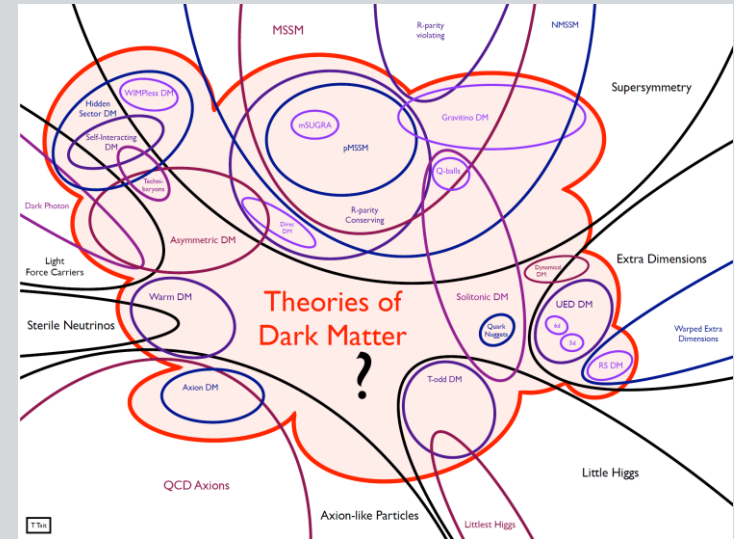
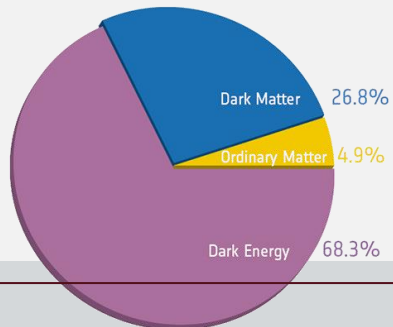
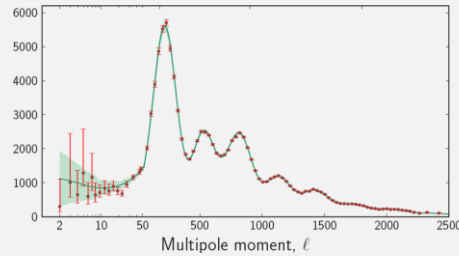
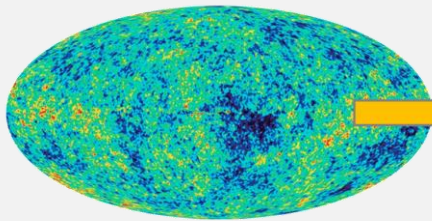
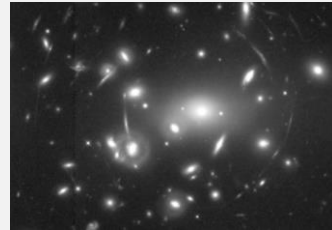
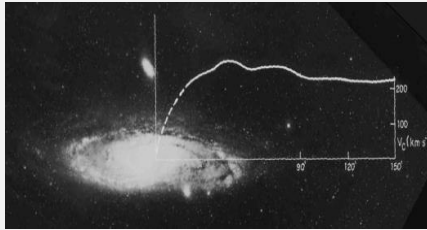


Low Mass Dark Matter Particle Search



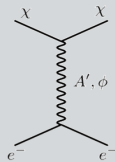
pre LHC searches,
largely motivated by SuSy-WIMPs with $m_\chi > 45$ GeV

wide variety of models
large possible mass range
need to search everywhere

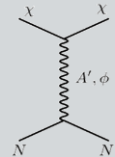
this talk: direct detection $m_\chi < 1$ GeV

Searches for Light Dark Matter Particles

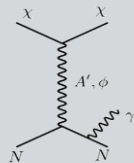
direct detection channels



elastic electron scattering

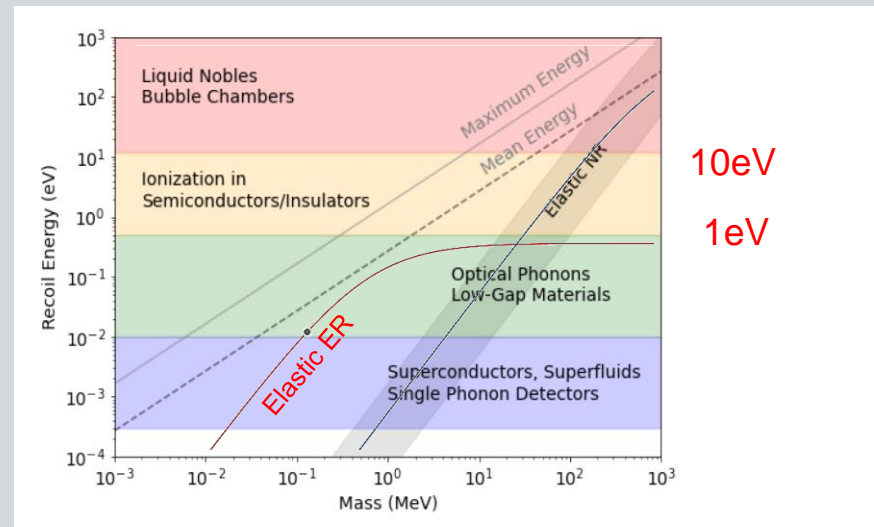
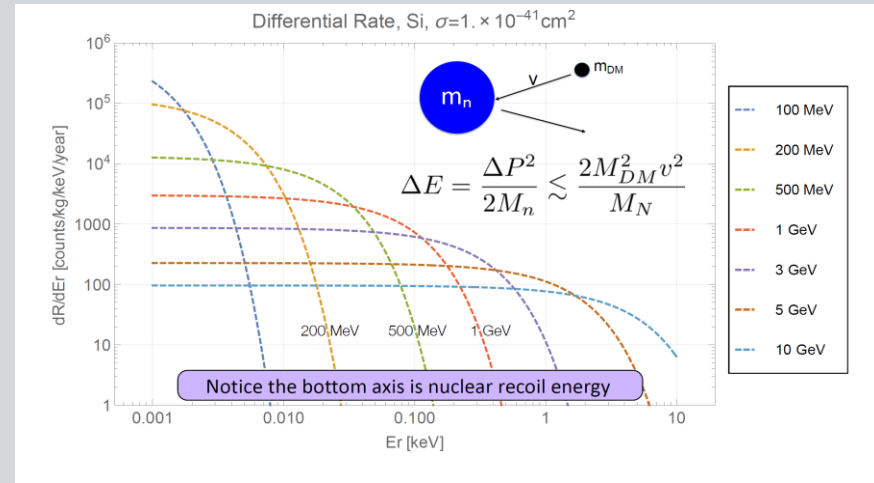


elastic nuclear scattering

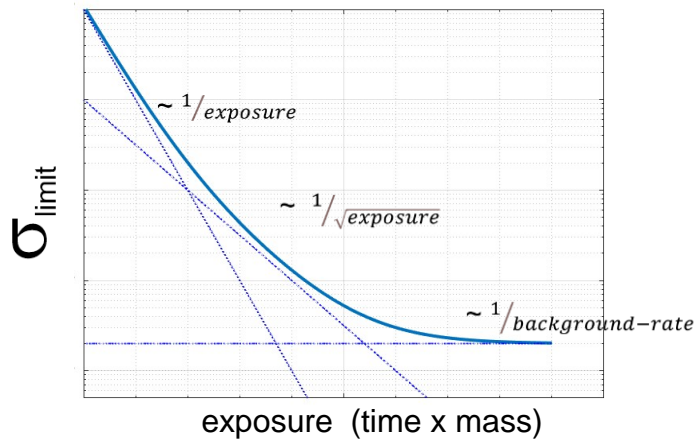


inelastic nuclear scattering
(migdal effect)

this talk:
MeV < WIMPS, hidden sector < 1GeV
only heavy mediator
and spin independent



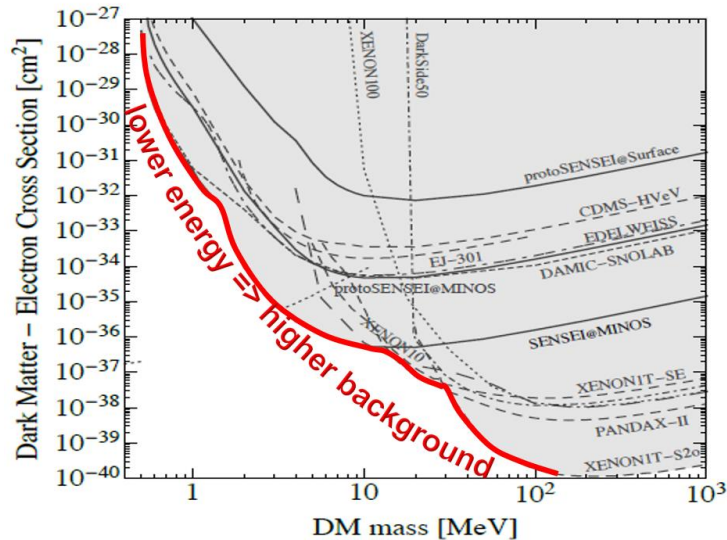
Searches for Light Dark Matter Particles



no background: $\sigma_{\text{limit}} \sim 1/\text{exposure}$
 distinguishable background: $\sigma_{\text{limit}} \sim 1/\sqrt{\text{exposure}}$
 irreducible background: $\sigma_{\text{limit}} \sim 1/\text{background-rate}$

$M_{\text{wimp}} \uparrow \Rightarrow E_{\text{recoil}} \uparrow \Rightarrow \text{background} \downarrow \Rightarrow \sigma_{\text{limit}} \sim 1/\text{exposure}$

$M_{\text{wimp}} \downarrow \Rightarrow E_{\text{recoil}} \downarrow \Rightarrow \text{background} \uparrow \Rightarrow \sigma_{\text{limit}} \sim 1/\text{background-rate}$



sub-GeV WIMP search => high background

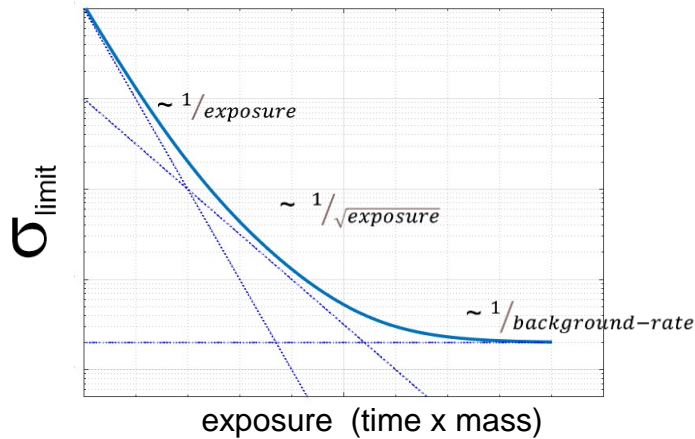
small exposures (small detectors, short time) reach limit

field (still) dominated by small detectors
 lowest background will win

=> good do have many ideas and a variety of techniques



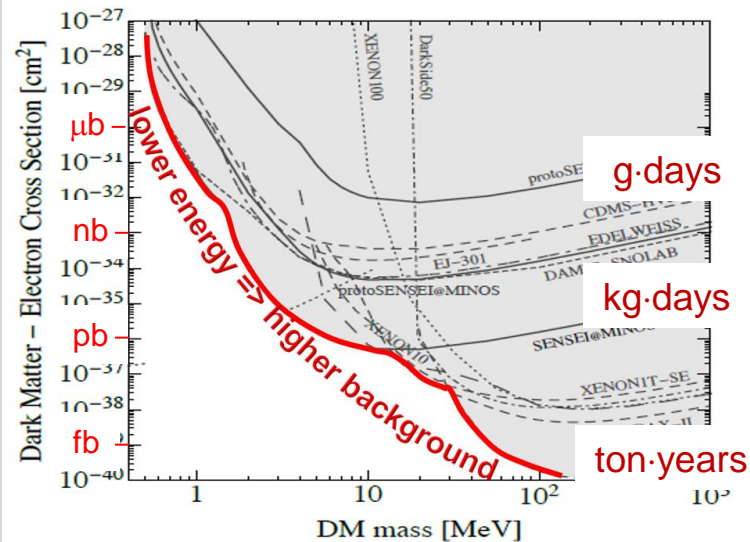
Searches for Light Dark Matter Particles



no background: $\sigma_{\text{limit}} \sim 1/\text{exposure}$
 distinguishable background: $\sigma_{\text{limit}} \sim 1/\sqrt{\text{exposure}}$
 irreducible background: $\sigma_{\text{limit}} \sim 1/\text{background-rate}$

$M_{\text{wimp}} \uparrow \Rightarrow E_{\text{recoil}} \uparrow \Rightarrow \text{background} \downarrow \Rightarrow \sigma_{\text{limit}} \sim 1/\text{exposure}$

$M_{\text{wimp}} \downarrow \Rightarrow E_{\text{recoil}} \downarrow \Rightarrow \text{background} \uparrow \Rightarrow \sigma_{\text{limit}} \sim 1/\text{background-rate}$



sub-GeV WIMP search => high background

small exposures (small detectors, short time) reach limit

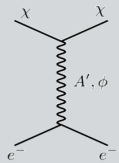
field (still) dominated by small detectors
 lowest background will win

=> good do have many ideas and a variety of techniques

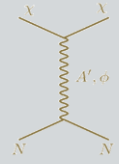


Searches for Light Dark Matter Particles

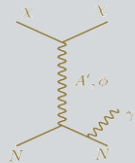
direct detection channels



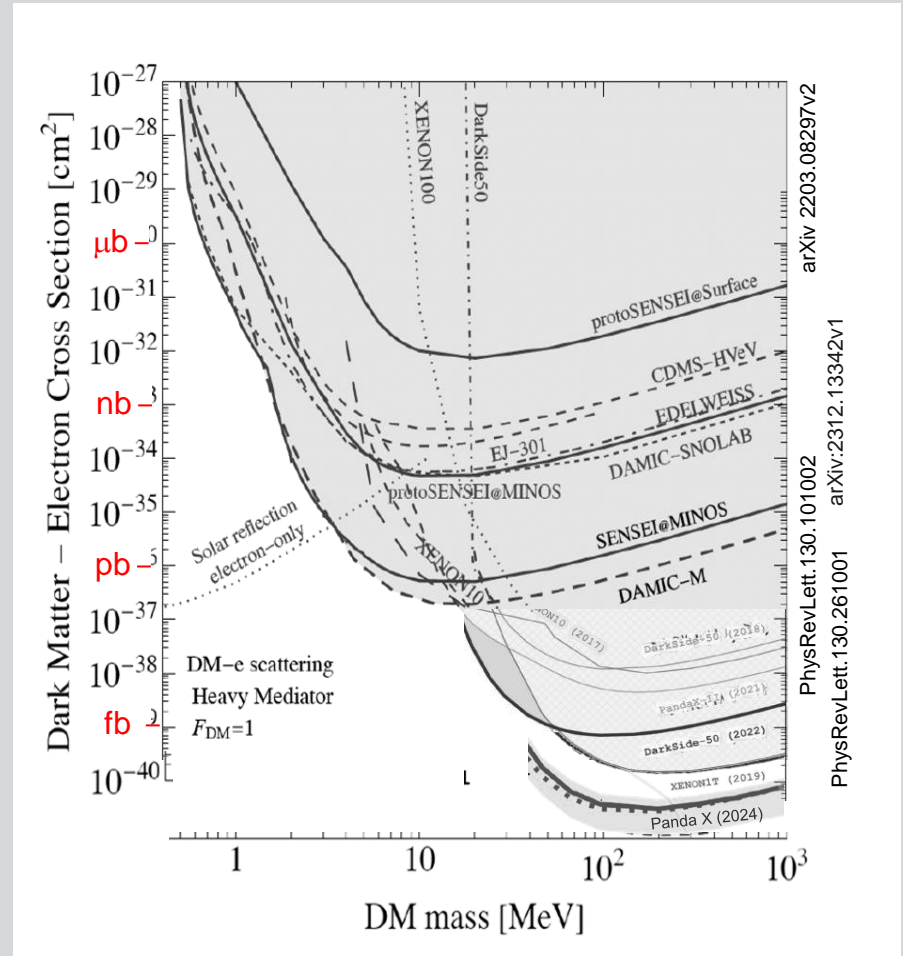
elastic electron scattering



elastic nuclear scattering

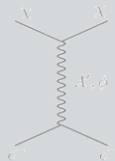


inelastic nuclear scattering
(migdal effect)

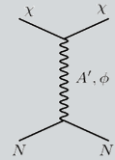


Searches for Light Dark Matter Particles

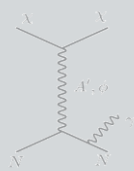
direct detection channels



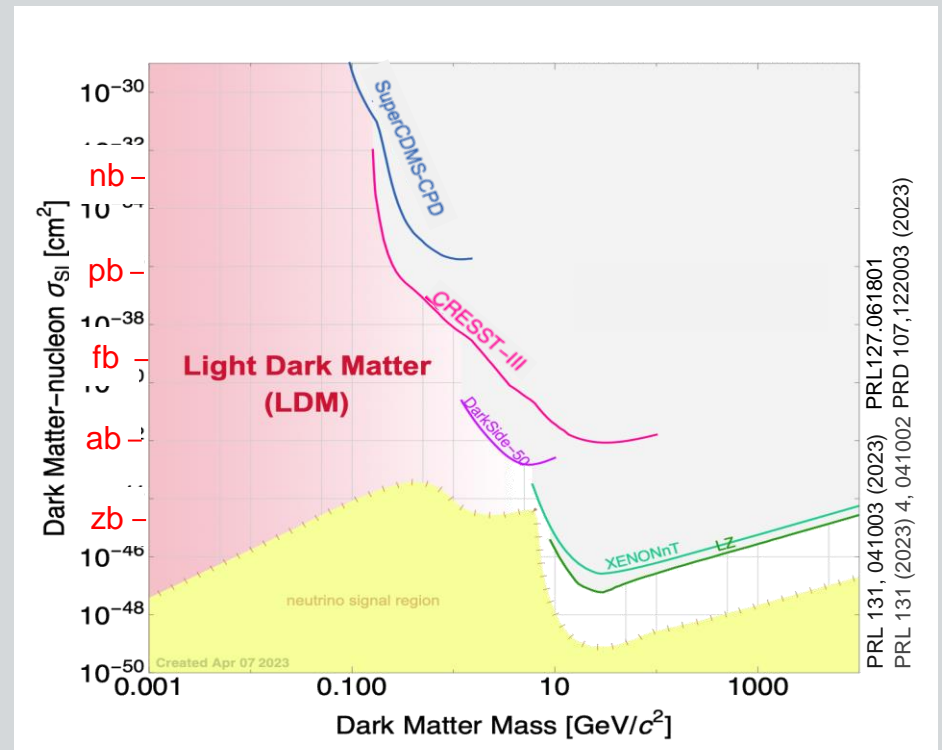
elastic electron scattering



elastic nuclear scattering



inelastic nuclear scattering
(migdal effect)



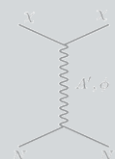
PRL 131, 041003 (2023) PRL127.061801
 PRL 131 (2023) 4, 041002 PRD 107,122003 (2023)

Searches for Light Dark Matter Particles

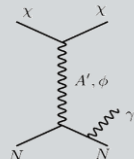
direct detection channels



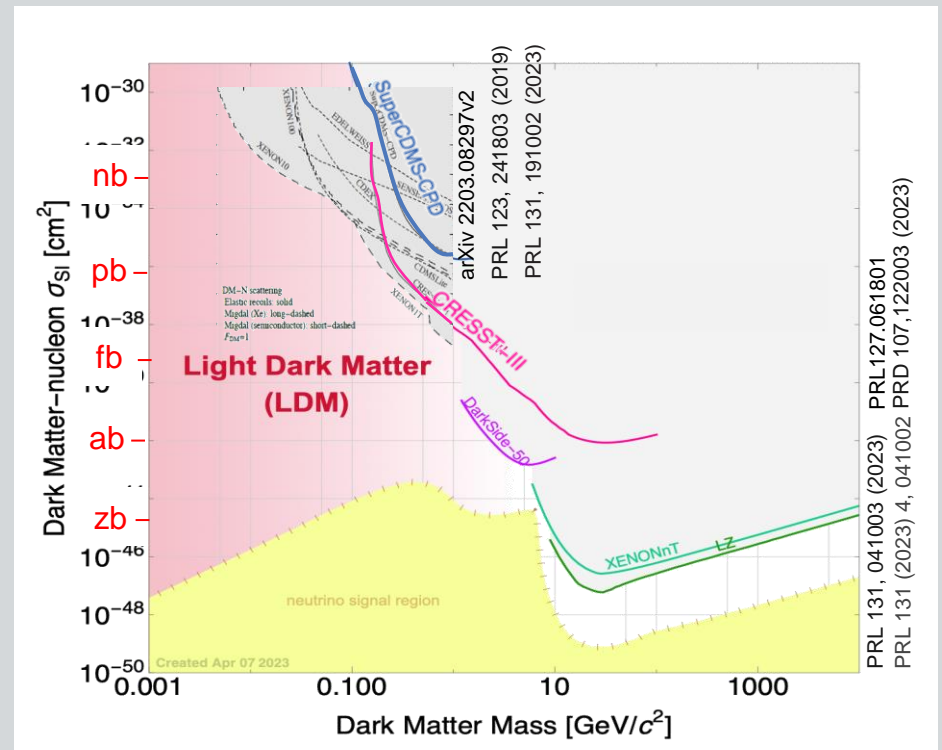
elastic electron scattering



elastic nuclear scattering



inelastic nuclear scattering
(migdal effect)



Searches for Light Dark Matter Particles

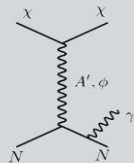
direct detection channels



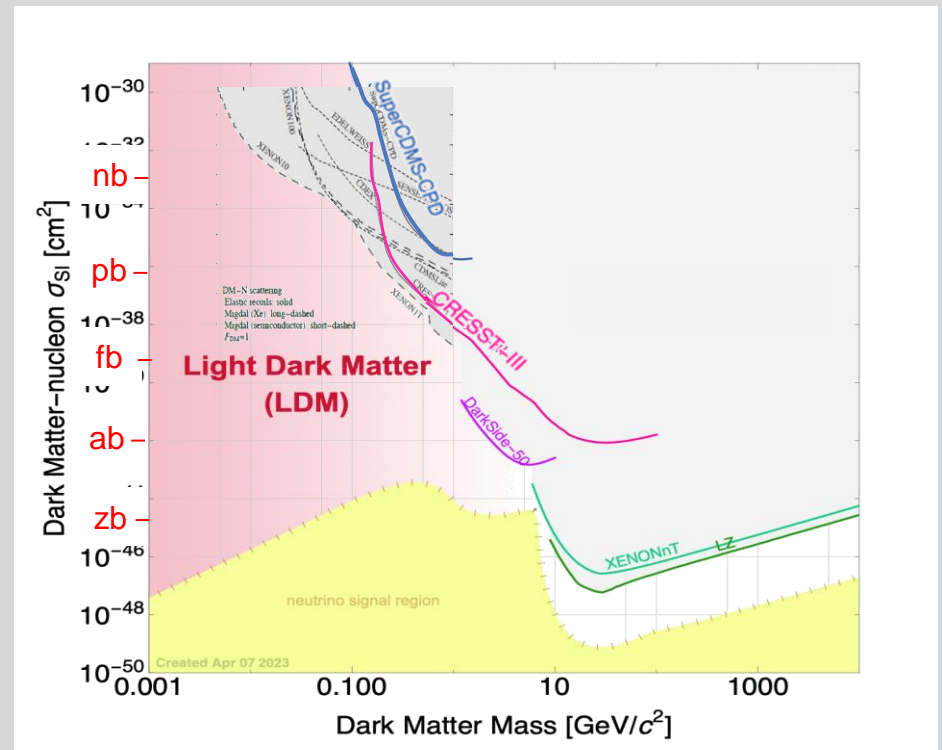
elastic electron scattering



elastic nuclear scattering



inelastic nuclear scattering
(migdal effect)



DM – electron Scattering

Looking for ionization

CCD

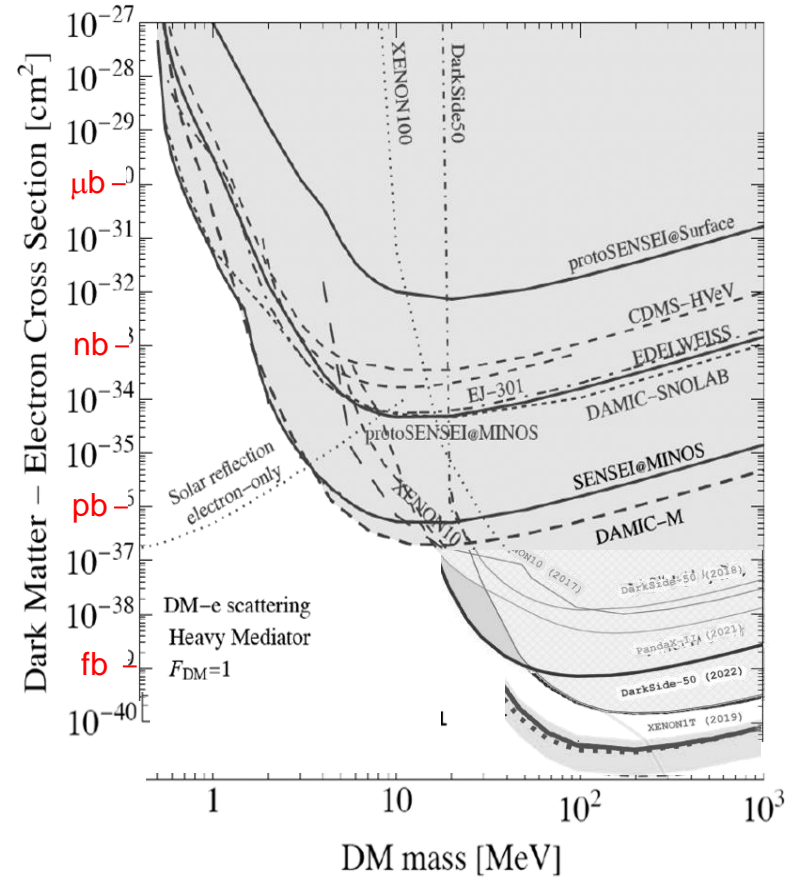
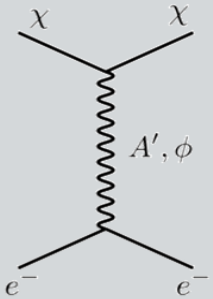
- DAMIC
- SENSEI
- OSCURA

Liquid Noble Gas TPCs

- ionisation (S2) only
- XENON
- DarkSide

Cryogenic

- Neganov-Luke
- SuperCDMS
- EDELWEISS



DM – electron Scattering

Looking for ionization

CCD

- DAMIC
- SENSEI
- OSCURA

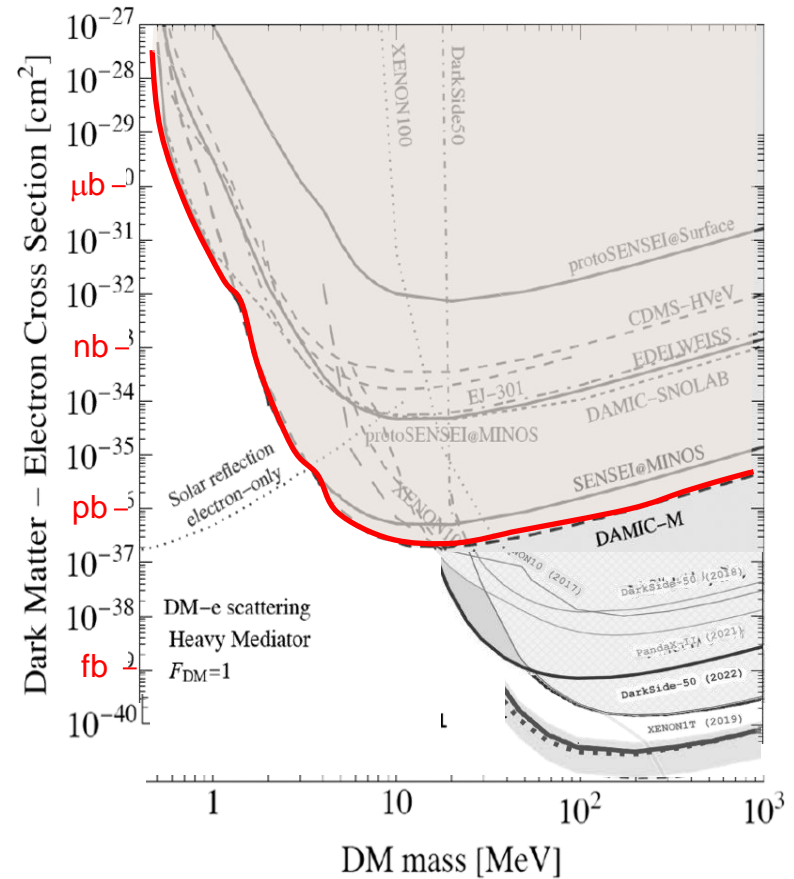
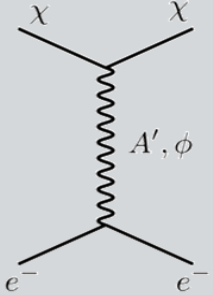
Liquid Noble Gas TPCs
- ionisation (S2) only

- XENON
- DarkSide

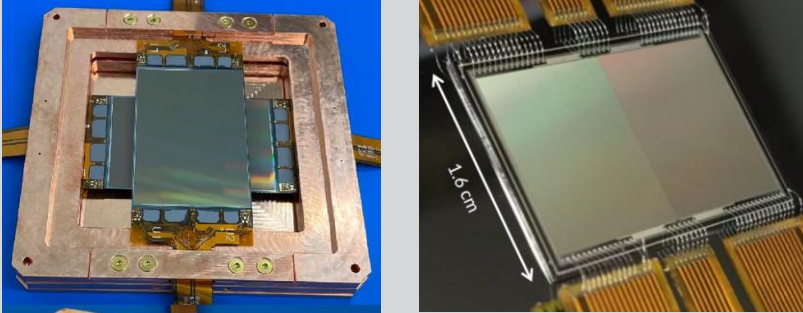
Cryogenic

- Neganov-Luke

- SuperCDMS
- EDELWEISS



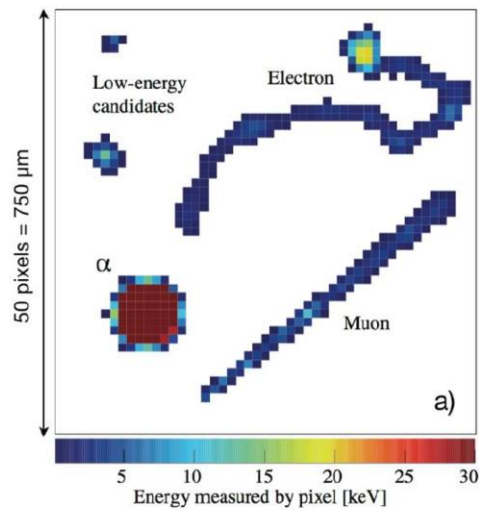
CCD DM - electron



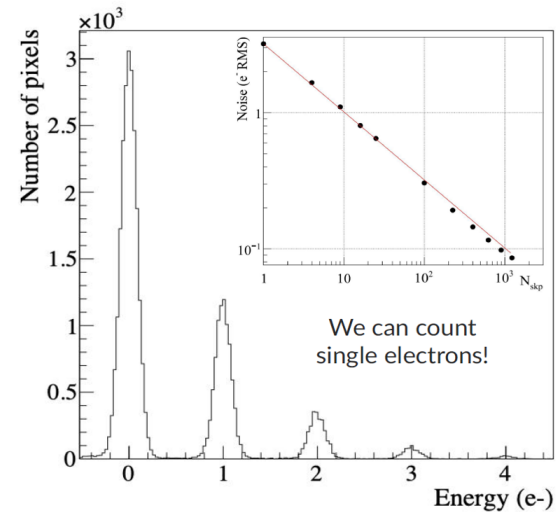
skimmer CCD:
same charge can be
measured many times

- ⇒ single e^- sensitivity
- ⇒ few eV threshold

signal = clusters of a few e^-



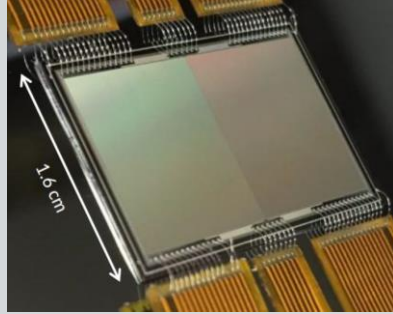
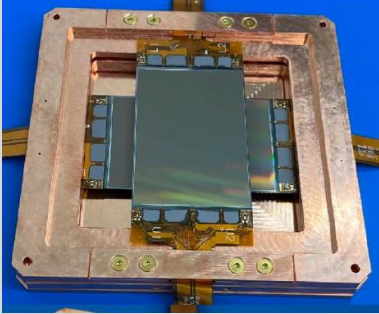
[detector-bkg.jpg \(1054×1362\) \(uchicago.edu\)](#)



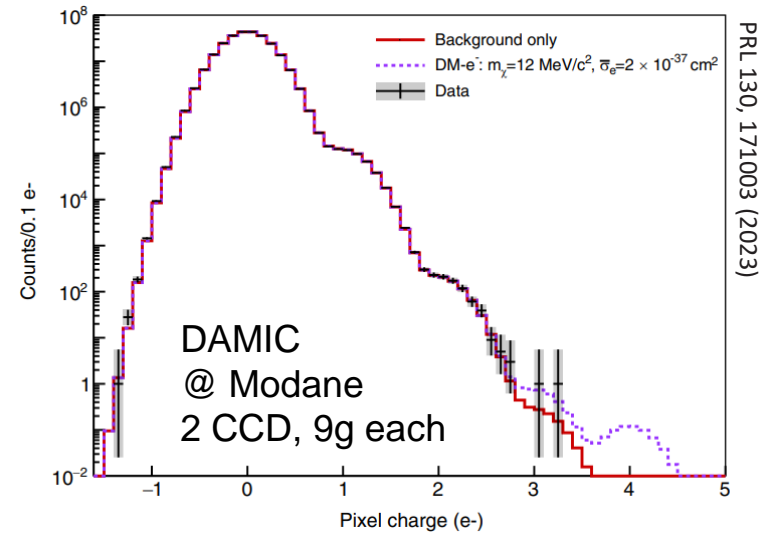
[NIMA 1046 (2023), 167681]
[JINST 18 (2023) 08, P08016]



CCD DM - electron



skimmer CCD:
 same charge can be
 measured many times
 ⇒ single e^- sensitivity
 ⇒ few eV threshold

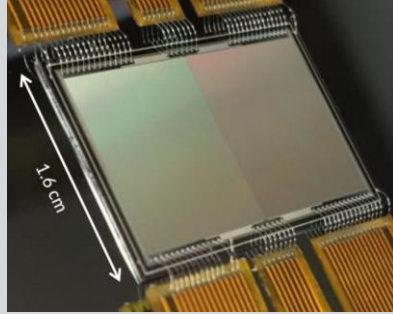
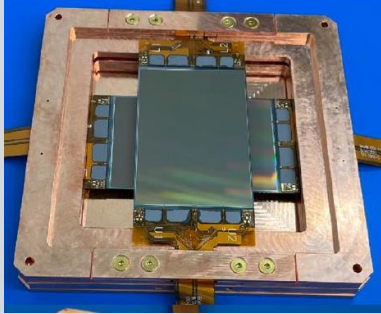


Sensei @MINOS @ SNOLAB
 USA, ARG, (40-100)g
 CHL, ISR

DAMIC @ LSM @SNOLAB
 USA, CAN, ARG, 20g goal 1kg
 ESP, FRA, CHE

OSCURA @ SNOLAB
 combines US groups

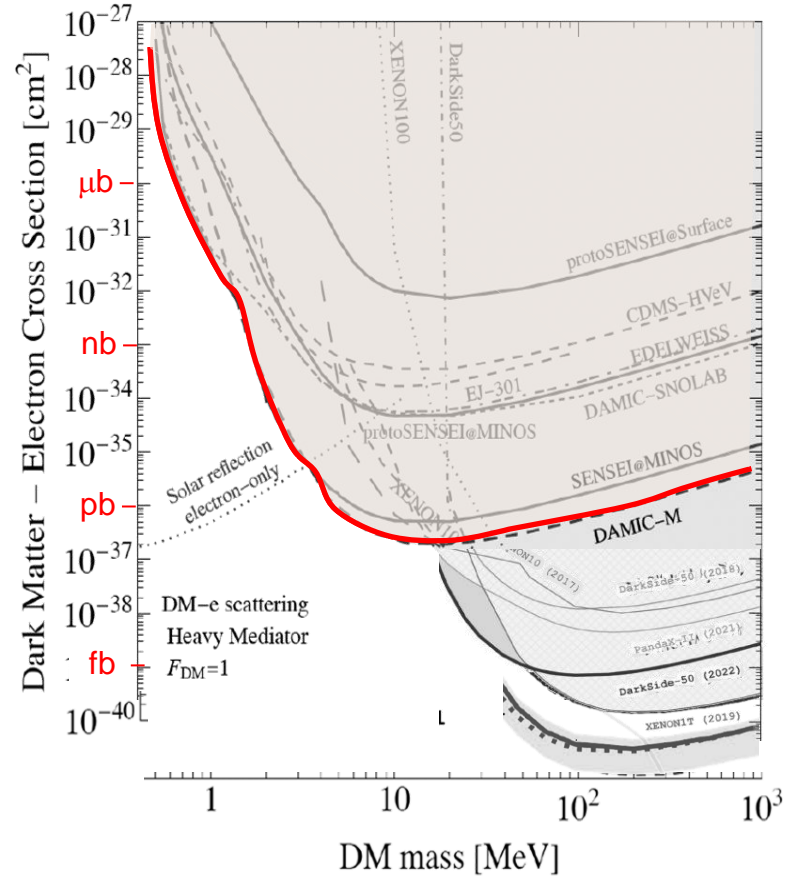
CCD DM - electron



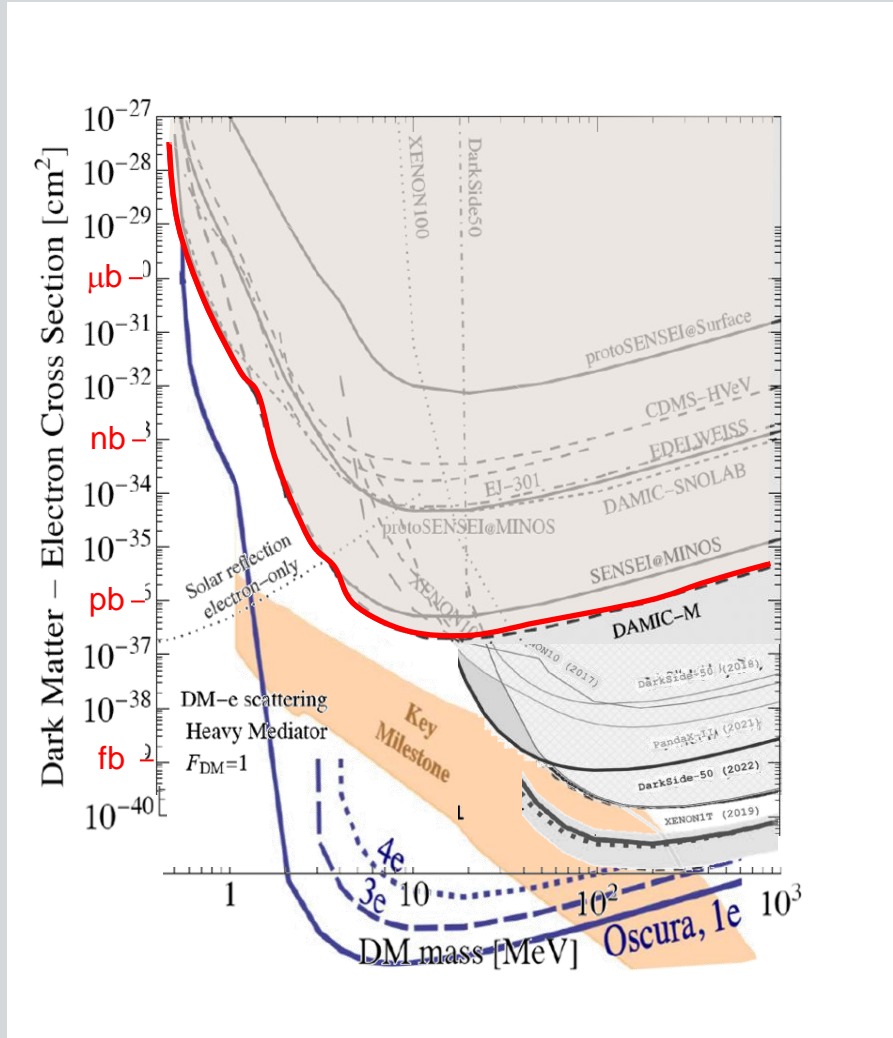
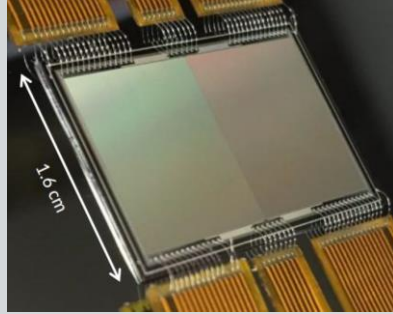
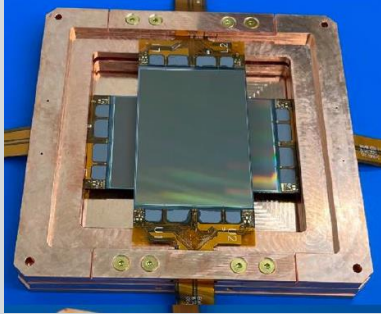
Sensei @MINOS @ SNOLAB
USA, ARG, CHL, ISR (40-100)g

DAMIC @ LSM @ SNOLAB
USA, CAN, ARG, ESP, FRA, CHE 20g goal 1kg

OSCURA @ SNOLAB
combines US groups



CCD DM - electron



Sensei @MINOS @ SNOLAB
USA, ARG, CHL, ISR (40-100)g

DAMIC @ LSM @SNOLAB
USA, CAN, ARG, ESP, FRA, CHE 20g goal 1kg

OSCURA @ SNOLAB 25.600 CCDs
combines US groups 10 kg
effective mass
~ 2029



DM – electron Scattering

Looking for ionization

CCD

- DAMIC
- SENSEI
- OSCURA

Liquid Noble Gas TPCs

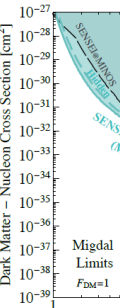
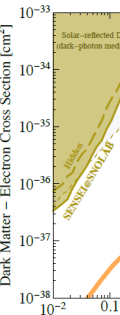
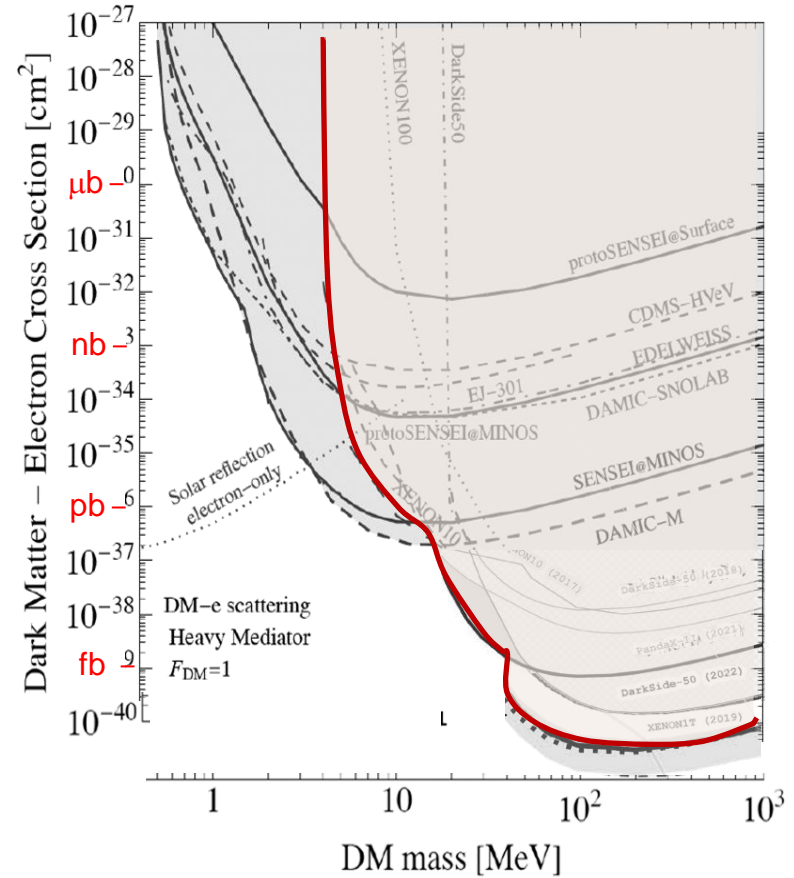
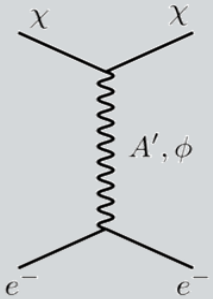
- ionisation (S2) only

- XENON
- DarkSide

Cryogenic

- Neganov-Luke

- SuperCDMS
- EDELWEISS



Liquid Noble Gas- S2(Ionisation)-only DM electron

multi-ton liquid Xenon TPC

charge and light readout \Rightarrow low nuclear recoil background
best results for (heavy) WIMPs

sacrifice light / ionization discrimination \Rightarrow high background
 \Rightarrow
lower threshold with ionization only



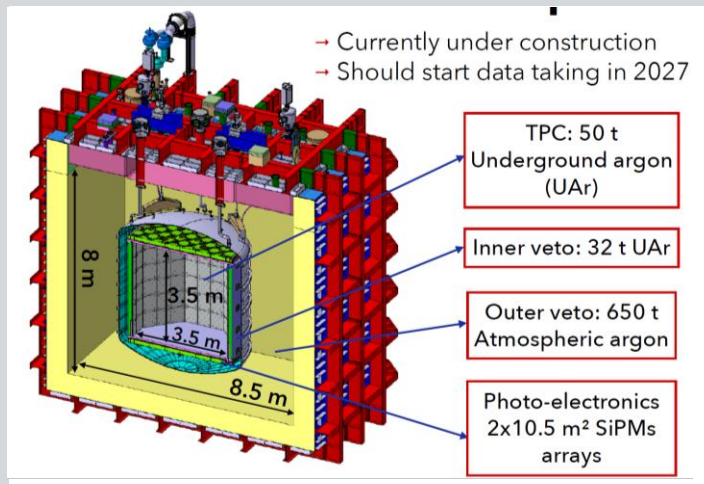
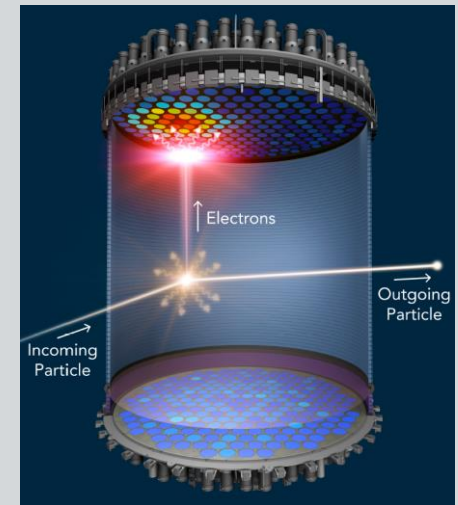
DarkSide
@ LNGS

USA, ITA,
GBR, POL,
RUS, UKR



XENON nT

@ LNGS Europe,
USA, ISR,
UAE, CHN, JPN



LZ (LUX/Zeplin)

@ Sanford USA, GBR,
PRT, KOR



PANDA X

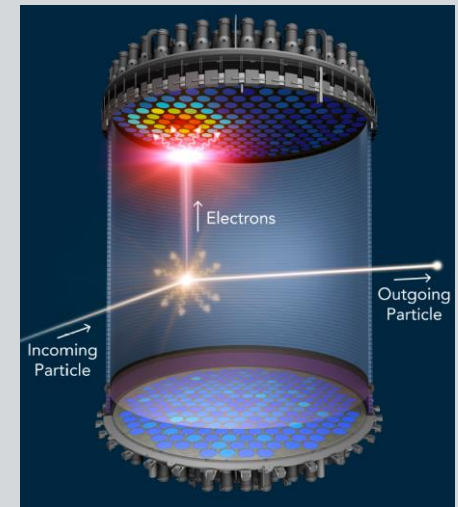
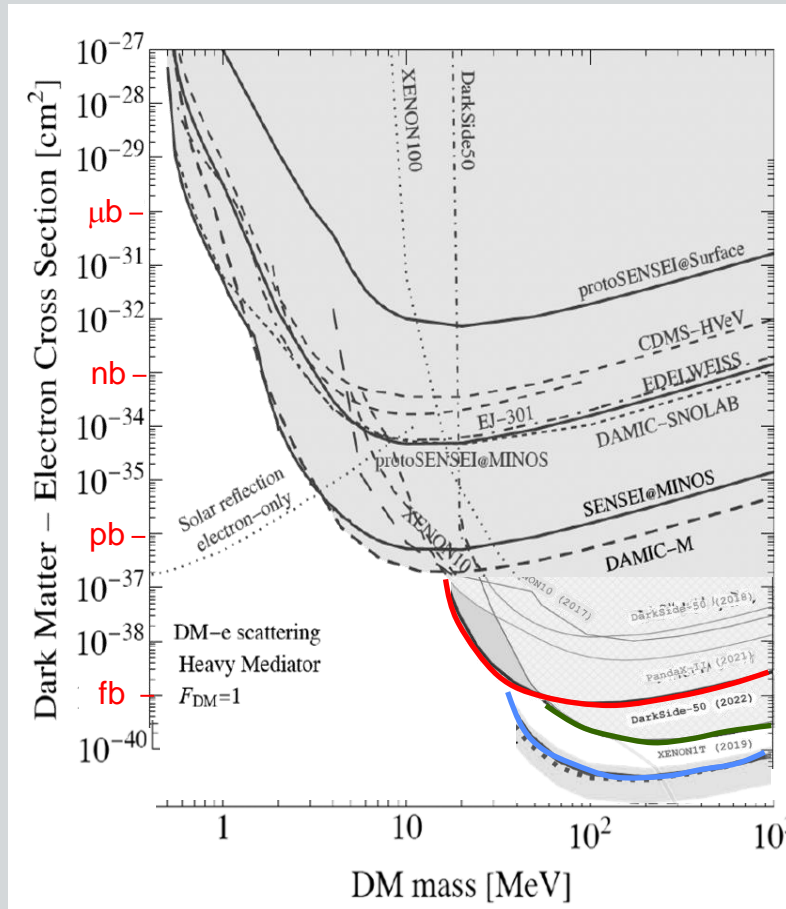
@ CPJL China



Liquid Noble Gas- S2(Ionisation)-only DM electron

multi-ton liquid Xenon TPC

ionization only results on DM-electron scattering



PRL 130, 101002 (2023)



PRL 129, 251801 (2019)



PRL 130, 261001 (2023)



DM – electron Scattering

Looking for ionization

CCD

- DAMIC
- SENSEI
- OSCURA

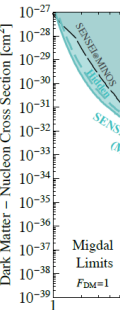
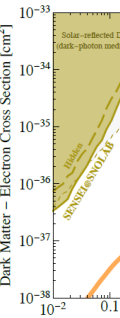
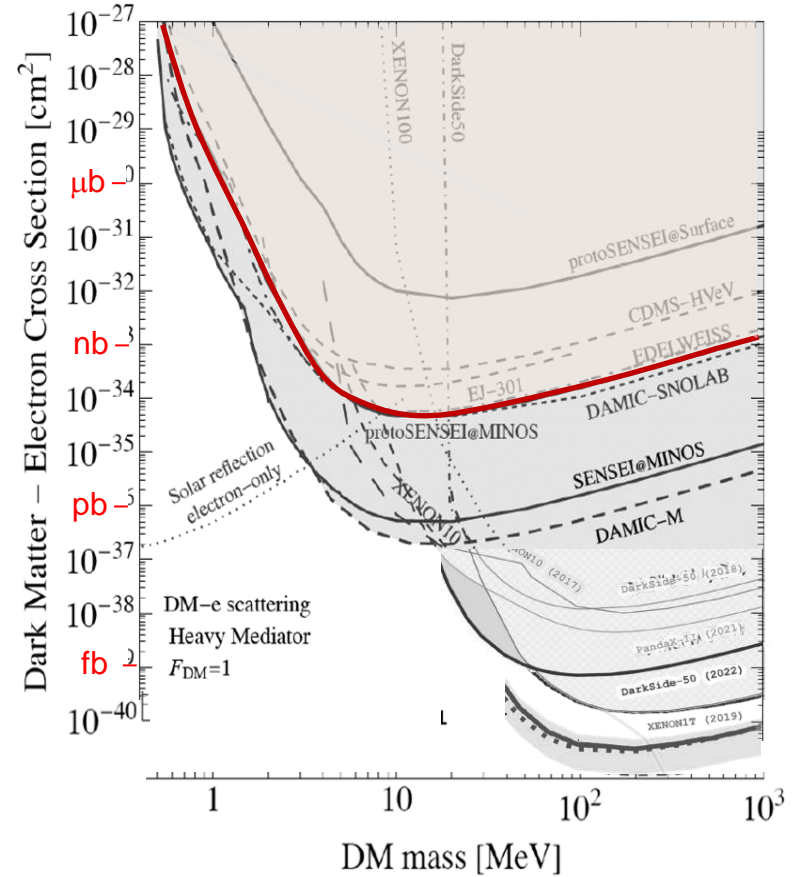
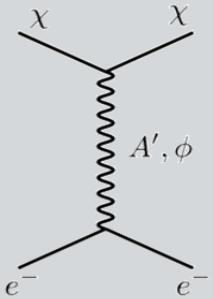
Liquid Noble Gas TPCs
- ionisation (S2) only

- XENON
- DarkSide

Cryogenic

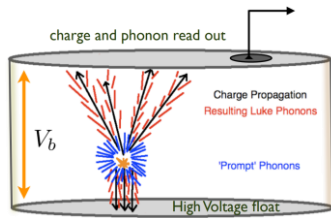
- Neganov-Luke

- SuperCDMS
- EDELWEISS

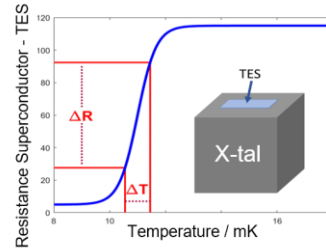


Neganov-Luke-Effekt / Single e-h pair Detection / Cryogenic Detectors DM electron

cryogenic detector: phonon detection



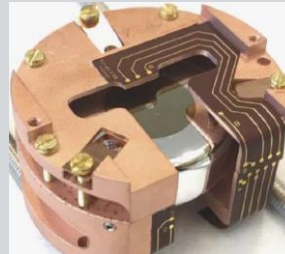
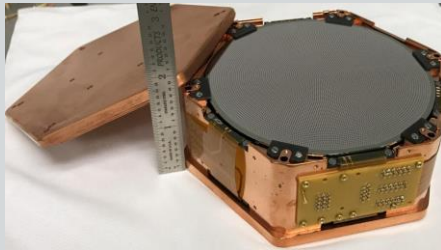
e-h pairs in E-field generate phonons



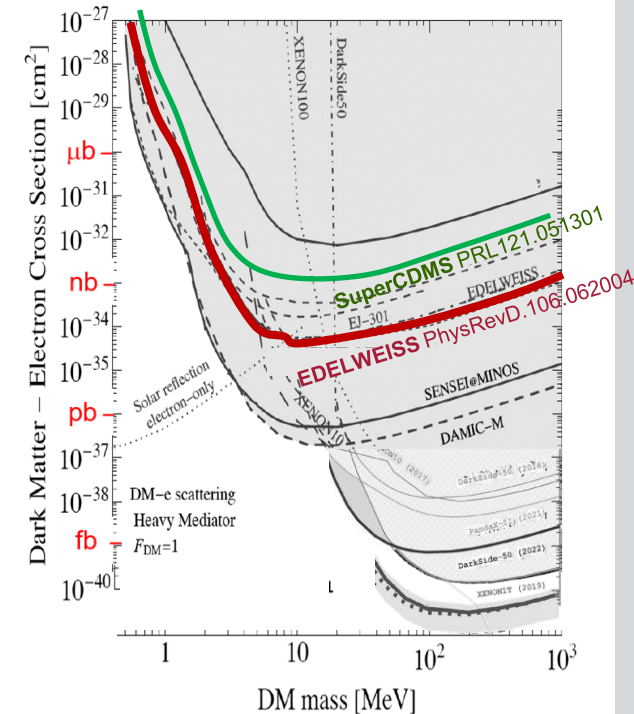
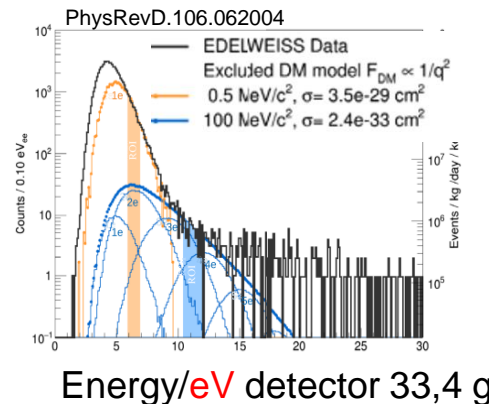
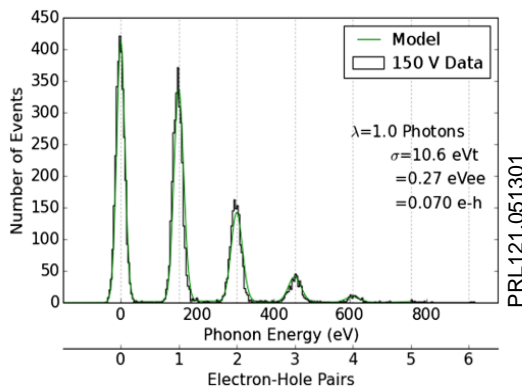
@SNOLAB
USA, CAN, FRA,
DEU, ESP, IND, UAE



@LSM
FRA, DEU,
RUS, GBR,

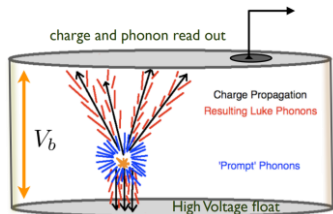


single e-h pair sensitivity

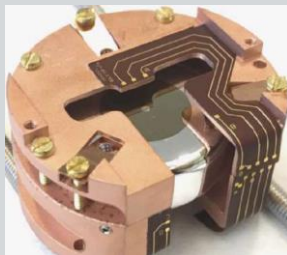
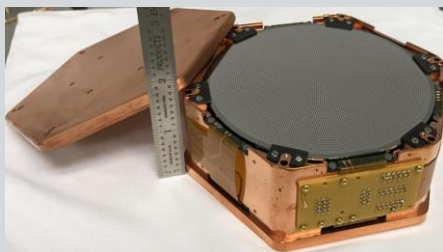
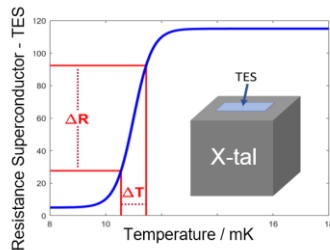


Neganov-Luke-Effekt / Single e-h pair Detection / Cryogenic Detectors DM electron

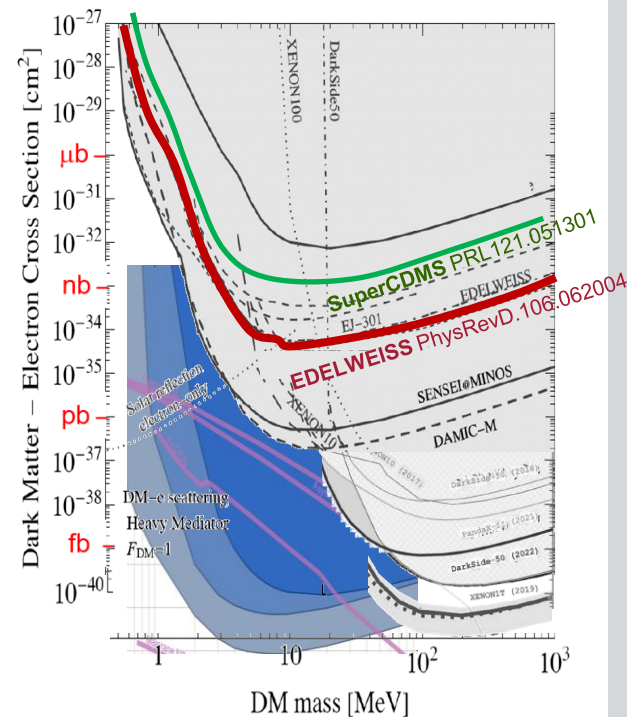
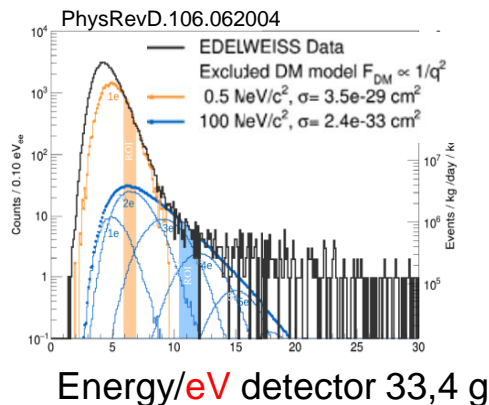
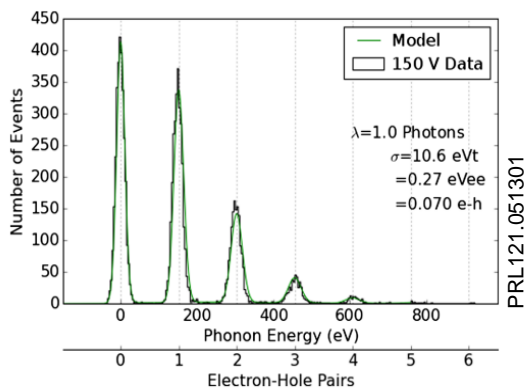
cryogenic detector: phonon detection



e-h pairs in E-field generate phonons

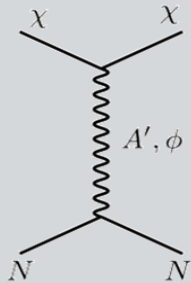


single e-h pair sensitivity

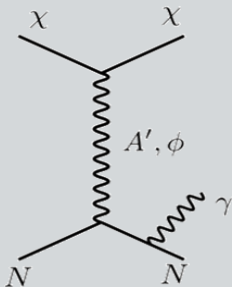
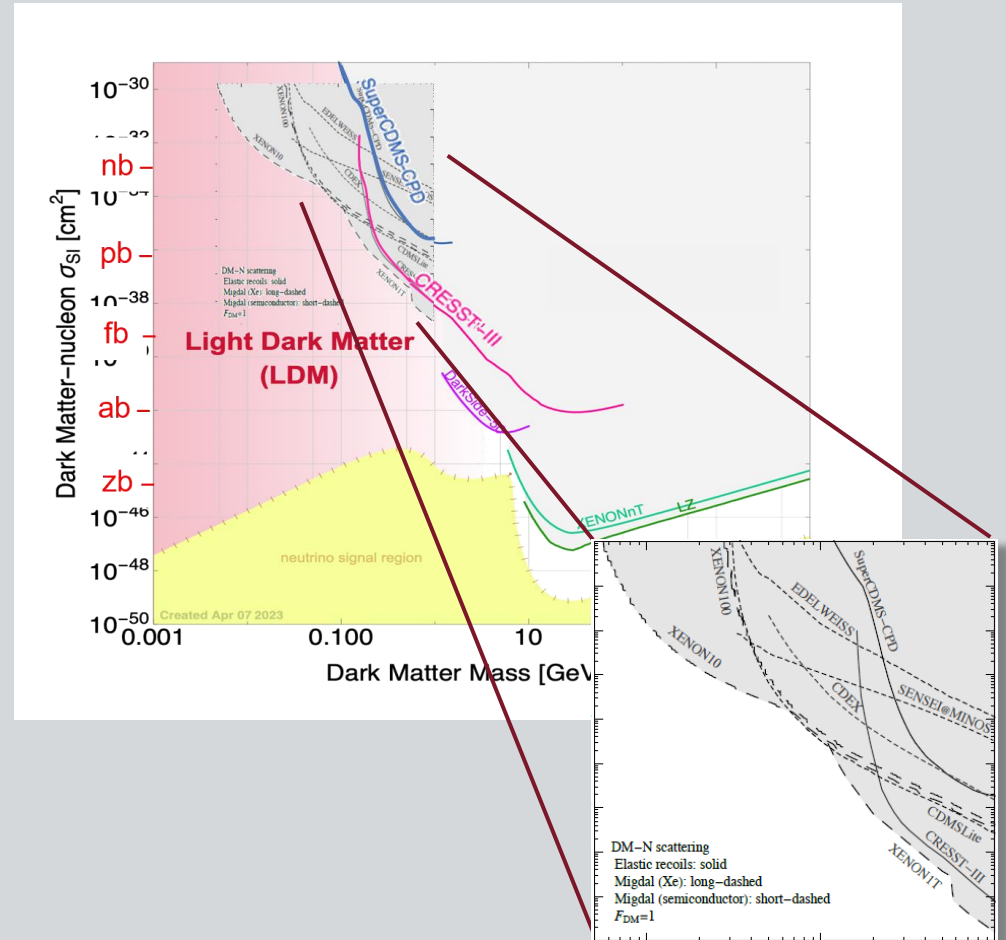


DM – Nucleon Scattering

Looking for nuclear recoils



- Cryogenic Detectors
 - SuperCDMS
 - EDELWEISS
 - CRESST
 - SPICE
- Gas Detectors
 - NEWS-G
- Bubble Chambers
 - SBC
- Quasiparticle Detection
 - DELIGHT
 - HERALD

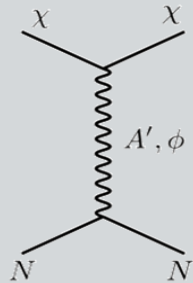


Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation



DM – Nucleon Scattering

Looking for nuclear recoils

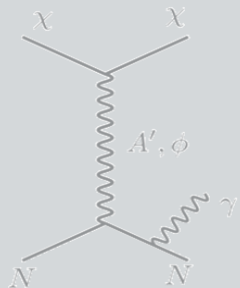


- Cryogenic Detectors
 - SuperCDMS
 - EDELWEISS
 - CRESST
 - SPICE

- Gas Detectors
 - NEWS-G

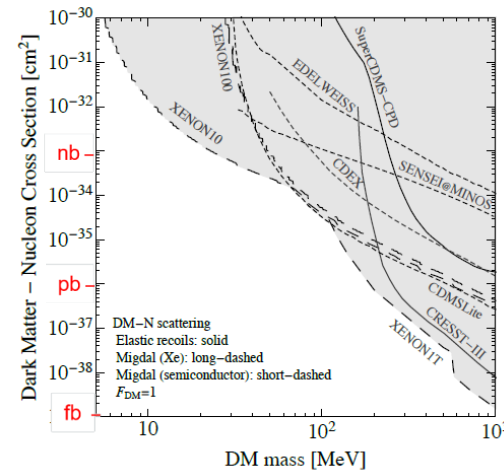
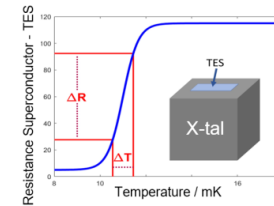
- Bubble Chambers
 - SBC

- Quasiparticle Detection
 - DELIGHT
 - HERALD



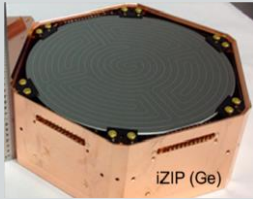
Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation

go for low mass WIMPS by
low energy threshold



Cryogenic Detectors

DM – Nucleon Scattering *Looking for nuclear recoils*



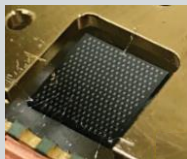
SUPER @SNOLAB
CDMS USA, CAN, FRA,
 DEU, ESP, IND, UAE



Edelweiss @LSM
 FRA, DEU,
 RUS, GBR,



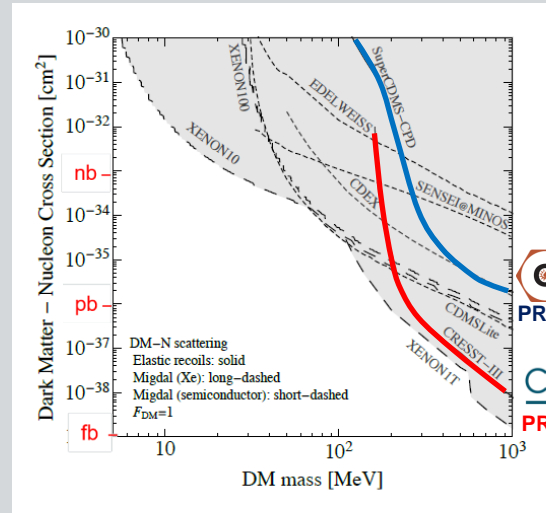
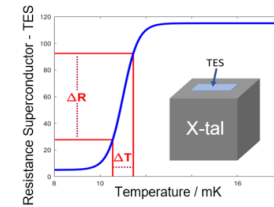
CRESST @LNGS
 Cryogenic Rare Event Search
 with Superconducting Thermometers
 DEU, ITA
 AUT, SVK, GBR



SPICE part of TESSERACT
 USA, CHE

no results yet – still R&D

go for low mass WIMPS by
low energy threshold



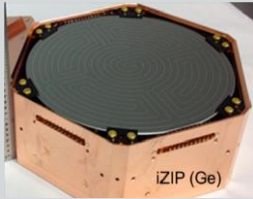
SUPER CDMS
 PRL127.061801

CRESST
 PRD 107,122003 (2023)



Cryogenic Detectors

DM – Nucleon Scattering *Looking for nuclear recoils*



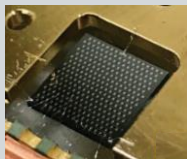
SUPER @SNOLAB
CDMS USA, CAN, FRA,
 DEU, ESP, IND, UAE



Edelweiss @LSM
 FRA, DEU,
 RUS, GBR,



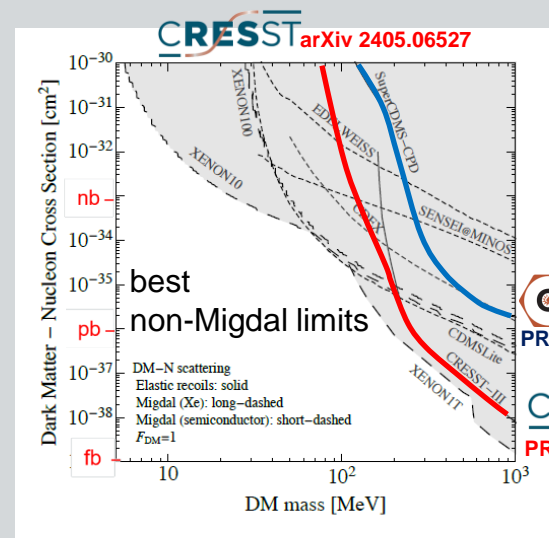
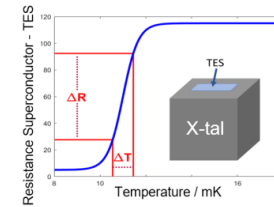
CRESST @LNGS
 Cryogenic Rare Event Search
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 AUT, SVK, GBR



SPICE part of TESSERACT
 USA, CHE

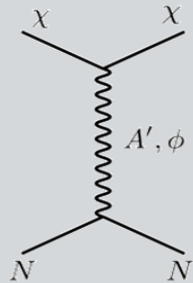
no results yet – still R&D

go for low mass WIMPS by
low energy threshold



Gas Proportional Detectors

DM – Nucleon Scattering *Looking for nuclear recoils*

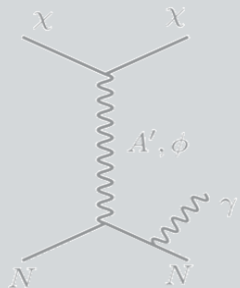


- Cryogenic Detectors
SuperCDMS
EDELWEISS
CRESST
SPICE

- Gas Detectors
NEWS-G

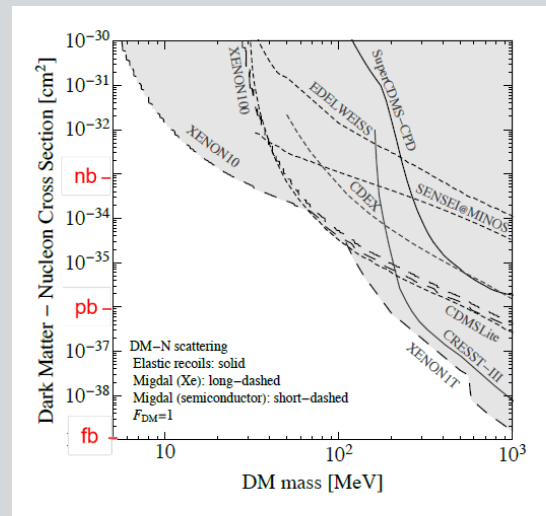
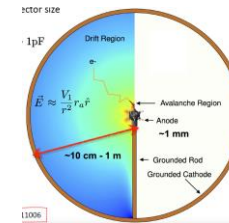
- Bubble Chambers
SBC

- Quasiparticle Detection
DELIGHT
HERALD



Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation

go for low mass WIMPS by
light target nuclei



Gas Proportional Detectors

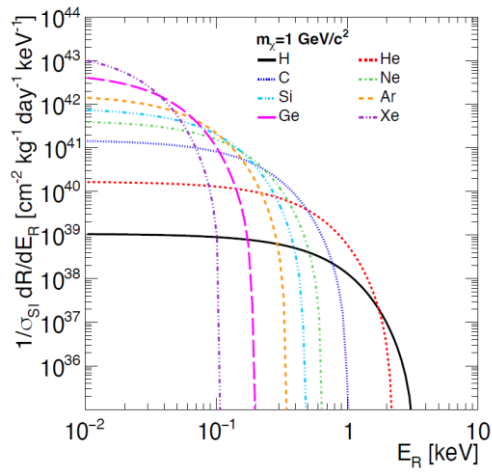
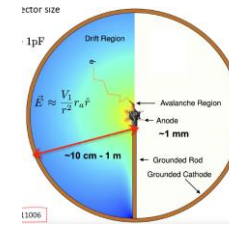
DM – Nucleon Scattering *Looking for nuclear recoils*



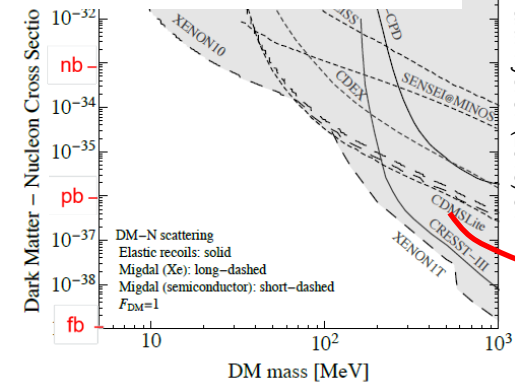
@LSM @SNOLAB
@Boulby
CAN, FRA, USA,
DEU, GBR, GRE

spherical proportional counter
Ne:CH₄

go for low mass WIMPS by
light target nuclei



NEWS-G @ LSM
results with 9,6 kg days



Astro. Part. Phys. 97 (2018) 54



Gas Proportional Detectors

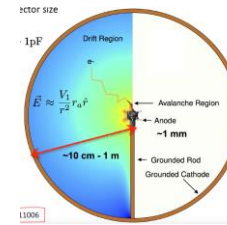
DM – Nucleon Scattering *Looking for nuclear recoils*



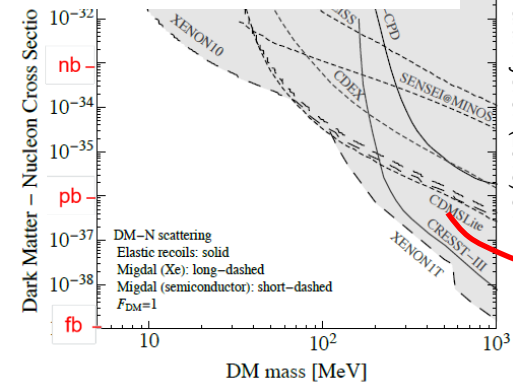
@LSM @SNOLAB
@Boulby
CAN, FRA, USA,
DEU, GBR, GRE

spherical proportional counter
Ne:CH₄

go for low mass WIMPS by
light target nuclei

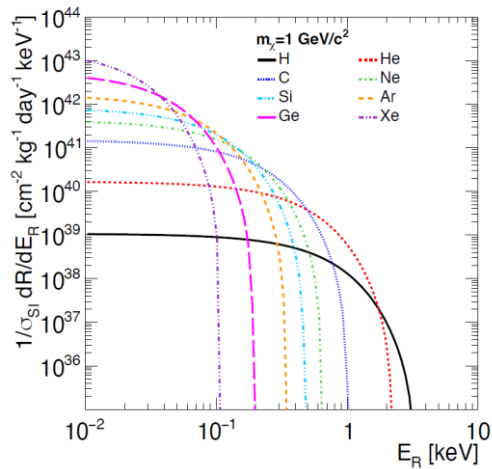
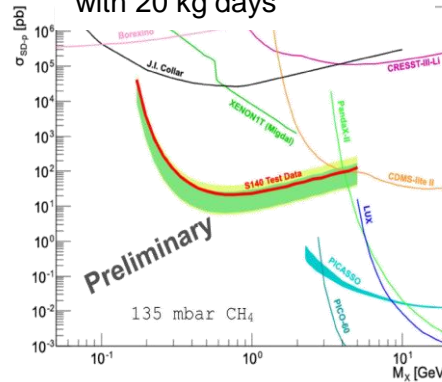


NEWS-G @ LSM
results with 9,6 kg days



Astro. Part. Phys. 97 (2018) 54

SEDINE @ SNOLAB
prelim results on
spin-dependent scattering
with 20 kg days



Gas Proportional Detectors

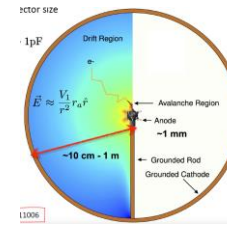
DM – Nucleon Scattering *Looking for nuclear recoils*



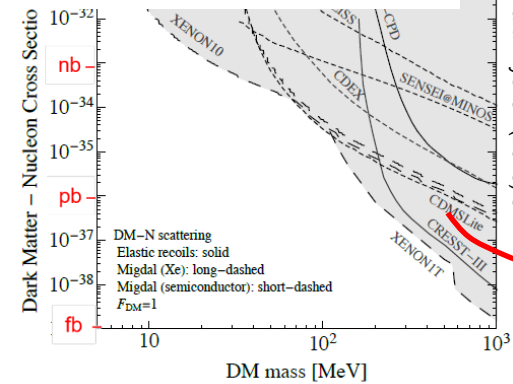
@LSM @SNOLAB
@Boulby
CAN, FRA, USA,
DEU, GBR, GRE

spherical proportional counter
Ne:CH₄

go for low mass WIMPS by
light target nuclei



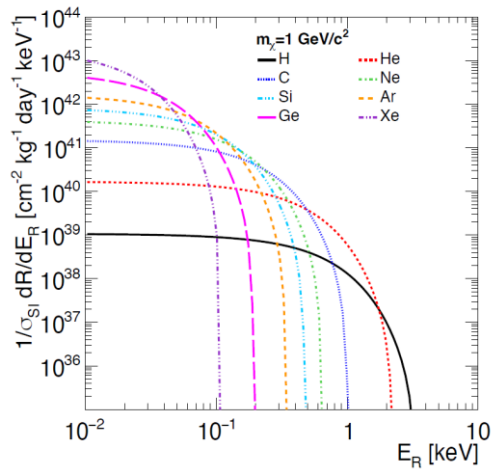
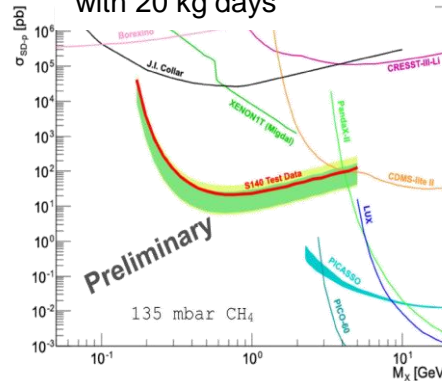
NEWS-G @ LSM
results with 9,6 kg days



Astro. Part. Phys. 97 (2018) 54

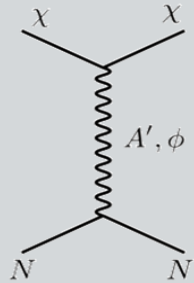
in preparation:
Dark SPHERE @ Boulby
underground electroformed copper
background reduction

SEDINE @ SNOLAB
prelim results on
spin-dependent scattering
with 20 kg days



Gas Proportional Detectors

DM – Nucleon Scattering *Looking for nuclear recoils*

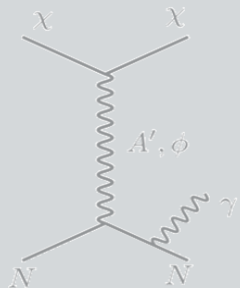


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HERALD

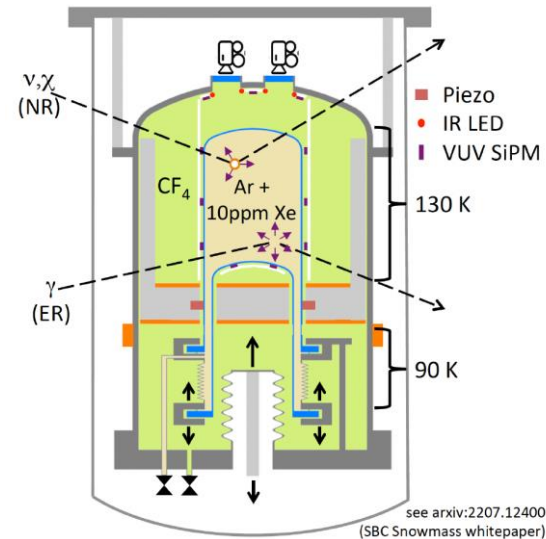


Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation

go for low mass WIMPS by
light target nuclei

Scintillating Bubble Chamber

bubble creation
almost background free
nuclear recoildetection



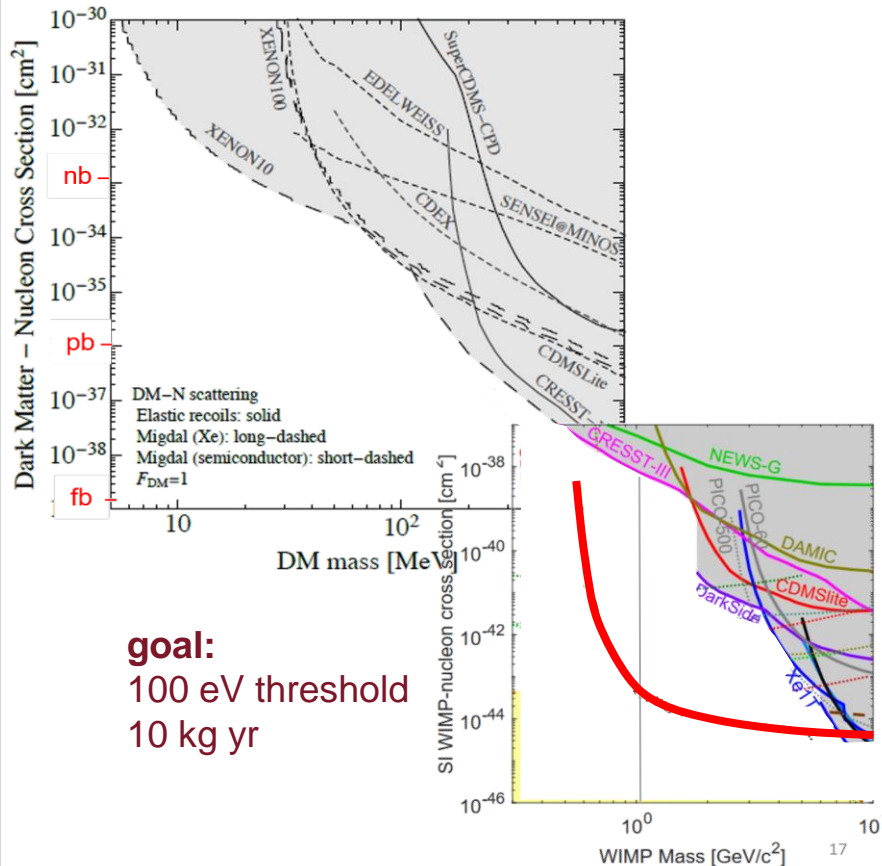
Scintillating Bubble Chamber

DM – Nucleon Scattering
Looking for nuclear recoils



Liquid Noble
Bubble Chambers
CAN, USA, MEX

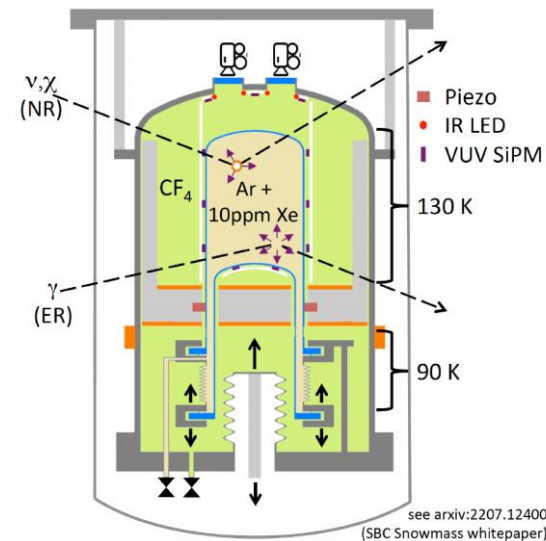
@MINOS
@SNOLAB



go for low mass WIMPS by
light target nuclei

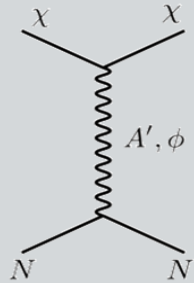
Scintillating Bubble Chamber

bubble creation
almost background free
nuclear recoildetection



Quasiparticle Excitation

DM – Nucleon Scattering *Looking for nuclear recoils*

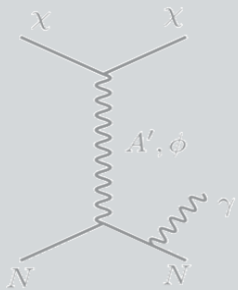


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HERALD

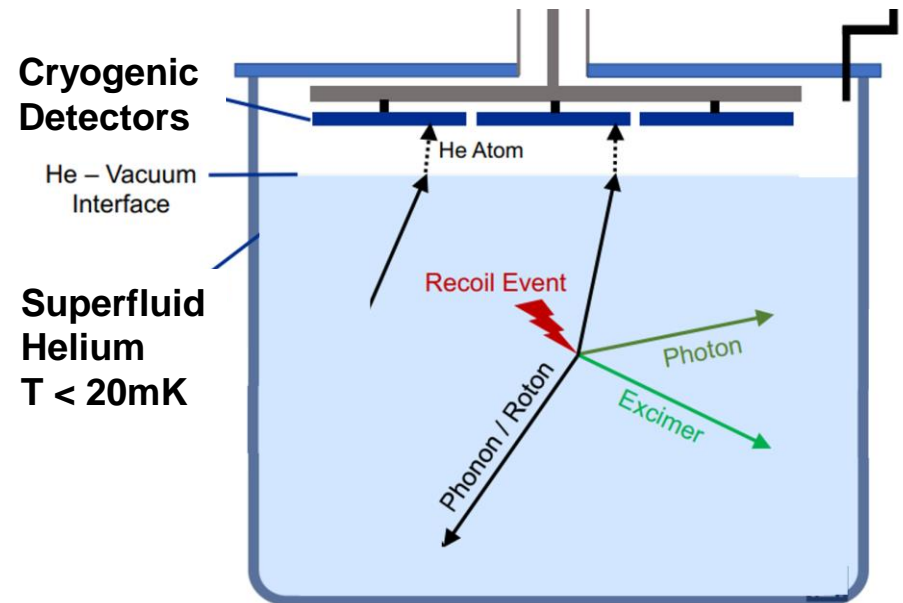


Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation

go for low mass WIMPS by
light target nuclei

low energy threshold
Quasiparticle excitations

excitations in superfluid Helium



Quasiparticle Excitation

DM – Nucleon Scattering *Looking for nuclear recoils*



HERALD
part of TESSERACT
USA, CHE

DElight
DEU

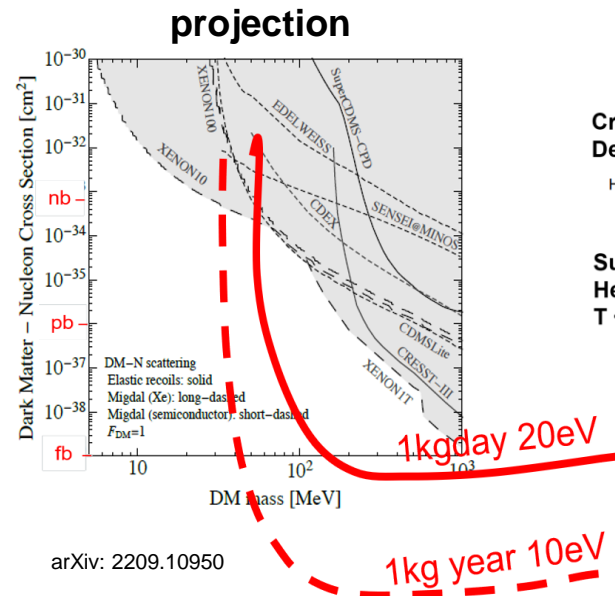
go for low mass WIMPS by
light target nuclei

low energy threshold
Quasiparticle excitations

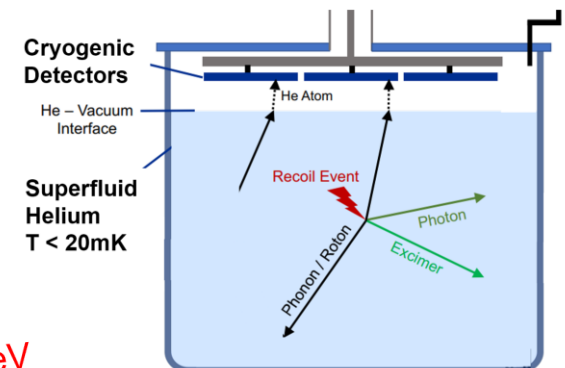
R&D

first proof of concept
with $E_{th} \sim 200\text{eV}$

arxiv: 2307.11877



excitations in superfluid Helium

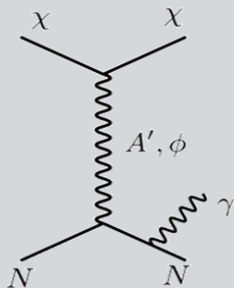


Migdal Effect

DM – Nucleon Scattering *Looking for nuclear recoils*

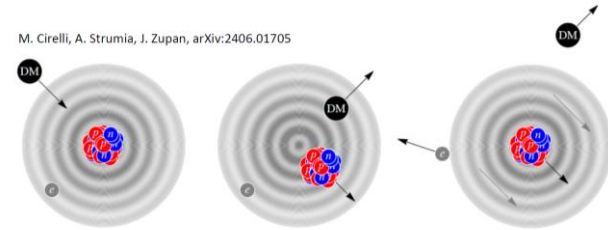


- Cryogenic Detectors
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EDELWEISS
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- Quasiparticle Detection
DELIGHT
HERALD



Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation

**boost signal energy by
inelastic scattering ionizing the
recoiling atom**



M. Cirelli, A. Strumia, J. Zupan, arXiv:2406.01705



**keV electron recoils
for**

sub-keV nuclear recoils

experiments looking for electron recoils
this way look as well to nuclear recoils

liquid noble gas



CCD



DAMIC

Neganov-Luke



Migdal Effect

DM – Nucleon Scattering *Looking for nuclear recoils*

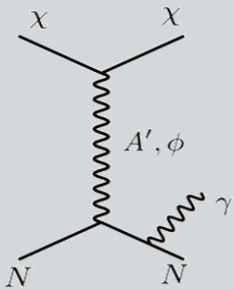


- Cryogenic Detectors
SuperCDMS
EDELWEISS
CRESST
SPICE

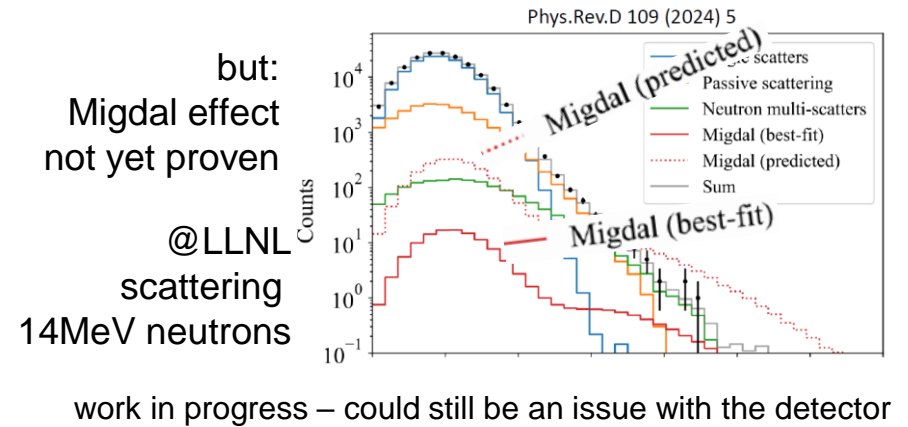
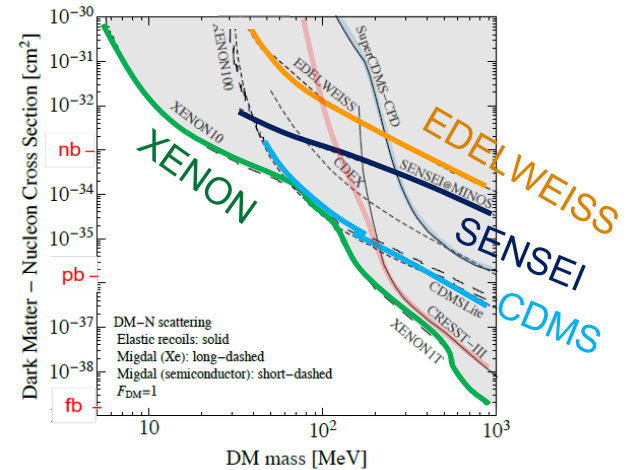
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NEWS-G

- Bubble Chambers
SBC

- Quasiparticle Detection
DELIGHT
HERALD



Inelastic DM-Nucleon
Migdal Effekt
Looking for ionisation



Searches for Light Dark Matter Particles

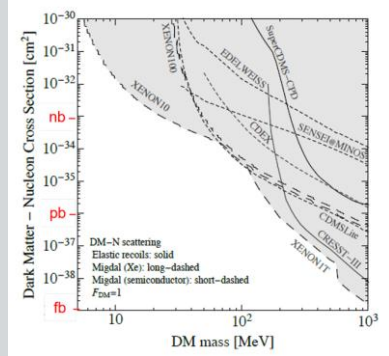
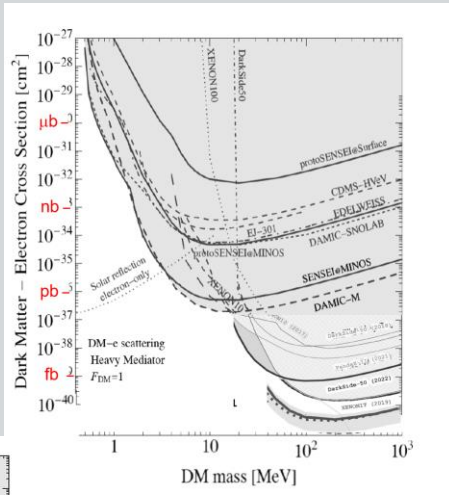
direct detection channels



elastic electron scattering
(migdal effect)

elastic nuclear scattering

inelastic nuclear scattering
(migdal effect)



Remarks

exclusion plots I did not show:
electron recoil light mediator,
nuclear scattering spin dependent,
Axion, Dark Photons

many more R&D to get low thresholds:
narrow gap semiconductors,
Qubits, MKIDs, hydrogen doped IXe

more ideas to boost recoil energy:
solar reflected or cosmic ray boosted WIMPs

Summary

field (still) dominated by small detectors

projects with more exposure will come up

lowest background will win

=> good to have many ideas and a variety of techniques

