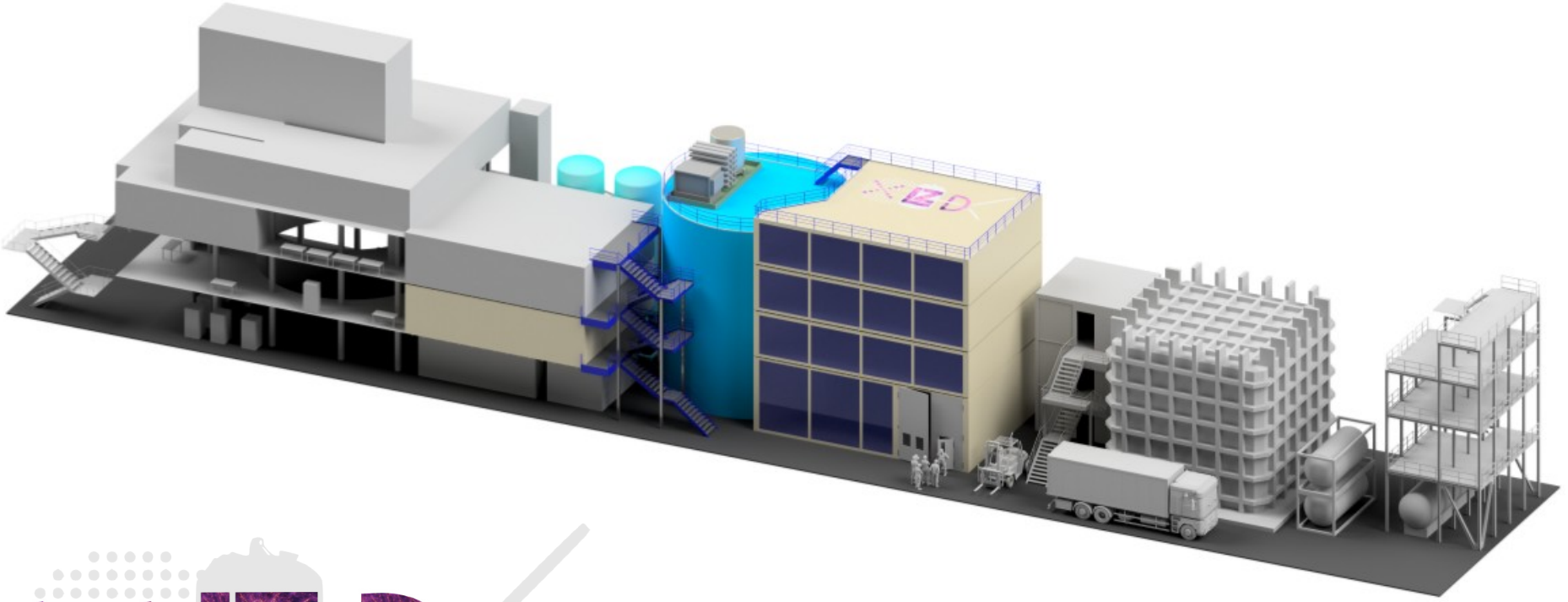
XLZD

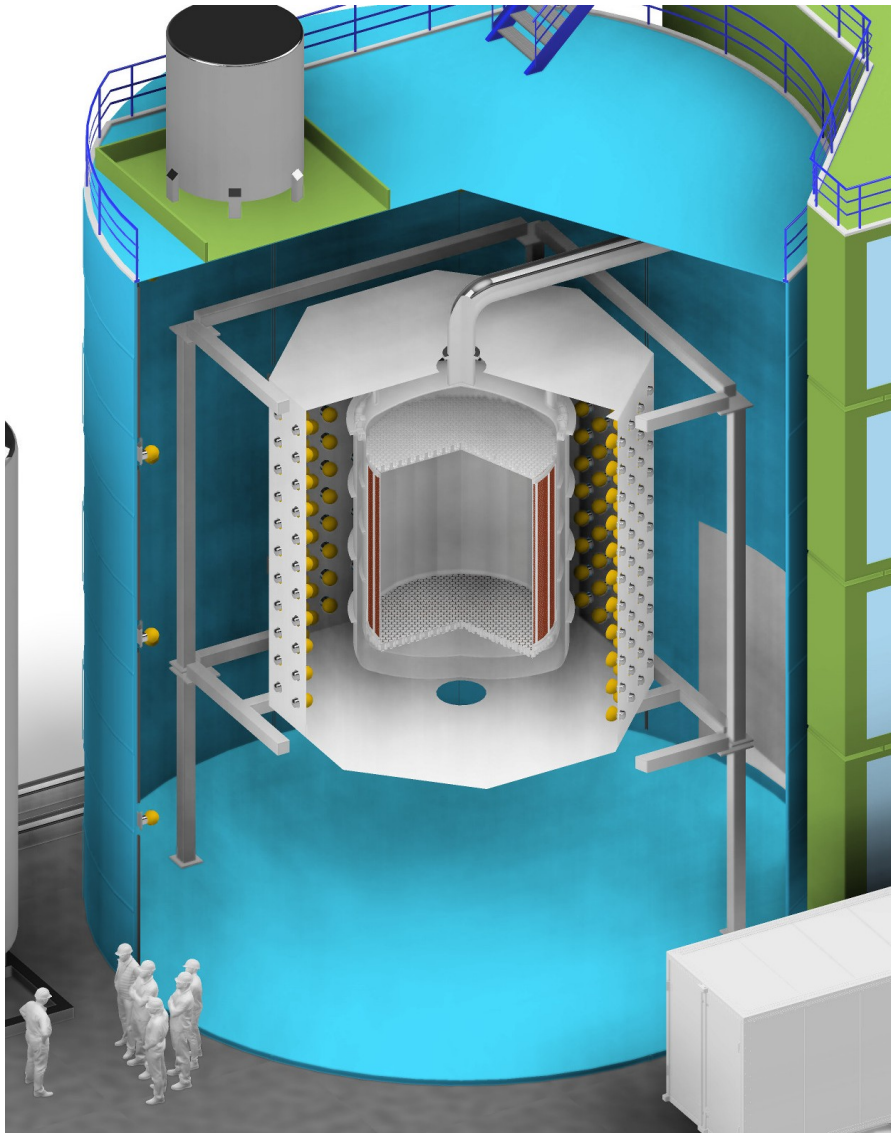
A xenon-based low-background observatory for astroparticle physics



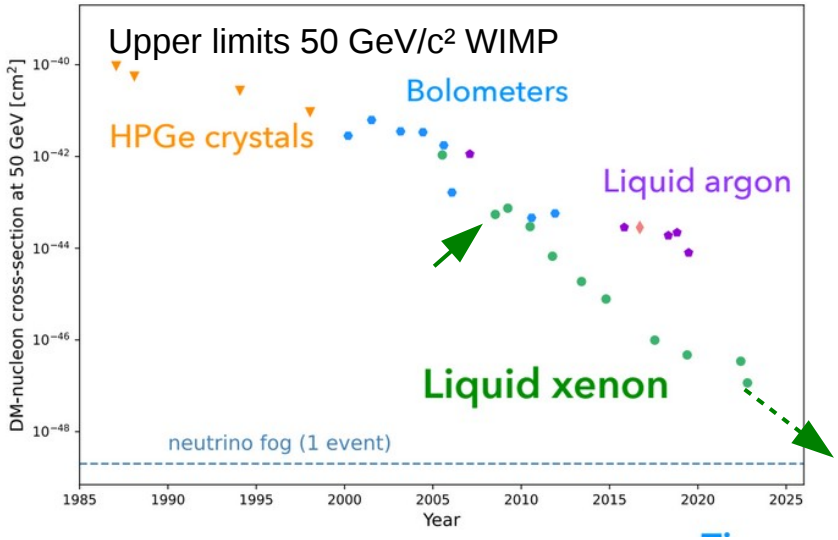
Marc Schumann (Freiburg)
Kathrin Valerius (KIT)

KAT Strategy Meeting, Karlsruhe, 18.10.2024

The XLZD Observatory

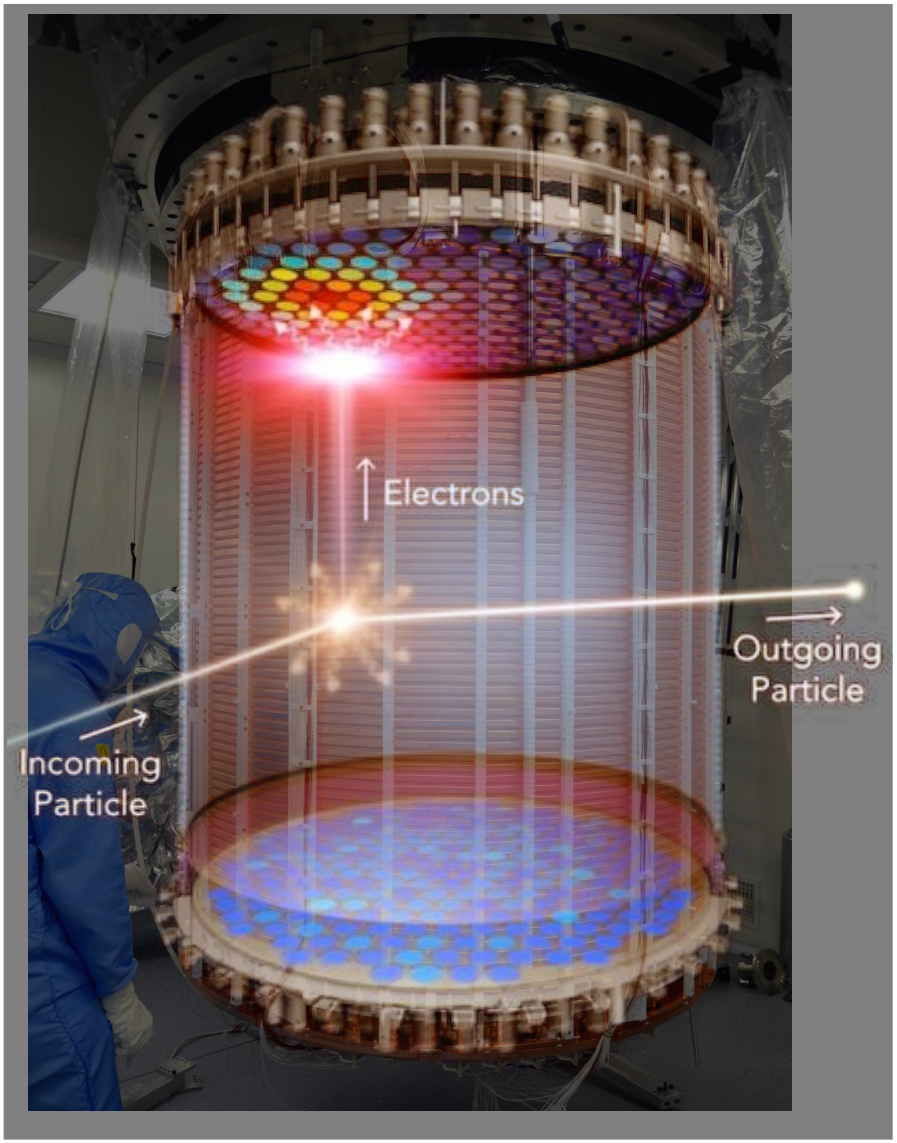


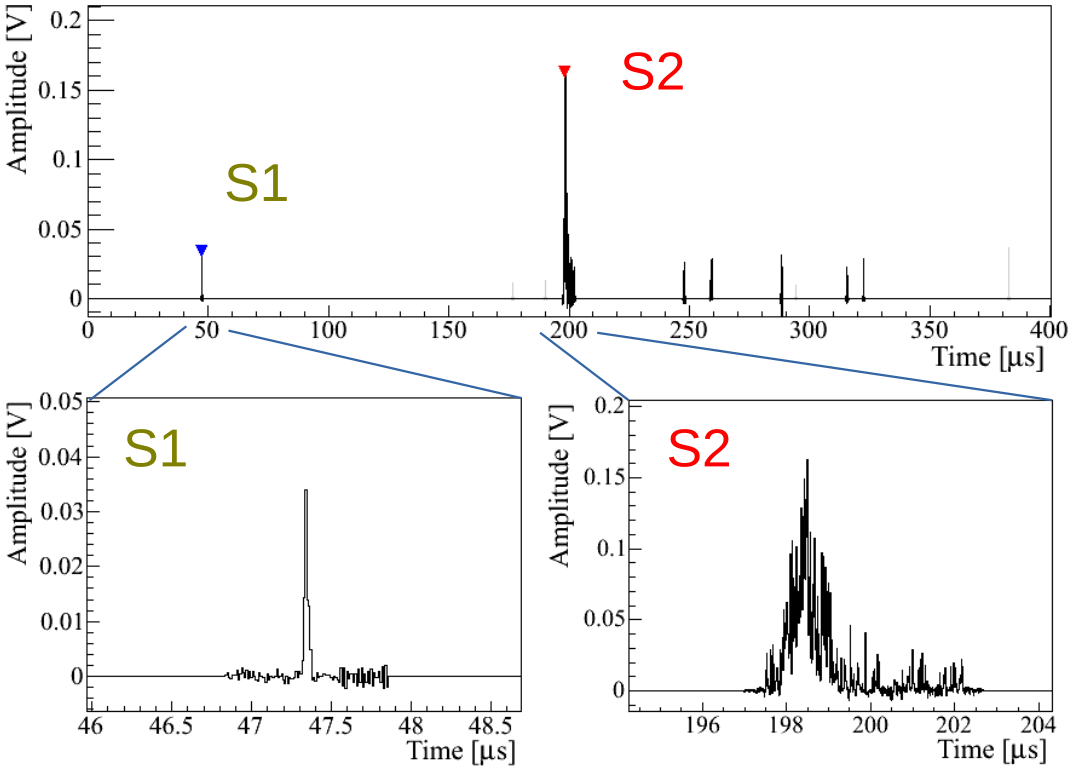
- **Liquid Xenon (LXe) dual-phase TPC with 60t active target**
- **Lowest threshold** (O(1) keV$_{NR}$) **Lowest background**
- Surrounded by 3 layers of active veto detectors
  – LXe „skin“
  – Neutron veto (Gd)
  – Muon Veto (water)
- Various subsystems to reduce backgrounds to neutrino level



Dual-phase TPC

Dolgoshein, Lebedenko, Rodionov, JETP Lett. 11, 513 (1970)





- 3D position reconstruction
- Energy reconstruction
- Event-mutiplicity
- Electronic vs. nuclear recoil discrimination

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XLZD Nominal Design

Design book close to publication

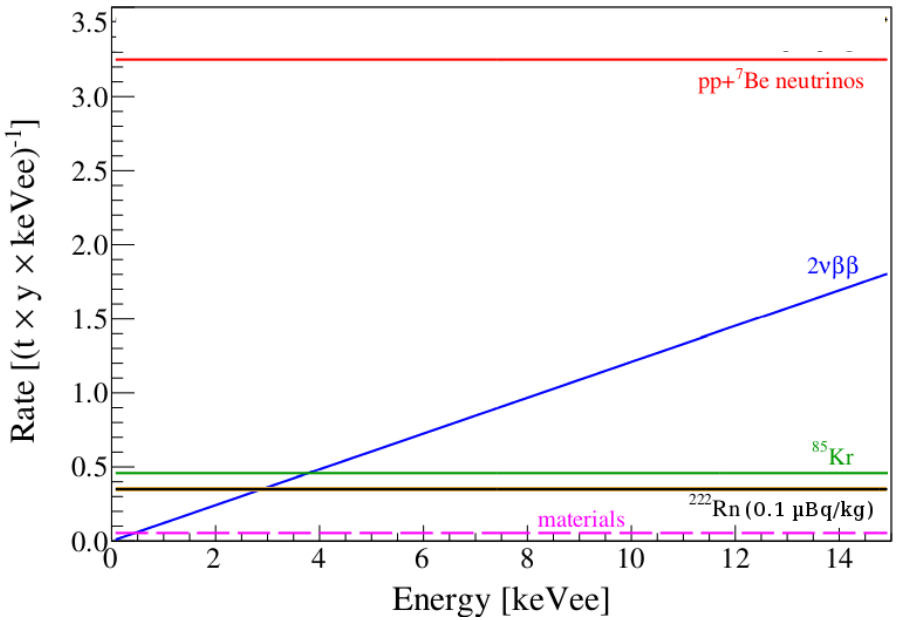
- 60t active LXe target (78t total)
- 2.97m height, 2.98m diameter
  (→ factor 2 larger than LZ and XENONnT)
- Drift field: 240-290 V/cm
  for optimal background rejection
- Two arrays of 3“ low-background PMTs
  (2362 tubes in total)
- Double-wall Ti cryostat

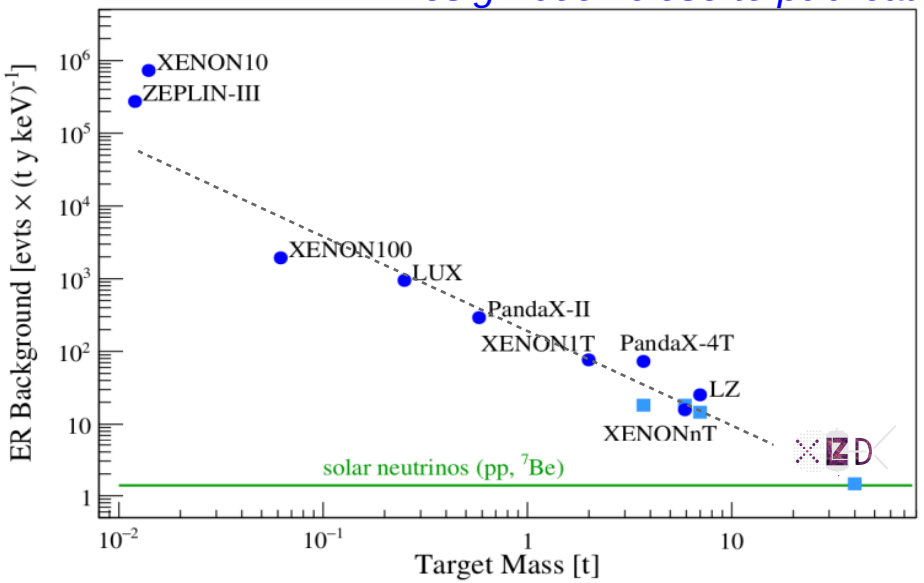
- **Early science** with ~45t detector
  (flatter but same diameter)
  → important for early commissioning
  and risk mitigation

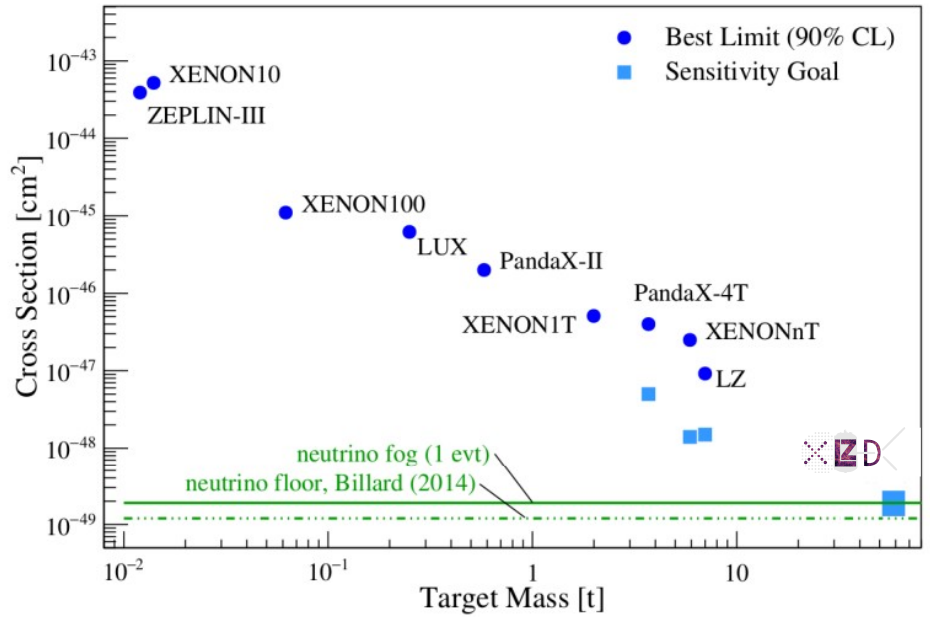
- Design allows for straighforward upgrade to 80t TPC to acquire very large exposure faster

Background: Neutrinos

Design book close to publication







Reduce all other backgrounds by

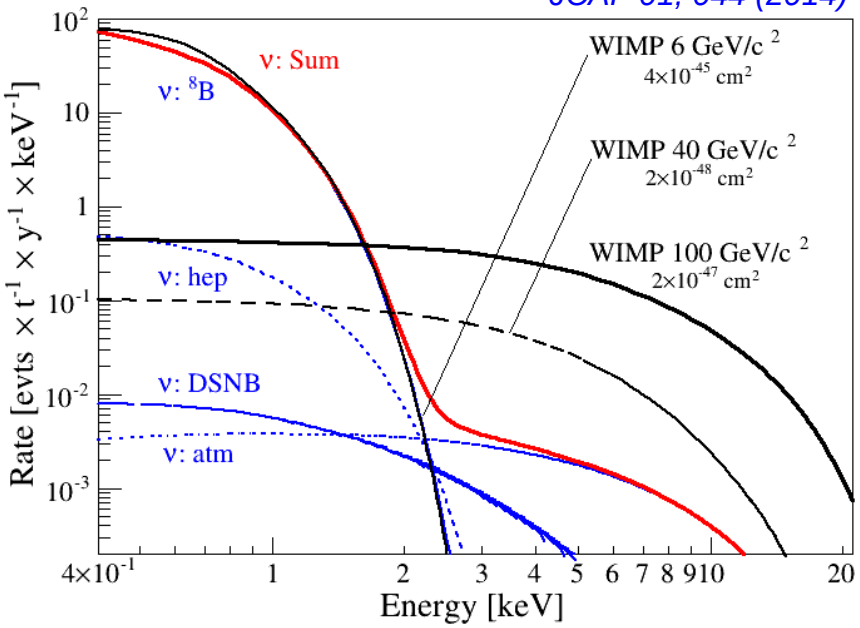
- Low-background materials, shielding
- Detector design, surface treatment
- Active vetoes (LXe, n, μ)
- ^{85}Kr removal (cryogenic distillation)
- Online ^{222}Rn removal (cryogenic distillation)
- Precautions against ^{3}H contamination
- Optimized HV system → avoid accidentals

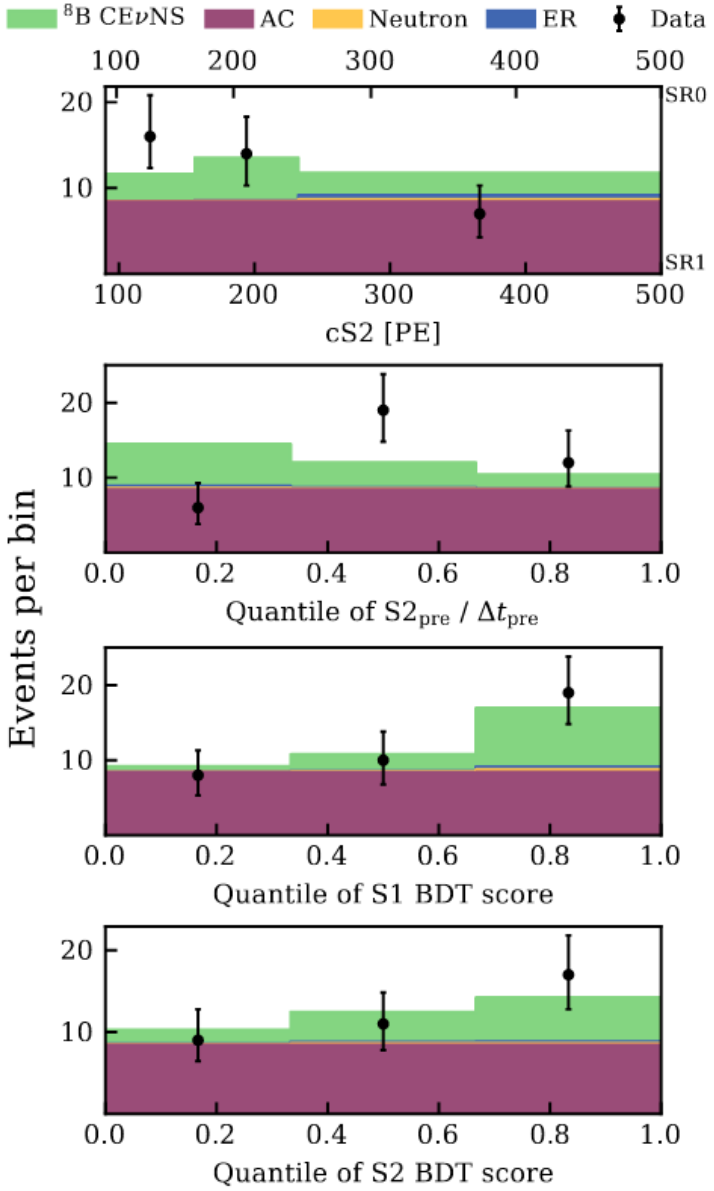
Evidence for ^{8}B ν-Floor

arXiv:2408.02877, accepted by PRL

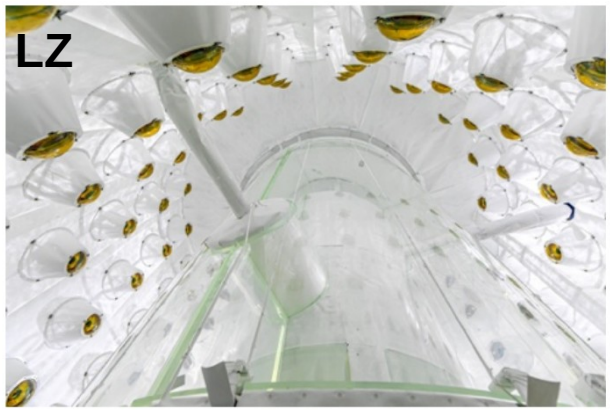
- First observation of CEνNS of astrophysical neutrinos with 2.7σ (3.2σ w/o $S2_{pre}/\Delta t_{pre}$)
- 11 events above backgrounds in 3.51 t×y exposure
- First step into the ultimate background for WIMP searches

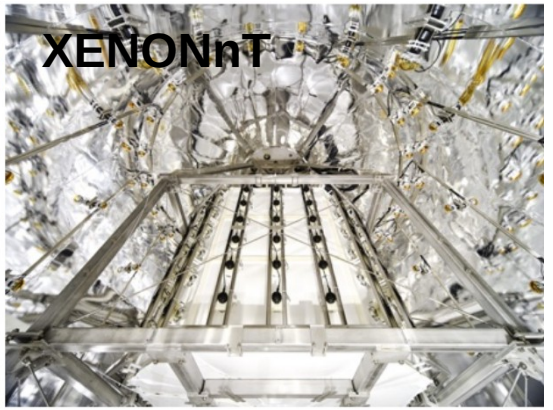
JCAP 01, 044 (2014)

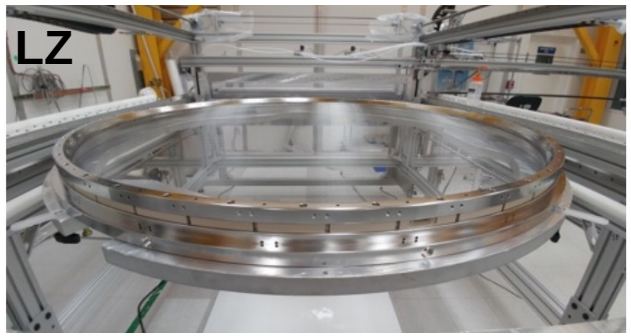


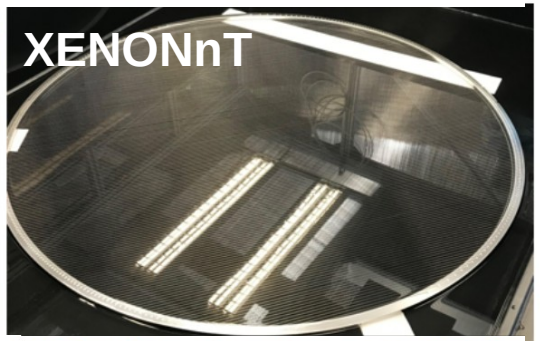


Two world-class demonstrators









- XENONnT and LZ are taking data
  → world-leading results
- Independent designs using the same detector principle
- **Important guidance for XLZD design**

Plus large-scale R&D Platforms

PANCAKE (Freiburg)

+Xenoscope (Zürich)

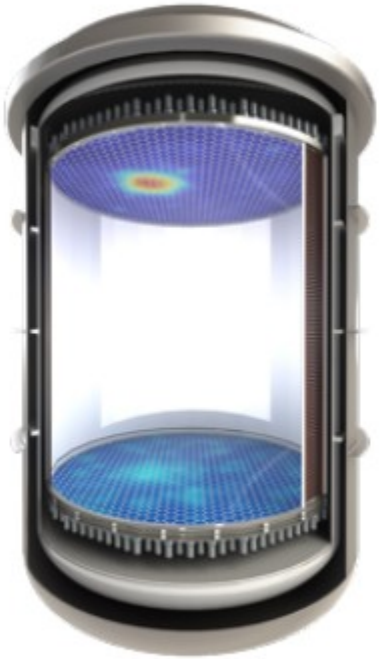
+LowRad (Münster)

+possibly XMASS infrastructure (Kamioka)

XLZD Science

Dark Matter
WIMPs
Sub-GeV
Inelastic
Axion-like particles
Planck mass
Dark photons

Neutrino nature
Neutrinoless double beta decay
Neutrino magnetic moment
Double electron capture

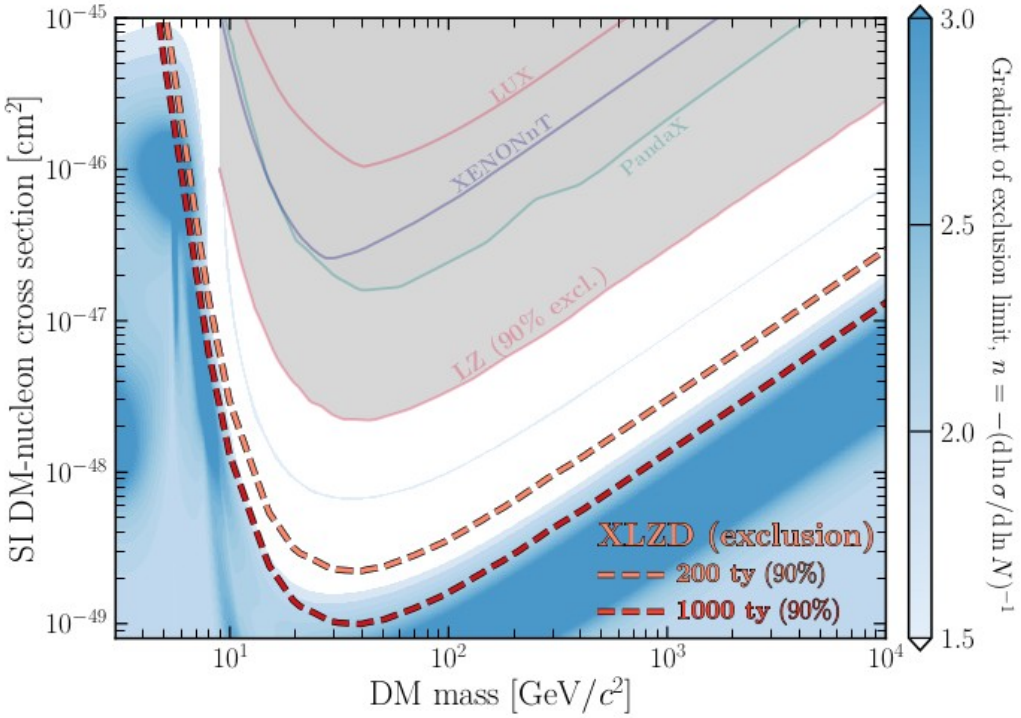


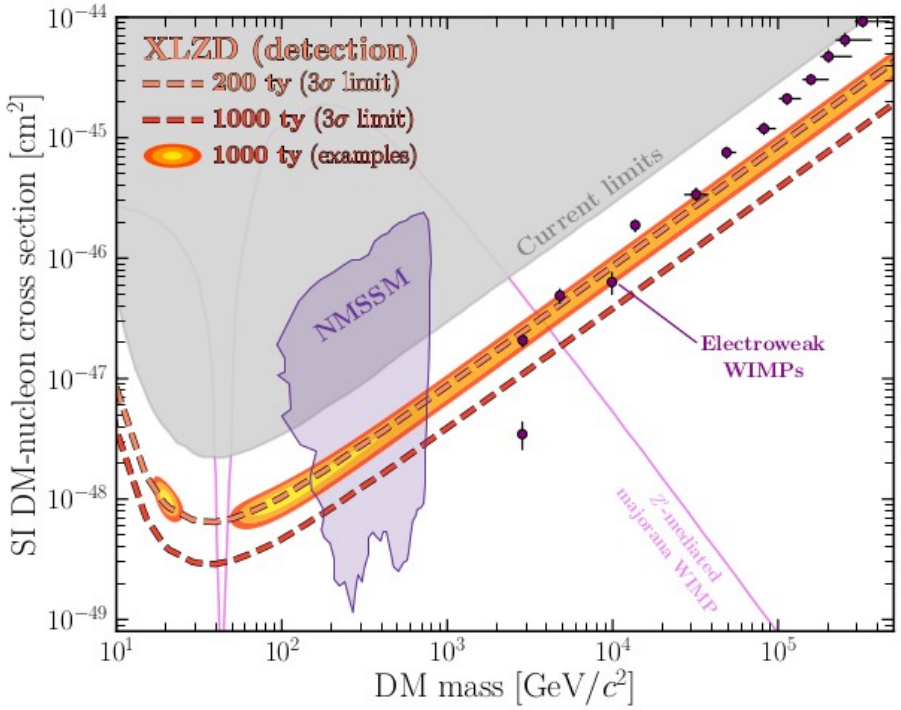
Supernovae
Early alert
Supernova neutrinos
Multi-messenger astrophysics

Sun
pp neutrinos
Solar metallicity
^{7}Be, ^{8}B, hep

A xenon-based low-background observatory for astroparticle physics

Science I: Dark Matter

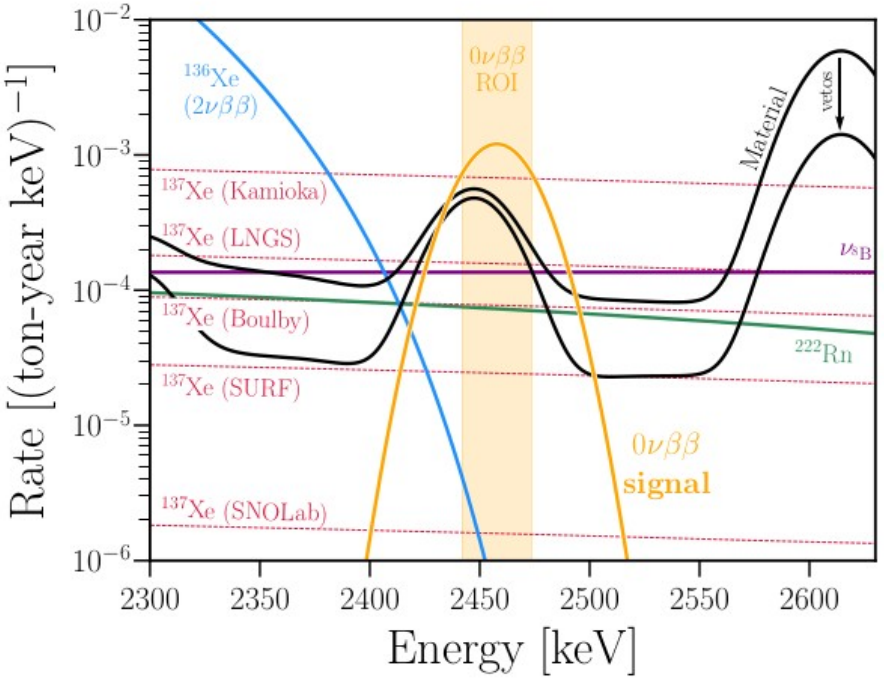


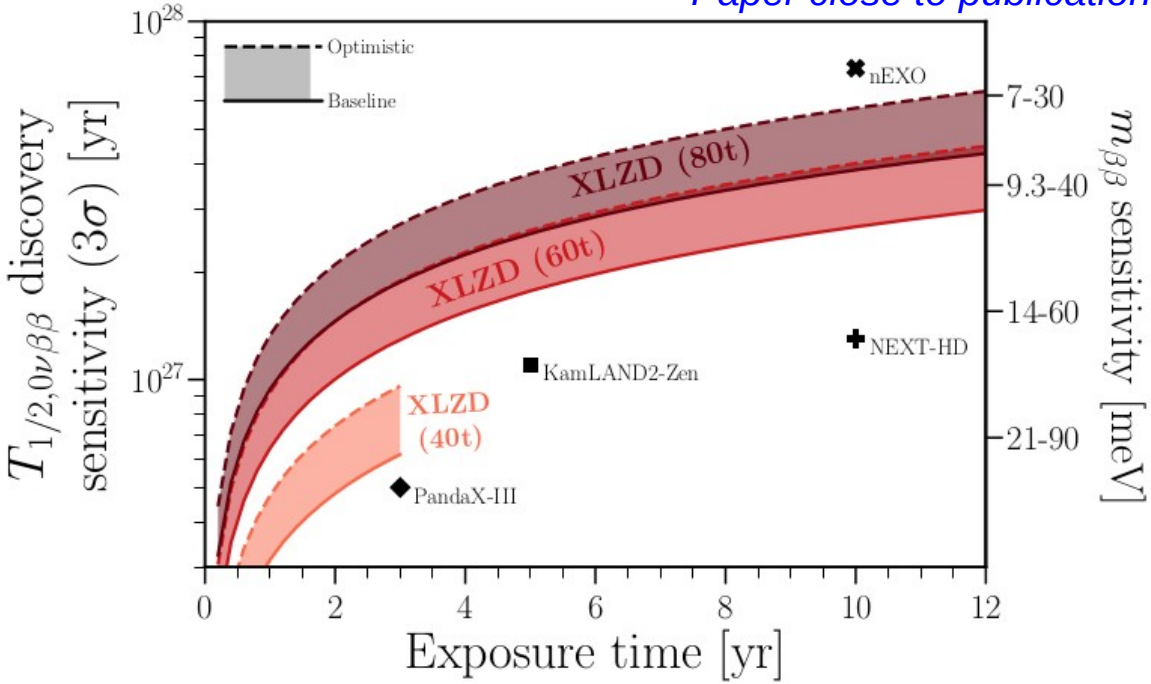


- Excellent sensitivity for spin-independent and spin-dependent WIMP-nucleon scattering
- Covers parameter space into the neutrino fog
- Minimum exposure: 200 t×y, aim for ~500 t×y
- Definite detector: up to 1000 t×y in case hint of signal is seen earlier

Science II: 0νββ

Paper close to publication

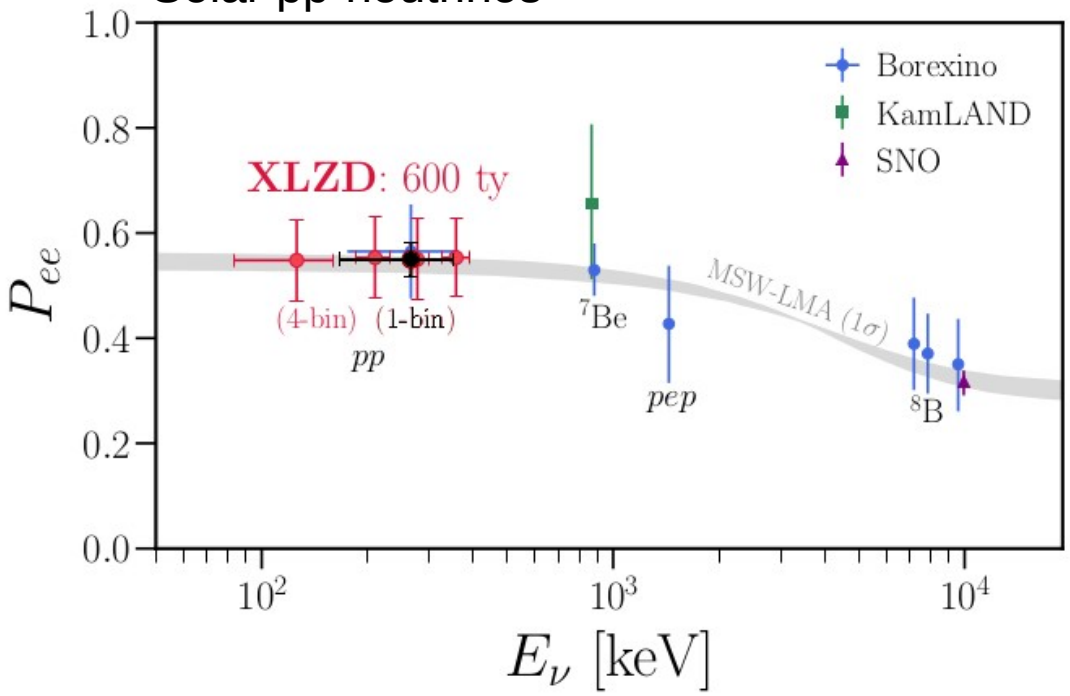




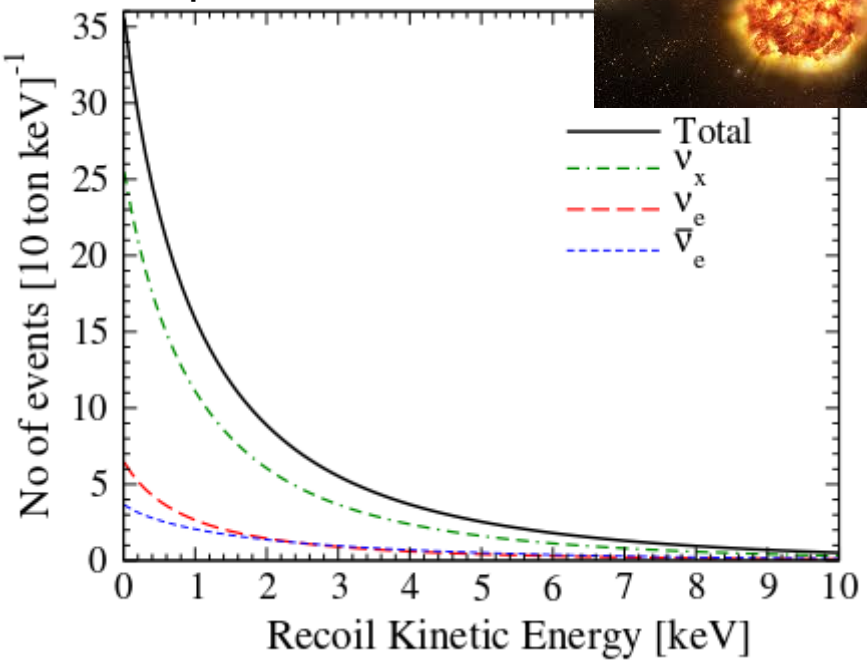
- ~10% natural abundance of ^{136}Xe (5.3t in 60t target)
  → no costly enrichment, Xe gas composition unchanged
- Resolution σ/E~0.8% at $Q_{\beta\beta}$ demonstrated
- Science channel determines lab depth
- Competitive sensitivity
- ^{124}Xe (0νECEC) also present in target

Science III: Neutrinos

Solar pp-neutrinos



Supernova neutrinos



- XLZD background dominated by neutrinos
  → precise measurements of rare processes possible
- Low-threshold: unique science possibilities
  → e.g. superova neutrinos (XENON already part of SNEWS)

More Science: Whitepaper

J. Phys. G 50, 013001 (2023)

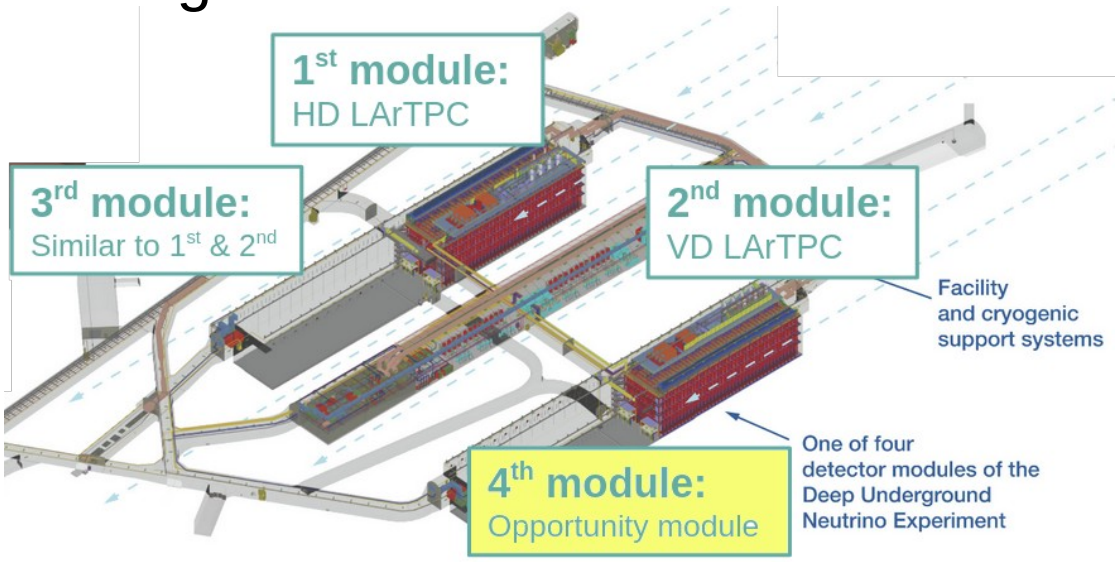
CONTENTS

Covers (probably) all science channels you can think of...

XLZD Siting

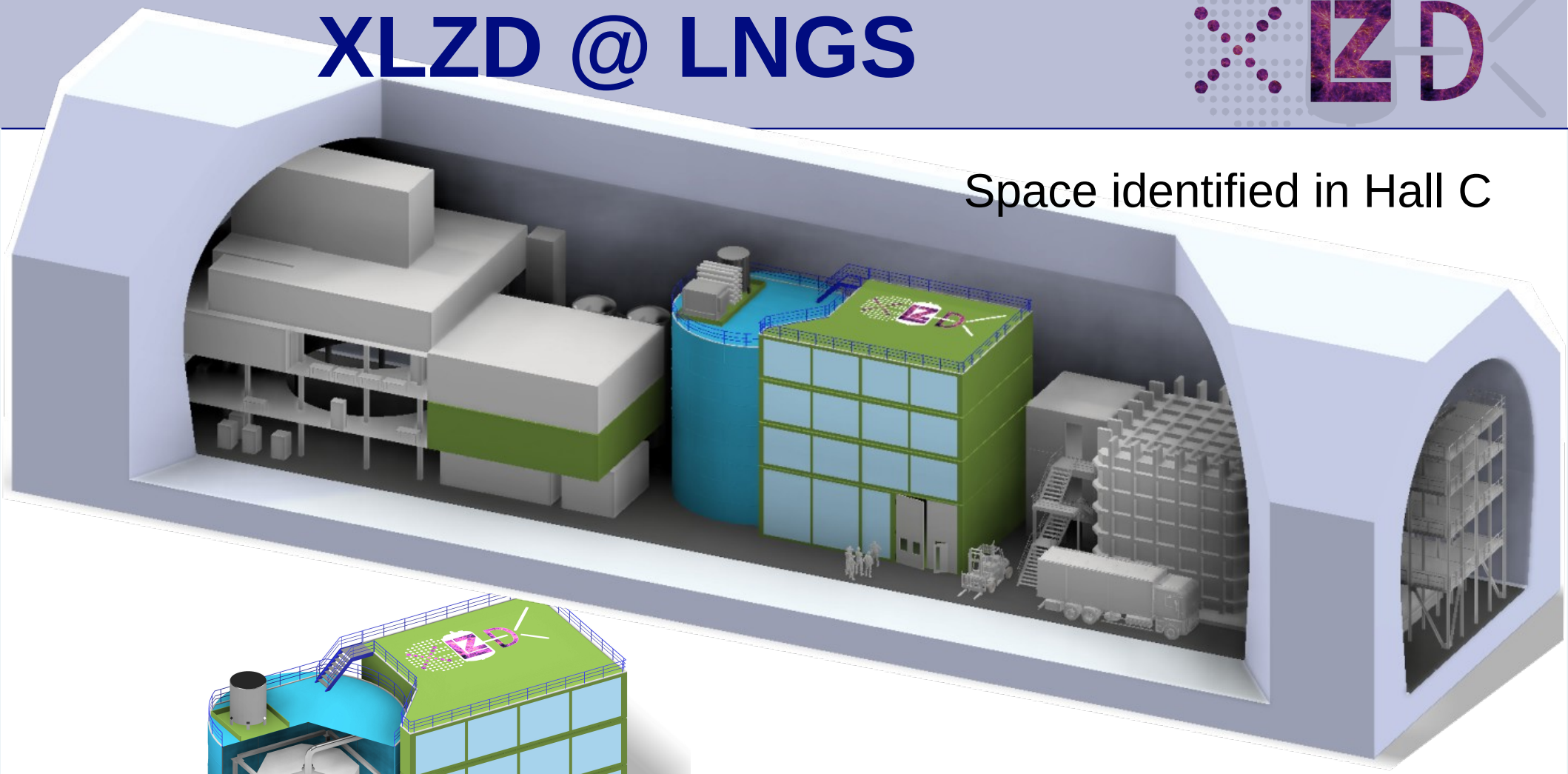
- Host laboratory not yet defined
- Minimal lab-depth driven by 0νββ
- Task-force has studied five laboratories and compiled a detailed siting report
  Boulby (UK), Kamioka (JP), LNGS (IT), SNOLab (CA), SURF (US)
  → depth, space, access, service, limitations etc.
- **Boulby**, **LNGS** and **SURF** are currently considered options
- Discussions with laboratories ongoing
- Lab access impacts some design decisions

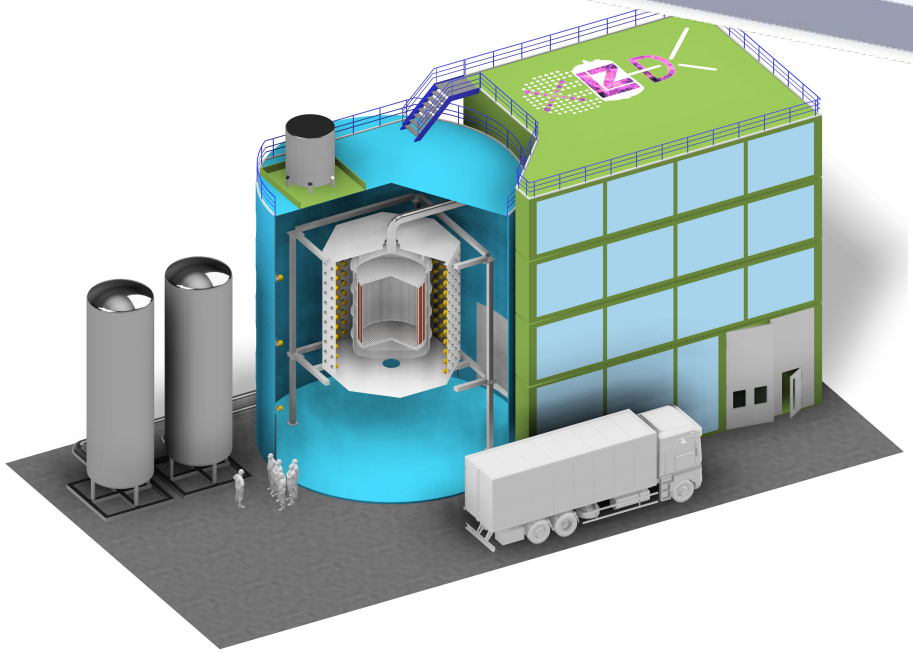
SURF option:



XLZD @ LNGS

Space identified in Hall C



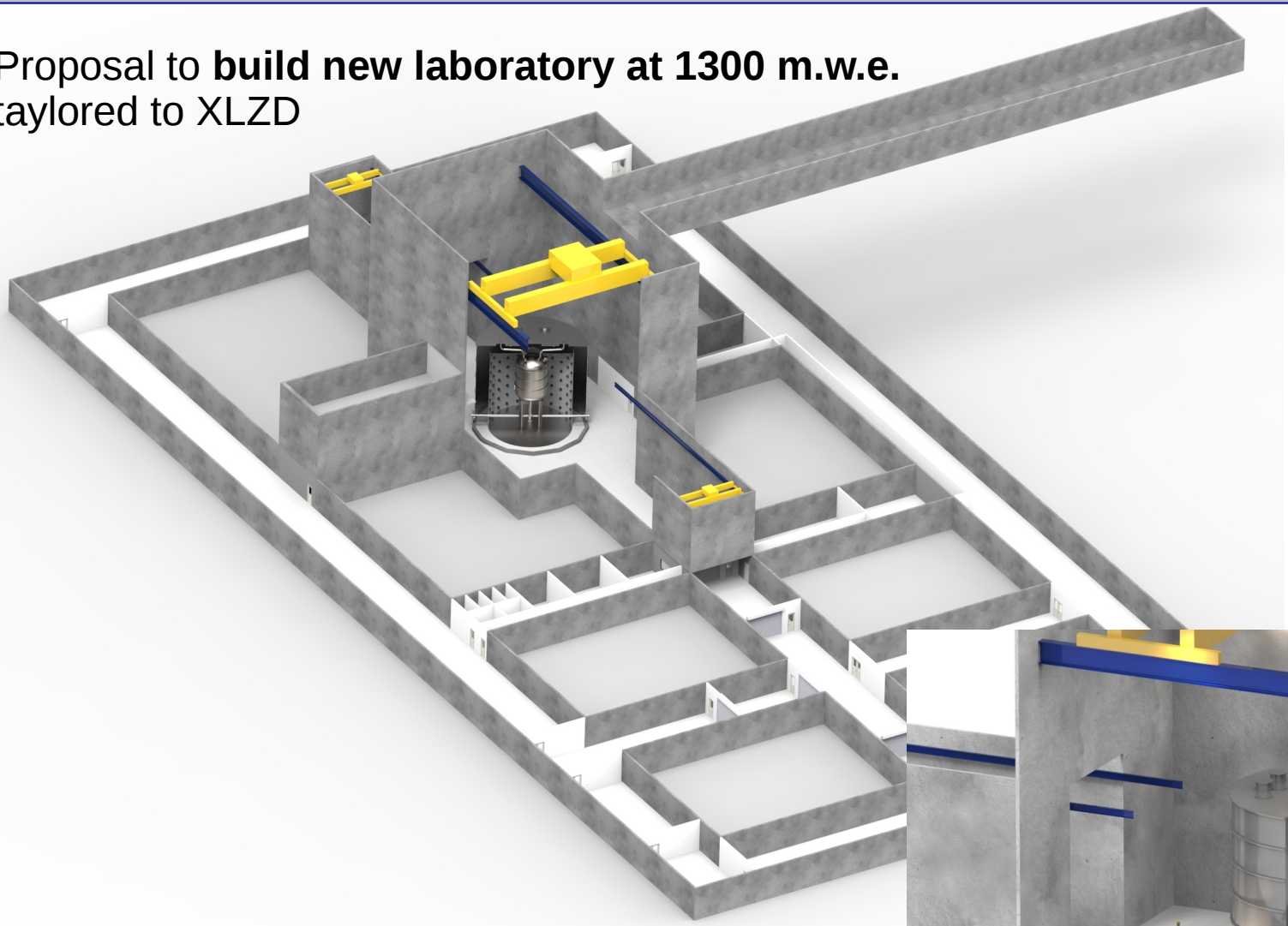


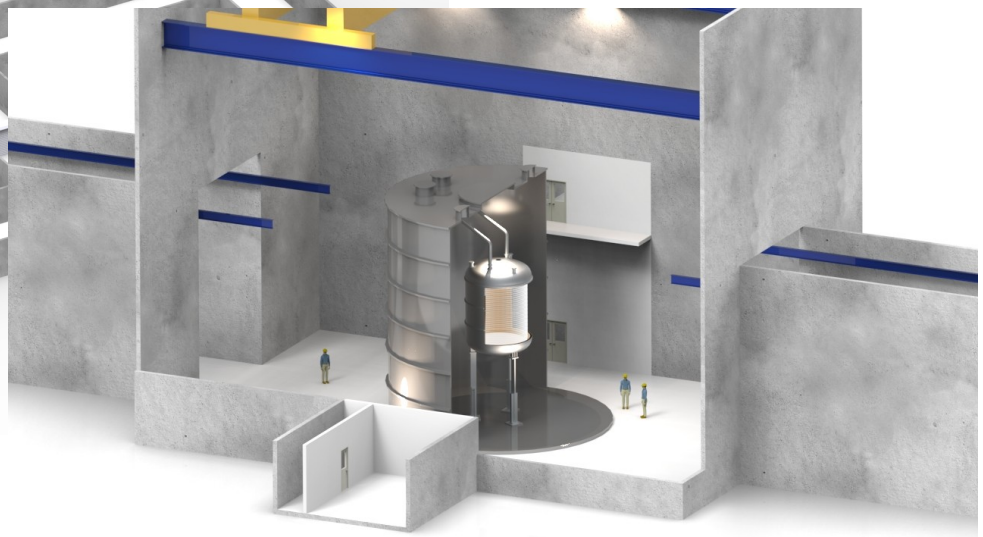
- XLZD in Hall C supported by LNGS scientific committee
- Regular contact with director and engineers
- Easy road access

XLZD @ LNGS

XLZD @ Boulby (UK)

Proposal to **build new laboratory at 1300 m.w.e.** taylored to XLZD





UK XLZD groups received 8.5 M£ to prepare XLZD @ Boulby from STFC

XLZD DE @ Boulby (UK)

- Boulby is the largest active mine in the UK
- Access via 2 shafts

XLZD Collaboration

www.xlzd.org

- Initial consortium established 2021
  → meetings, working groups, collaboration building
- September 2024: **Collaboration formed**
  Collaboration Agreement signed by 73 institutions
- **8 German groups:**
  KIT, MPIK, Mainz, Münster, Freiburg, Dresden, Heidelberg, Darmstadt
- Collaboration has currently ~430 authors (~20% German)

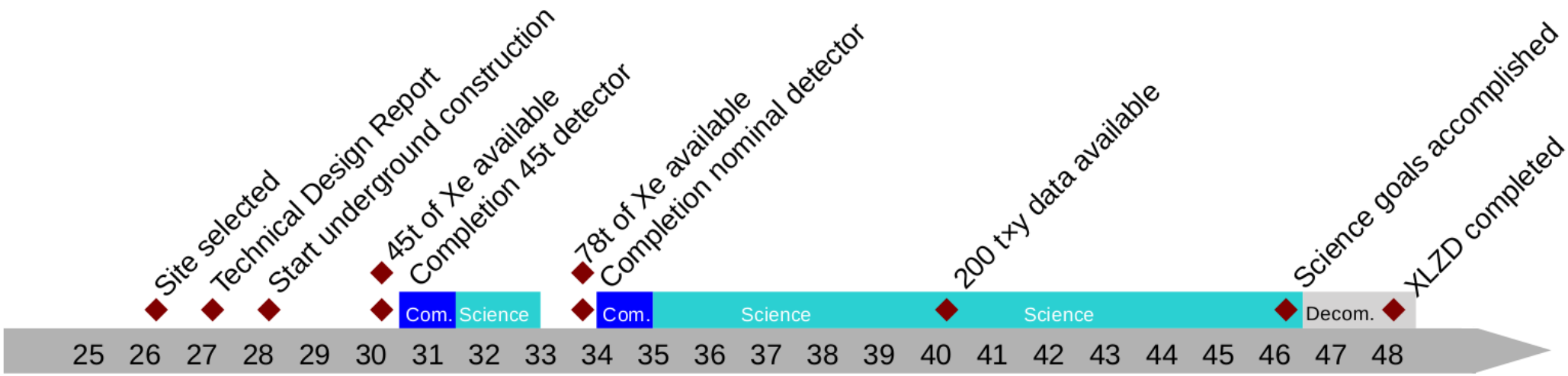
DARWIN

XENON

FIS Proposal: XLZD Project

- XLZD: a xenon-based low-background observatory for astroparticle physics
- Responsible Institution: KIT (Kathrin Valerius)
- Total cost construction: **254.4 M€** (incl. 19% VAT)
  („European accounting“ = no overheads, no funding of lab personnel, no ECRs)
- German contribution: **59.9 M€** (23.5%)
  supplemented by significant own funds (KIT, …), incl. Xe gas
  (not included in this number)
- Operation phase: **1.0 M€/year**
- **Goal: keep German leadership in LXe-based physics**
- German contributions to vetoes, cryostat, TPC, Kr/Rn removal, DAQ, computing, screening, +Xe gas procurement (40 M€)
  → fully exploit our unique and proven expertise
- Possible capitalization of Xe gas after decomissioning: 40 M€

Timeline



- Technology well proven
- Detectors scaled up by factor ~500 in the last 20 years
- 2 demonstrated options exist for most subsystems or components
- Early procurement of Xe gas and photosensors important for timely start of science phase
- Science phases tied to Xe procurement,
  early science phase also for risk mitigation

Conclusions

- Exciting, unique, broad science
  → lots of complementarity
- XLZD endorsed by
  - APPEC mid-term roadmap
  - Helmholtz roadmap
  - P5 (US)
  - UKRI funds to develop XLZD
  - SERI roadmap (CH)
  - several national roadmaps
- XLZD is the merger of the two leading collaborations of the field
- Work is moving swiftly
- Goal: keep German leadership role
  → capitalize key experience and competences