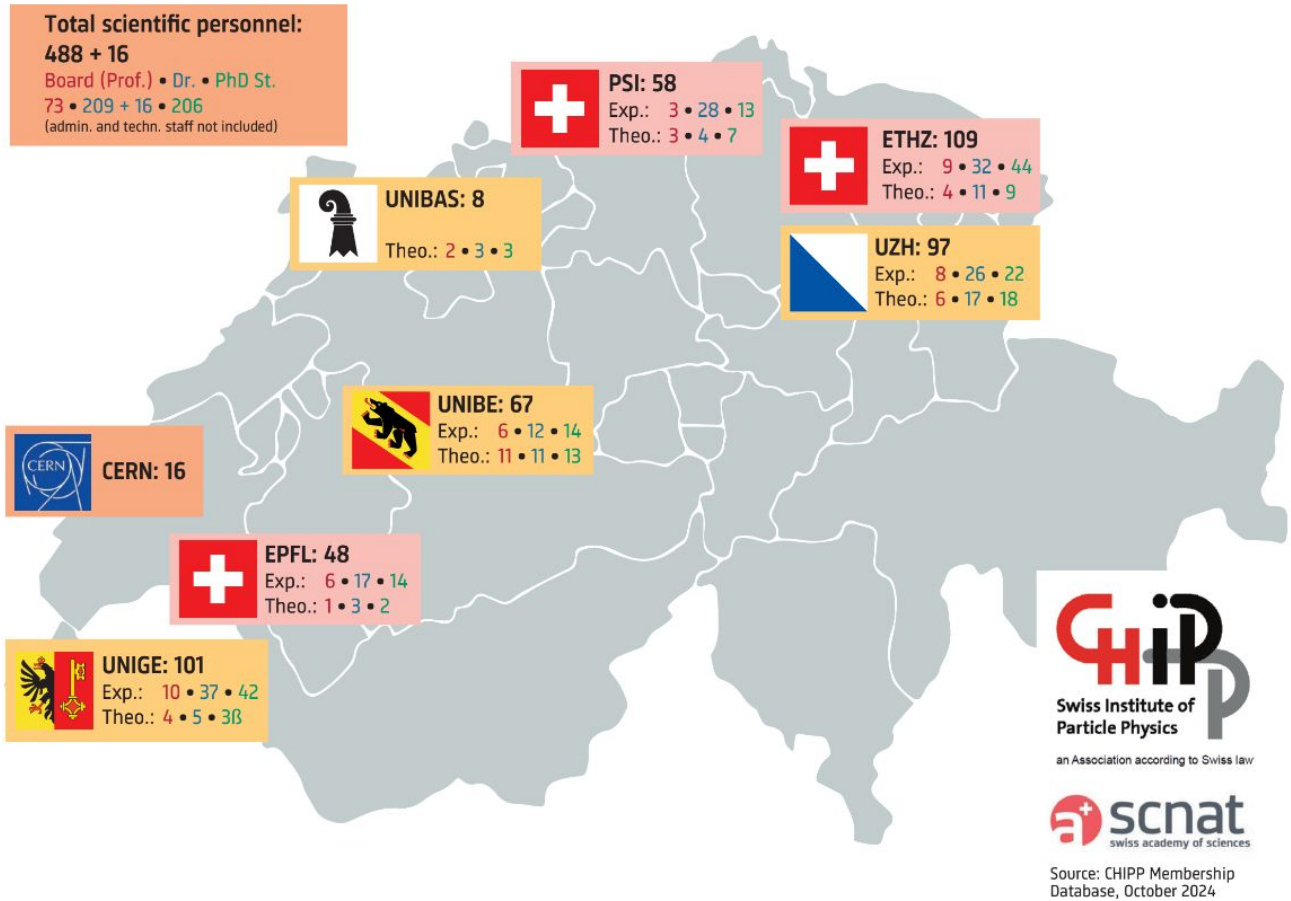
The Swiss Dark Matter Program

Overview

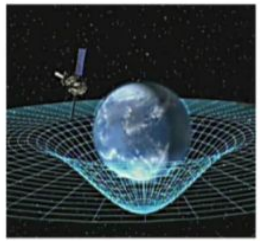
- The Swiss Landscape
- Experimental Programs
- Deepening the UK-Swiss Collaboration

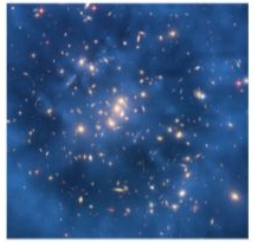
The Swiss Landscape



Gravitational waves:

LIGO, Einstein Telescope (ET), LISA





Dark matter direct and indirect detection:

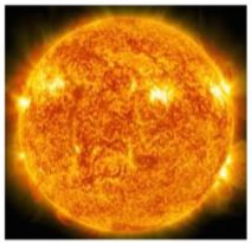
XENON, LZ, DARWIN/XLZD

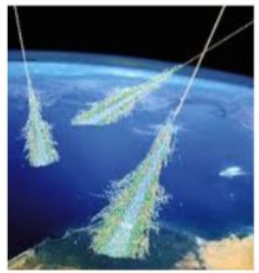
DAMIC, Qrocodile, Tesseract

AMS, CTA, LIGO, ET, LISA

Solar neutrinos:

XENON, LZ, DARWIN/ XLZD





Cosmic rays, gamma ray astronomy and multi-messenger physics:

AMS, CTA, DAMPE, HERD, LIGO, ET, LISA

Supernova remnants and SN neutrinos:

LIGO, ET, LISA, CTA, XENON, LZ, DARWIN/XLZD

Red: Flagship projects on SWISS Roadmap

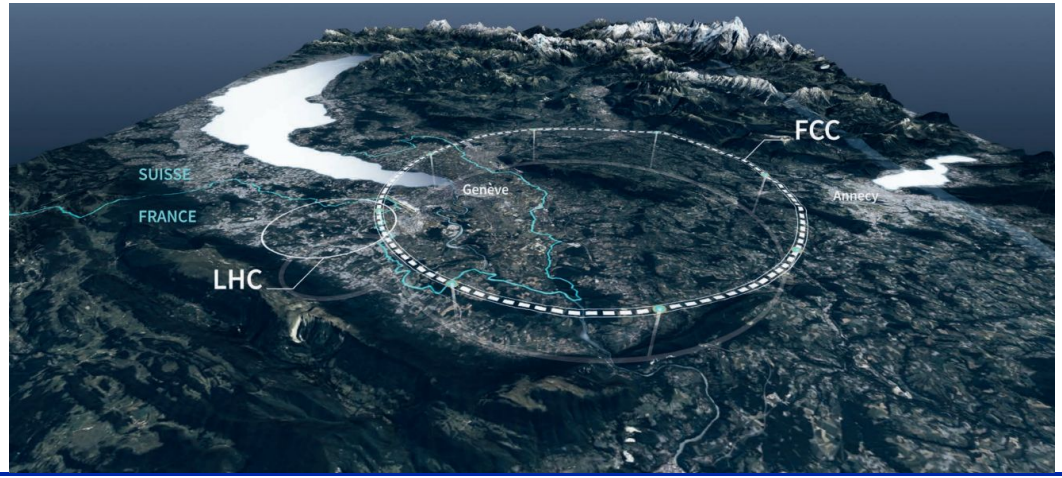
Green: Overlap with Astrophysics Community

Slide taken from LB

LB, RECFA visit to Switzerland, March 2024

Other Experiments Relevant to DM

X- and γ-rays, cosmic rays, and neutrinos	
From space	
AMS-02	(UNIGE)
DAMPE	(UNIGE, EPFL)
HERD	(UNIGE, EPFL)
NUSES	(UNIGE)
POLAR-2	(UNIGE)
From the ground	
CTAO	(EPFL, ETHZ, UNIGE, UNIBE)
MAGIC	(UNIGE, ETHZ)
IceCube	(UNIGE)
ET	(UNIGE, UZH)
LVK	(UNIGE, UZH)

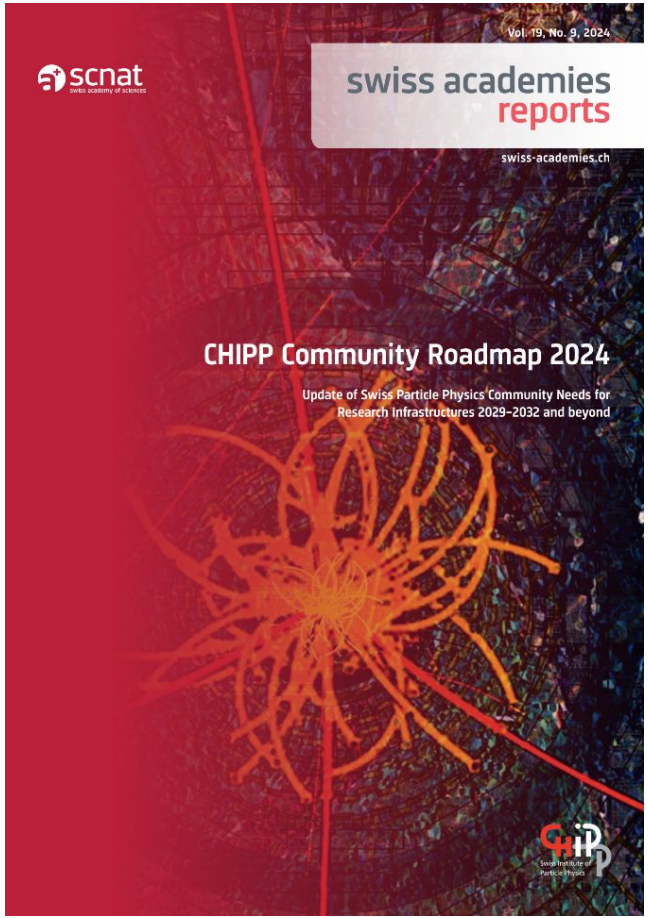


- Several **DM related experiments** hosted at many universities
- Strong **LHC and low-energy beam** program
  - **UZH leading Swiss FCC** effort

Institution	Main involvements
UNIBE	Experiments at CERN: ATLAS and FASER Experiments at PSI: n2EDM , Beam EDM, QNeutron Detector R&D: Tracking detectors, data acquisition
UNIGE	Experiments at CERN: ATLAS and FASER Experiments at PSI: Mu3e Detector R&D: Tracking detectors, trigger and data acquisition
UZH	Experiments at CERN: CMS, LHCb, SHIP Experiments at PSI: Mu3e Detector R&D: Tracking detectors, trigger
EPFL	Experiments at CERN: LHCb, SND@LHC, NA62, SHiP Detector R&D: Tracking detectors, trigger
ETHZ	Experiments at CERN: CMS, NA64, GBAR, BASE, FASER Experiments at PSI: Mu3e, n2EDM, CREMA, mu-Mass, muX, piHe Detector R&D: Calorimetry, tracking detectors
PSI	Experiments at CERN: CMS Experiments at PSI: Mu3e, MEG II, n2EDM, CREMA, mu-Mass, muX, piHe, muEDM, τSPECT Detector R&D: Tracking detectors

Direct Detection Experiments

- All Swiss direct DM experiments presently hosted at the **University of Zurich** (UZH)
- **LXe experiments**
  - **XENONnT** (Baudis)
  - **LZ** (Penning)
  - **XLZD/DARWIN** (Baudis, Penning)
- Low Mass DM via **quasiparticle** sensing:
  - **TESSERACT** (Penning)
  - **QROCODILE** (Baudis, Penning)
- Low Mass DM via **ionisation**:
  - **DAMIC-M, OSCURA** (Kilminster)

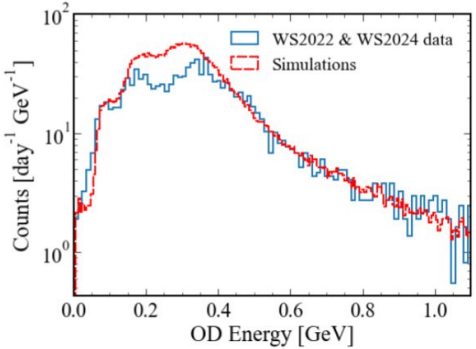


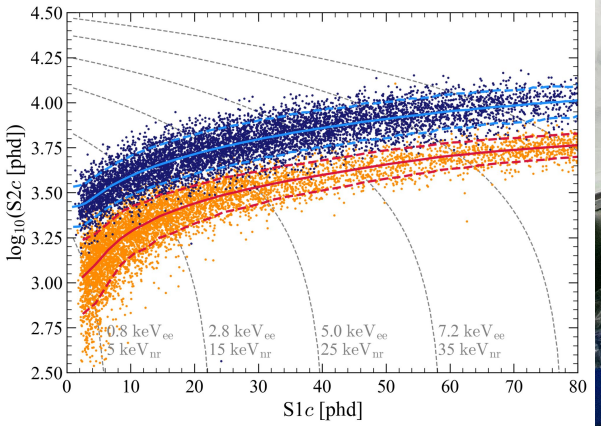
Recommendation 10: CHIPP considers the support of the ongoing and future direct dark matter searches a high priority of the Swiss programme. The ongoing operation and data analysis of the current generation XENONnT and LZ experiments are at the forefront of dark matter direct detection research. CHIPP advocates for continued Swiss leadership and instrumentation contributions to the future DARWIN/XLZD multi-tonne dark matter search facility. To explore low-mass dark matter and foster novel instrumentation, CHIPP also supports with lower priority smaller-scale cryogenic dark matter experiments employing quantum sensors, such as TESSERACT and DAMIC-M.

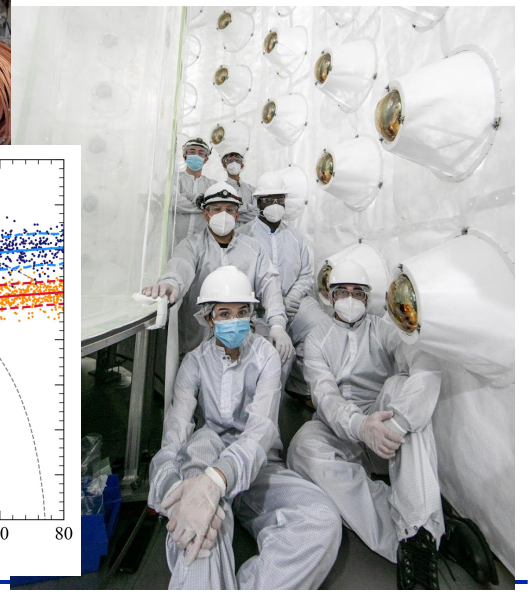
- Particle DM was on the Swiss & CHIPP Strategic Plan in the past
- CHIPP recommendations now also include LZ and TESSERACT

LXe

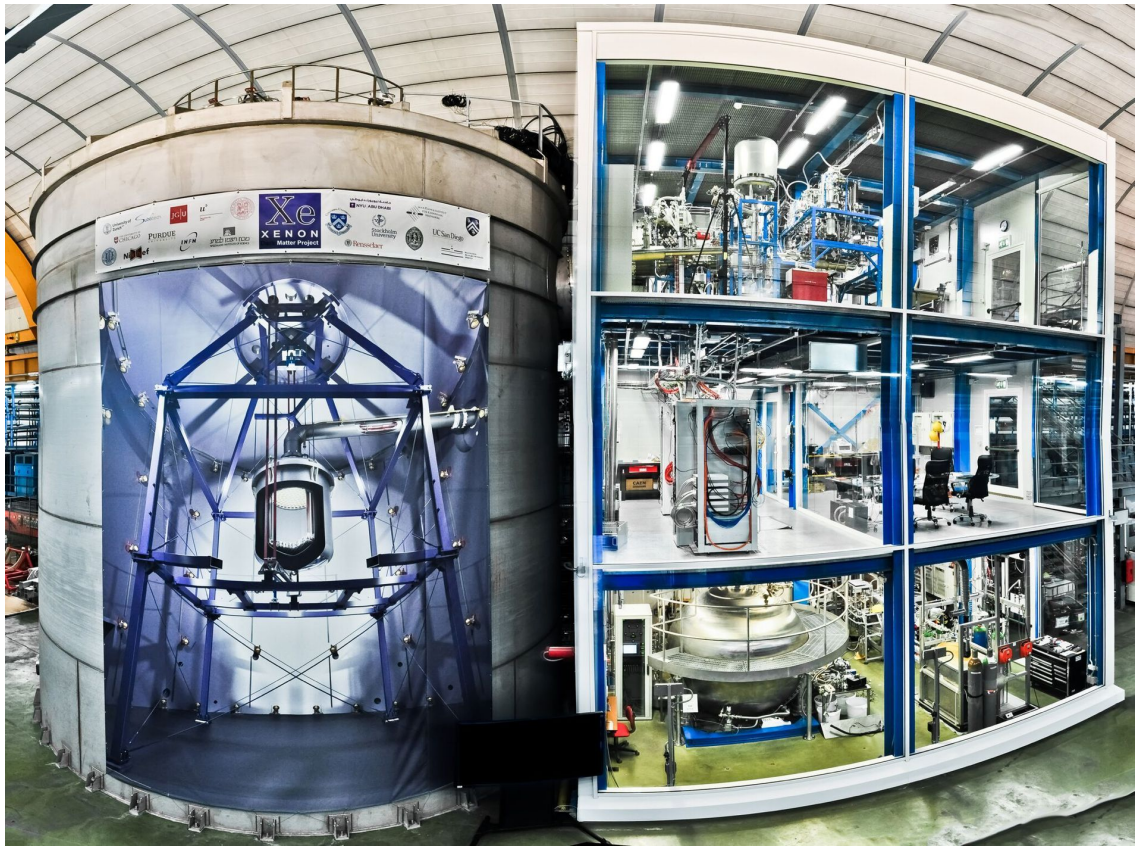
- Design, manufacturing, fabrication, installation, operation, and analysis of most of **LZ's Outer Detector**
- Strong presence **on-site presence**
- Involved in **reconstruction, simulation, underground operations, calibration** and **calibration analyses**
- Group operated **small LXe chamber** at Michigan (W-value)
- **Main analysis**: Standard WIMP, high energy NR, high ER, Cosmic Muons
- Strongly evolving towards XLZD/Darwin and integrating into the Swiss DM effort
    - XLZD R&D and Precision LXe measurements

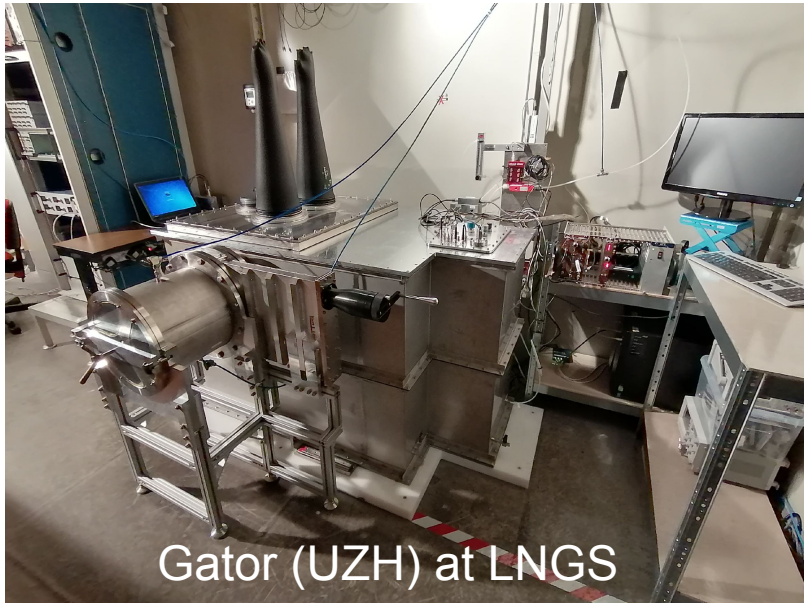


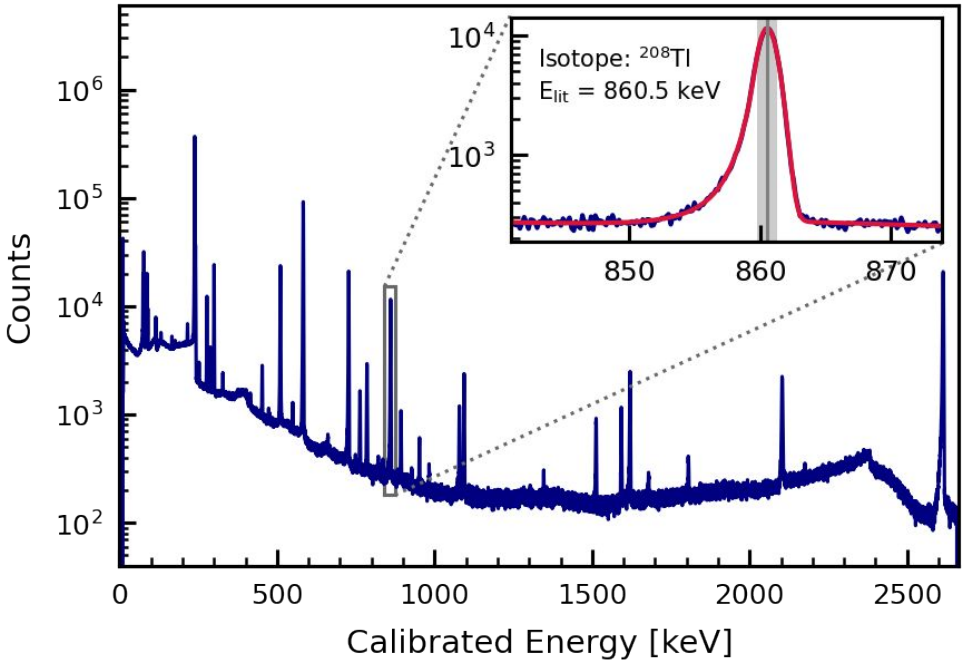




- XENON group strongly lead by **Laura Baudis** at UZH
- **Low-background PMT development,** LXe tests and readout
- **Design & construction of the TPC,** including photosensor array
- **Prototyping the XLZD TPC** in the full-scale z-dimension
- **Test** of new **photosensors** (SiPMs, 2-inch square PMTs) and their readout
- Development and prototyping of gravity-assisted **LXe storage system** (BoX) Identification of radio-pure materials with Gator (HPGe detector)
- Many **Analysis & Leadership** responsibilities

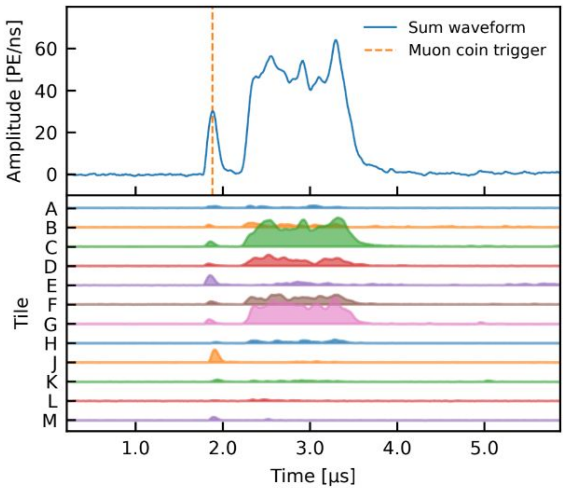






- **GATOR**: HPGE facility operated by **Baudis group** at LGNS
- **HPGe detector** inside Cu-OFE cryostat (cooled with LN2 via copper coldfinger)
  - Remote operations (incl. alarms , detector stability, data quality), regular LN refilling, calibrations

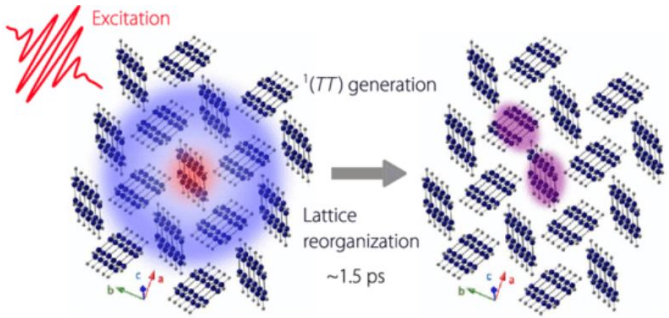
- **Xenoscope**: Full DARWIN/XLZD 2.6m TPC to demonstrate drifting of S2 signals over full length scale and measure its properties
- **First signals** in TPC mode obtained in summer **2024**:
  - 400 kg LXe TPC
  - ~100 V/cm field
  - SiPM readout
- **Planned measurements**:
  - S2 propagation
  - Xe optical properties
  - Photosensor R&D
  - Light calibration system
- See arXiv:2105.13829

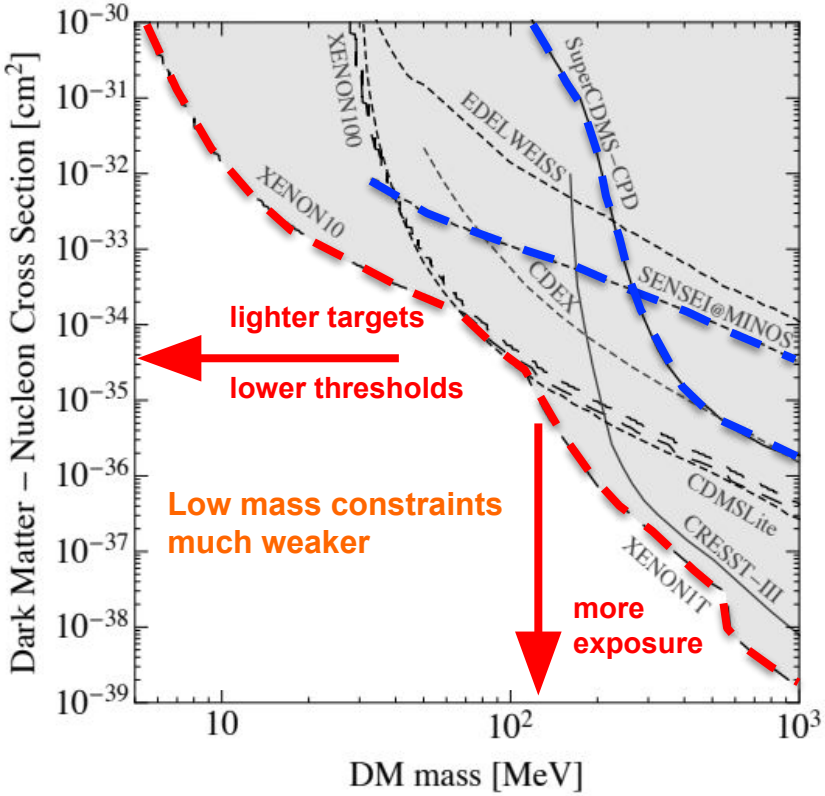


- **Several small scales TPCs** are operated or being built to measure W-value, recombination measurements, test calibrations source and materials
- Long term goal: Operation small scale TPCs (or DF) underground
  - **Crucial R&D** for XLZD and other future experiments

Low Mass DM

- Lower DM searches require **light targets** and **very low energy thresholds**
- **New landscape,** beneath **ionization scale** we must consider solid state physics, statistical mechanics, chemistry, etc.
- **New backgrounds**: Not only radioactive but also: IR, parasitic power, vibrations etc
  - **Low Energy Excess** (‘Dark backgrounds’)
- DM wavelength longer than lattice spacing → DM sees material

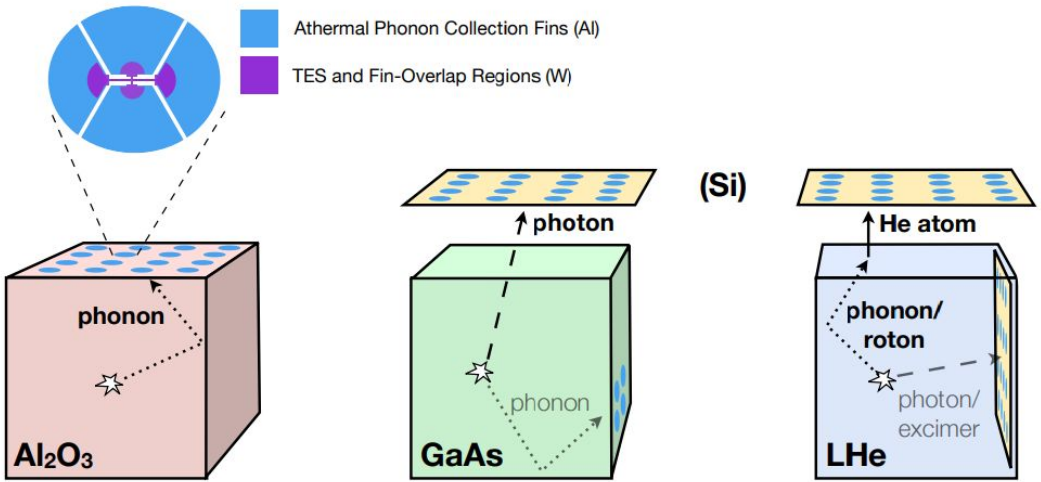




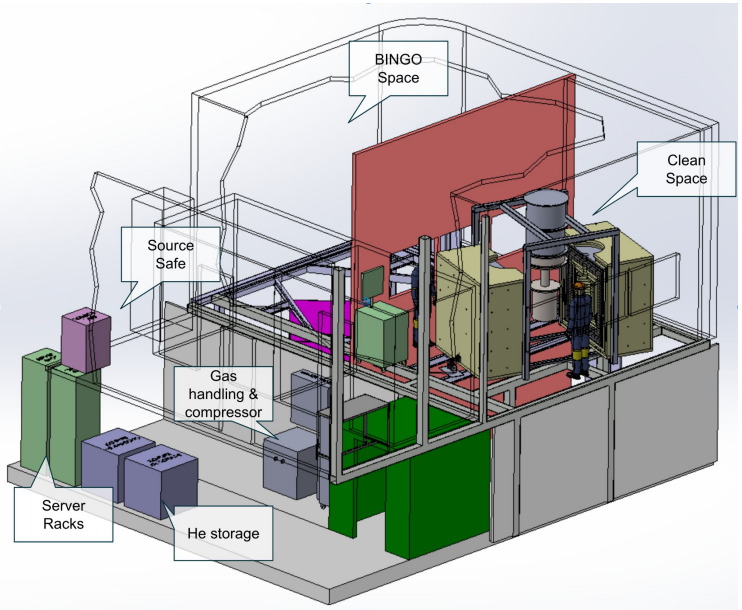
$$R = \sigma n_{\mathrm{DM}} N_{exp} = \sigma \frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}} N_{exp}$$

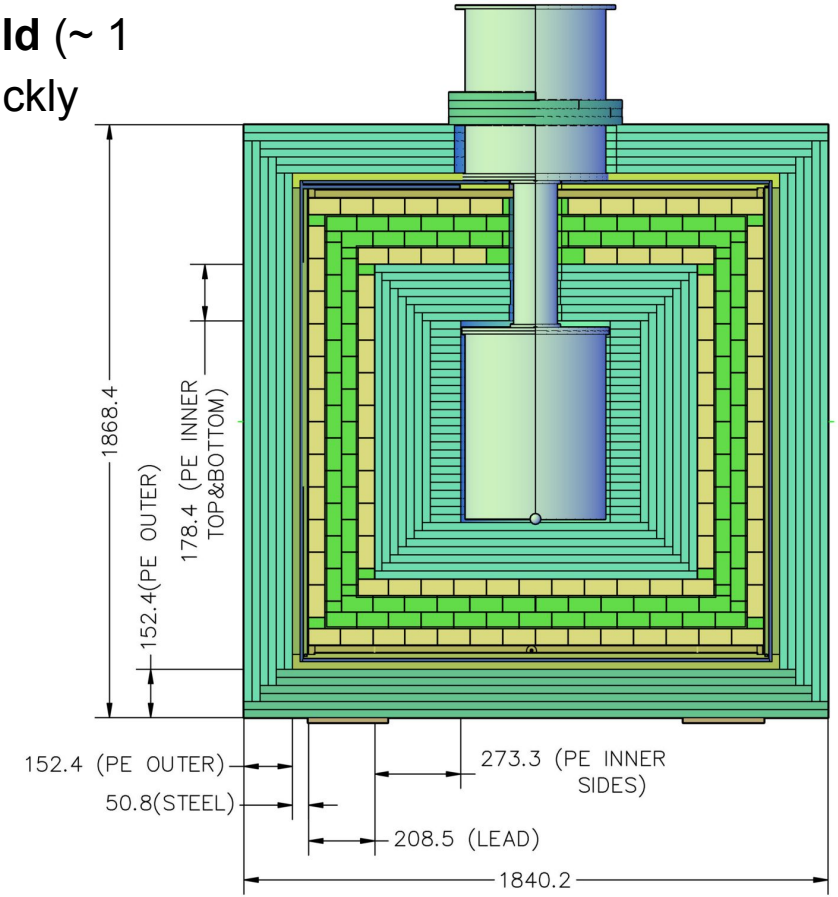
Small masses have large impact

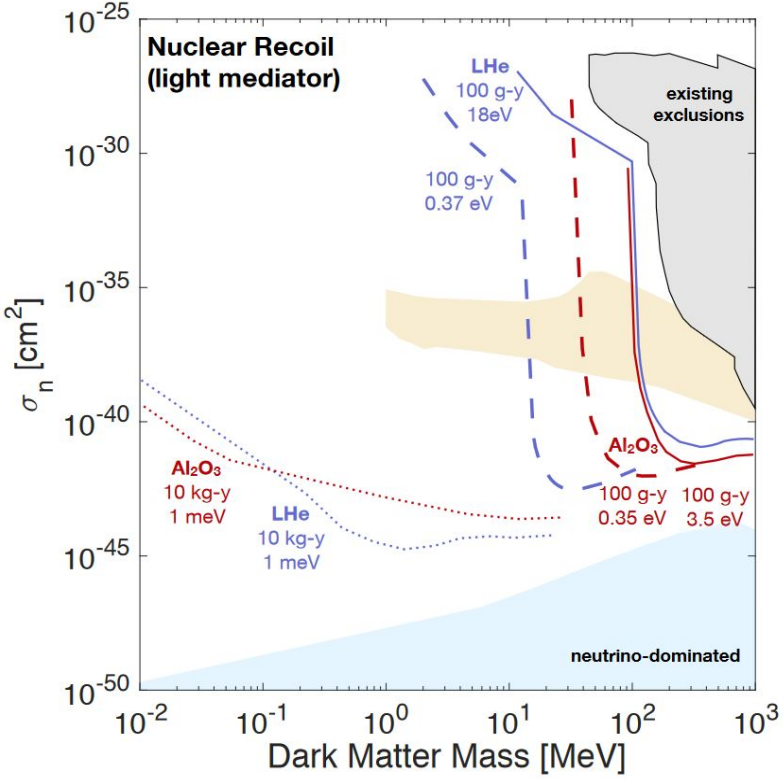
- **Tesseract**: Use different targets that probe different DM models and affected by different backgrounds
- **Energy sensitivity** is primary driver for low mass DM → need detectors with thresholds of 1-100 meV
- All targets read out using **Transition Edge Sensor** (TES) readouts, no E-field (no dark-currents)

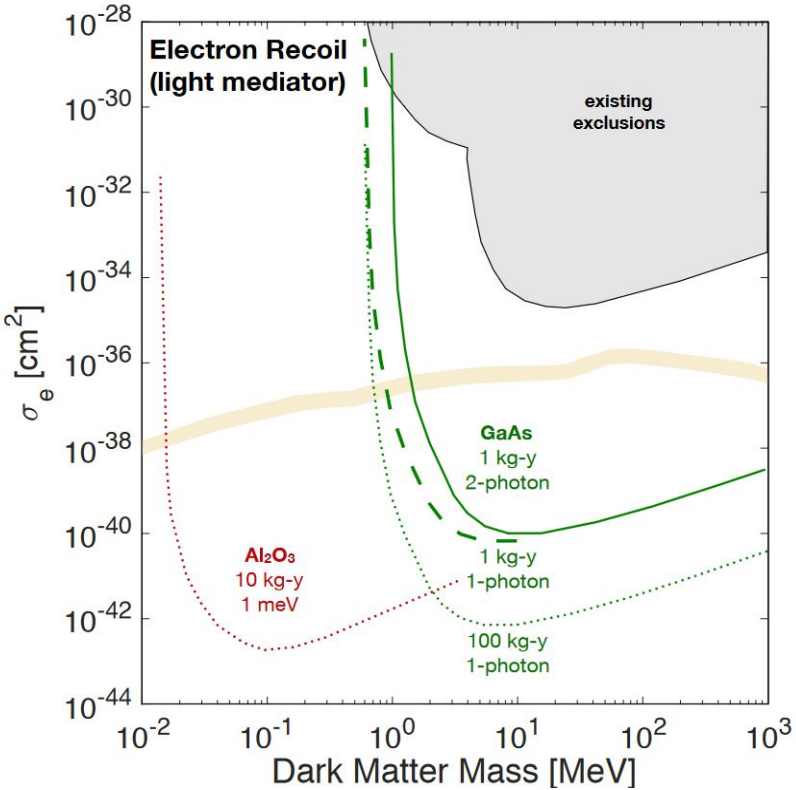


- At UZH we developed **a low background shield** (~ 1 DRU@1 keV) allowing to to swap detectors quickly
- Setting up c**ryogenic lab for sensor R&D**
- Experiment will be hosted in **Modane**





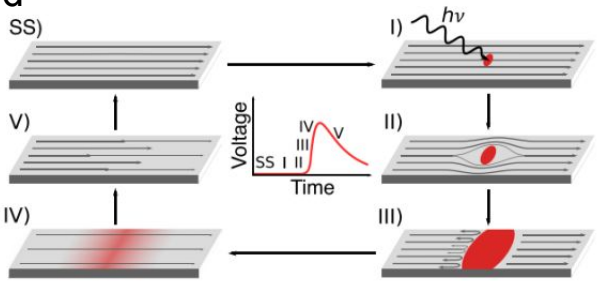


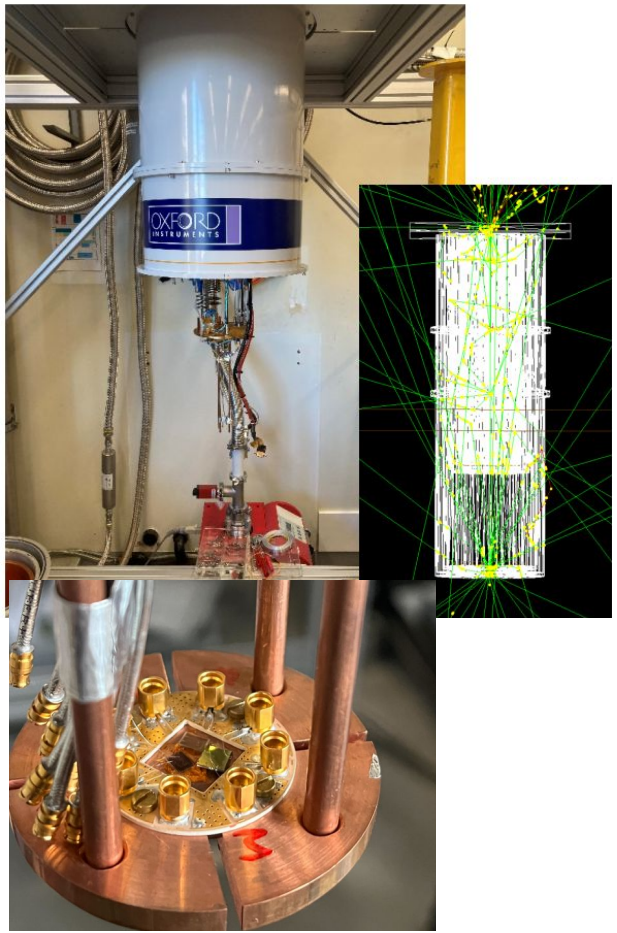


- Even scale experiment can probe new parameters masses →Paper in preparation
- Aiming for UG operations in 2028

- **Q**uantum senso**R** cry**O**geni**C** search f**O**r **D**ark matter **I**n **L**ight mass rang**E**

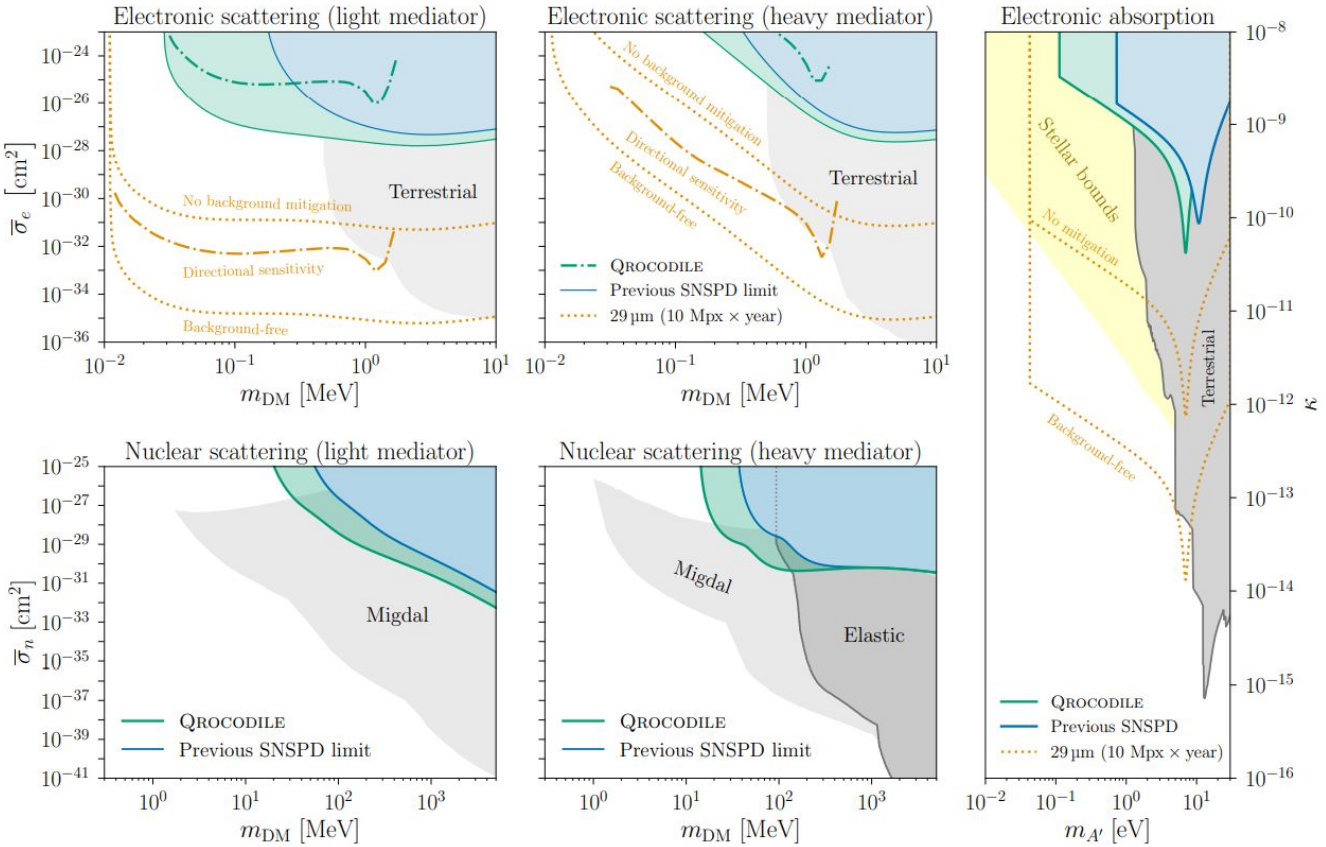
- New experiment: (UZH, MIT, Hebrew Univ of Jerusalem)
  - Condensed matter/astroparticle/quantum sensing/particle theory
- Use **superconducting nanowires (SNSPD)** for sub-GeV DM particles (scatters on electron and |absorption)
- **TES** and **SNSPD** are complementary in terms of properties and Signal



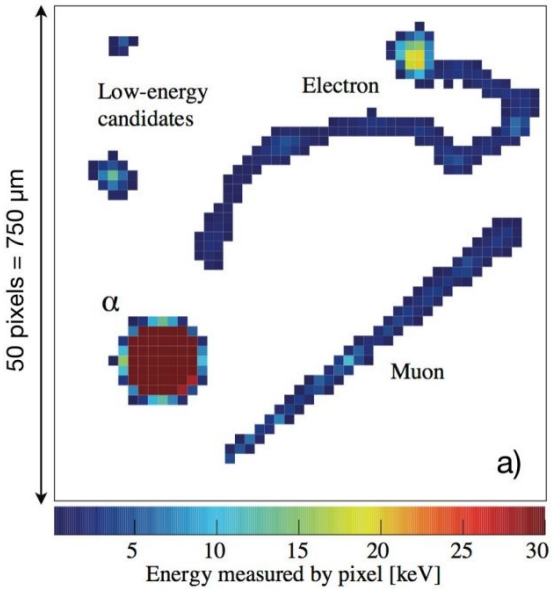


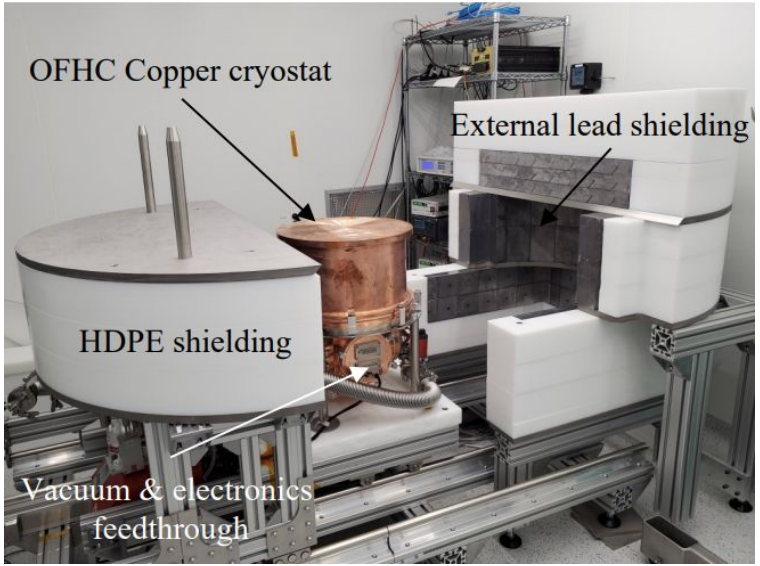
- Just submitted our **first paper**: 2412.16279

- Probing **new phase space** for electron scattering and lowest masses for NR independent of Migdal effect

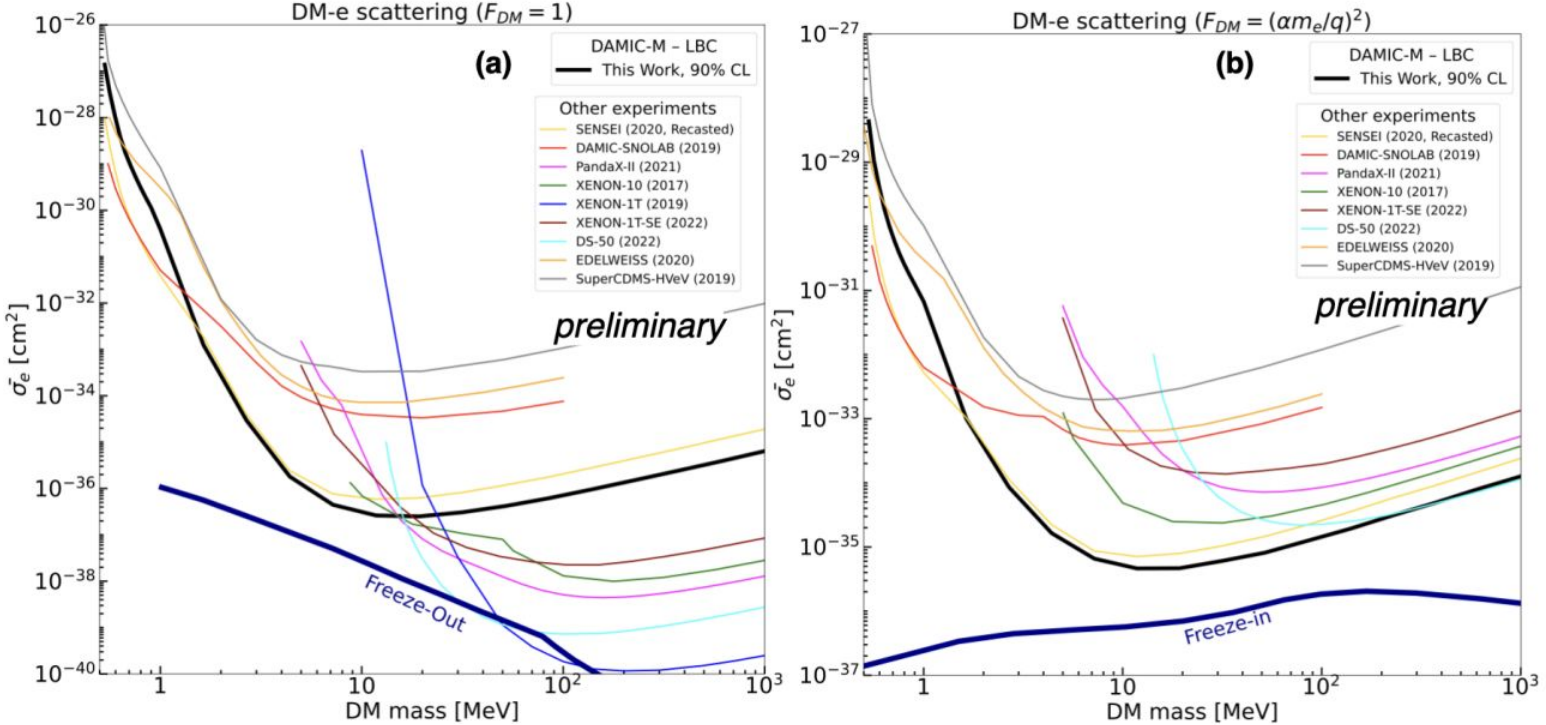


- **DAMIC-M**
  - Aims to detect nuclear and electron scattering
  - Recoils in Silicon CCDs to search for Light dark matter candidates (eV to GeV)





- Operate with "**skipper**" amplifier readout to provide single electron energy resolution (sub-eV) and self calibration
- Pixelization for background rejection



- **First results** for 115 g-day exposure for heavy (left) and light (right) mediators
- arXiv:2210.12070

- **Strong connection** between UK and Swiss scientists:
  - BP was fellow and then lecturer in UK, LB served on many committees and adv. boards
  - Collaborative ties with LZ, XLZD, LEGEND, working with **Henrique/IC on LXe** procurements etc
- **Similar** science and R&D **interests** with **complementary aspects**:
  - **UK** strong focus on XLZD project/**Boulby**
  - **Swiss hardware support** enables **operating system** offering **all learning opportunities** in LXe and cryogenic DM

- **Opportunities!**
  - Explore **funding opportunities**:
    - E.g. UZH global initiative has strong UK component, others?
  - **Student exchange** between UK and Switzerland
    - **Kim P**. considered last year sending a student on LTA to Zurich
    - BP hosted three UK students on LTA already in the past in the US

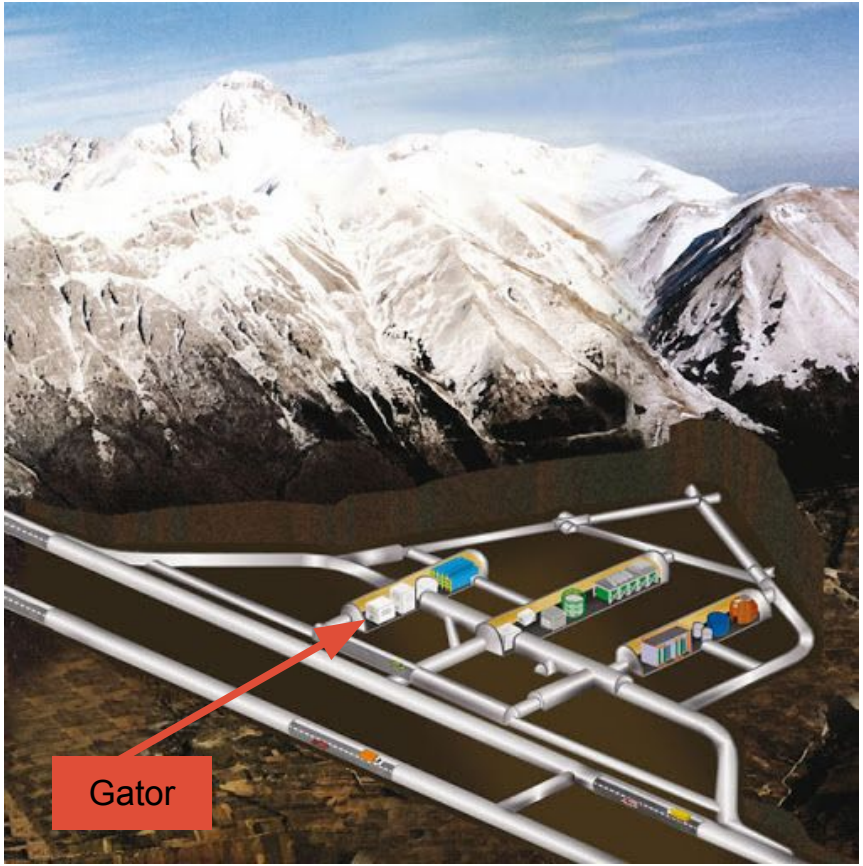
Summary

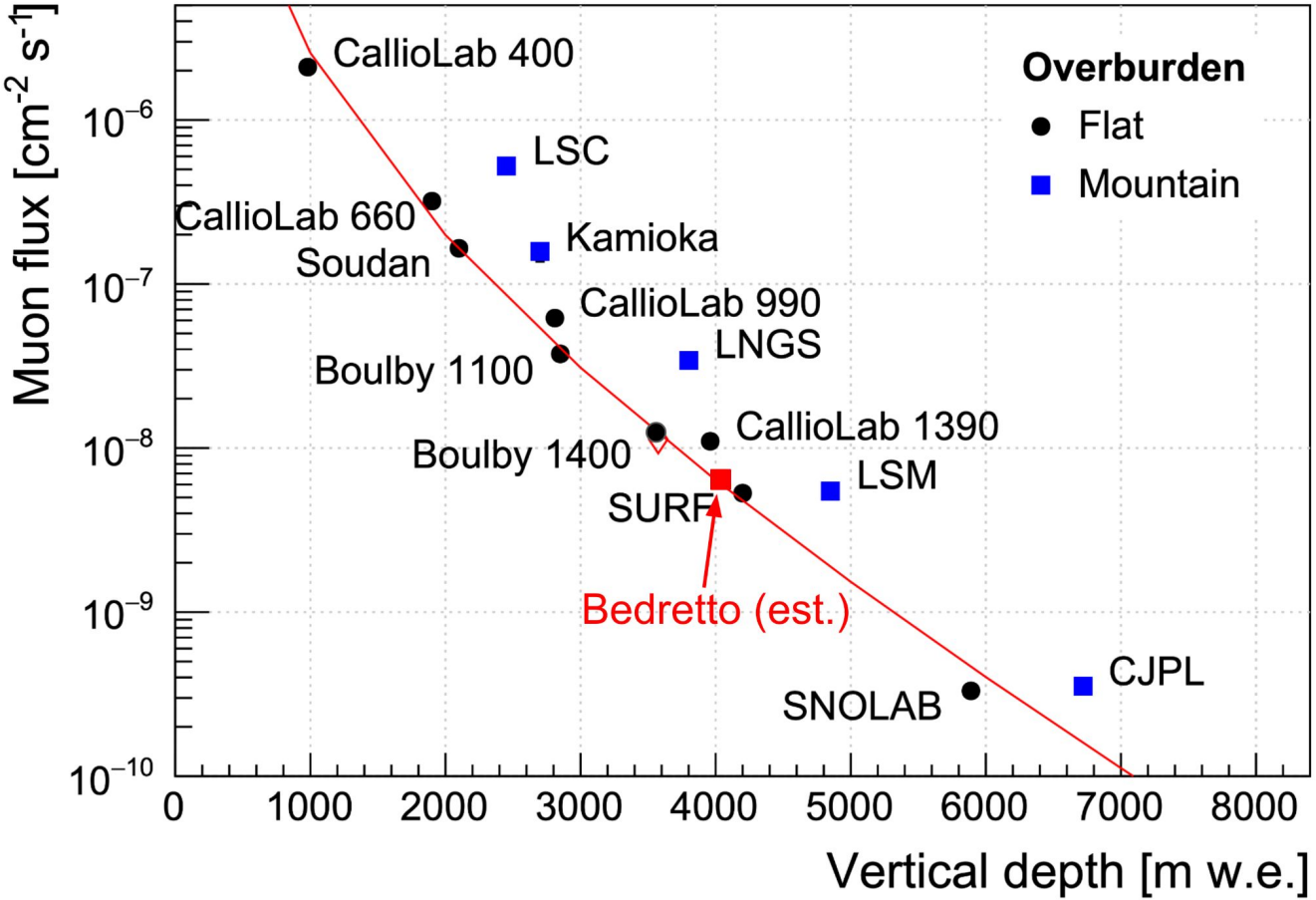
- **Direct DM is a pillar of the Swiss and UK** science landscape
  - **Noble Liquid TPCs are the most sensitive WIMP detector** today and in the future
  - New **sensors sensitive below ionization energies** starting to explore **entirely unprobed energies**
- **Strengthen the natural connection** between Switzerland and UK, by pursuing shared funding opportunities and student exchanges
- **Our field is characterized by a vibrant and diverse scientific landscape**:
  - **R&D** ranging from engineering, radiopurity, cryogenic and noble-gas physics to blue-sky ideas
  - Addressing **science questions** in particle-, nuclear- and solid-state physics
- **Smaller setups** have real impact
- The successful operation of LZ and XENONnT and novel efforts truly means **a discovery can happen any time**

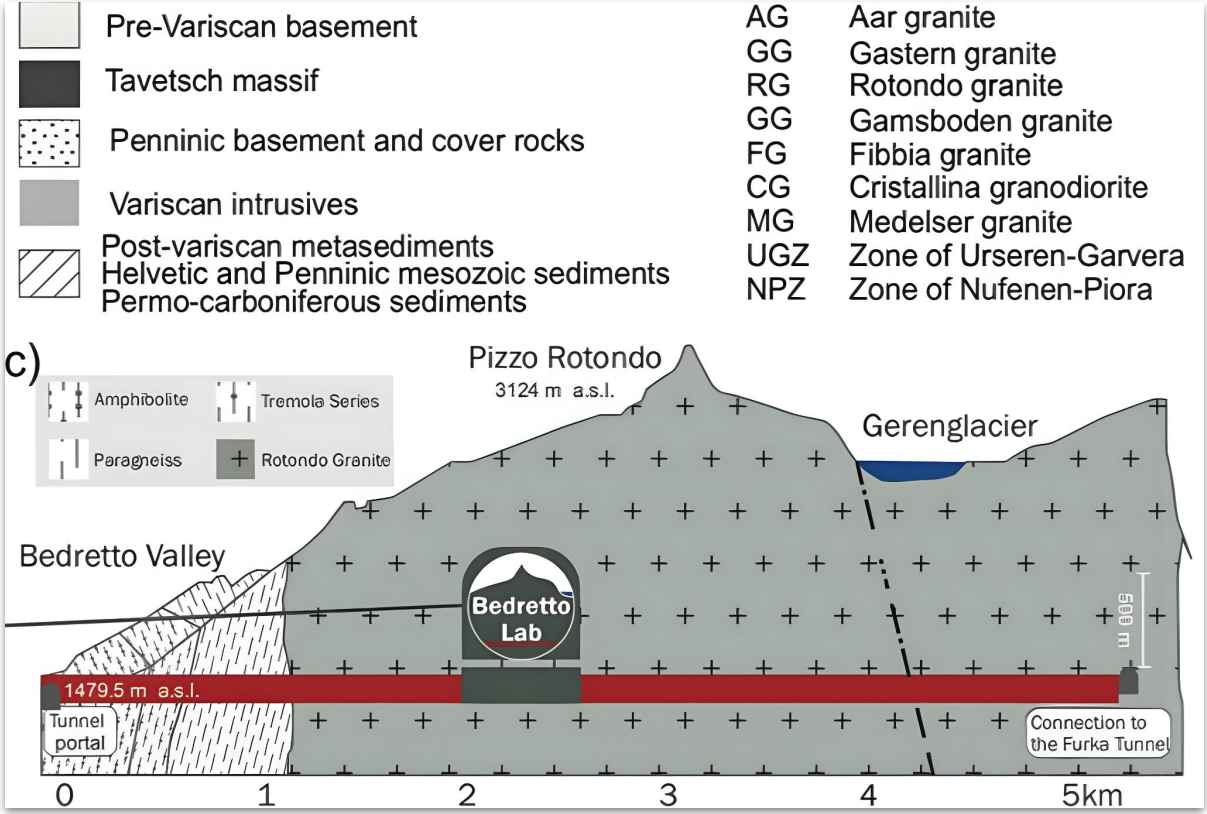
Backup

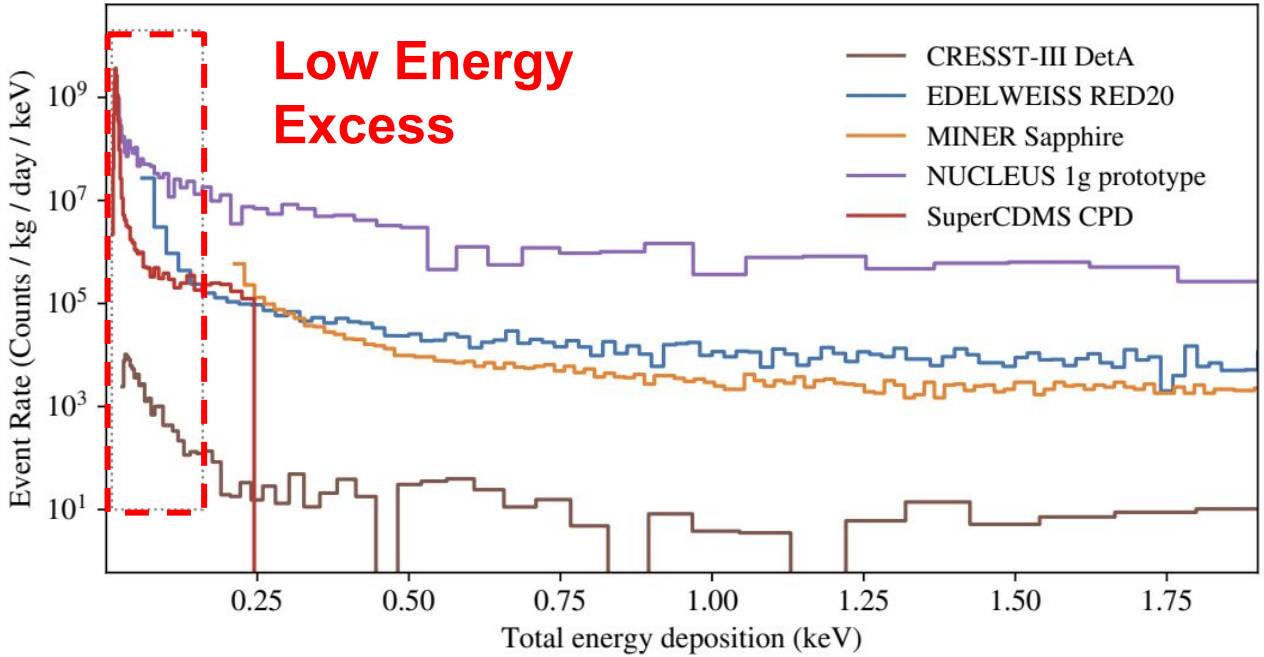
Gator Counting Facility

- Low-background germanium counting facility for high-sensitivity γ-ray spectrometry
- Located at the Gran Sasso underground laboratory in Italy (LNGS) at a depth of
- 3600 m water equivalent
- Core: p-type coaxial high-purity germanium (HPGe) detector with 2.2 kg sensitive mass and a relative efficiency of 100.5%
- Sample chamber volume: 25×25×33 cm^3
- Currently used for material radioassay for rare-event search experiments in astroparticle physics (DARWIN/XLZD, LEGEND,...)




Muon flux [cm^{-2} s^{-1}]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
1000
2000
3000
4000
5000
6000
7000
8000
Vertical depth [m w.e.]
Overburden
Flat
Mountain
CallioLab 400
LSC
CallioLab 660
Soudan
Kamioka
CallioLab 990
LNGS
Boulby 1100
CallioLab 1390
Boulby 1400
LSM
SURF
Bedretto (est.)
CJPL
SNOLAB


Pre-Variscan basement
Tavetsch massif
Penninic basement and cover rocks
Variscan intrusives
Post-variscan metasediments
Helvetic and Penninic mesozoic sediments
Permo-carboniferous sediments
AG Aar granite
GG Gastern granite
RG Rotondo granite
GG Gamsboden granite
FG Fibbia granite
CG Cristallina granodiorite
MG Medelser granite
UGZ Zone of Urseren-Garvera
NPZ Zone of Nufenen-Piora
c)
Amphibolite
Tremola Series
Paragneiss
Rotondo Granite
Pizzo Rotondo
3124 m a.s.l.
Gerenglacier
Bedretto Valley
Bedretto Lab
1479.5 m a.s.l.
Tunnel portal
Connection to the Furka Tunnel
0
1
2
3
4
5km

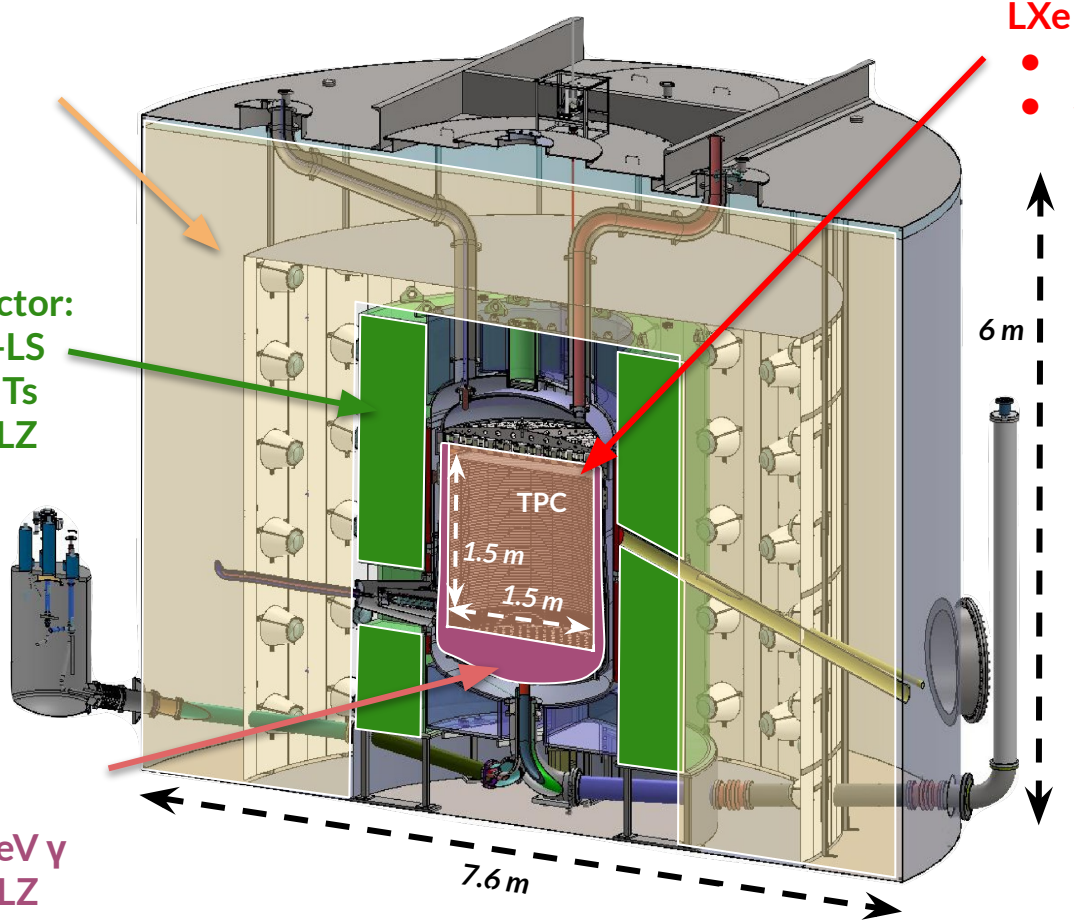


- **Low energy excess** at O(eV) in many experiments: SuperCDMS, Edelweiss, Nucleus, DAMIC, etc
- New landscape w.r.t backgrounds: Nuclear backgrounds not the only significant ones, many novel backgrounds: IR backgrounds, parasitic power, **vibrations**
- LEE likely vibrations, but also probably some other components

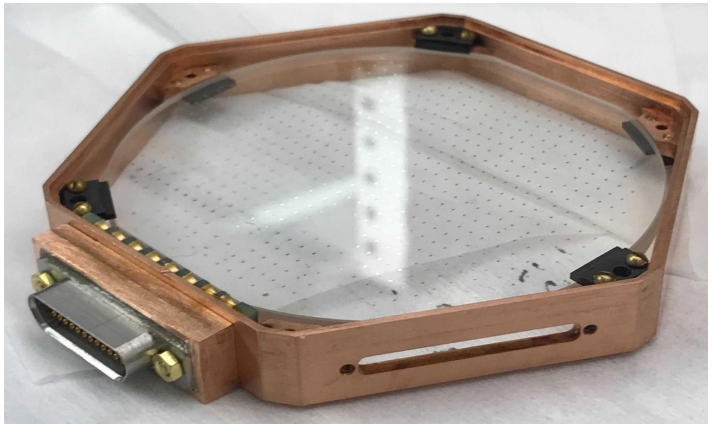
Water shield:
- 230 t DI water
- Instrumented

LXe target:
- 7t LXe TPC
- 40x LUX

Outer Detector:
- 17 t Gd-LS
- 120 PMTs
- New in LZ

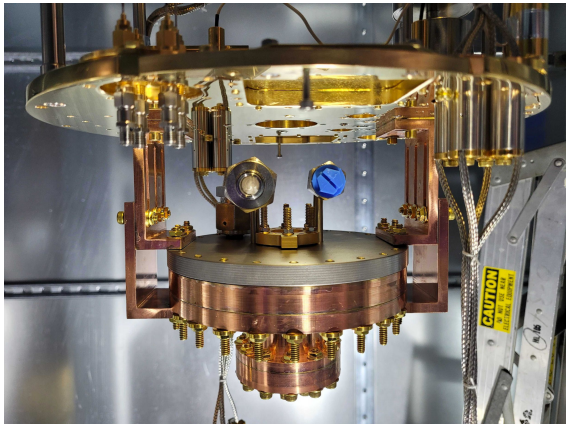


LXe "skin" region:
- Veto MeV γ
- New in LZ



- **Sapphire** (Al_2O_3): Many optical phonon modes that are kinematically well-matched to low-mass DM, high dark photon sensitivity

- **GaAs**: polar crystal, band gap matched well to low mass region. Reduce backgrounds via photons and phonons ratio/coincide



- **Superfluid helium** provides low mass NR sensitivity and multiple signal channels

- Most **sensors operating** in demonstrator setups, but more **R&D** needed
- **Novel & challenging backgrounds** due to femto and attoWatts sensitivity in TES
- **Advantage of Tesseract**: Ability to discriminate and characterize these backgrounds
- At **UZH setting** up cryo lab TESSERACT sensor R&D