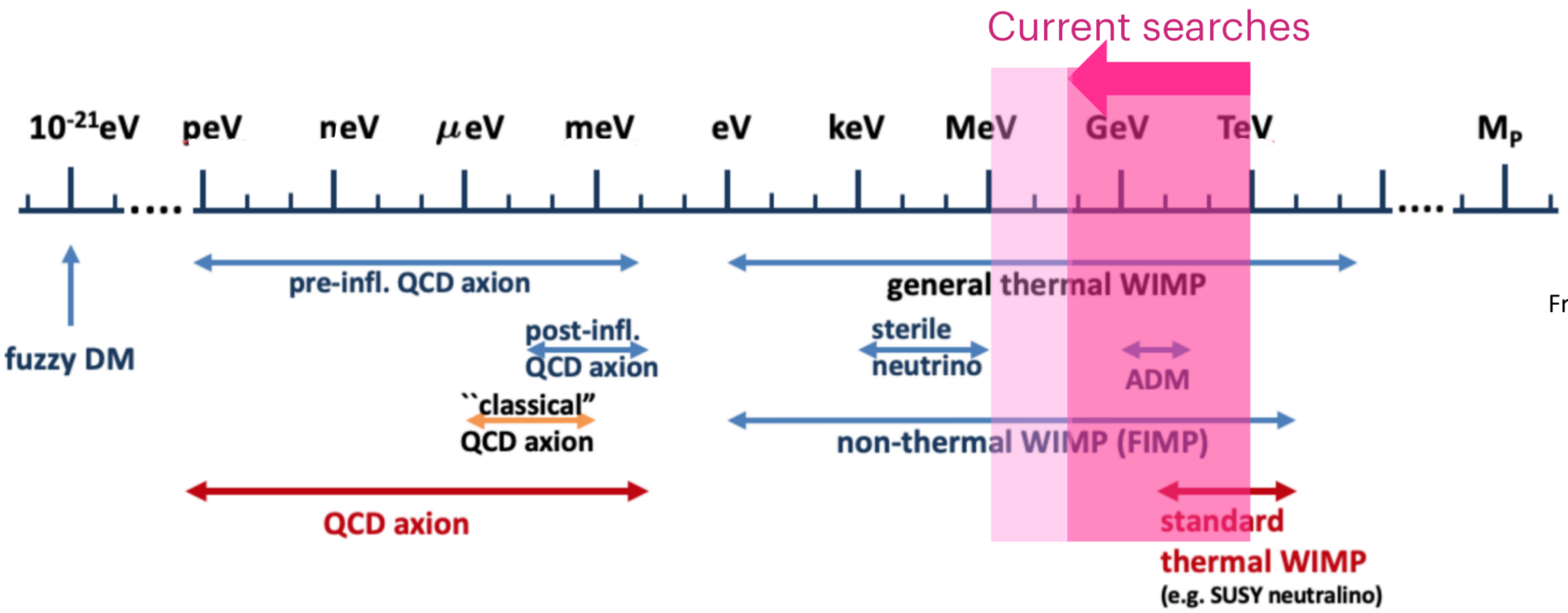
Scintillator based Dark Matter Search

Dr. Dipanwita Dutta
NPD, BARC

Collaboration:
NPD and TPD, Physics Group, BARC
and SINP

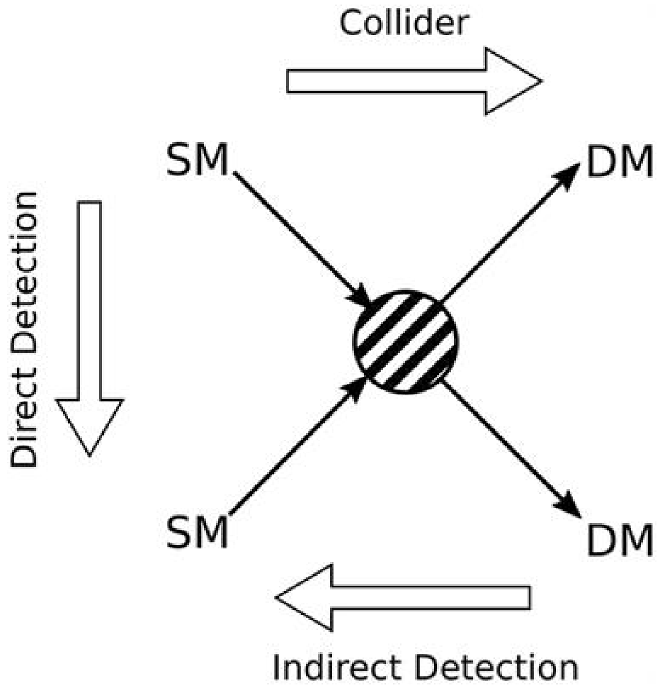
Different DM Candidates



From: *Direct Detection of Dark Matter - APPEC Committee Report*
arXiv:2104.07634

Great variety of theoretical motivated dark matter particle candidates with a wide range of mass and cross section

Dark Matter Detection



Direct Detection:

WIMP- Nuclear recoil from slow moving Dark Matter (DM) elastic scattering
WIMP-Electron Recoil - inelastic scattering
Axion Searches ... (CAST / ADMX)
Resonant axion-γγ conversion in large B-field

Indirect Detection:

– Observation of WIMP annihilation products
- Gamma-ray telescopes (MAGIC, HESS, VERITAS, MACE...)
- Anti-matter experiments (HEAT, PAMELA...)
- Neutrino detectors/telescopes (IceCUBE, ANTARES, AMANDA, Super-Kamiokande...)

Collider Experiment (Indirect Detection):

– Missing energy/transverse momenta in collision

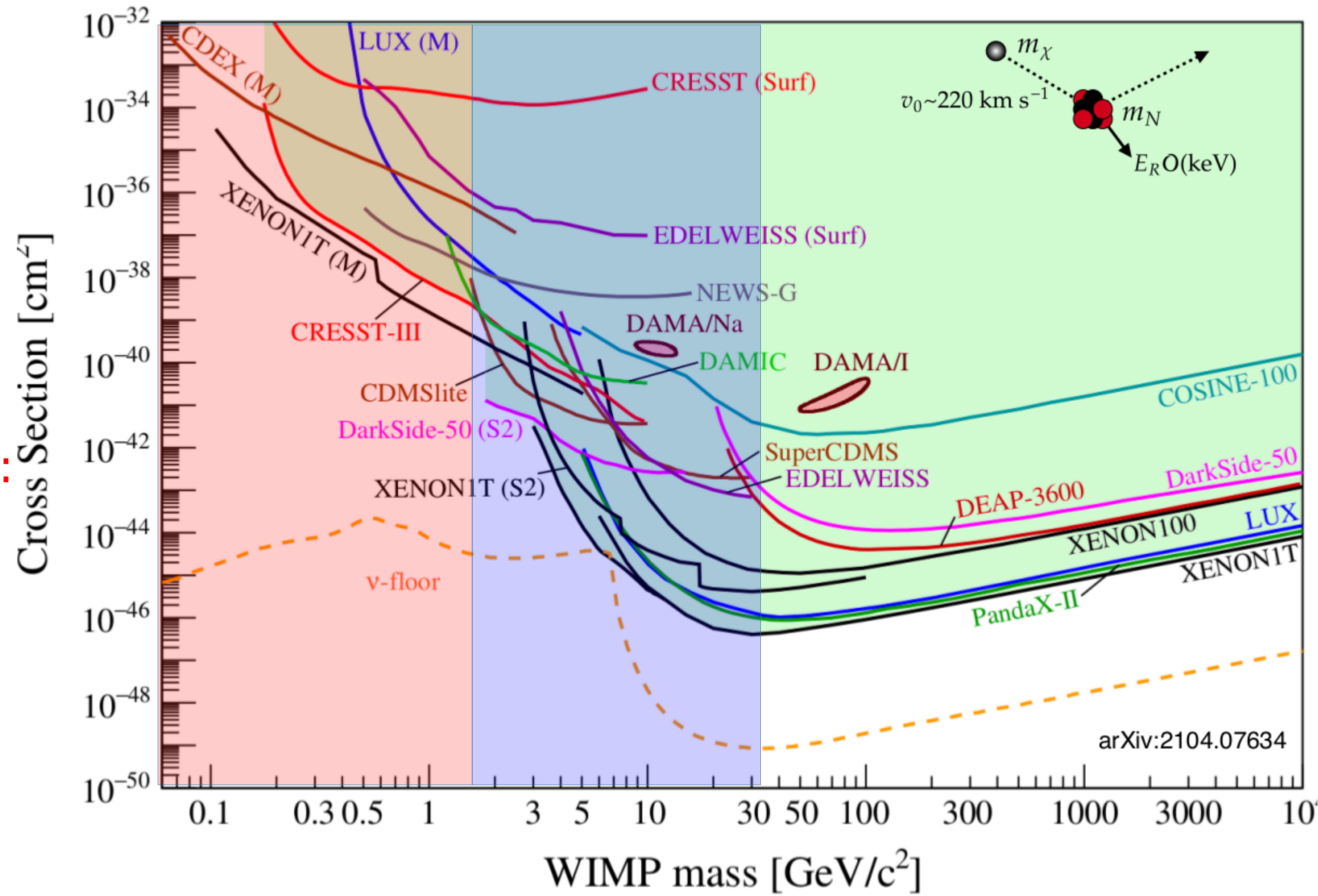
Landscape of Direct DM search

Several different experiments with different technologies

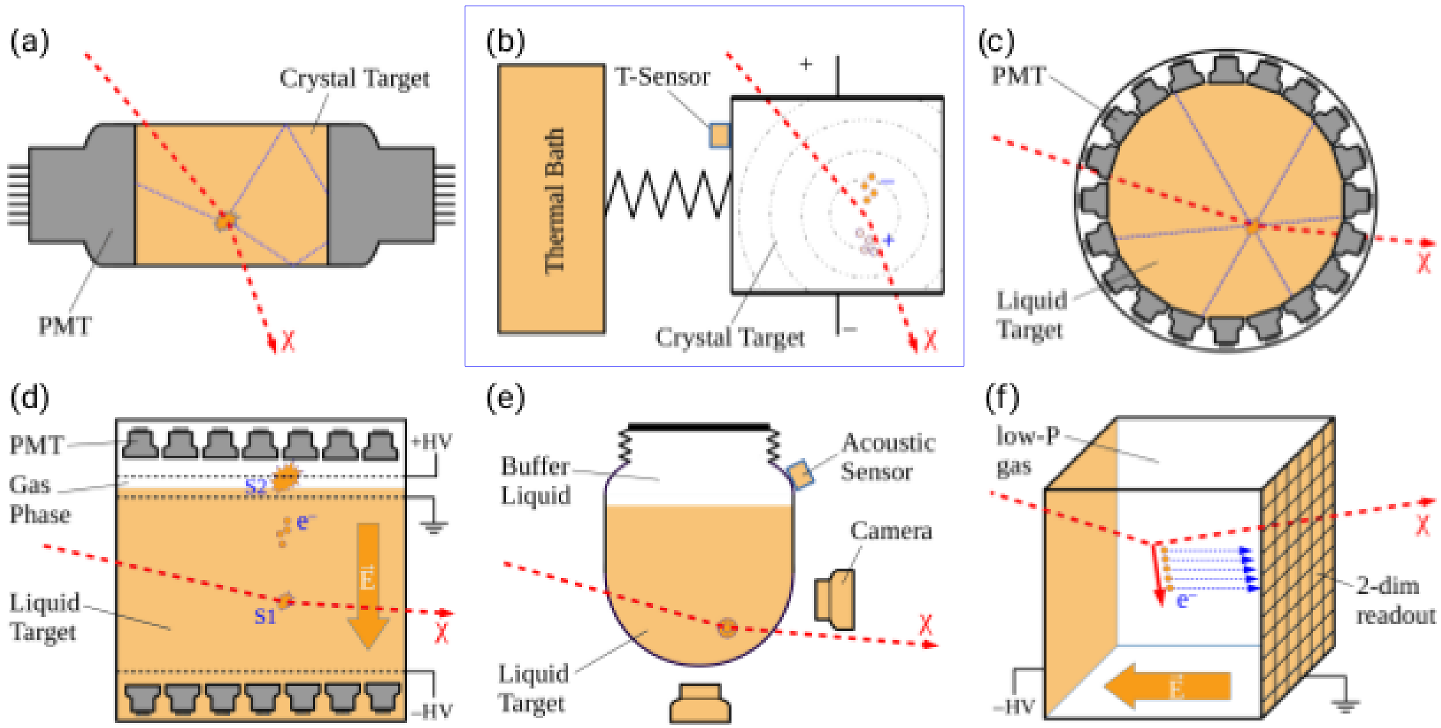
The sensitivity is dominated by:

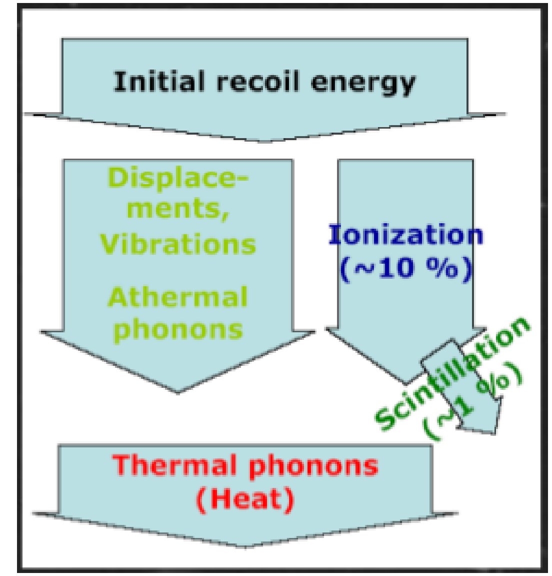
Noble liquids TPCs: M_{DM} > few GeV

Cryogenic detectors: M_{DM} < few GeV



Different DM detection Concepts





(a) Scintillating crystal, (b)Cryogenic detectors (here with additional charge-readout), (c) single-phase and (d) dual-phase liquid noble gas detectors, (e)bubble chamber, (f) directional detector. Images adapted from 1903.03026

Scintillation :

Target Crystal: DAMA/LIBRA, SABRE (NaI) KIMS (CsI(Tl))

Liquid Noble Gas: ZEPLIN, XENON, XMASS, LUX(Xe), DEAP,CLEAN,Warp, DarkSide,ArDM (Ar), CLEAN (Ne)

Photon Detection: PMT

Cryogenic Detectors

Target Crystal:

Ionisation+Phonon - CDMS , Super CDMS (Ge, Si ZIP),CUORE(Al_2O_3), EDELWEISS (Ge, Si)

Scintillation+Phonon CRESST ($CaWO_4$)

Phonon Detection: W-TES, ZIP

Photon Detection: SOS + W-TES, ZIP

Scintillator Detector concept for DM Detection

CRESST detectors

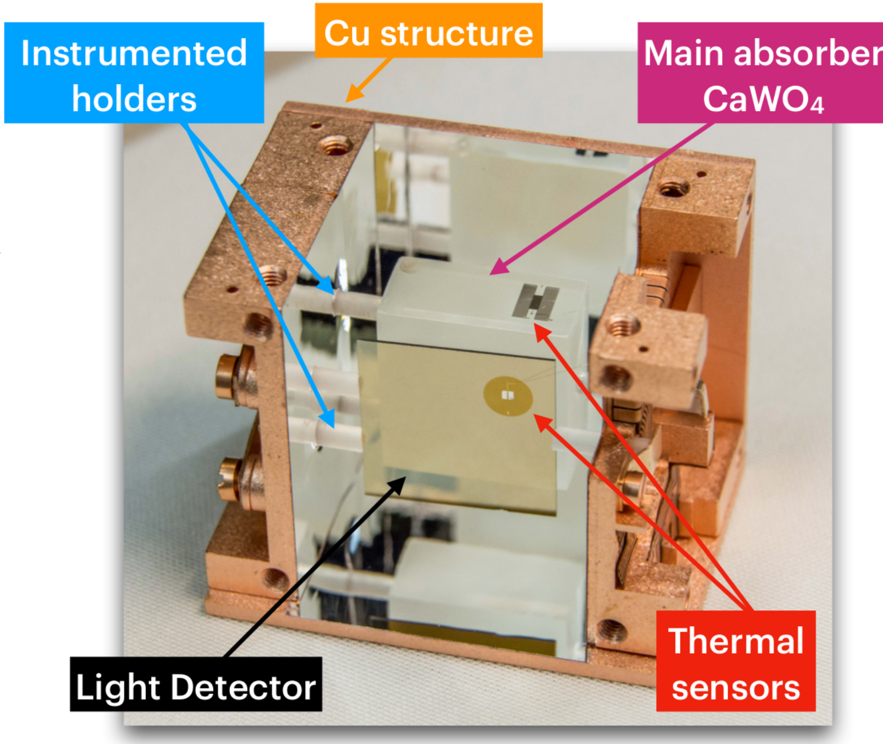
Cryogenic Rare Event Search with Superconducting Thermometers

$CaWO_4$ target crystals (24 g each)

Detector operated as: **cryogenic calorimeters** @ 10 mK

Temperature read-out with **Transition Edge Sensor**

Double read-out cryogenic detector:
heat ($CaWO_4$) and **light** (LD - Light Detector)



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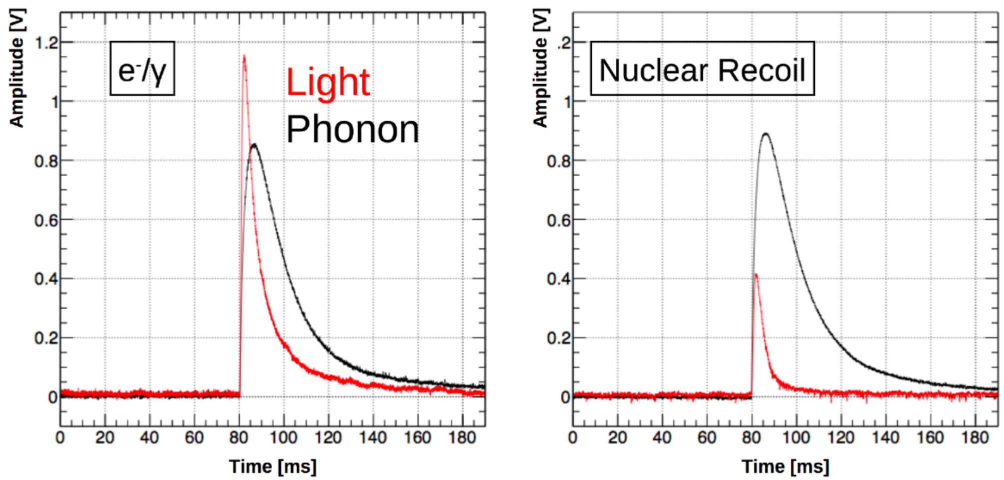
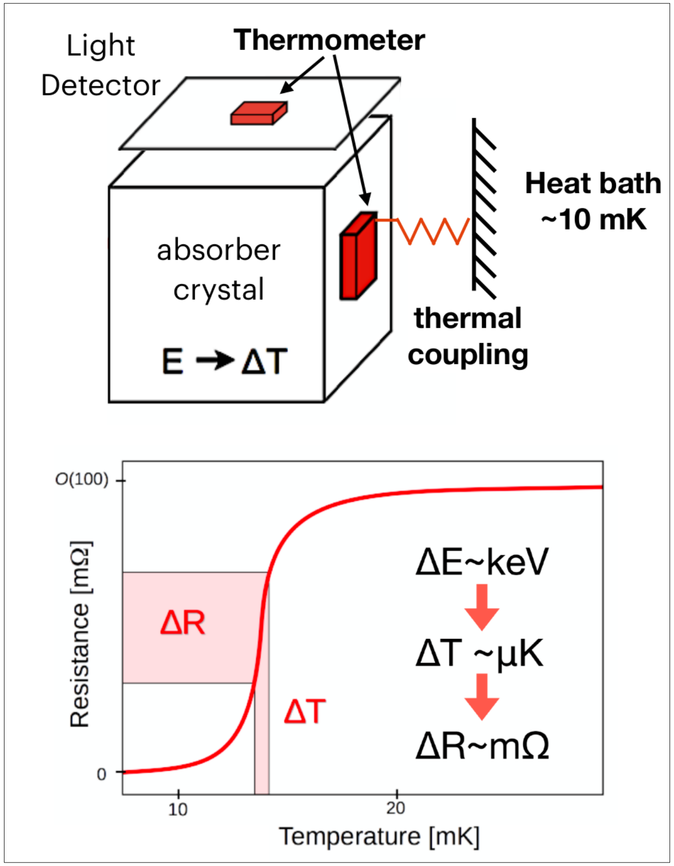
Scintillator Detector concept for DM Detection

DM-Nuclear Recoil Energy deposits are measured as temperature variations

Detection of Temperature Rise with TES Detector

Absorber as efficient Scintillator crystal, Energy will be converted as heat and light (phonon and photon)





Excellent discrimination between potential signal events (nuclear recoils) and dominant radioactive background (electron recoils)

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Scintillators for DM and R&D

Properties Scintillator Crystal:

- High Light Yield
- The crystals must have high purity (RadioPure)
- High radiative efficiency
- Few native defects
- Operable in Cryogenic Temp

Most promising Scintillators for DM search :

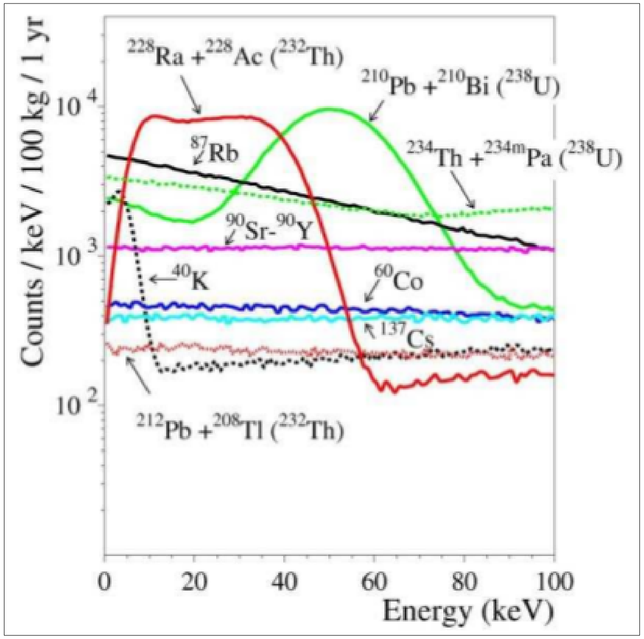
- NaI, CsI, GaAs, $ZnWO_4$, CaWO4, CaMnO4
- $ZnWO_4$, CaWO4, CaMnO4 with high light output for cryogenic DM search
- $ZnWO_4$ and $CdWO_4$ are good example of radio pure scintillators (~0.2−1 mBq/kg level)

Requirements of Radio Pure Crystal

- Minimise Radioactive contamination of scnitillator crystal
- Should not exceed ~10 µBq/kg (EURECA requirement)
- Probable radio contamination (internal)
  ^{40}K, ^{60}Co, ^{87}Rb, ^{90}Sr - ^{90}Y, ^{137}Cs, ^{232}Th, ^{238}U
- Cosmogenic radionuclides (e.g. ^{14}C)
  (the radioactive ^{14}C can be produced by hadronic component of cosmic rays in any materials composed of elements heavier than carbon)

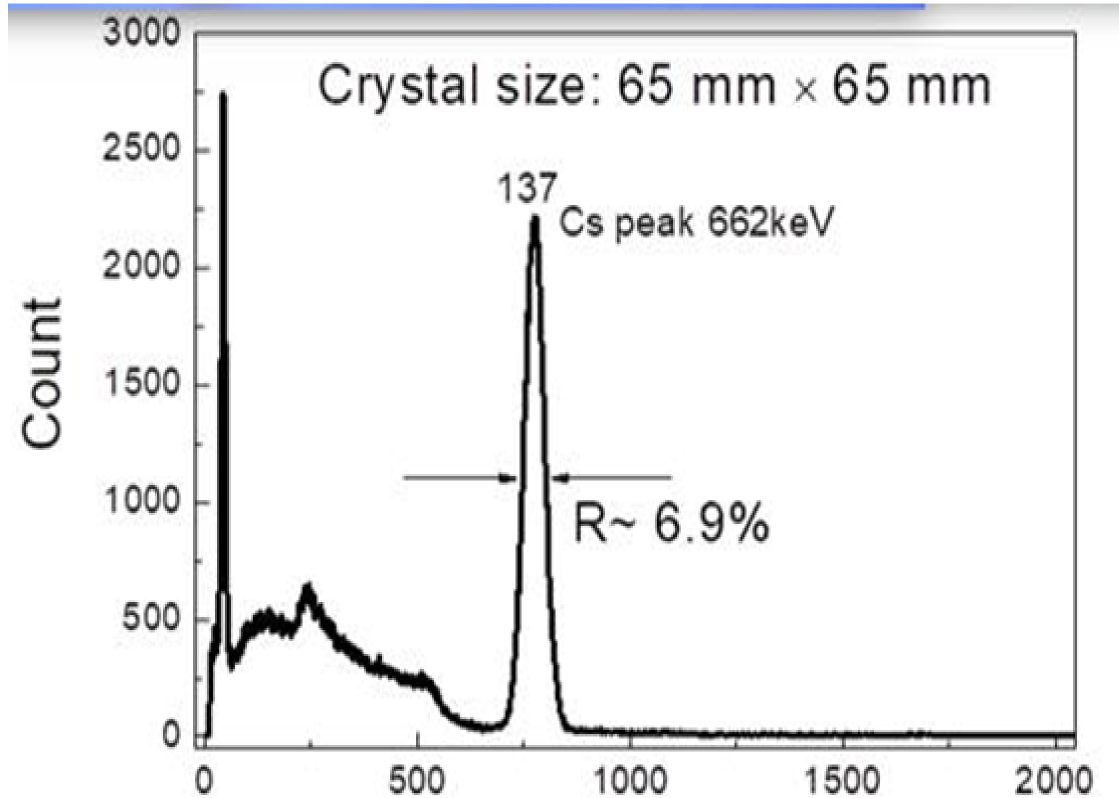
R&D and production of scintillator crystals in collaboration with TPD,BARC

- Already it was initiated from the program of DINO(in coll. with SINP and others) and lot of R&D was done
- **Large size CsI crytal** (~3Kg) with good resolution was produced by Crystal Technology Section, TPD, BARC (next slide)



MC study of EURECA, arXiv:0903.1539 correspond to the activity of 0.1 mBq/kg

Growth Of ~3kg CsI:Tl Single Crystals (75 mm Dia X 100 mm L) for Gamma Ray Detection



- CsI:Tl Crystal of size 100 mm length and 75 mm diameter Growth by Bridgman Technique using carbon coated quartz crucible.
- Crystal grown in 2017-18 for DINO.
- Gamma Spectra of ^{137}Cs recorded using 65 mm diameter and 65 mm length CsI:Tl single crystal has ER ~6.9% @ 662keV

Simulation, Background and Shielding

Shielding against background radiation (simulation, passive & active shielding):

- Cosmogenic background (muons, neutrons) → **reduced by going underground**
- Radiogenic background
  alpha, neutrons, Gamma rays, surface beta particles
  reduced by using radiopure crystal and shielding

Use passive shielding to reduce γ / neutrons
Copper (Low energy X-rays), Lead (gamma rays),
Polypropylene / Borated Plastic (neutrons)

Active shielding for muons
Plastic scintillators (muon veto)

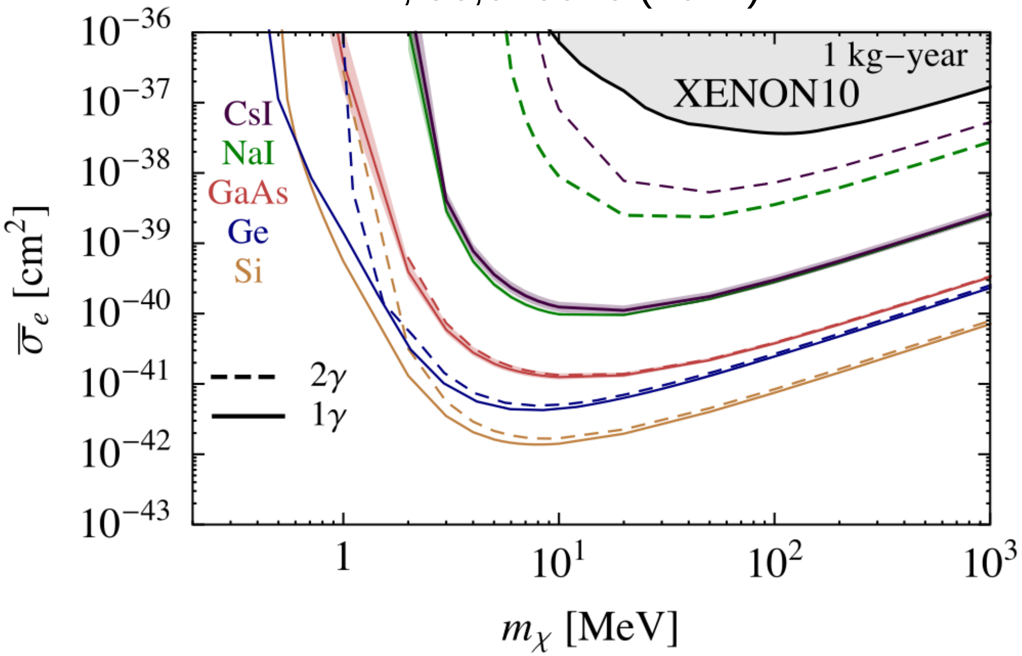
Simulations of Physics and Detector
Simulations of different background, shielding
R&D on Detector shielding
Testing of Detector with Shielding

Electron vs Nuclear Recoil

DM Nucleus scattering- Nuclear Recoil (NR):

- NR is traditionally used for Direct DM Detection
- Recoil energy ~ few keV
- Background from γ/e- few keV, discrimination done by generally scintillation/phonon or ionisation/phonon

PRD, 96,016026 (2017)

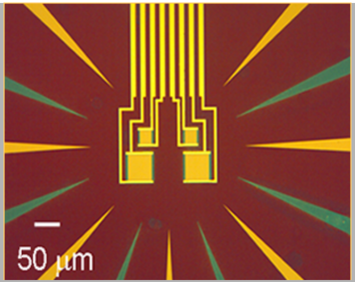
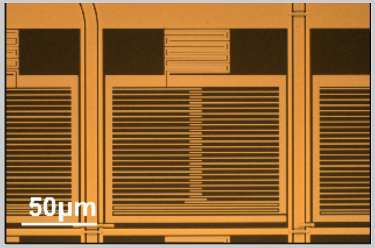
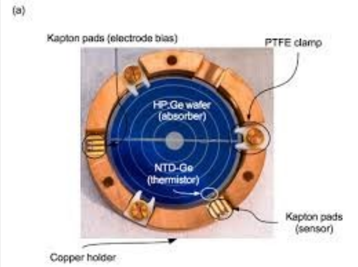
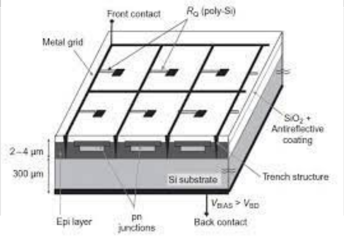


Sub-GeV DM scatterings off Electron :

- New ideas for DM detection from DM-Electron Recoil
- Background discrimination by sparation of energy range
- In principle all DM kinetic energy can be transferred to electron (in sub-GeV DM-nucleus scattering only fraction transferred)
- The signal rate is larger in semi-conductors with low band-gap (ΔE~1-2eV) than insulators(ΔE>5eV) or noble liquids (ΔE>12eV)
- The annual modulation signal rate is larger due to inelastic scattering
- To detect single photon new Photo Detectors with low dark counts are needed
- MKIDs and TESs, operates at cryogenic temperature, have sub-eV energy resolution
- and μs time response, SiPM is also potential candidate, R&D required

SINP has shown interest in SiPM R&D and simulation studies

Photon/Phonon Detection

W-TES	Tunsten-Transition Edge Sensor	CRESST, CDMS	Detects changes in temperature of an absorber by change in resistivity of superconducting film at $T \sim T_c$	
MKID	Microwave Kinetic Inductance Detector	Under Consideration	Detects changes in temperature of a superconducting absorber by measuring change in resonant frequency of holding planar cavity	
NTD Ge	Neutron Transmutation Doped Germanium	EDELWEISS	Detects change in temperature of Ge absorber by measuring its resistance	
PMT	Photo Multiplier Tube	XENON100, LAr, DarkSide	Photoelectric emission of electrons from substrate used to detect photons	
SiPM	Silicon Photo Multiplier		Detects photons by measuring breakdown current	

Summary

- **Lot of effort has gone in R&D from SINP and TPD, BARC et al. for DINO**
- **Expertise exist, Scintillator, Detection, Simulation, Detector fabrication**
- **DM detection @ sub-GeV energy : possible interest**

- Choice of active element: Scintillators

- DM detection method: Response to low energy nuclear recoil (E_{rec} ~ 1 – 200 keV)
  Electron Recoil (E_{rec} ~ few eV) – new idea, may be considered

- Detection strategy: Scintillation photons and phonons at low temperature (cryogenics)
  SiPM photon detection, R&D interest shown by SINP

- Desirable properties: High light output, Low temperature operation, Low intrinsic radioactivity background
  CsI (Tl) / CsI / ZnWO4 [Crystal Technology Section, TPD, BARC]

- Shielding (passive and active):
  Cu (low energy X-rays), Pb (gamma rays), Polypropylene / Borated Plastic (neutrons)
  Plastic scintillators (muon veto)

- Simulations: On different aspects of the experiment:
  Physics Detector Shielding Background

Thank you