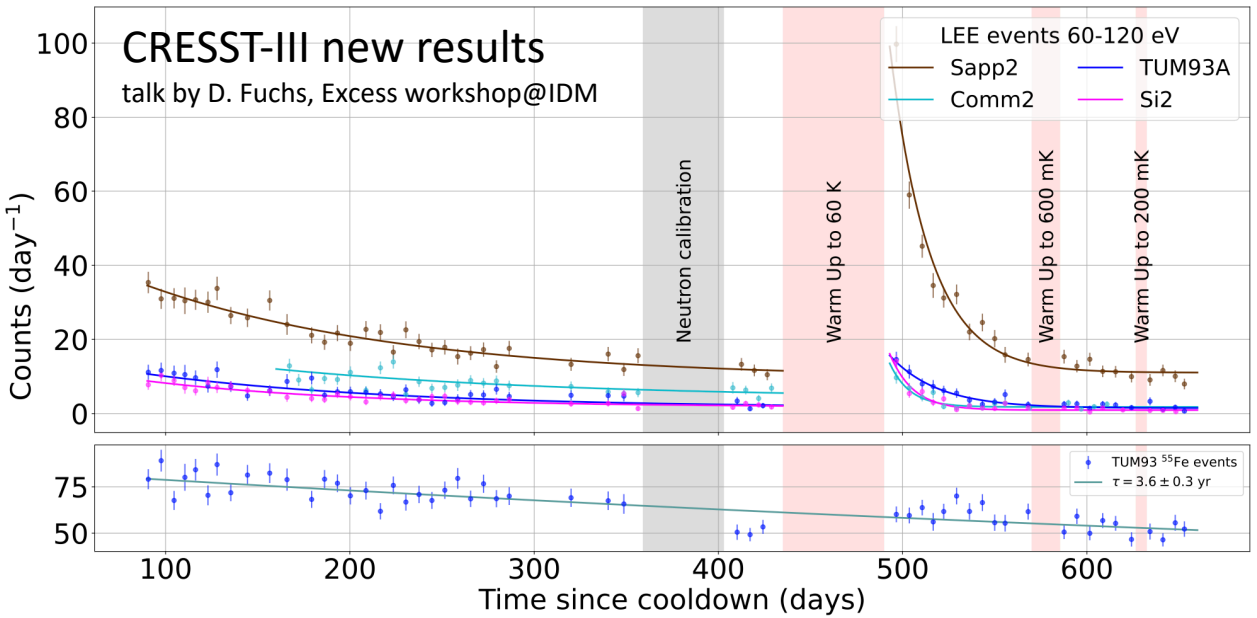


Currently limiting the sensitivity globally !
Origin still unknown, but a lot of R&D is going on …

The EXCESS initiative, van Krosigk & Kaznacheeva, Wed 9:00

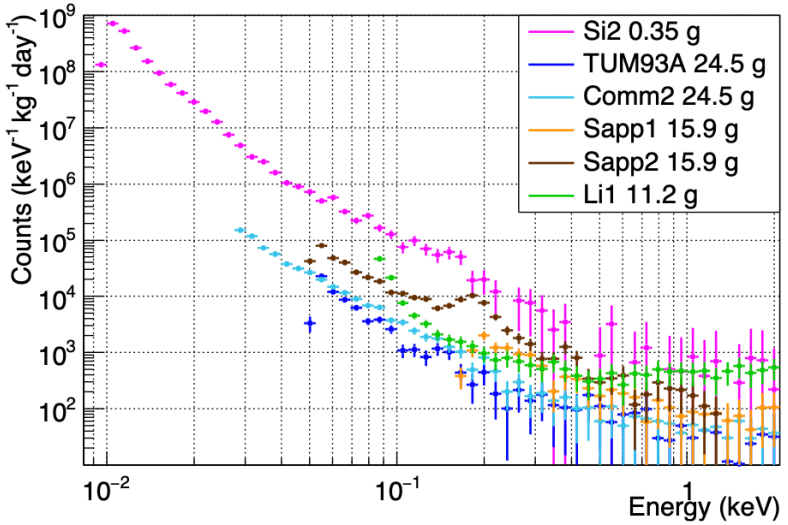
EXCESS – towards understanding its origin?

Decay of EXCESS rate after Cryostat Warmup



Confirms earlier EDELWEISS observations!

CRESST-III



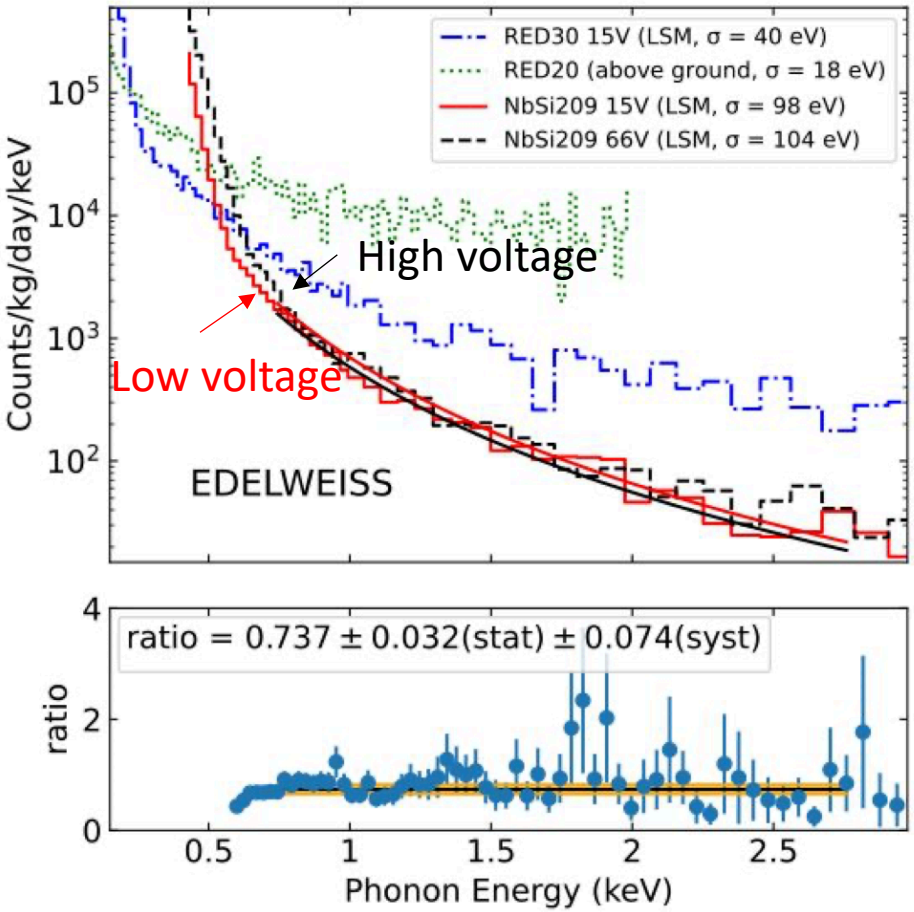
Talk by D. Fuchs @EXCESS

Excess rate does not scale with mass!

Excludes radioactive origin!
Excludes (widely) crystal related effects!
Excludes DM explanations!

EXCESS – towards understanding its origin?

Talk by H. Lattaud @EXCESS



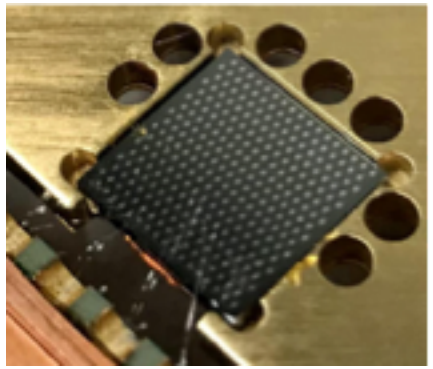
High voltage applied doesn't change spectrum
(in agreement with SuperCDMS observations, talk by V. Novati @Excess)

→ No charges involved $x < 0.04\%$ at 90% C.L.

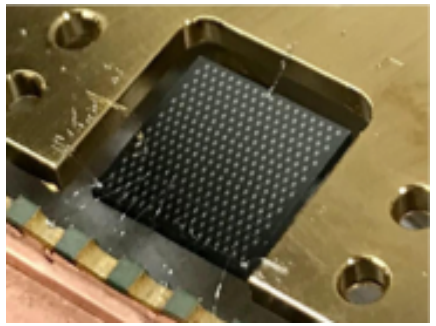
→ Most events are "**heat-only**"

Mechanical stress?
Thermal contractions

EXCESS – towards understanding its origin?

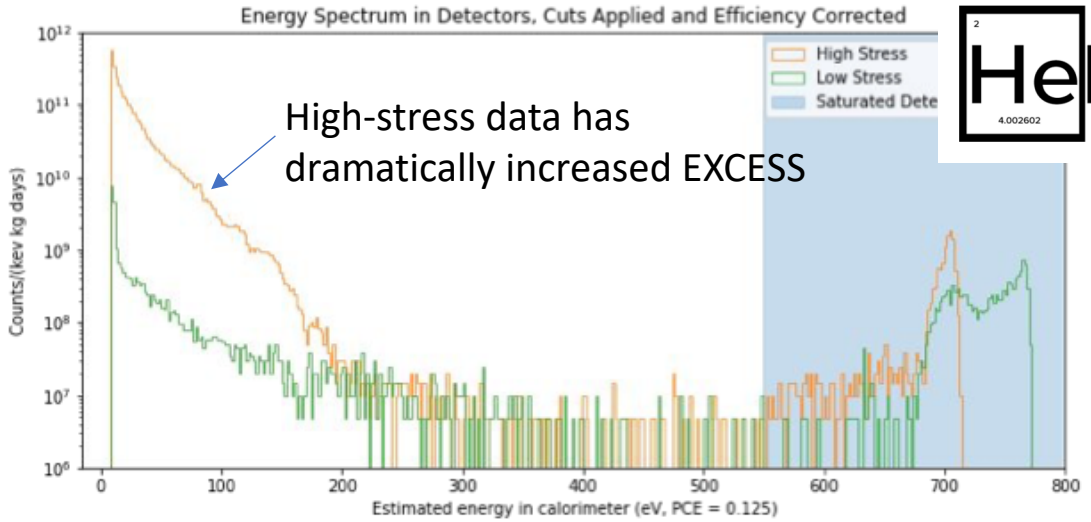


Detector
glued to holder
→ High stress



Detector hangs
on bond wired
→ Low stress

TESSERACT: New collaboration for 10MeV scale DM search



Mc Kinsey @Excess

Strong hint for stress-induced origin of EXCESS (Holder? Sensor interface?)

TESSERACT, Dan Kinsey,
Wed 9:30

Everyone, please reduce the stress-level !

More Challenges: Calibration at low energies

New sub-keV calibration techniques and their way

Electron recoils:

- Low energy X-rays
- Laser / LED sources
- Material activation
- Compton edges.
- …

Nuclear recoils:

- Low-energy neutron scattering
- Neutron capture reaction
- …

"Calibration sessions"

Neutron capture CRAB, V. Wagner, Thu 14:00

Laser calibration, K. Stifter, Thu 14:50

Neutron calibration for CRESST (poster), A. Fuß, Tue 19:00

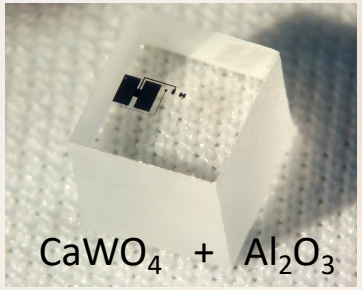
100eV ionization measurement at TUNL, V. Novati, Mo 15:20

The CEvNS Spin-Offs

CRESST

Construction

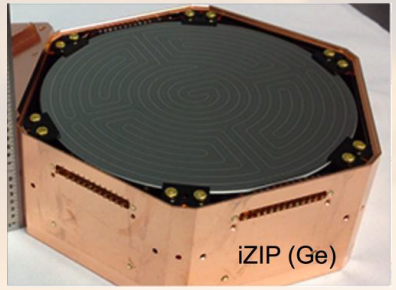
nucleus EXPERIMENT



SuperCDMS

Commissioning

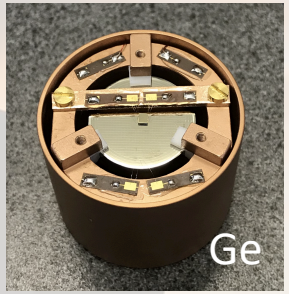
MINER

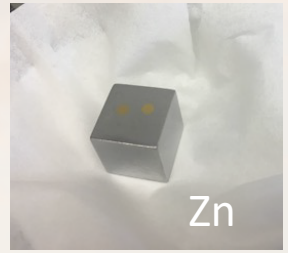


EDELWEISS

Construction

RICOCHET





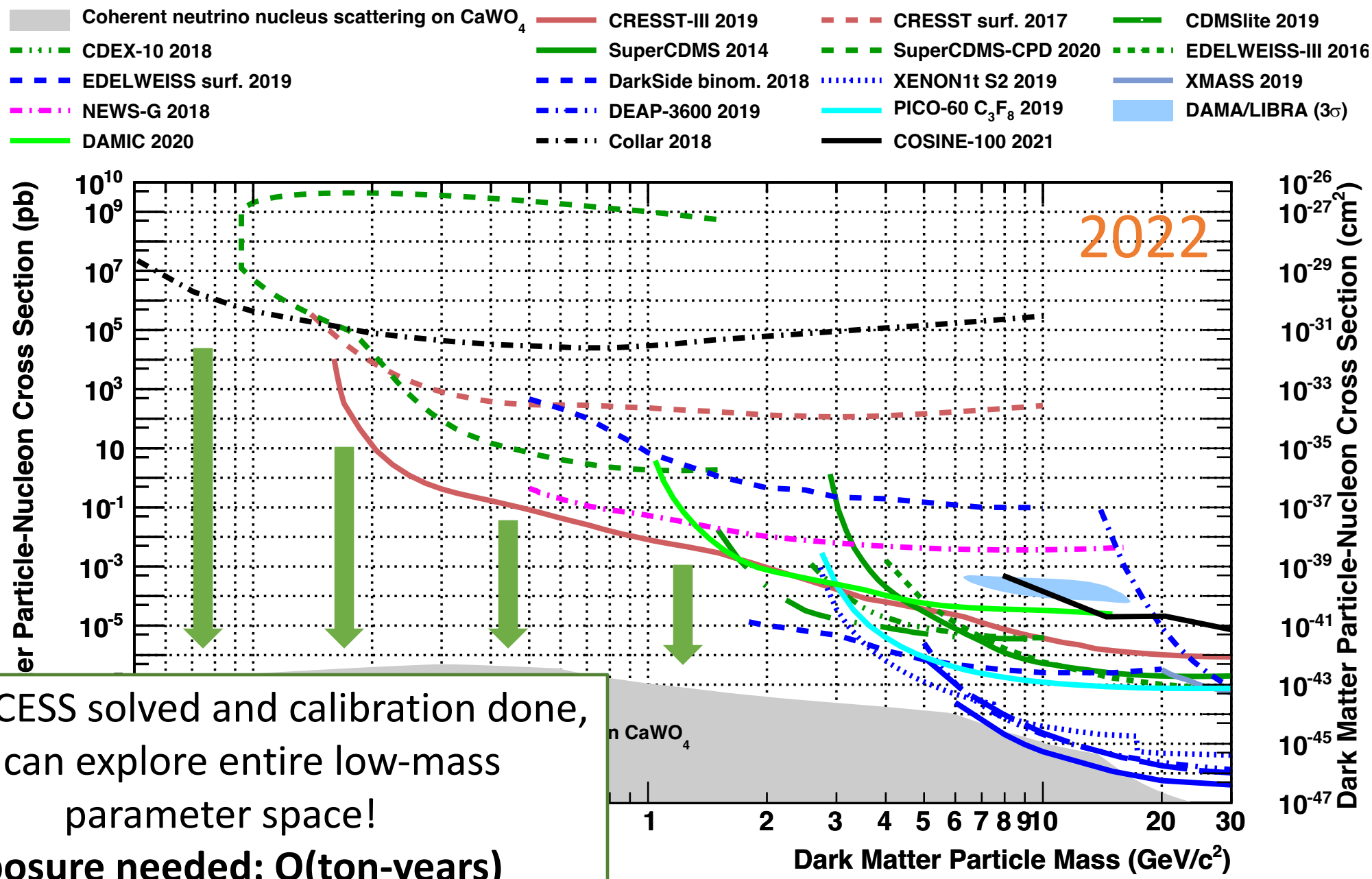
ILL
France

What's the point for DM searches?

Nail-down CEvNS cross-section

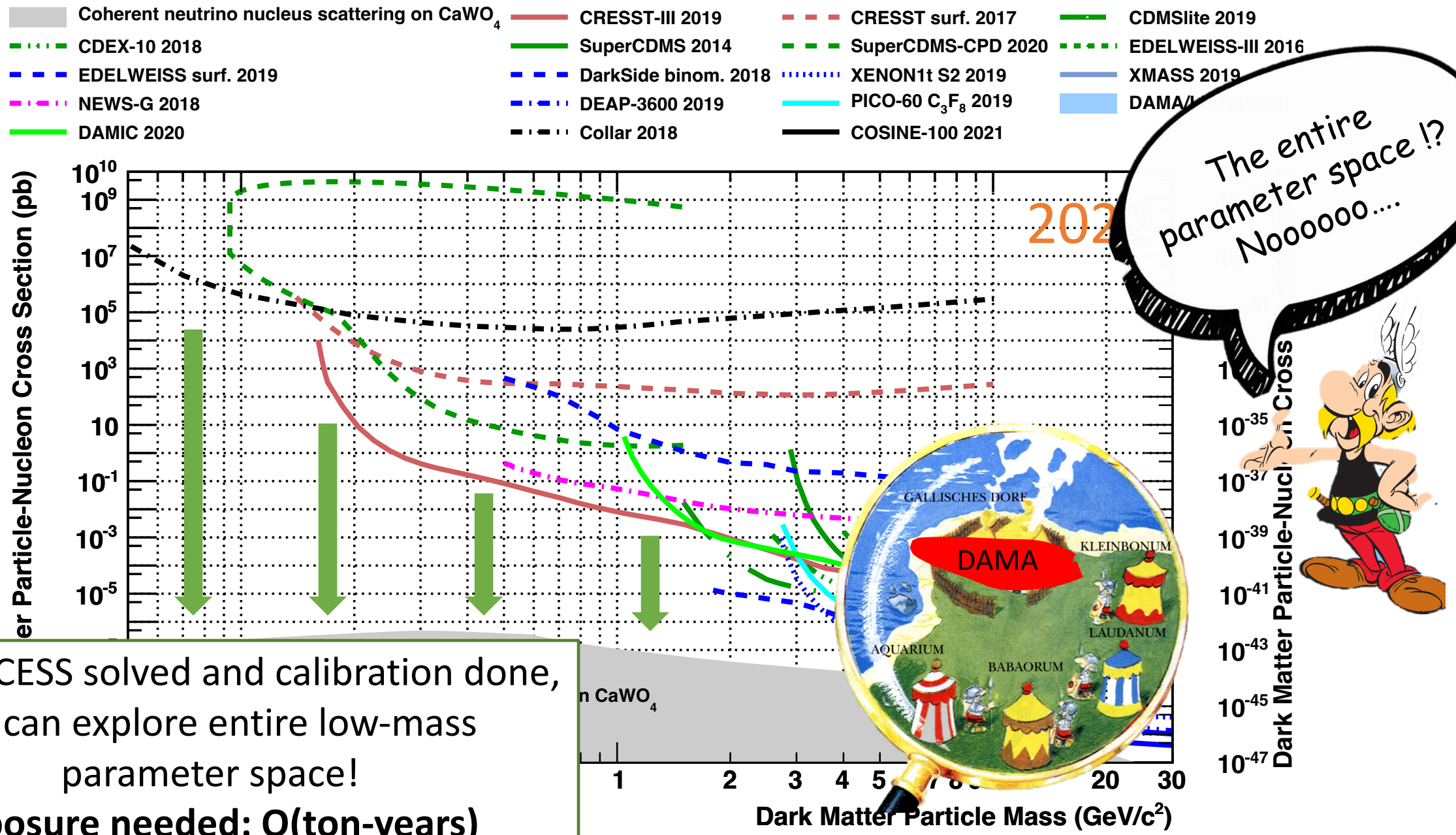
Boost for detector R&D

Calibration of detectors via CEvNS(!)



With EXCESS solved and calibration done, we can explore entire low-mass parameter space!

Exposure needed: O(ton-years)



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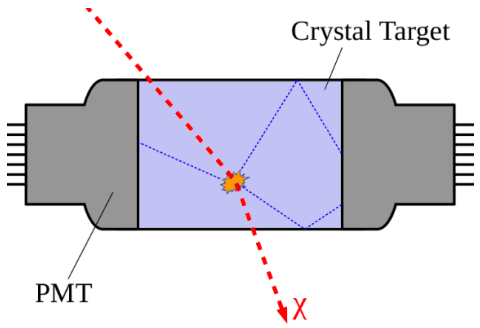
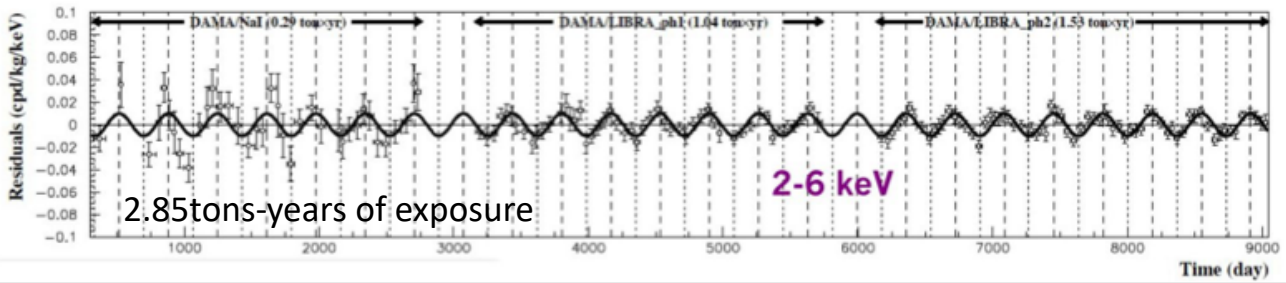


A CRESST Spin-Off

COSINUS

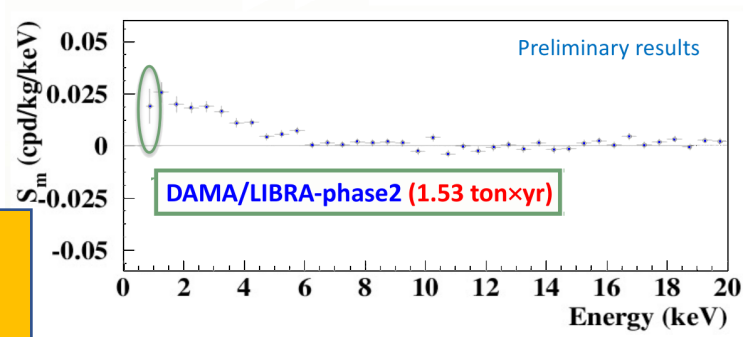
Phonon-light will shed light on nature of DAMA signal!

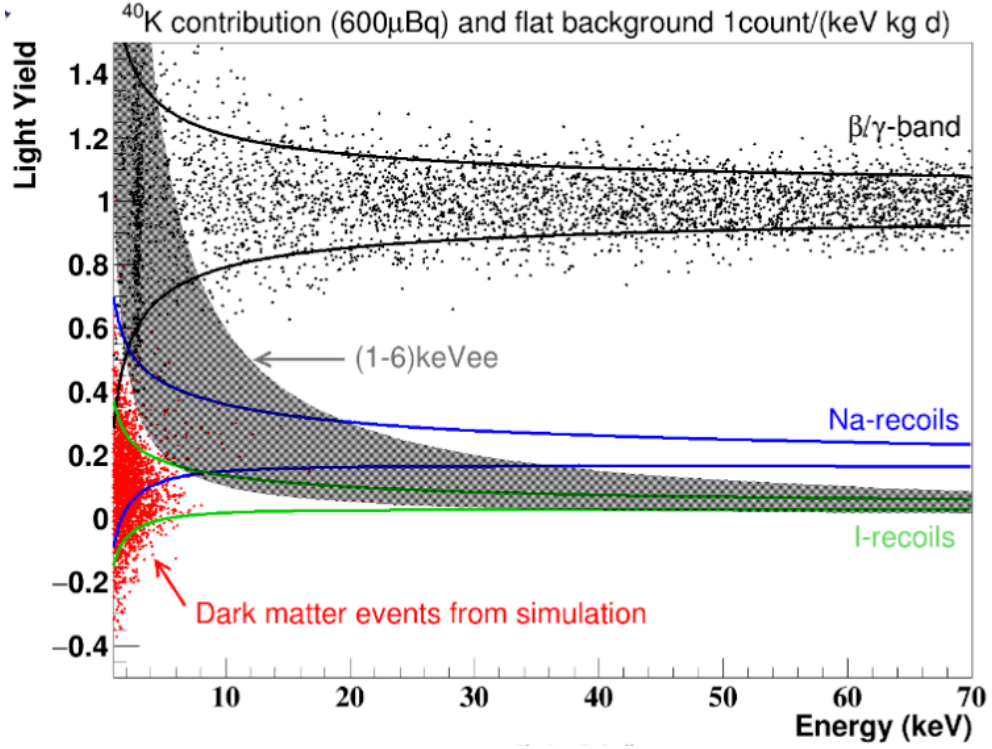
Long-standing 13.6σ modulation signal observed
Currently running: 245kg NaI(Tl)



New results with lower threshold: E_{th}=0.75keV$_{ee}$

Modulation confirmed!



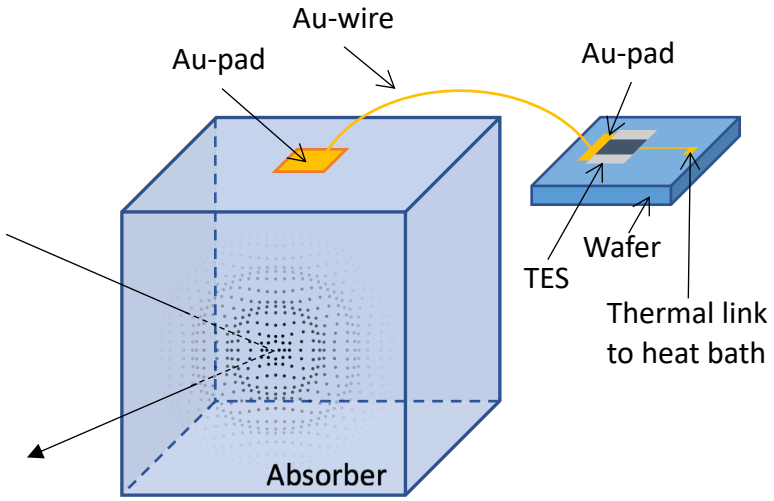


DAMA/Libra, P. Belli, Tue 17:00

COSINUS

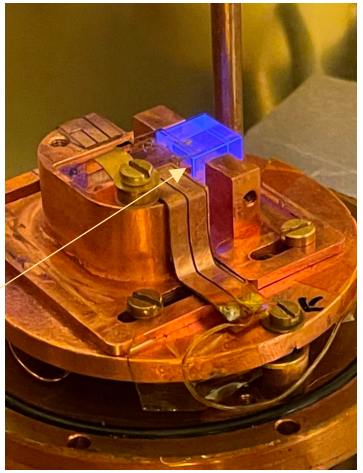
New cryogenic facility at LNGS

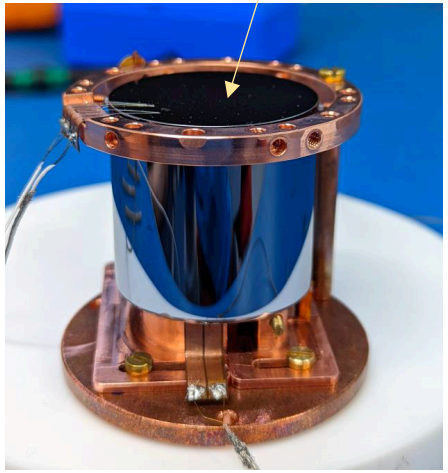
New TES design: remoTES



Si light detector “beaker”

NaI





New results from detector tests presented at IDM

COSINUS, K. Schäffner,
Tue 18:00

Conclusion on cryogenic DM detectors

They are **low threshold**

They are **multi-target**

They are **diverse**

They are **small**

They are **big**

not so much

They are ~~(sometimes)~~

a pain

any more

They are **beautiful**

They are **clever**