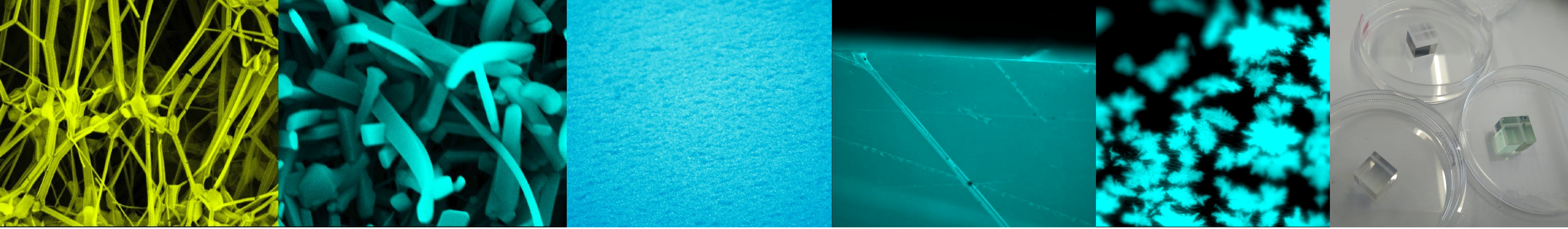


ADVANCING NEUTRINOLESS DOUBLE BETA DECAY SEARCH WITH GERDA, LEGEND & MONUMENT, & EXPLORING PASSIVE NEUTRINO DETECTORS WITH PALEOCCENE

CHIPP ANNUAL MEETING - 20.06.2024

GABRIELA R. ARAUJO

LAURA BAUDIS - ASTROPARTICLE PHYSICS GROUP

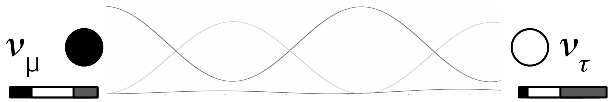
University of Zurich[UZH]

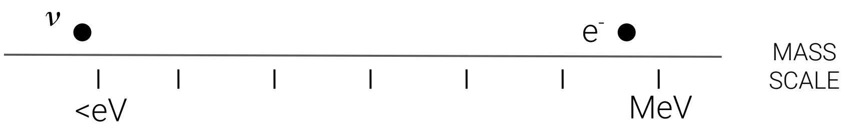
GERDA LEGEND Monument PALEOCCENE

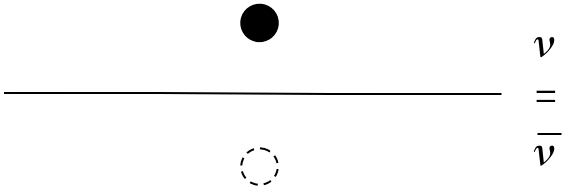
BEYOND THE STANDARD MODEL OF PARTICLE PHYSICS (BSM)

THE NEUTRINO MASS PROBLEM

NEUTRINO FLAVOUR OSCILLATION MEASUREMENTS SHOW THAT NEUTRINOS HAVE MASS.





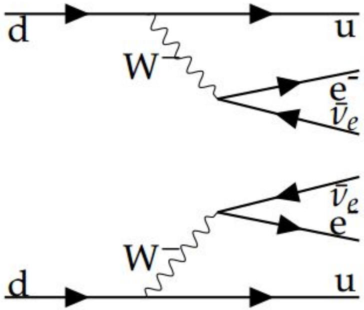


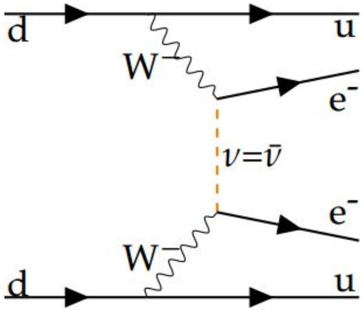
NEUTRINOS ARE MUCH LIGHTER THAN OTHER ELEMENTARY PARTICLES.

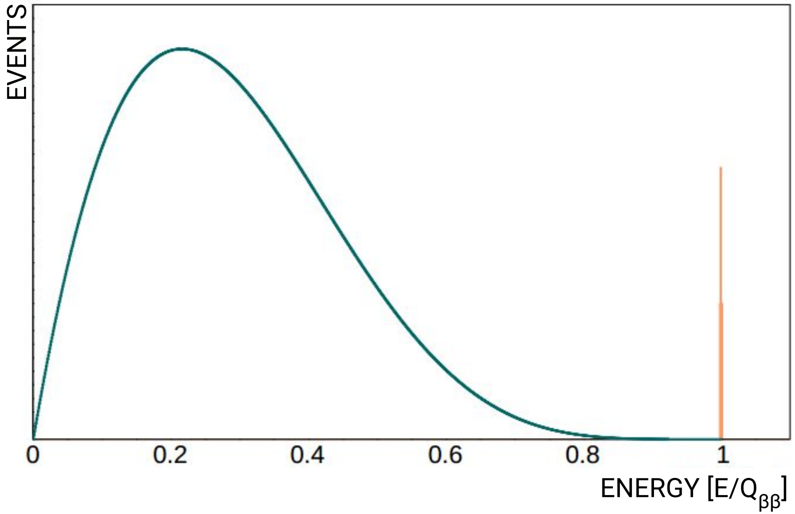
DO NEUTRINOS HAVE A MAJORANA MASS?
ARE THEY THEIR OWN ANTIPARTICLE?

A HYPOTHETICAL “RARE” PROCESS MIGHT GIVES US ANSWERS

NEUTRINOLESS DOUBLE BETA DECAY







TWO NEUTRINO DOUBLE BETA DECAY ($2\nu\beta\beta$):

- $2n \rightarrow 2p + 2e^- + 2\bar{\nu}_e$ ($\Delta L=0$)
  (IN A NUCLEUS)

NEUTRINOLESS DOUBLE BETA DECAY ($0\nu\beta\beta$):

- $2n \rightarrow 2p + 2e^-$ **($\Delta L=+2$)**
  (IN A NUCLEUS)

NO NEUTRINOS ARE EMITTED. THIS **LEPTON NUMBER VIOLATING** PROCESS COULD HAPPEN IF NEUTRINOS HAVE A MAJORANA MASS.

VIOLATION OF LEPTON NUMBER CONSERVATION COULD BE CONNECTED TO THE MATTER-ANTIMATTER ASYMMETRY OF THE UNIVERSE.

SEARCHING FOR NEUTRINOLESS DOUBLE BETA DECAY WITH GERDA & LEGEND

THE GERDA & LEGEND EXPERIMENTS

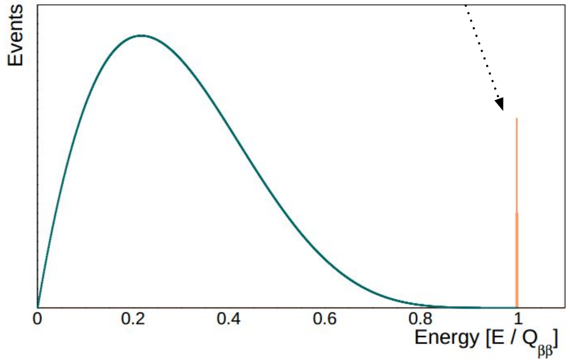
SEARCH FOR 0νββ DECAY IN HIGH-PURITY GERMANIUM (HPGe) DETECTORS

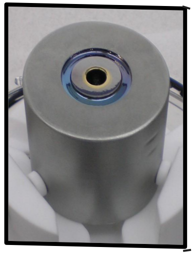
NEUTRINOLESS DOUBLE BETA DECAY (0νββ):

- $^{76}Ge \rightarrow {}^{76}Se + 2e^{-}$ **$T_{1/2} > 10^{26}$ yr**

$Q_{\beta\beta}$ ENERGY: 2039 keV

ENERGY RESOLUTION OF ~0.1% FWHM AT 0νββ: PEAK IS CLEARLY DISTINCT FROM CONTINUOUS SPECTRUM





(*)HPGe FWHM: <2.5 keV at $Q_{\beta\beta}$.

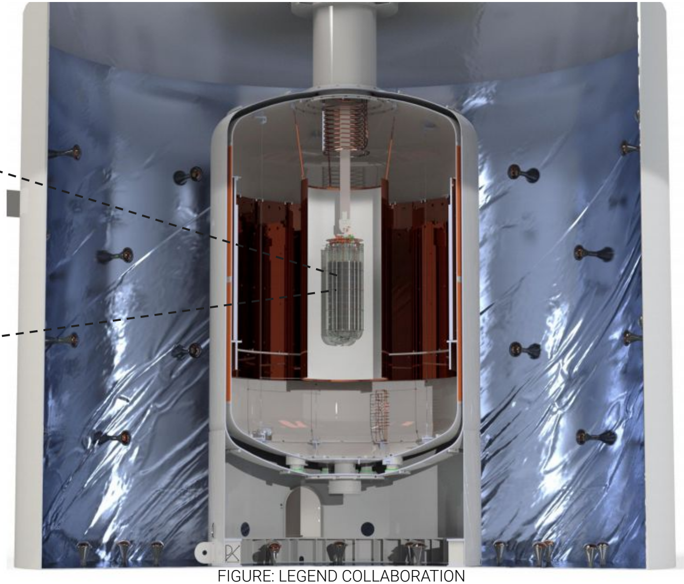
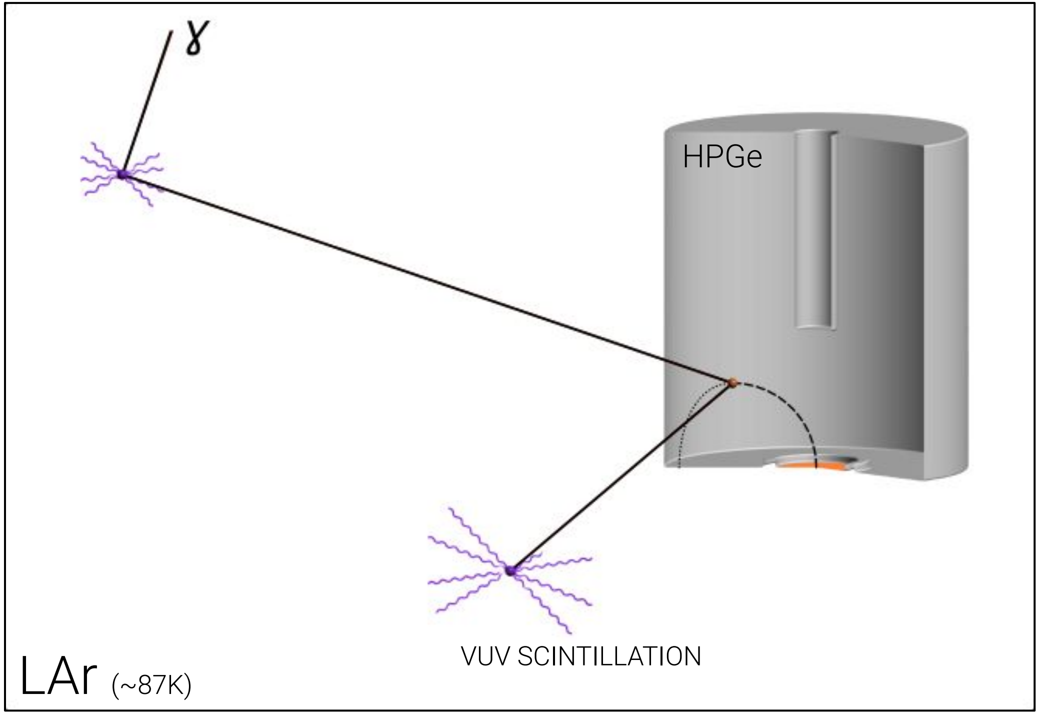


FIGURE: LEGEND COLLABORATION

HPGe DETECTORS OFFER THE EXCELLENT ENERGY RESOLUTION(*) & EFFICIENCY NEEDED TO GUARANTEE HIGH SENSITIVITY TO THIS **RARE PROCESS.** PASSIVE & ACTIVE **BACKGROUND SUPPRESSION** FURTHER ENHANCES THE SENSITIVITY.

THE GERMANIUM DETECTORS ARE OPERATED IN LIQUID ARGON (LAr)

LAr SERVES AS A COOLANT, PASSIVE SHIELD AND ACTIVE VETO.



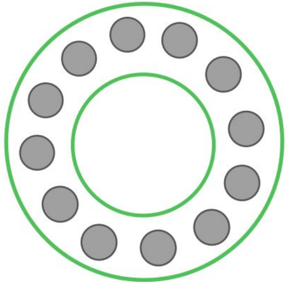
LAr SCINTILLATES IN RESPONSE TO BACKGROUND EVENTS, WHILE $0\nu\beta\beta$ DECAYS ARE FULLY CONTAINED WITHIN THE CRYSTAL & HAVE A SINGLE-SITE TOPOLOGY.

LAr INSTRUMENTATION OF THE GERDA/LEGEND EXPERIMENTS

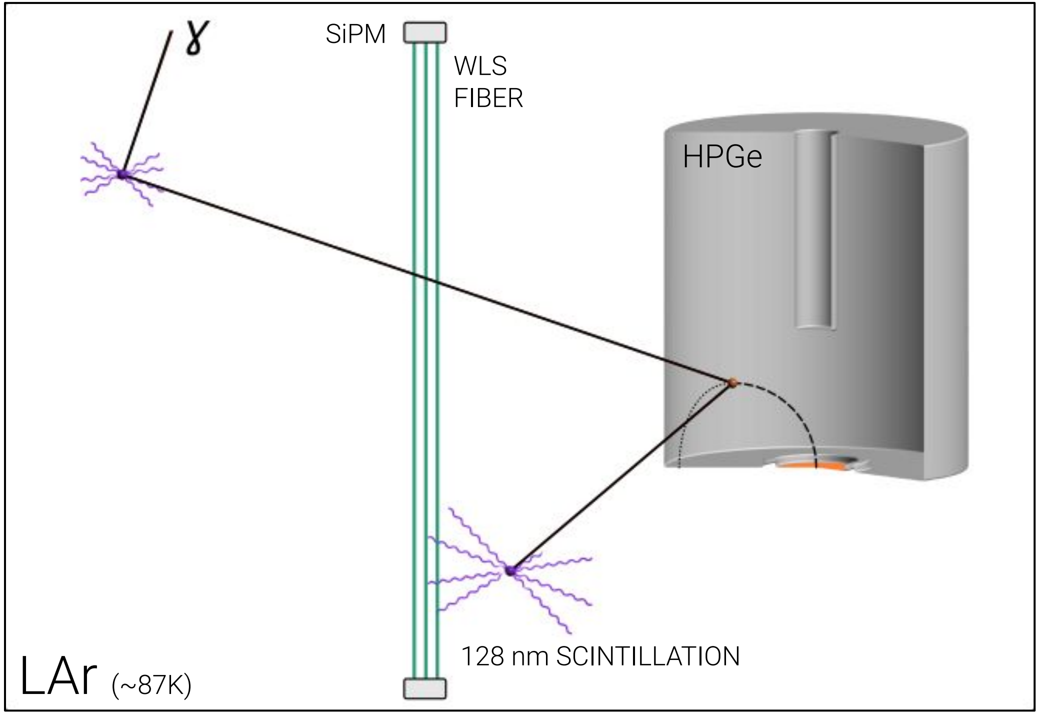
TO COLLECT THIS SCINTILLATION, WAVELENGTH-SHIFTING (WLS) FIBERS SURROUND THE DETECTORS.

P. KRAUSE

HPGe CRYSTAL ARRAY SURROUNDED BY FIBERS



SCHEMATIC SECTION (TOP VIEW)



THIS SYSTEM IS THE CORE OF THE **LAr INSTRUMENTATION** USED TO **VETO BACKGROUND** EVENTS.

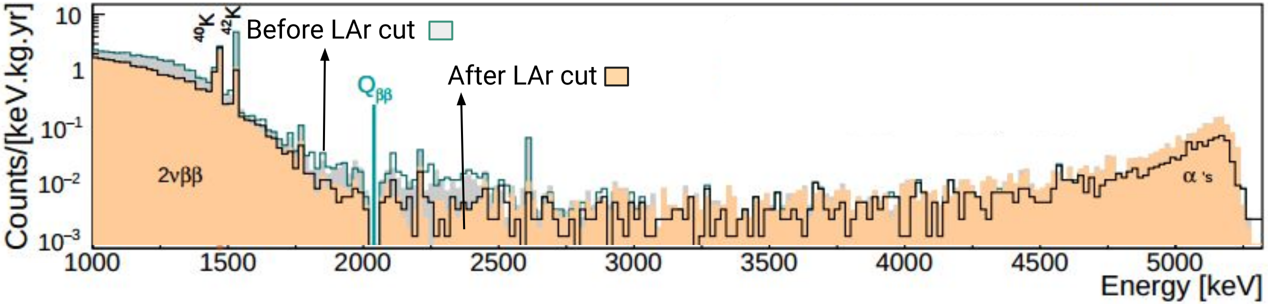
GERDA: THE FIRST EXPERIMENT TO OPERATE HPGe IN AN ACTIVE LAr VETO

THE LAr VETO IN GERDA WAS KEY TO GUARANTEEING ITS BACKGROUND-FREE STATE

P. KRAUSE

IF THE **FIBERS** READOUT A SIGNAL, **THE EVENT IS TAGGED** (**LAr CUT**).

Spectra before and after LAr veto cut, pre- and post-upgrade, and before unblinding the ROI around $Q_{\beta\beta}$.



The LAr cut suppresses ~80% of events around ^{42}K line (**which often involve energy deposition in Argon**).

GERDA: THE FIRST EXPERIMENT TO OPERATE HPGe IN ACTIVE LAr VETO

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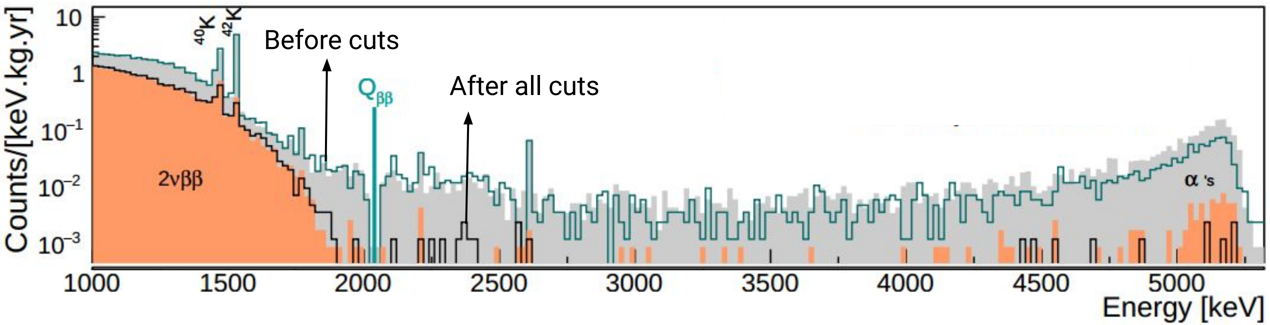
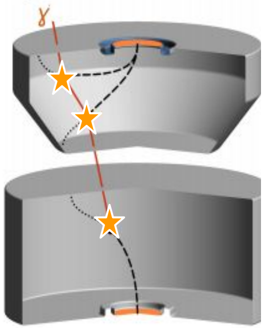


The LAr cut suppresses ~80% of events around ^{42}K line (which usually involves energy deposition in Argon). **Combining it with other multiscatter cuts, the background suppression in the ROI is ~ 20x**.

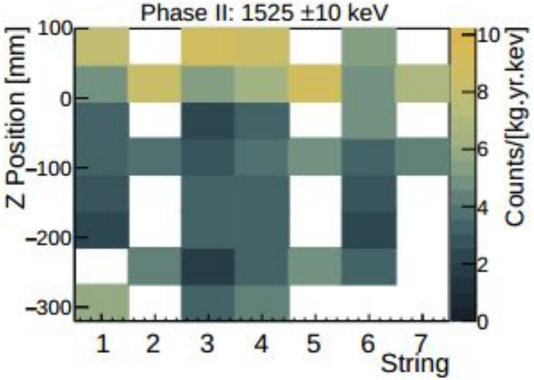


EVENTS DEPOSITING ENERGY IN **MULTIPLE DETECTORS AND SITES** CAN BE FURTHER DETECTED

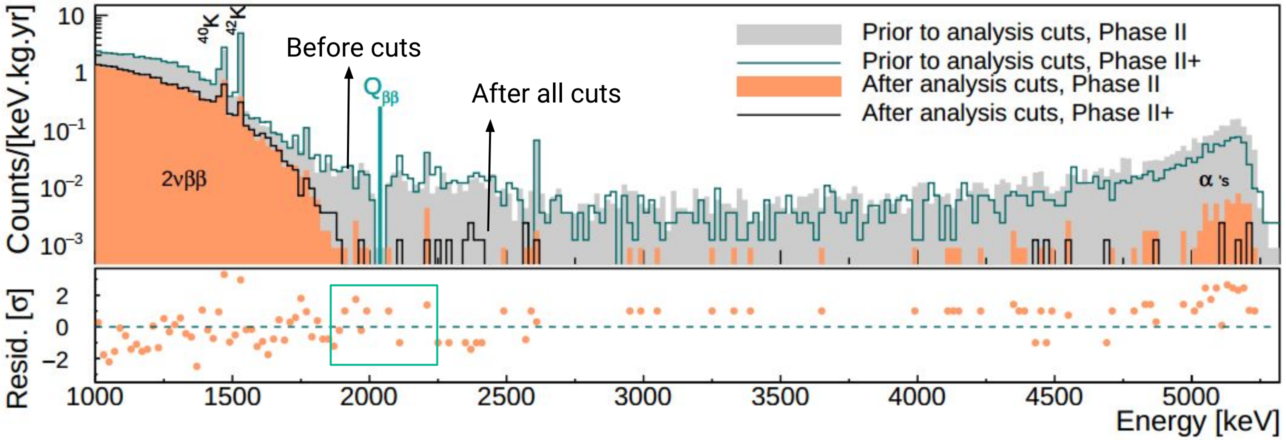
MY CONTRIBUTIONS TO GERDA

CHARACTERIZATION OF BACKGROUND IN GERDA'S FINAL DATASET

Detector Count rates around ^{42}K line



Spectra before and after analysis cuts, pre- and post-upgrade, and before unblinding the ROI around $Q_{\beta\beta}$.



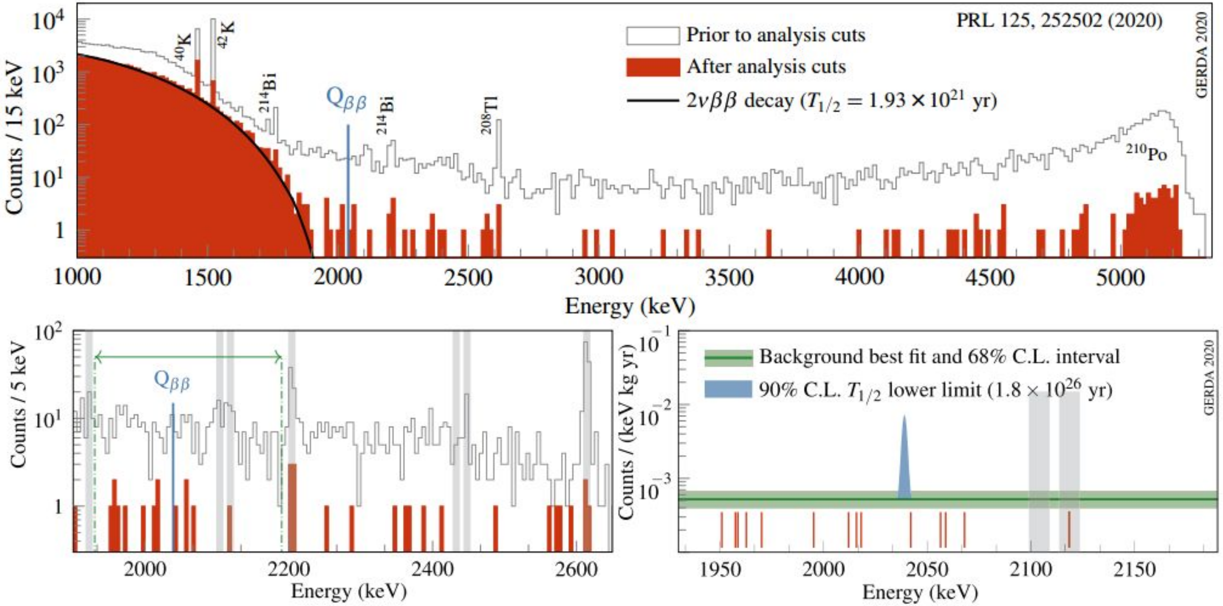
OVERALL AGREEMENT IN EVENT RATES PRE- AND POST-UPGRADE AROUND THE ROI AFTER ANALYSIS CUTS.

THE LEGACY OF GERDA

GERDA'S FINAL RESULTS

GERDA STOPPED DATA TAKING IN NOV. 2019, ACCUMULATING OVER 100 kg.yr OF EXPOSURE.

Final results of GERDA on the search for neutrinoless double-β decay. PRL, 125:252502, 2020. *Editor's suggestion*



NO SIGNAL HYPOTHESIS IS FAVORED:
GERDA SET THE (BACK THEN*) **WORLD'S BEST LIMIT ON** THE HALF-LIFE OF $0\nu\beta\beta$:
$\mathbf{T_{1/2} \gtrsim 1.8x10^{26}}$ **yr** (90% C.L.)

& **THE LOWEST BACKGROUND IN THE FIELD**: 5.2 $\times10^{-4}$cts/(keV.kg.yr)

(*) Now surpassed by KamLAND-Zen ($T_{1/2} \gtrsim 2.3x10^{26}$ yr), obtained with a much larger exposure.

THE LEGEND-200 EXPERIMENT

SEARCH FOR 0νββ DECAY WITH 200 kg of HIGH-PURITY GERMANIUM (HPGe) DETECTORS, TARGETING $T_{1/2}>10^{27}$ yr

NEUTRINOLESS DOUBLE BETA DECAY (0νββ):

- $^{76}Ge \rightarrow {}^{76}Se + 2e^-$ $Q_{\beta\beta}$ ENERGY: 2039 keV

LEGEND EXPECTS TO MEASURE **≲1 DECAY PER YEAR IN 10^{27} ATOMS.**

TO GUARANTEE THE TARGET SENSITIVITY, WE NEED **LOW BACKGROUND** (2-3X LOWER THAN IN GERDA).

FOCUS HERE: **ENHANCE LAr VETO** LIGHT COLLECTION **EFFICIENCY.**

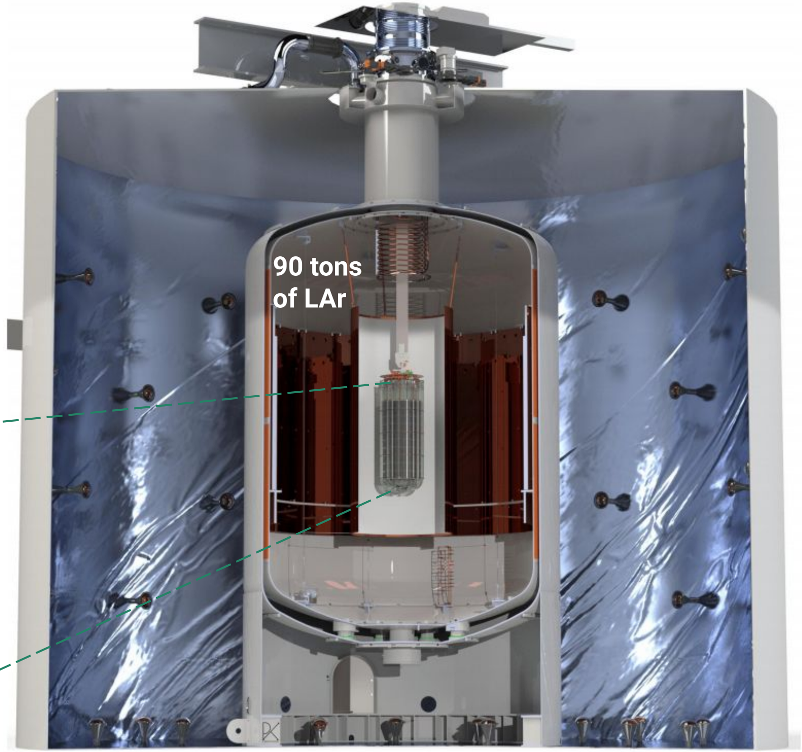
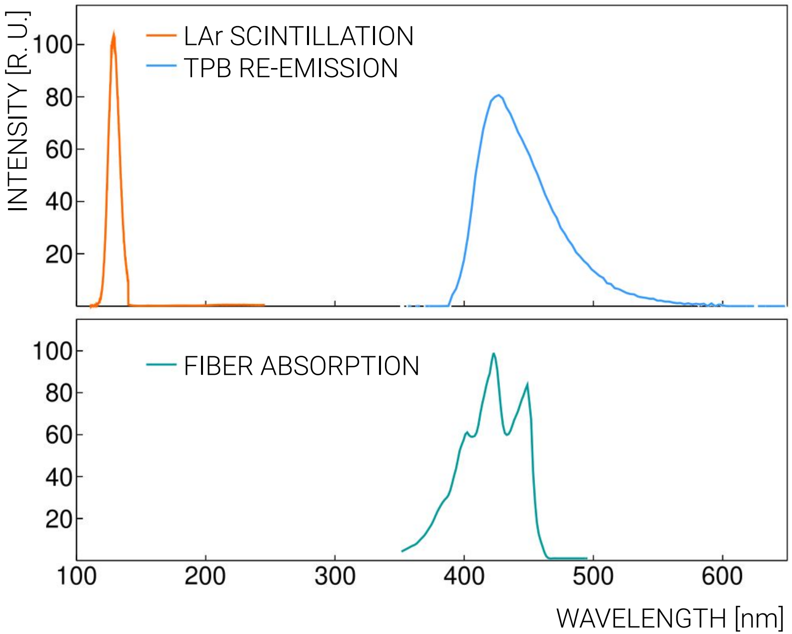
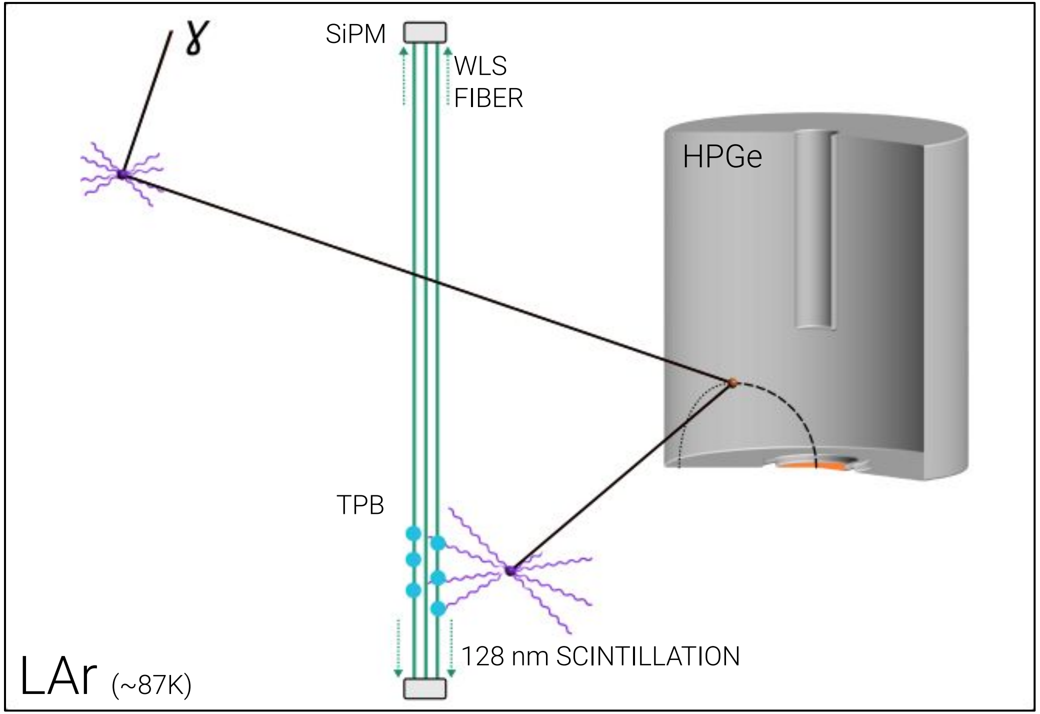


FIGURE: LEGEND COLLABORATION

LAr INSTRUMENTATION OF THE LEGEND EXPERIMENT

LIQUID ARGON (LAr) SCINTILLATION PEAKS AT 128 nm. TPB[*], SHIFTS THIS LIGHT TO THE BLUE.

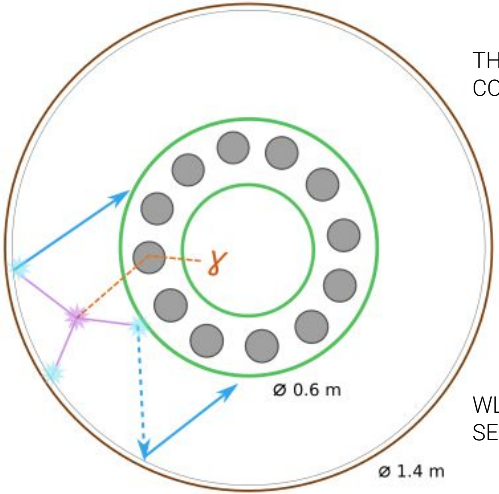




BLUE LIGHT CAN BE COLLECTED BY THE FIBERS AND GUIDED TO SiPMs. **BUT SOME OF THE LIGHT DOES NOT GO DIRECTLY TOWARDS THE FIBERS.**

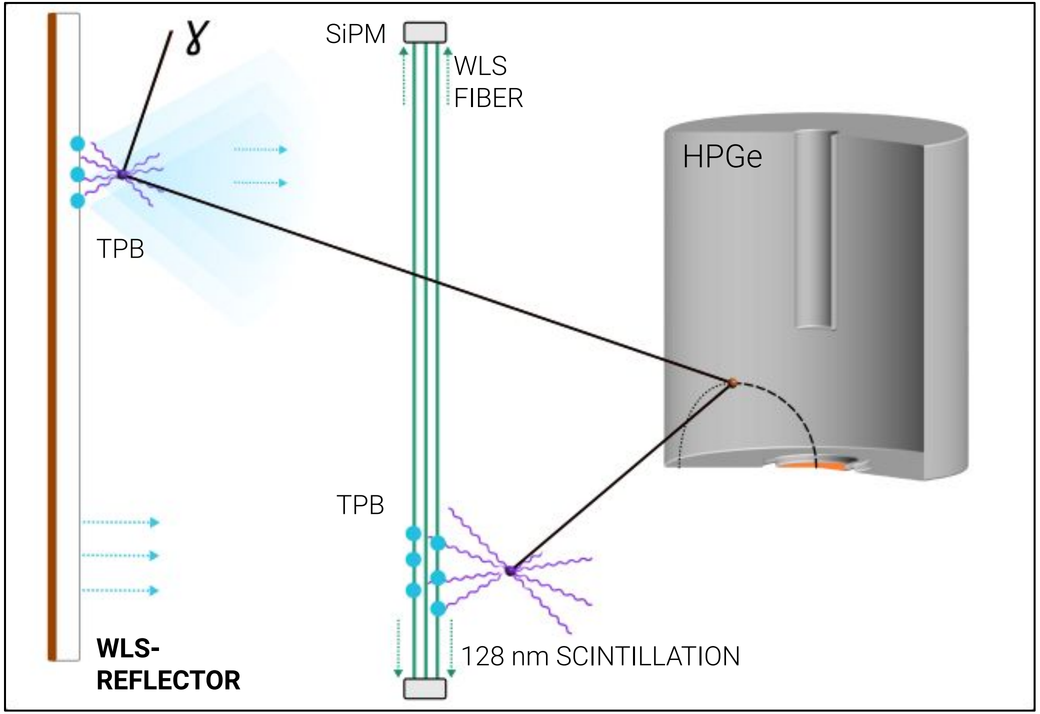
[*] TETRAPHENYLBUTADIENE

TO INCREASE LIGHT COLLECTION, WAVELENGTH-SHIFTING (WLS) REFLECTORS SURROUND THE FIBERS.



THE REFLECTOR IS ALSO COATED WITH TPB.

WLS-REFLECTOR SCHEMATIC SECTION

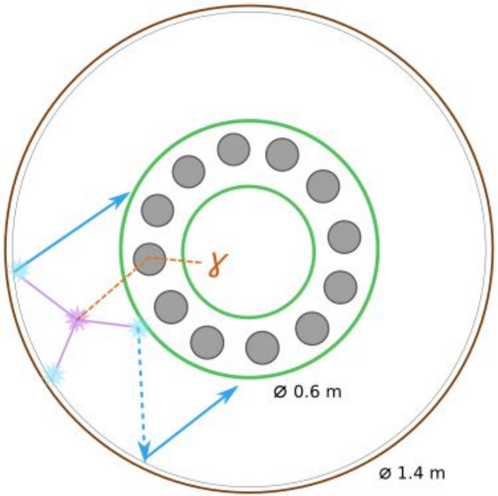


THE **WLS-REFLECTORS** HELP IN DETECTING **γ-SCATTERS** A BIT FURTHER AWAY FROM THE FIBERS AND RECOVERS LIGHT NOT YET COLLECTED BY THEM.

[*] TETRAPHENYLBUTADIENE

MY CONTRIBUTIONS TO LEGEND

R&D, CONSTRUCTION AND CHARACTERIZATION OF LEGEND'S WLS-REFLECTORS (WLSR)*.



WLSR

R&D STAGE, MATERIAL SELECTION — 2019-20

CONSTRUCTION STAGE, WLS COATING — 2020

CHARACTERIZATION IN-SITU COATED & PEN-BASED WLS-REFLECTOR — 2021-22

FIGURE: LEGEND COLLABORATION

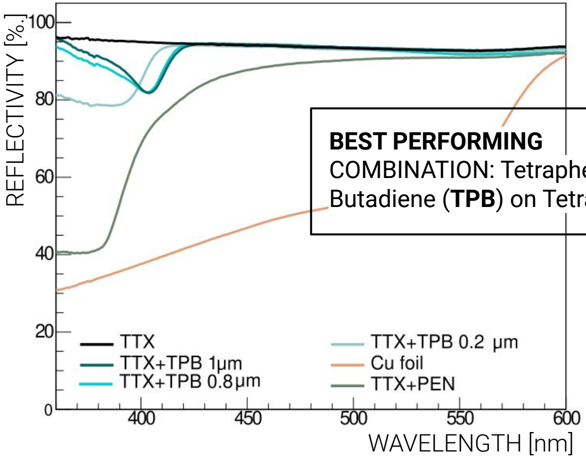
(*) Work performed in collaboration with other scientists from LEGEND & a MSc. student.

MY CONTRIBUTIONS TO LEGEND: R&D STAGE

OPTICAL MEASUREMENTS TO DETERMINE THE BEST REFLECTOR & WAVELENGTH SHIFTER (WLS)

IMAGE BY P. KRAUSE

HIGHLY - REFLECTIVE & EFFICIENT



BEST PERFORMING COMBINATION: Tetraphenyl Butadiene (**TPB**) on Tetratex (**TTX**)

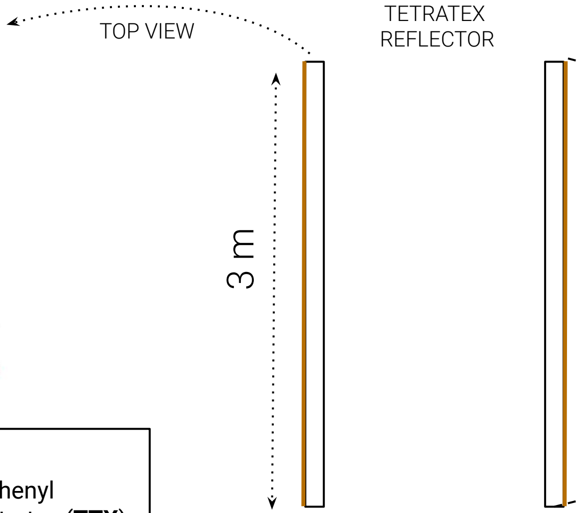


FIGURE: LEGEND COLLABORATION

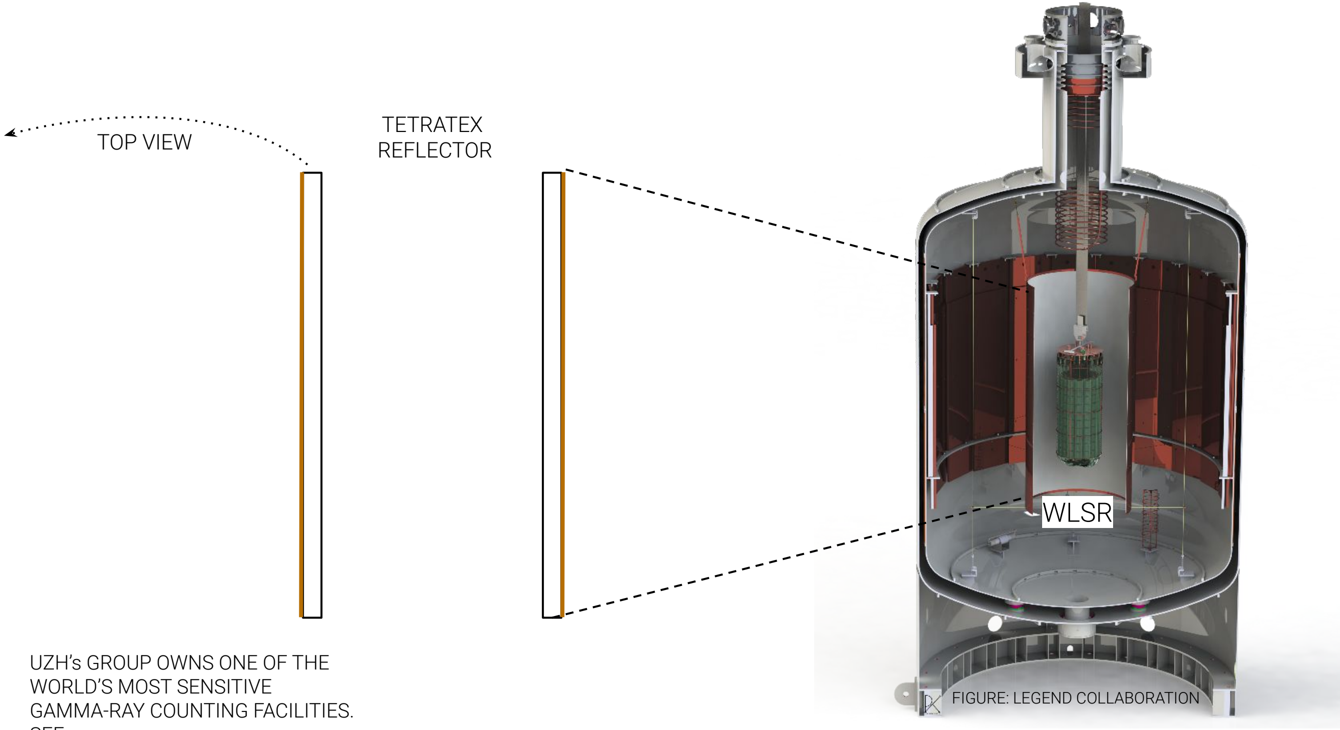
R&D OF WLSR. G ARAUJO ET AL, EPJ. C, 2022

1: SELECTION OF WLSR MATERIALS FOR LEGEND. 2: **INFORMATIVE FOR THE DESIGN OF WLSR FOR ANY LAr BASED DETECTOR**

MY CONTRIBUTIONS TO LEGEND: R&D STAGE, MATERIAL SELECTION

RADIOPURITY MEASUREMENTS: REFLECTOR FULFILLED LEGEND's REQUIREMENTS

- ☑ HIGHLY - REFLECTIVE
- ☑ LOW OUTGASSING
- ☑ **RADIOPURE**



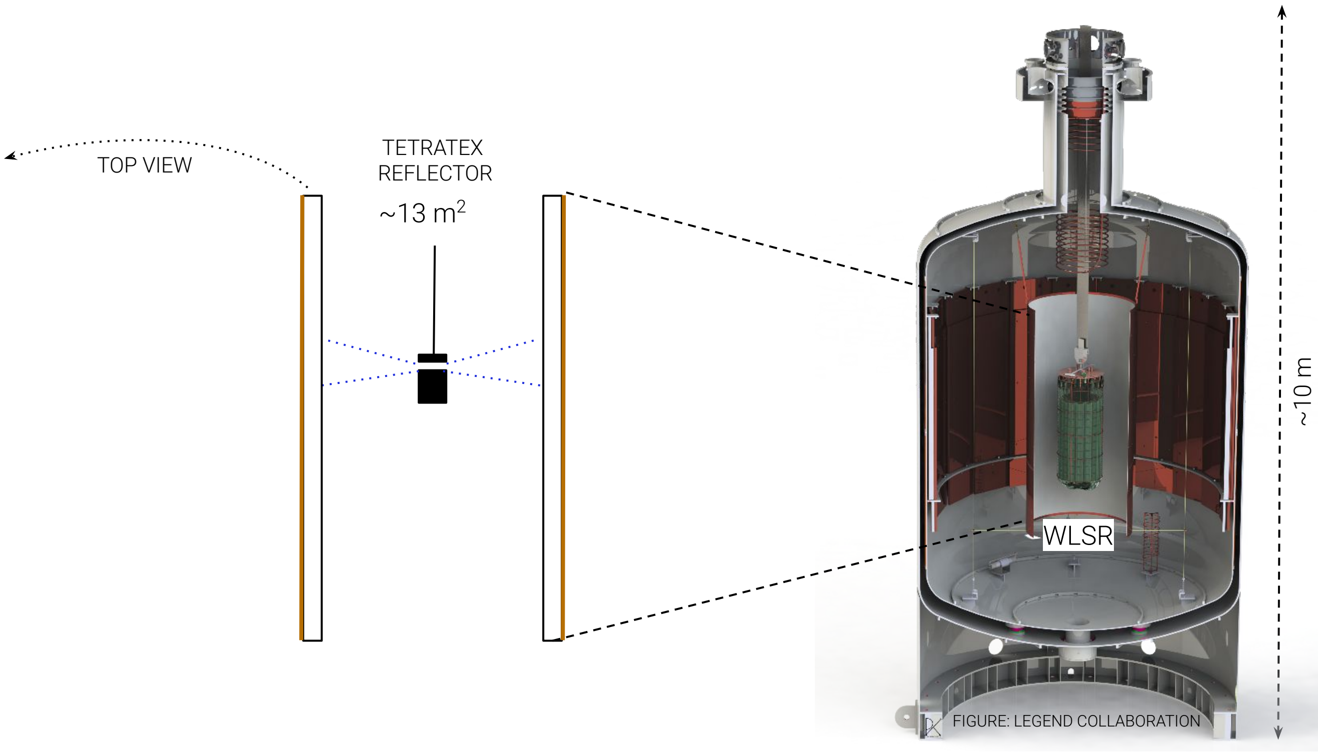
UZH's GROUP OWNS ONE OF THE WORLD'S MOST SENSITIVE GAMMA-RAY COUNTING FACILITIES. SEE:

THE (...) COUNTING FACILITY GATOR.
G ARAUJO ET AL, JINST 2022)

1: SELECTION OF WLSR MATERIALS.
2: **INPUTS FOR LEGEND'S BACKGROUND SIMULATION**.

MY CONTRIBUTIONS TO LEGEND: CONSTRUCTION STAGE

NEXT LAYER: TPB COATING



TPB VACUUM EVAPORATION OF SUCH A LARGE SURFACE WAS **PERFORMED INSIDE THE CRYOSTAT** AT 10^{-5} mbar.

MY CONTRIBUTIONS TO LEGEND: CONSTRUCTION STAGE

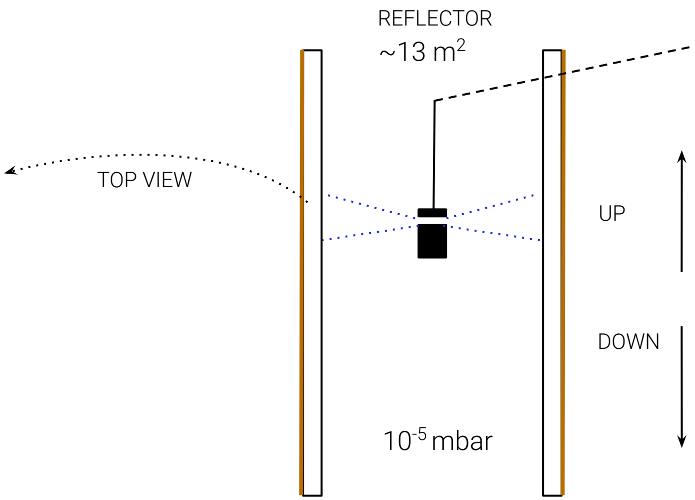
DESIGN & CONSTRUCTION OF A SYSTEM TO MOVE THE WAVELENGTH SHIFTER (WLS) EVAPORATOR

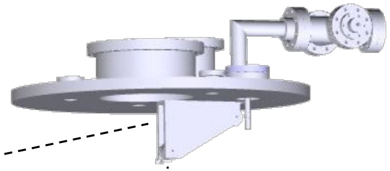
IMAGE BY P. KRAUSE

REFLECTOR BEFORE WLS EVAPORATION

THE EVAPORATION WAS SUCCESSFUL:

FLUORESCENT REFLECTOR AFTER WLS EVAPORATION





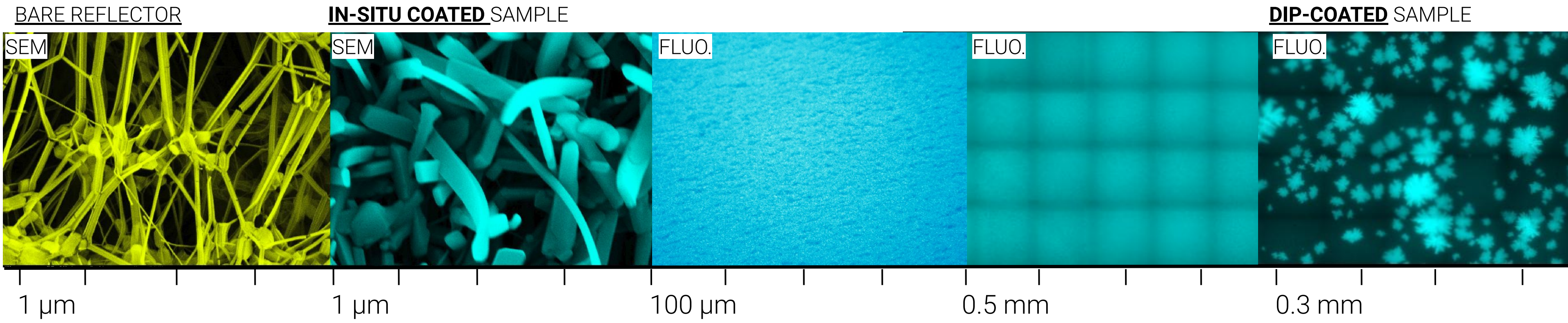
CRYOSTAT NECK

SOFTWARE-CONTROLLED SYSTEM PULLS THE EVAPORATOR IN VACUUM, ALONG ~10m INSIDE THE CRYOSTAT

1: CONSTRUCTION OF EFFICIENT WLSR THAT ENHANCES LIGHT COLLECTION.
2: THE **LARGEST IN-SITU VACUUM EVAPORATION OF THE WIDELY USED WAVELENGTH SHIFTER TPB**.

MY CONTRIBUTIONS TO LEGEND: WLSR CHARACTERIZATION

MICROSCOPY MEASUREMENTS SHOW HIGH HOMOGENEITY ACHIEVED BY SUCCESSFUL IN-SITU COATING



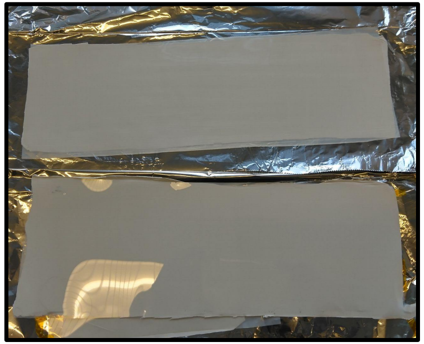
TPB COVERS WELL THE REFLECTOR

SEM: SCANNING ELECTRON MICROSCOPY. FLUO.: FLUORESCENCE MICROSCOPY

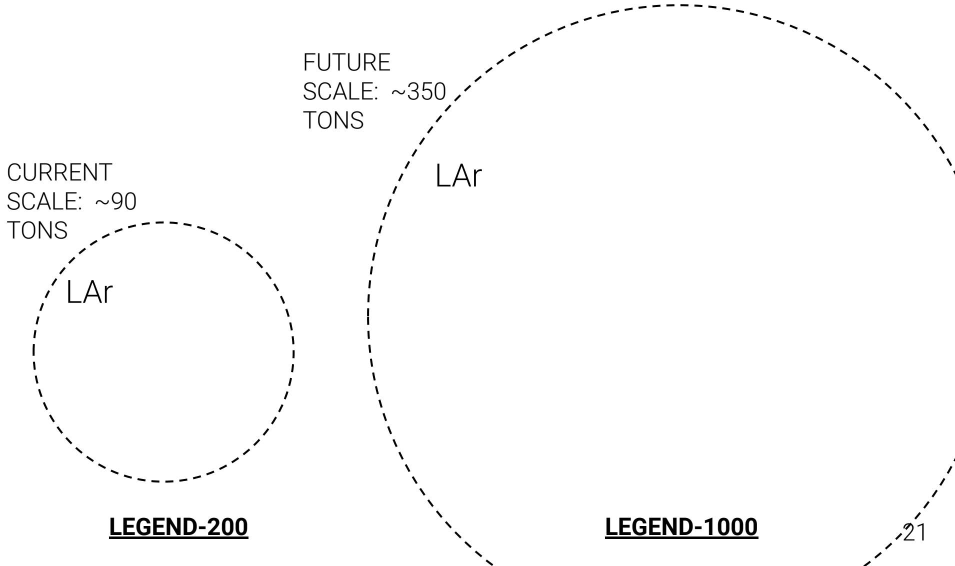
R&D OF WLSR.
G ARAUJO ET AL,
EPJ. C, 2022)

MY CONTRIBUTIONS TO LEGEND: WLS-REFLECTOR CHARACTERIZATION

TESTING LEGEND’S WLS-REFLECTOR IN LAr & SCALABLE OPTIONS FOR FUTURE LARGER EXPERIMENTS



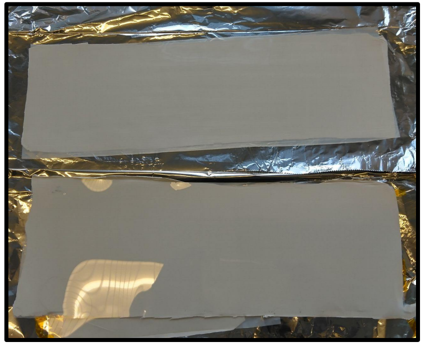
POSSIBLY MORE SCALABLE **MATERIAL FOR FUTURE EXPERIMENTS: PEN** (POLYETHYLENE NAPHTHALATE)*

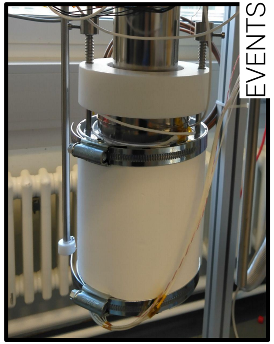


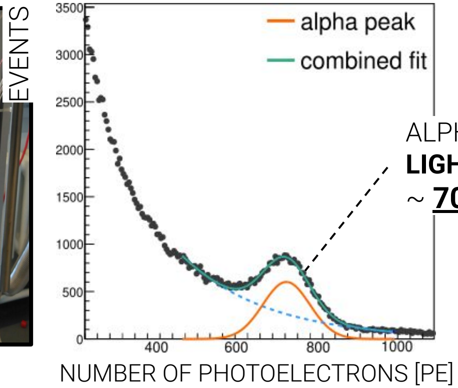
MY CONTRIBUTIONS TO LEGEND: WLS-REFLECTOR CHARACTERIZATION

MEASUREMENT OF WLS-REFLECTORS IN RESPONSE TO LAr SCINTILLATION INDUCED BY ALPHA PARTICLES.

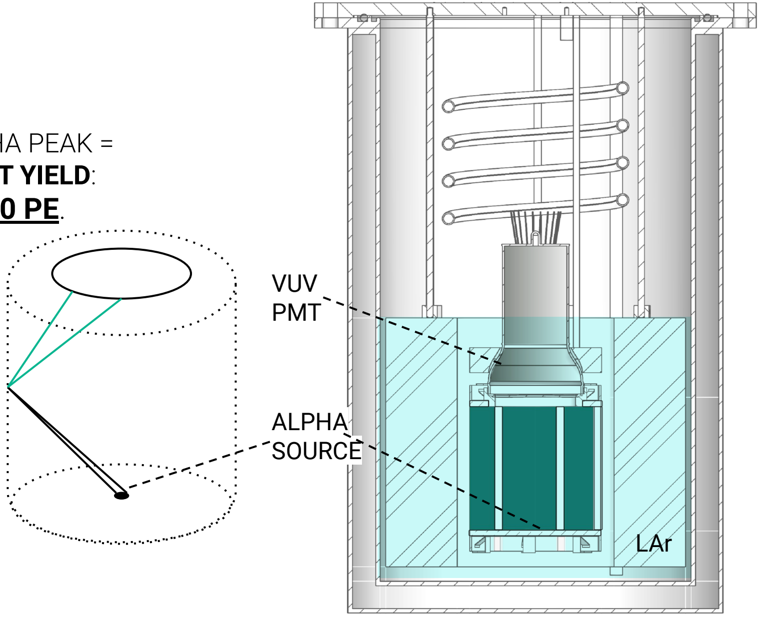
12 SAMPLES: IN-SITU EVAPORATED LEGEND-200 SAMPLE &,PEN-BASED LEGEND-1000 CANDIDATES, WITH VARIOUS THICKNESSES, GRADES, SURFACE TREATMENTS & REFLECTORS (TETRATEX, TYVEK, ESR, ALUMINUM)







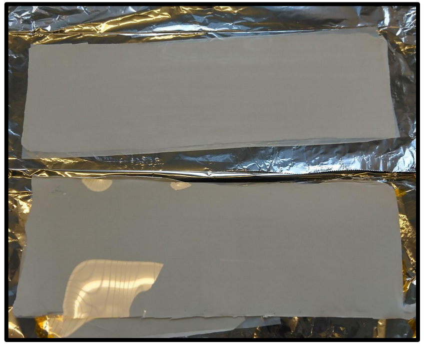
ALPHA PEAK = **LIGHT YIELD**: ~ **700 PE**.

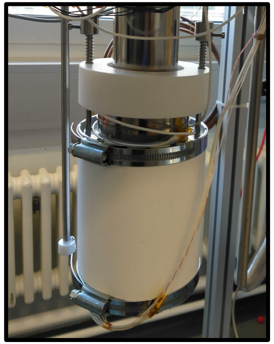


THE MORE EFFICIENT A SAMPLES IS IN SHIFTING LAr LIGHT AND REFLECTING BLUE LIGHT, **THE LARGER THE LIGHT YIELD** (NUMBER OF PHOTOELECTRONS, PE).

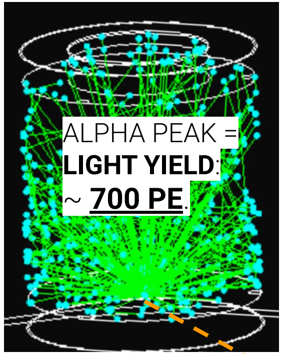
MY CONTRIBUTIONS TO LEGEND: WLSR CHARACTERIZATION

SIMULATIONS OF THE EFFICIENCY OF WLS-REFLECTORS IN LIQUID ARGON (LAr)

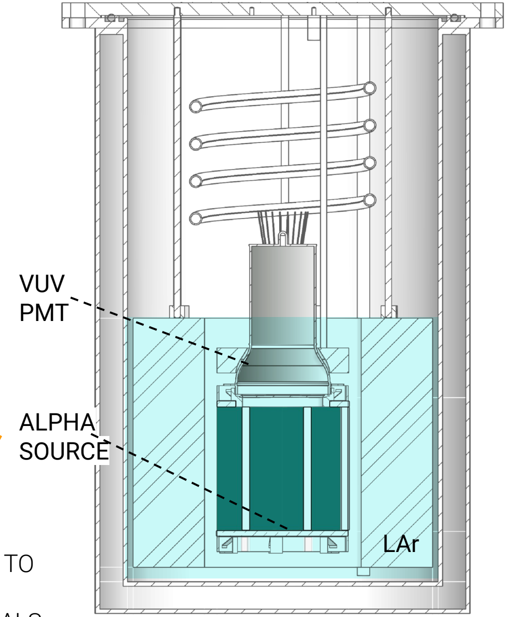




REFERENCE ABSORBER



GEANT4 SIMULATIONS



R&D OF WLSR.
G ARAUJO ET AL, EPJ. C, 2022)

1: CHARACTERIZATION OF WLSR FOR LEGEND-200 & FUTURE LAr-SCINTILLATION DETECTION SYSTEMS. 2: INPUTS FOR LEGEND'S OPTICAL SIMULATIONS. **3. FIRST MEASUREMENTS OF THE QE* OF TPB AND PEN IN LAr.**

USE OF AN ABSORBER (& SIMULATIONS) TO EXTRACT THE SYSTEM'S LIGHT YIELD & QUANTUM EFFICIENCY (***QE**) OF MATERIALS.

LEGEND TIMELINE

FROM CONSTRUCTION TO PHYSICS DATA TAKING & FIRST RESULTS

2020-2022 — **CONSTRUCTION STAGE**: INCLUDING R&D & CONSTRUCTION OF WLSR

2022-2023 — **COMMISSIONING** OF DETECTORS, LAr AND CALIBRATION SYSTEMS.

03.2023 — **START OF DATA TAKING** WITH 142 kg OF HPGe DETECTORS

09.2023 — **FIRST RESULTS** RELEASED IN TAUP.

06.2024 — **NEW RESULTS** 50 kg.yr COMING NOW IN NEUTRINO 2024

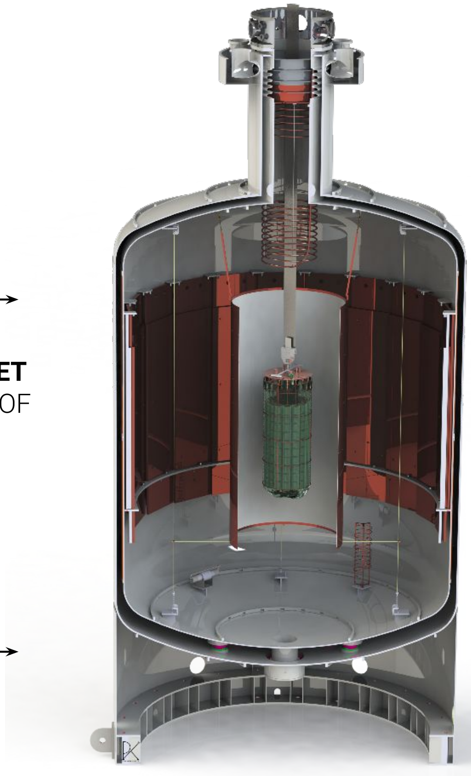
~2029 — **REACH TARGET SENSITIVITY** OF $T_{1/2}>10^{27}$ yr

IN PARALLEL: **R&D FOR LEGEND-1000**

2020-2021 — **FIRST WLSR MEASUREMENTS** FOR L-1000

07.2021 — **PRE CONCEPTUAL DESIGN** (arxiv: 2107.11462)

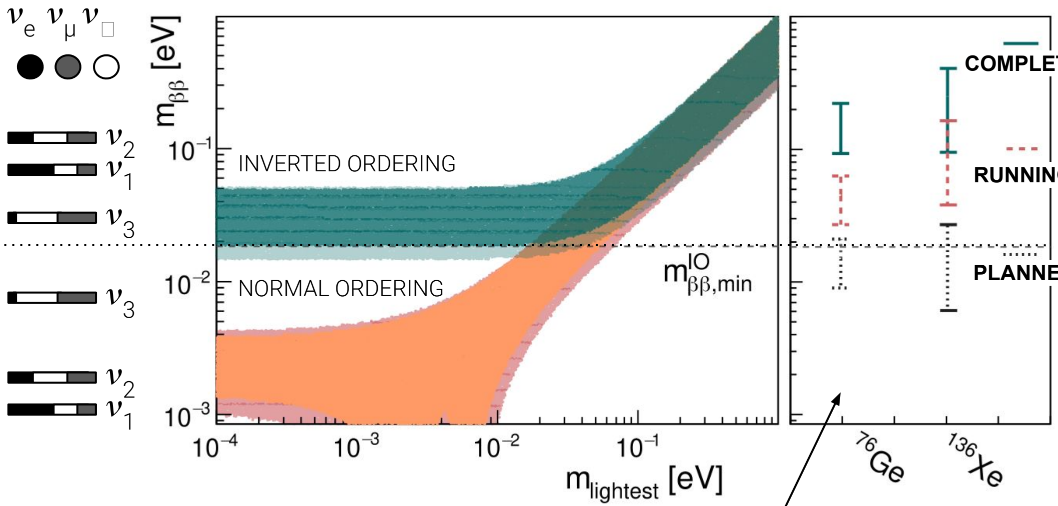
CURRENTLY — **ONGOING at UZH:** R&D of WLSR, calibration system & sources



THE FUTURE OF 0νββ-DECAY SEARCH

PROBING NEUTRINO MASS ORDERING VIA THE EFFECTIVE MAJORANA MASS ($m_{\beta\beta}$)

THESE MASS ORDERINGS CAN BE PROBED BY 0νββ-DECAY SEARCHES IF NEUTRINOS ARE MAJORANA PARTICLES*.



GERDA: $T_{1/2} \gtrsim 1.8 \times 10^{26}$ yr (90% C.L.), $|m_{\beta\beta}| \lesssim$ 79-180 meV
KamLand-Zen (^{136}Xe): $T_{1/2} \gtrsim > 2.3 \times 10^{26}$ yr (90% C.L.), $|m_{\beta\beta}| \lesssim$ 38–164 meV (CURRENT BEST LIMITS! PRL 130, 05180)

LEGEND-200: $T_{1/2} \gtrsim 10^{27}$ yr (99.7% C.L.), $|m_{\beta\beta}| \lesssim$ 33-71 meV

LEGEND-1000#: $T_{1/2} \gtrsim 10^{28}$ yr (99.7% C.L.), $|m_{\beta\beta}| \lesssim$ 10-20 meV

NEXT GENERATION OF EXPERIMENTS MAY FULLY COVER INVERTED ORDERING REGION.

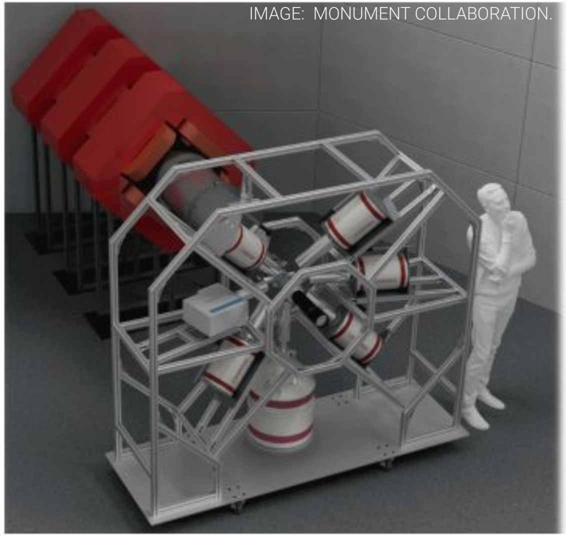
SENSITIVITY TO $m_{\beta\beta}$ HAS LARGE THEORETICAL UNCERTAINTIES.

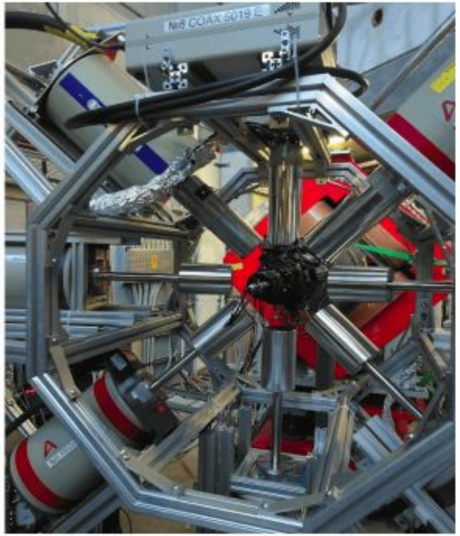
*AND IF THE DECAY MECHANISM IS OF LIGHT NEUTRINO EXCHANGE.

[#] For 10yr exposure and BI of ~ 1×10^{-5} cts / (keV kg yr)
ps: only a few of the results and projections are shown here.

DECREASING NEUTRINOLESS DOUBLE BETA DECAY NUCLEAR MATRIX ELEMENTS ($M^{0\nu}$) UNCERTAINTIES WITH MONUMENT

IMAGE: MONUMENT COLLABORATION.





$$[T^{0\nu}_{1/2}]^{-1} \propto |M^{0\nu}|^2 m^2_{\beta\beta}$$

AT PSI, in collaboration with other CHIPP members

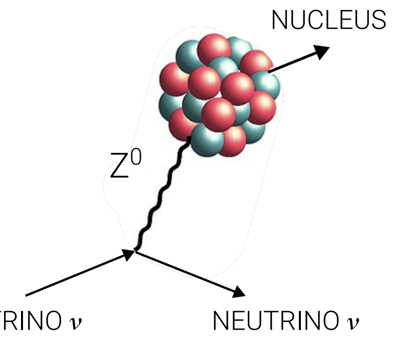
PSI

A NOVEL CONCEPT FOR THE DETECTION OF NEUTRINOS: PALEOCCENE

PALEOCCENE TARGETS REACTOR CEνNS DETECTION

LOW-ENERGY THRESHOLDS ARE REQUIRED TO DETECT CEνNS , ESPECIALLY FOR NUCLEAR REACTOR NEUTRINOS (ν)

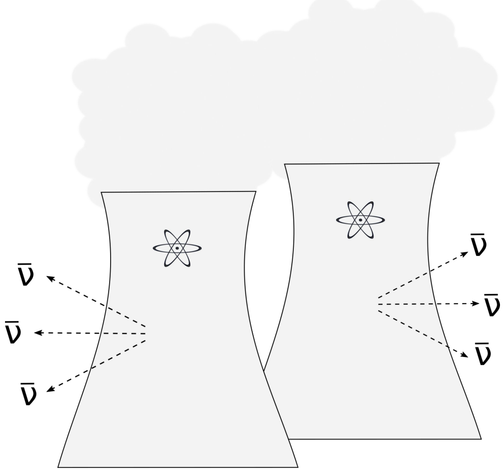
CEνNS: COHERENT ELASTIC
ν-NUCLEUS SCATTERING



Science, Aug 2017, Vol 357

1ST CEνNS DETECTION:
$E_\nu \lesssim$ 50 MeV,
~5 KeV threshold

CEνNS FROM REACTOR νs :



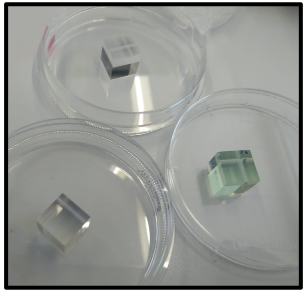
NOT YET DETECTED
$E_\nu \lesssim$ 8 MeV.
E_{NR}~10-100 eV threshold

THE PALEOCCENE CONCEPT

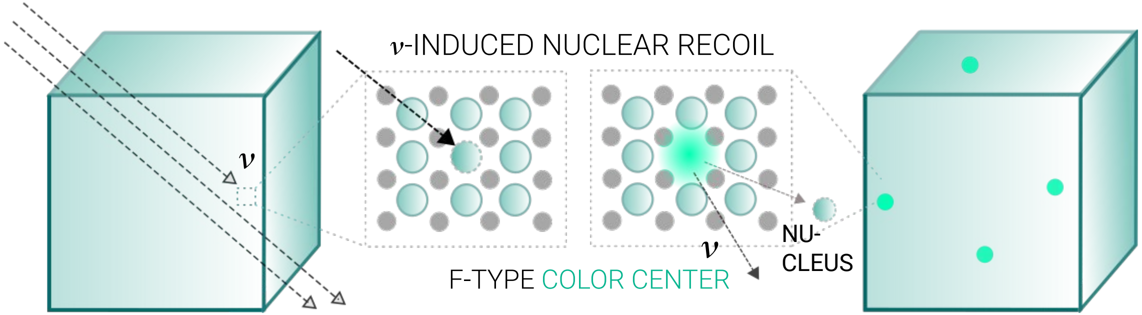
PASSIVE DETECTION OF LOW-ENERGY NUCLEAR RECOILS VIA OPTICAL COLOR CENTERS

B. Cogswell, A. Goel, P. Huber. PRA 16 (2021)

TRANSPARENT CRYSTALS



ANION DISPLACEMENT HAS A **LOW THRESHOLD**(*): SENSITIVITY TO LOW-ENERGY EVENTS

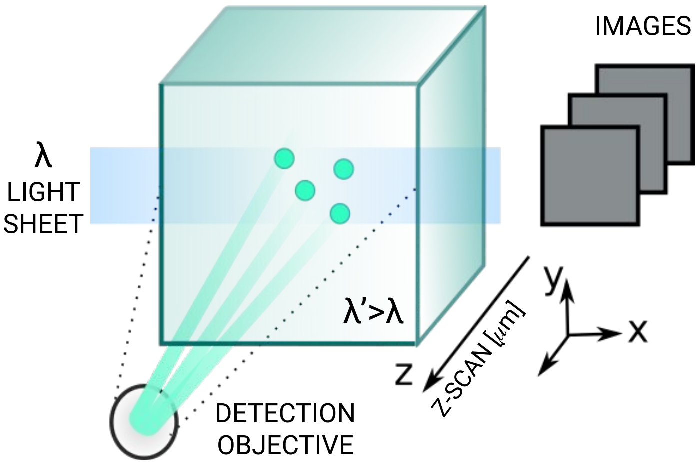


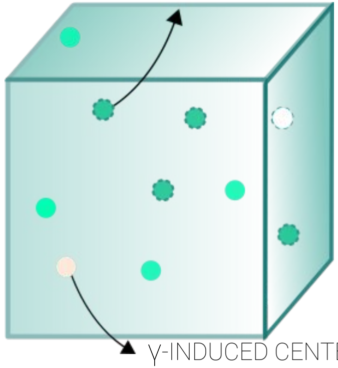
LOW-THRESHOLD DETECTORS COULD ENABLE THE **1ST CEνNS DETECTION.**

(*)STOPPING POWER FOR MOST IONS IS AROUND 20–100 eV/nm. ENERGY OF RECOILING NUCLEUS ~20–200 eV.

DESPITE THE **nm-SIZE OF DISLOCATIONS**, THESE SIGNALS CAN BE OBSERVED IN **OPTICAL WAVELENGTHS (~500 nm)**.

IMAGING COLOR CENTERS USING LIGHT-SHEET FLUORESCENCE MICROSCOPY

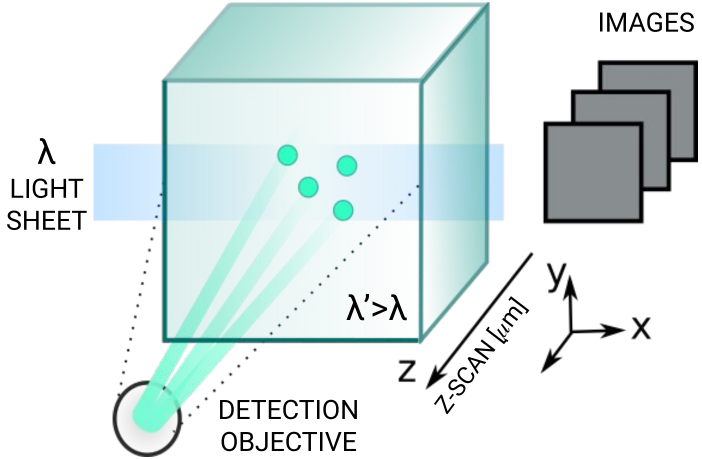




COLOR CENTERS ABSORB AND RE-EMIT LIGHT IN OPTICAL WAVELENGTHS, ENABLING A FAST READ-OUT.

TESTING THE PALEOCCENE CONCEPT

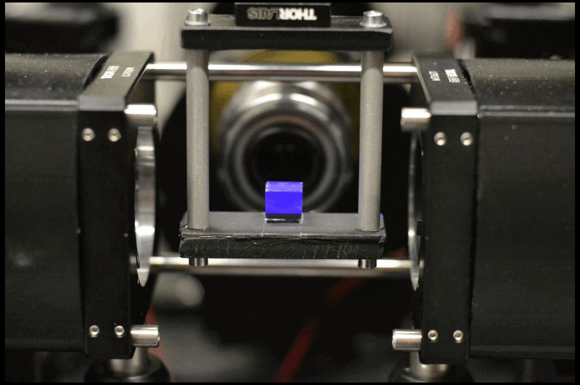
READOUT OF COLOR CENTERS WITH



Scan speed at ~ 4 μm XYZ resolution: <10min/cm^3

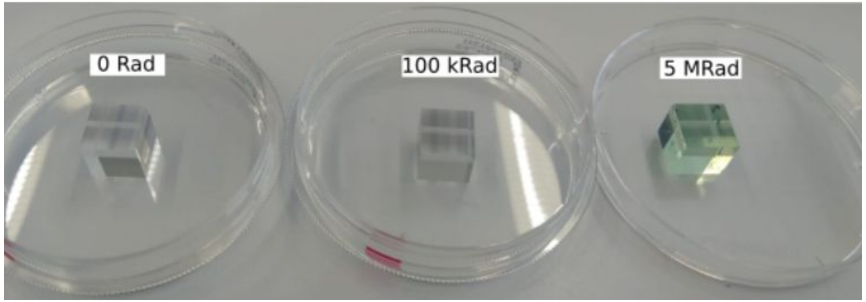
THE MESOSPIM

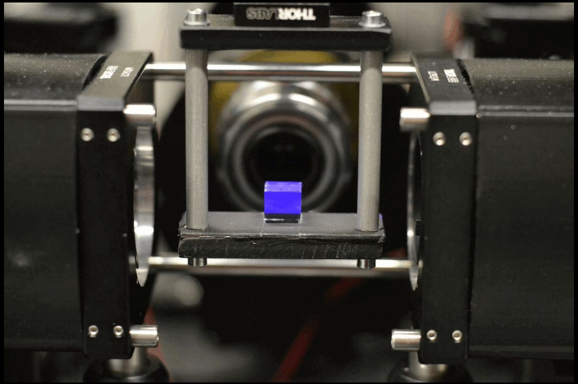
STATE-OF-THE-ART LIGHT-SHEET FLUORESCENCE MICROSCOPE **(LSFM)** THAT IMAGES CENTIMETER -SIZED SAMPLES WITHIN MINUTES.
Nature Communications (2024)



TO CREATE COLOR CENTERS, WE IRRADIATE CRYSTALS WITH γ-RAYS OR NEUTRONS

1 cm^3 **CaF_2, LiF and Sapphire transparent crystals** were **irradiated** and imaged in comparison to a **blank**.





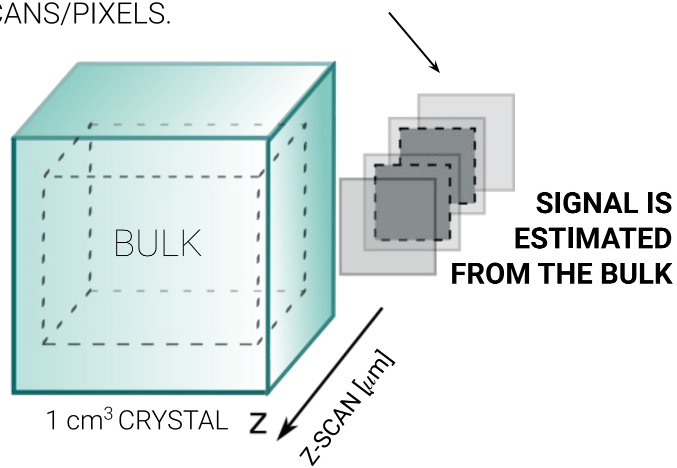
γ-RAY DOSES: from 100 Rad to 5 MRad*
(*~10^{10}-10^{14} ph/cm^2 from a ~1 MeV ^{60}Co source)

NEUTRON DOSES: ~10^8 n/cm^2
(100mCi AmBe source, shielded by lead)

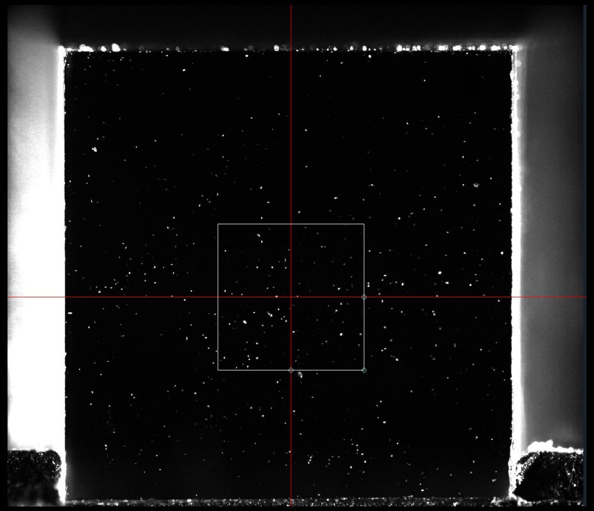
TESTING THE PALEOCCENE CONCEPT

ESTIMATING THE FLUORESCENCE SIGNAL FROM COLOR CENTERS

- SURFACE BACKGROUND IS AVOIDED BY DISCARDING SURFACE SCANS/PIXELS.



- CAMERA DARK COUNTS NOISE IS ESTIMATED IN DARK

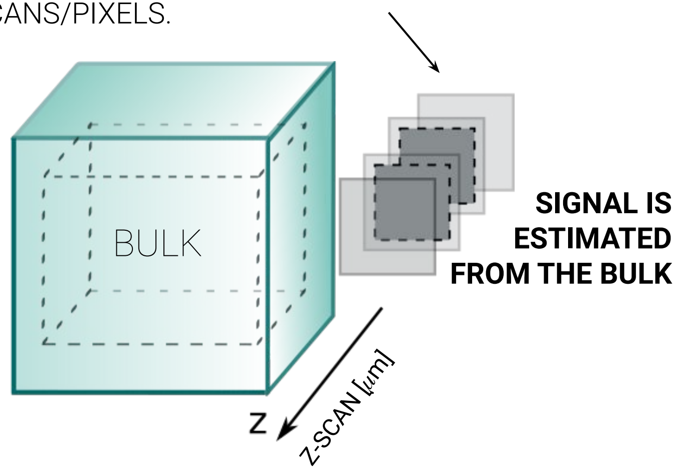


SURFACE IMPURITIES & SCRATCHES ARE FLUORESCENT **BACKGROUND**

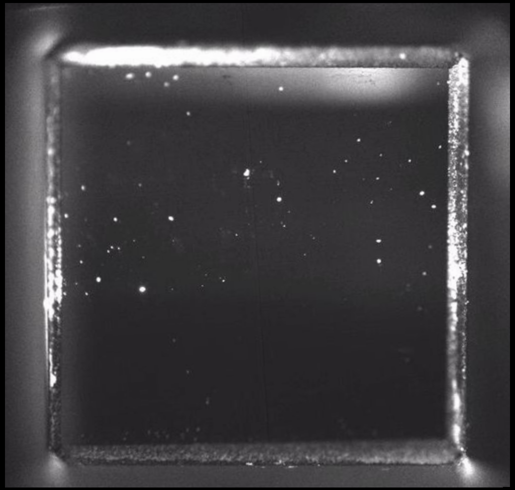
TESTING THE PALEOCCENE CONCEPT

ESTIMATING THE FLUORESCENCE SIGNAL FROM IRRADIATED CRYSTALS

- SURFACE BACKGROUND IS AVOIDED BY DISCARDING SURFACE SCANS/PIXELS.



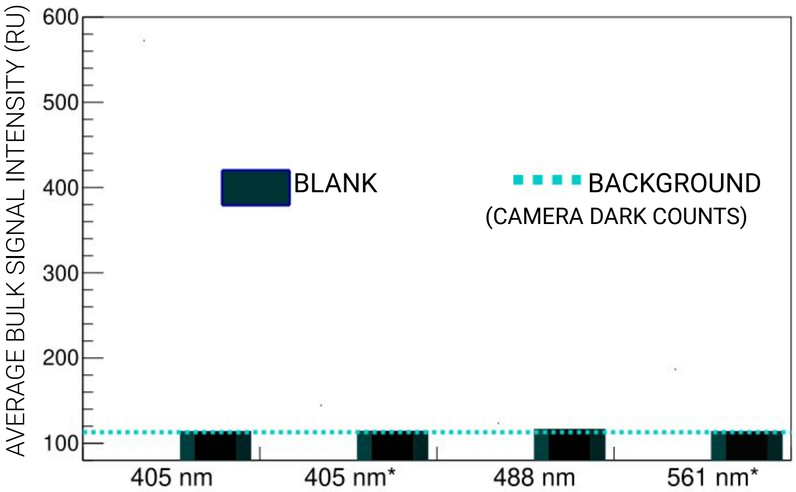
- CAMERA DARK COUNTS NOISE IS ESTIMATED IN DARK
- **BLANK VS IRRADIATED CRYSTALS ARE COMPARED**



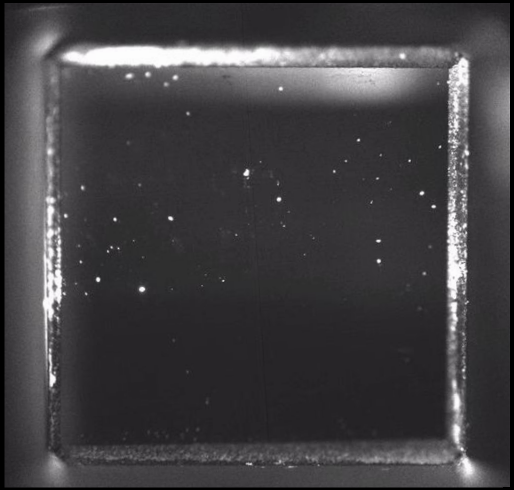
BLANK CaF_2 CRYSTALS YIELDED **NO** BULK **SIGNAL**

TESTING THE PALEOCCENE CONCEPT

ESTIMATING COLOR CENTER FLUORESCENCE SIGNAL



EXC. WAVELENGTH VS. FLUORESCENCE INTENSITY.



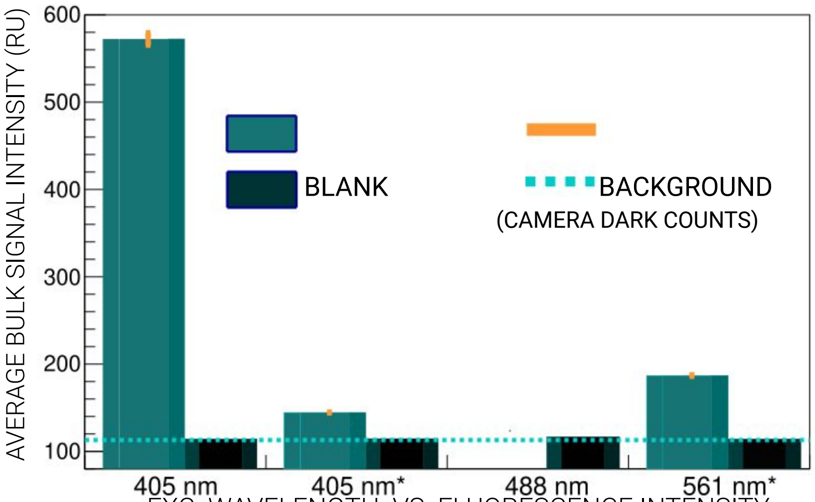
BLANK CaF_2 CRYSTALS YIELDED **NO** BULK **SIGNAL**

NO SIGNAL ABOVE THE BACKGROUND LEVEL WAS OBSERVED FROM BLANK CaF_2 CRYSTALS

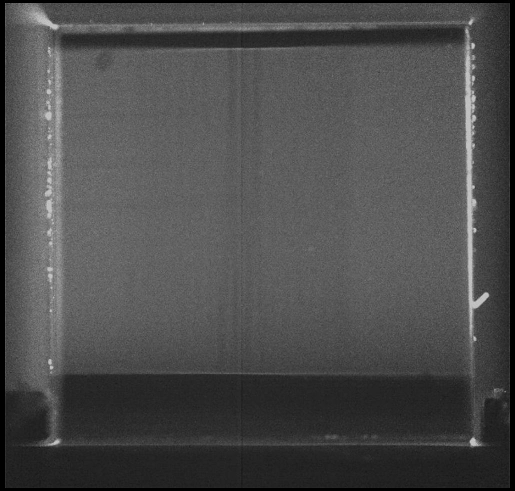
(*)MEASUREMENT WITH LONG-PASS FILTER

TESTING THE PALEOCCENE CONCEPT

COLOR CENTER FLUORESCENCE SIGNAL BLANK VS IRRADIATED



EXC. WAVELENGTH VS. FLUORESCENCE INTENSITY.



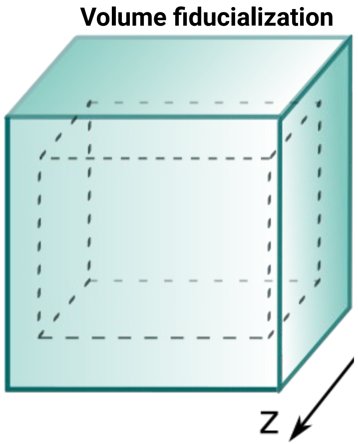
CRYSTAL IS **FLUORESCENT** AFTER **IRRADIATION***

INTENSITY IS THE HIGHEST IN RESPONSE TO 405 nm EXCITATION. *100 kRad dose from ^{60}Co source.

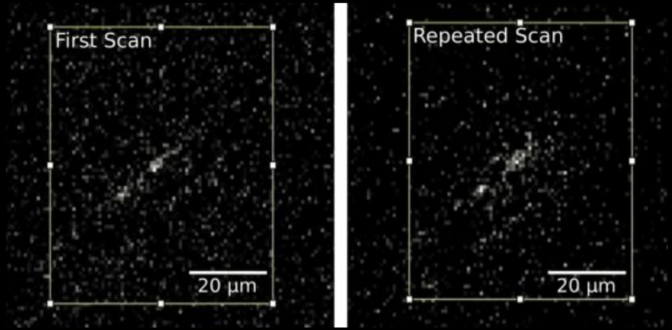
IMAGING TRANSPARENT CRYSTALS WITH THE MESOSPIM

METHODS & ANALYSIS

FOR THE CRYSTALS THAT SHOW FLUORESCENCE RESPONSE TO IRRADIATION, WE DEFINE A VOLUME OF INTEREST:



THEN, WE LOOK FOR CLUSTERS OF FLUORESCENT PIXELS (TRACK-LIKE STRUCTURES)



& match them in repeated scans.

THE NEW MESOSPIM VERSION

A “LARGE SCALE” LIGHT-SHEET FLUORESCENCE MICROSCOPE

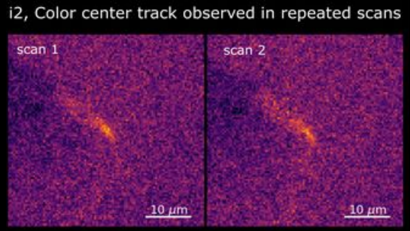
FEATURING:

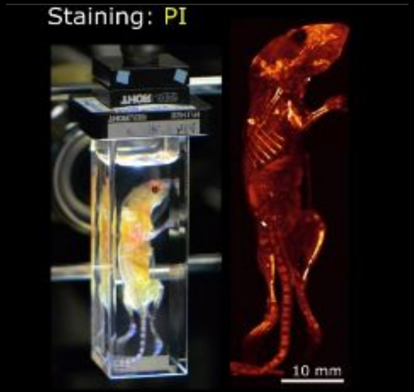
- **IMPROVEMENTS FOR IMAGING** WHOLE-BODY RATS & **COLOR CENTERS** IN **CRYSTALS:** pixel sizes down to 0.21 µm*, larger sCMOS camera** and new sample holder for crystal imaging - all of this at smaller footprint and cost.

- **FIRST IMAGES OF RADIATION-INDUCED COLOR CENTERS WITH LIGHT-SHEET MICROSCOPY** *Nature Communications* 15, 2679 (2024)

(*) magnification up to 20x (1.5 µm x-y resolution), (**) 5056x2960 pixels, 4.25 µm pixel size. File sizes for a full crystal scan and ~4 µm isotropic resolution: ~30 Gb.

Nature Communications (2024)

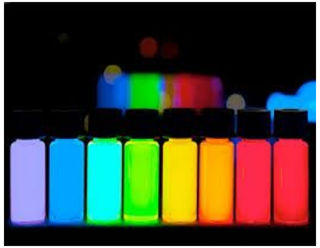


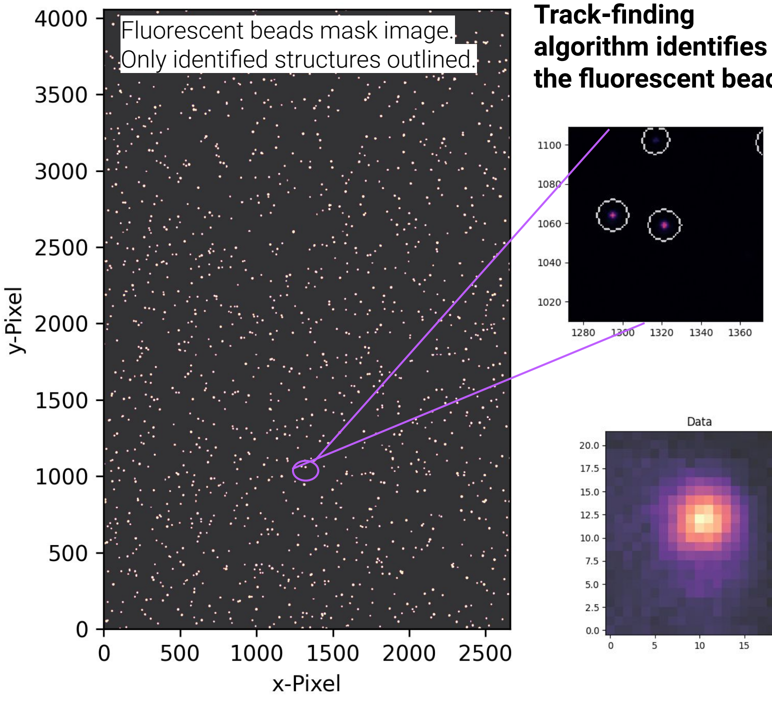


CALIBRATION FOR IMAGING COLOR CENTERS WITH LIGHT SHEET MICROSCOPE

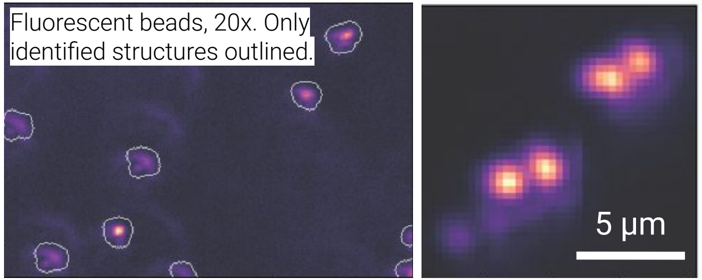
MIMICKING LOW-ENERGY SIGNALS: FLUORESCENT BEADS & QUANTUM DOTS AS CALIBRATION REFERENCES

NEUTRINOS AND DARK MATTER MAY CREATE SMALL CLUSTERS OF COLOR CENTERS IN CRYSTALS: **QUANTUM DOTS AND NANO-FLUORESCENT BEADS** IN A TRANSPARENT TARGET SERVE **AS CALIBRATION REFERENCES.**

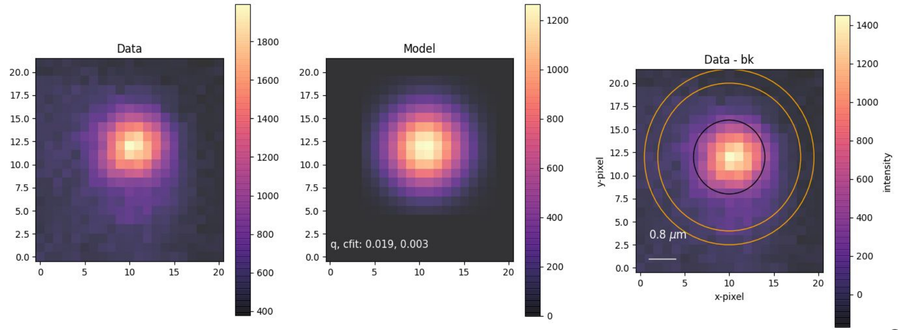




Track-finding algorithm identifies the fluorescent beads

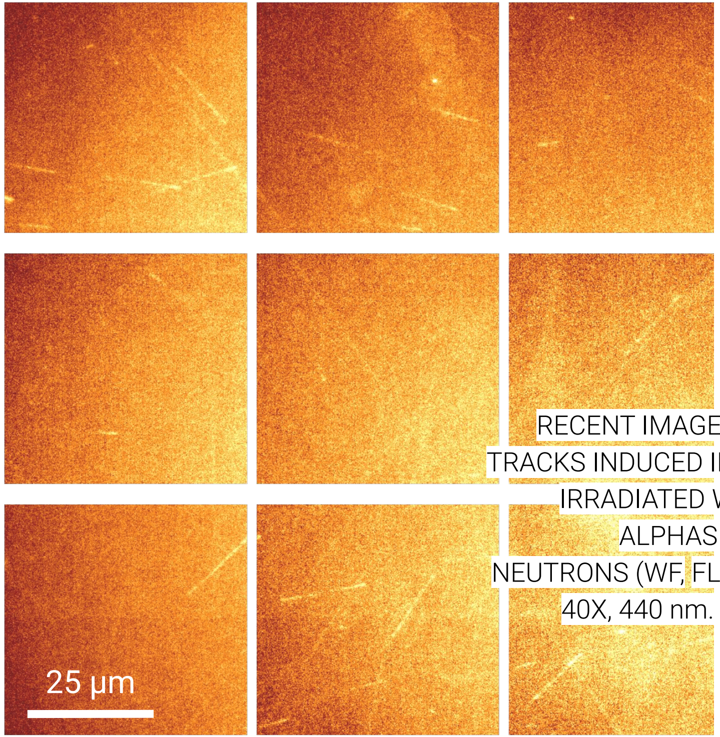


Reference data used to optimize algorithms. Software identifies features, match them in repeated scans, model/fit them & output parameters such as their sizes.



CONCLUSIONS & NEXT STEPS FOR PALEOCCENE

PALEOCCENE IS A PROMISING CONCEPT FOR THE DETECTION OF νS & DARK MATTER.



RECENT IMAGES OF TRACKS INDUCED IN LiF IRRADIATED WITH ALPHAS AND NEUTRONS (WF, FLUOR., 40X, 440 nm. Exc.)

THE PALLEOCCENE COLLABORATION:

NEUROSCIENTISTS, MICROSCOPY DEVELOPERS, PARTICLE PHYSICISTS, NUCLEAR ENGINEERS, GEOLOGISTS, SOLID STATE PHYSICISTS

FIRST EXPERIMENTAL TESTS OF PALEOCCENE DEMONSTRATED SUCCESSFUL IMAGING OF RADIATION-INDUCED COLOR CENTERS.

PALEOCCENE FAST PATH FORWARD & HIGHLIGHTED CONTRIBUTIONS

- CONCEPT PROPOSED BY COGSWELL et. al. (12. 2021)
- PALEOCCENE WHITE PAPER (2022)
- MINERAL DETECTION OF νS & DM Phys. Dark Univ. (2023)
- NEW MESOSPIM Nat. Comm. (2024)
- MINERAL DETECTION OF νS & DM. Proceedings (2024)
- & MORE TO COME (UZH POSTDOC, 2024)

PALEOCCENE APPLICATIONS: NEUTRON DETECTORS, **DARK MATTER** DETECTION (Eg. LOW MASS WIMPs & INVESTIGATION OF LOW-ENERGY EXCESS)**, CEνNS** (BSM PHYSICS / NUCLEAR REACTOR SAFEGUARDING), PALEO DETECTORS, ROCK DATING (GEOLOGY), ETC.

TAKE AWAY MESSAGES

NEUTRINOLESS DOUBLE BETA DECAY

COULD SHED LIGHT ON THE ORIGIN OF NEUTRINO MASS AND MATTER-ANTIMATTER ASYMMETRY OF THE UNIVERSE. GERDA WAS A LEADING EXPERIMENT IN THE SEARCH FOR THIS DECAY AND SET THE PATH FOR LEGEND. THE LAr INSTRUMENTATION & WLS-REFLECTOR IS ESSENTIAL TO ATTAIN THE LOW BACKGROUND LEVEL REQUIRED FOR LEGEND.

ORDINARY MUON CAPTURE IS A POWERFUL TOOL TO DECREASE THE UNCERTAINTIES ON $0\nu\beta\beta$-DECAY NUCLEAR MATRIX ELEMENTS (NME). MONUMENT'S UPCOMING RESULTS AIM TO IMPROVE $m_{\beta\beta}$ SENSITIVITY ESTIMATES FOR THE LEADING $0\nu\beta\beta$-DECAY ISOTOPES ^{76}Ge, ^{136}Xe (^{76}Se, ^{136}Ba).

PALEOCCENE DETECTORS HOLD PROMISE FOR THE DETECTION OF νS & DARK MATTER & COULD ENABLE THE FIRST REACTOR CEνNS DETECTION. THE FIRST TESTS OF THE CONCEPT WERE PROMISING AND INDICATE A WIDE RANGE OF APPLICATIONS OF THIS CONCEPT IN PHYSICS & OTHER FIELDS.

THE PHD JOURNEY & HIGHLIGHTED PUBLICATIONS

PhD journey	Highlighted publications
DATA CHARACTERIZATION FOR GERDA (2019) ●	● GERDA Final results PRL, 125 (2020)
WLSR TPB EVAPORATION (2020) ●	● LEGEND-200 WLSR R&D & CHARACTERIZATION (2019-21)
MONUMENT BEAM-TIMES (2021-22) ■	● R&D OF WLSR (ARAUJO ET AL, EPJ. C, 2022)
WLSR CHARACTERIZATION LEGEND-1000 (2022) ●	● GATOR PAPER (ARAUJO ET AL, JINST 2022)
MONUMENT DATA ANALYSIS (2022-23) ■	
FIRST LSFM IMAGES OF COLOR CENTERS (2023) ▲	▲ PALEOCCENE WHITE PAPER (2022)
MINERAL DETECTION OF νs & DM (Phys. Dark Univ. 2023) ▲	▲ MESOSPIM PAPER Nat. Comm. (2024)