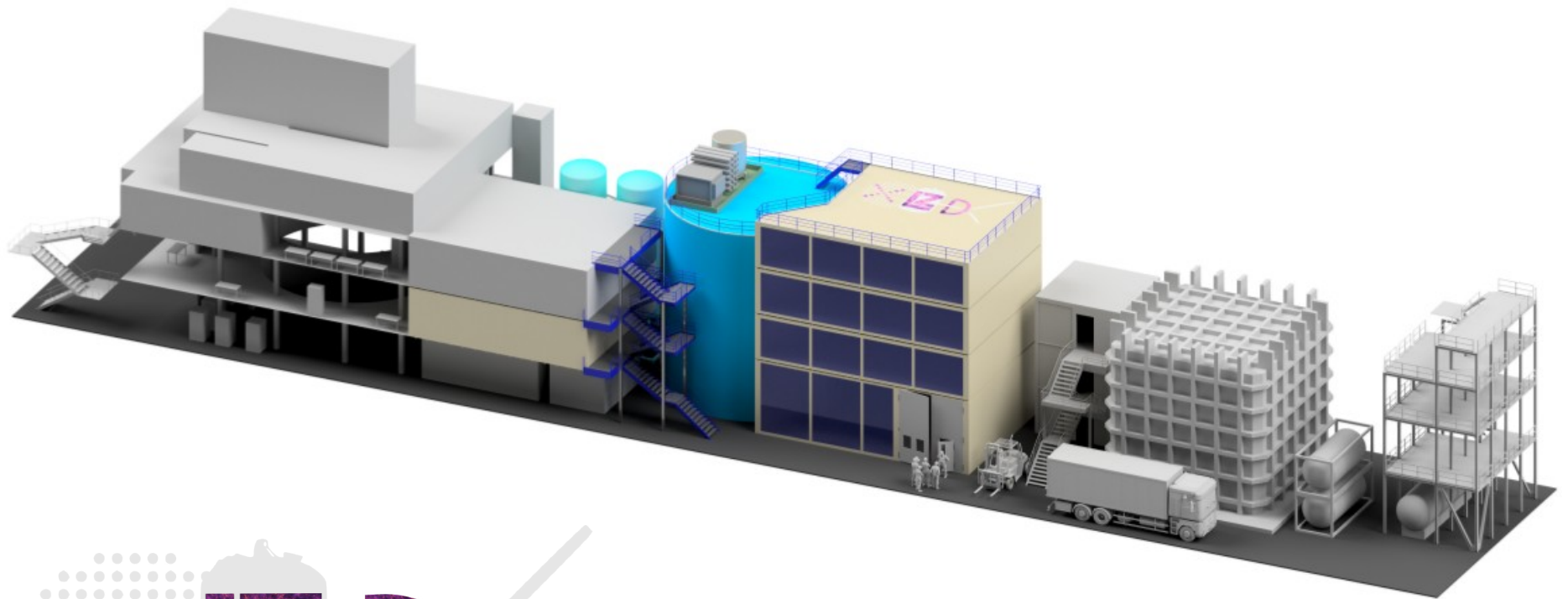


XLZD

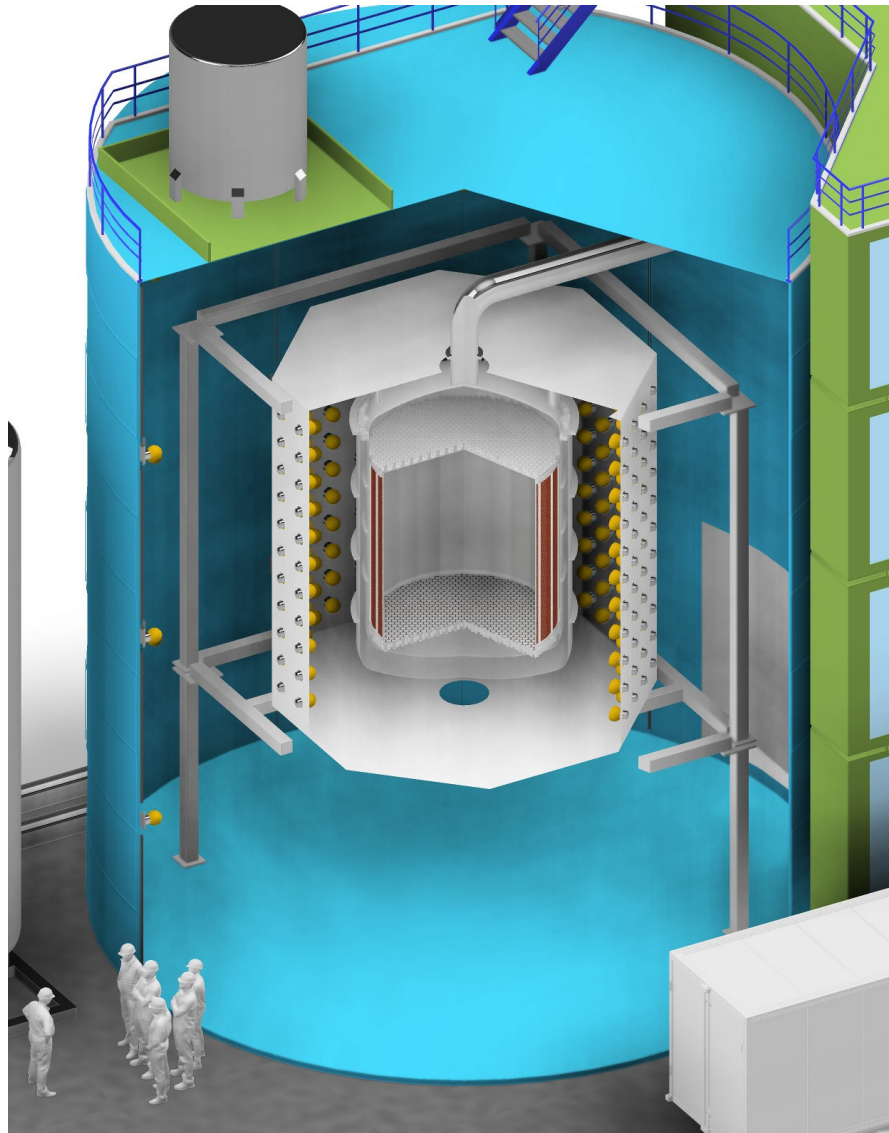
A xenon-based low-background observatory for astroparticle physics



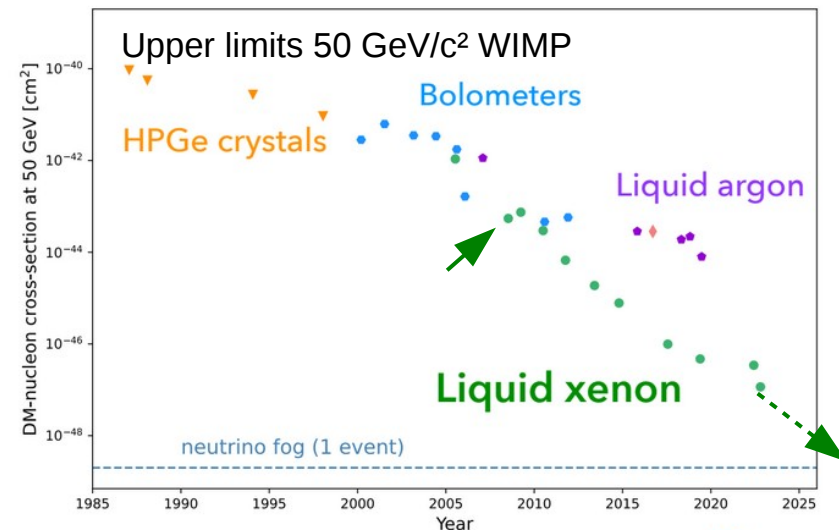
Marc Schumann (Freiburg)
Kathrin Valerius (KIT)

KAT Strategy Meeting, Karlsruhe, 18.10.2024

The XLZD Observatory



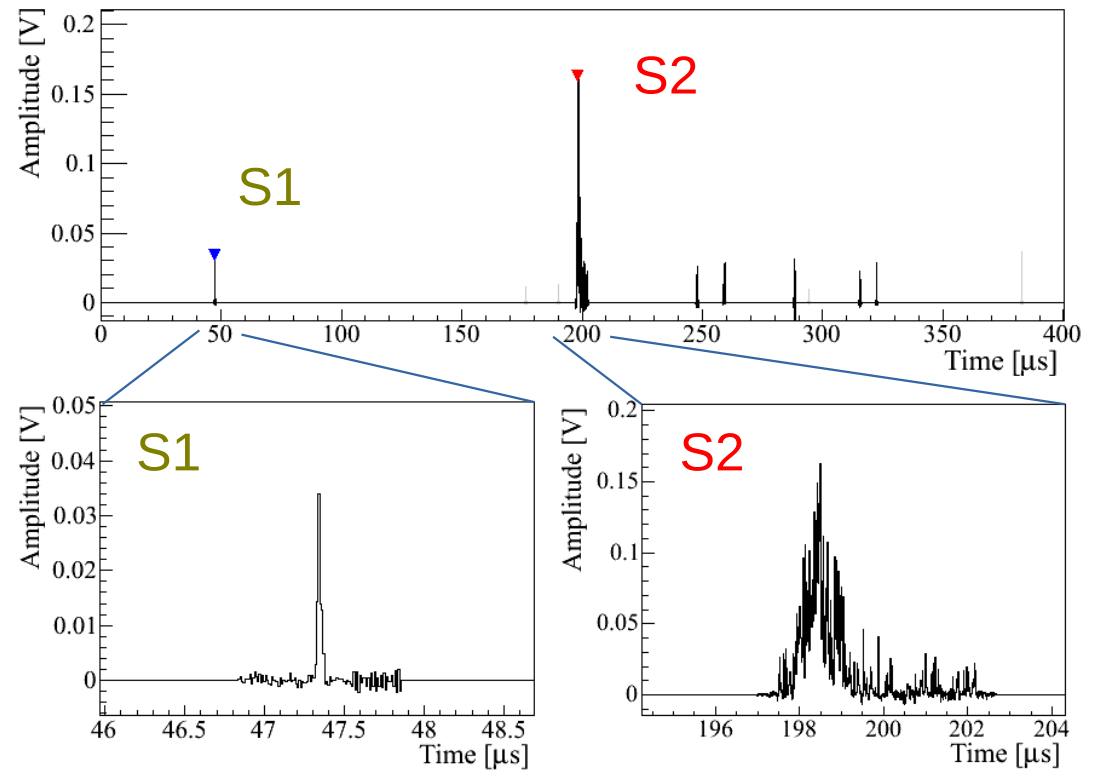
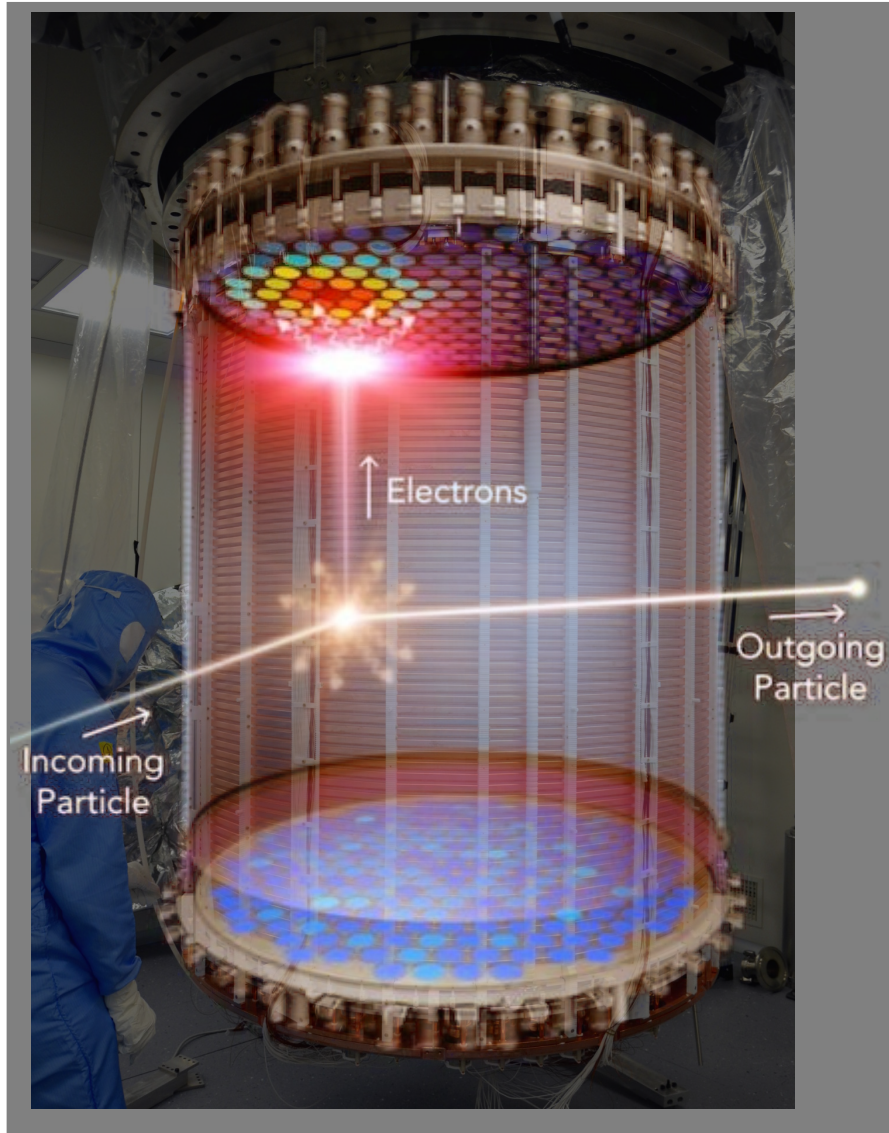
- Liquid Xenon (LXe) dual-phase TPC with 60t active target
- **Lowest threshold ($O(1) \text{ keV}_{\text{NR}}$)**
Lowest background
- Surrounded by 3 layers of active veto detectors
 - LXe „skin“
 - Neutron veto (Gd)
 - Muon Veto (water)
- Various subsystems to reduce backgrounds to neutrino level



Dual-phase TPC



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



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

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XLZD Nominal Design



Design book close to publication

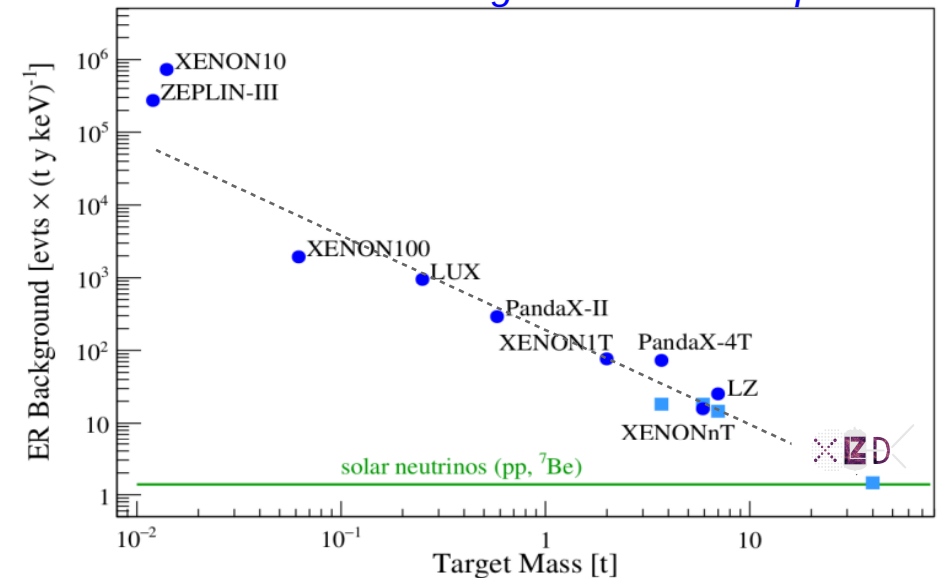
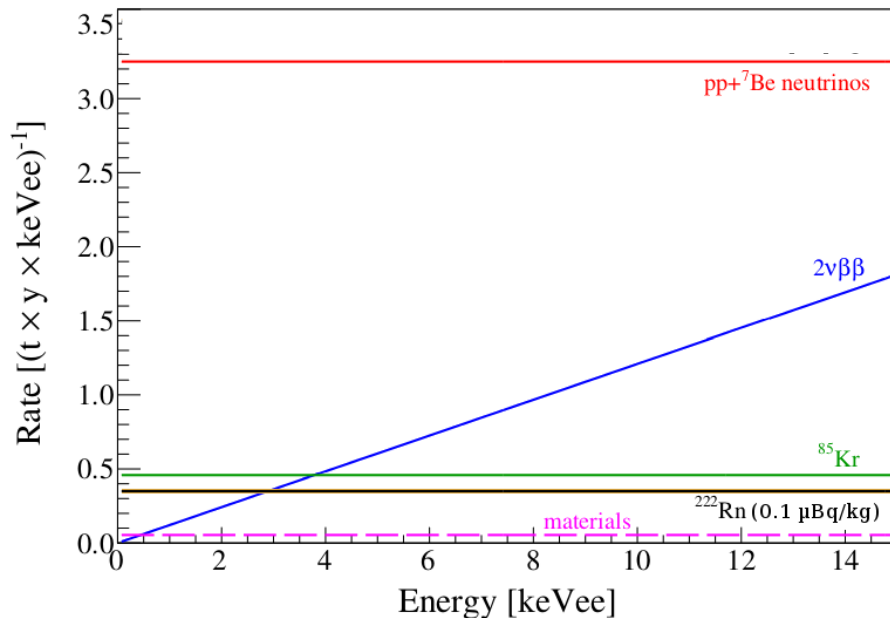
- 60t active LXe target (78t total)
- 2.97m height, 2.98m diameter
(→ factor 2 larger than LZ and XENONnT)
- Drift field: 240-290 V/cm
for optimal background rejection
- Two arrays of 3" low-background PMTs
(2362 tubes in total)
- Double-wall Ti cryostat
- **Early science** with ~45t detector
(flatter but same diameter)
→ important for early commissioning
and risk mitigation
- Design allows for straightforward
upgrade to 80t TPC to acquire very
large exposure faster



Background: Neutrinos

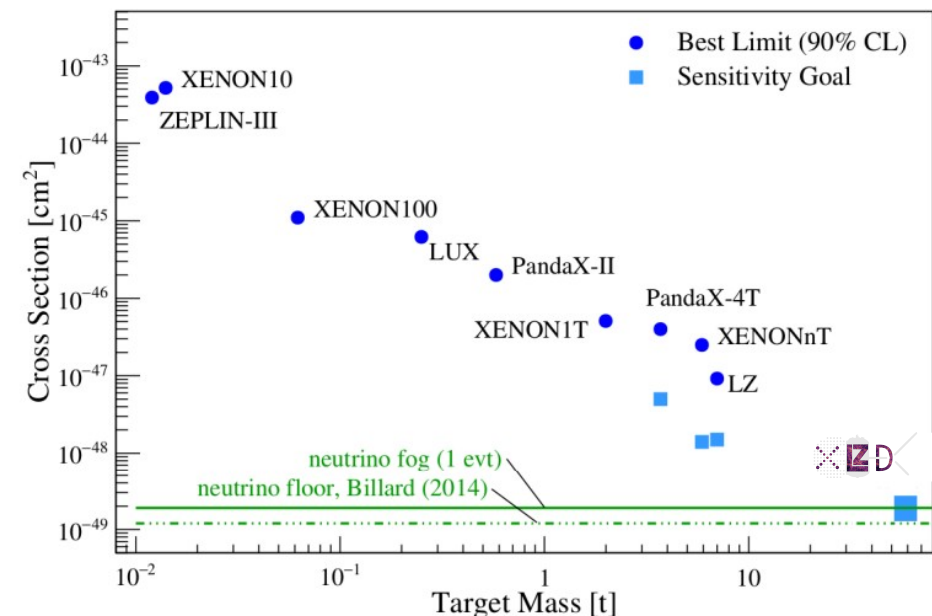


Design book close to publication

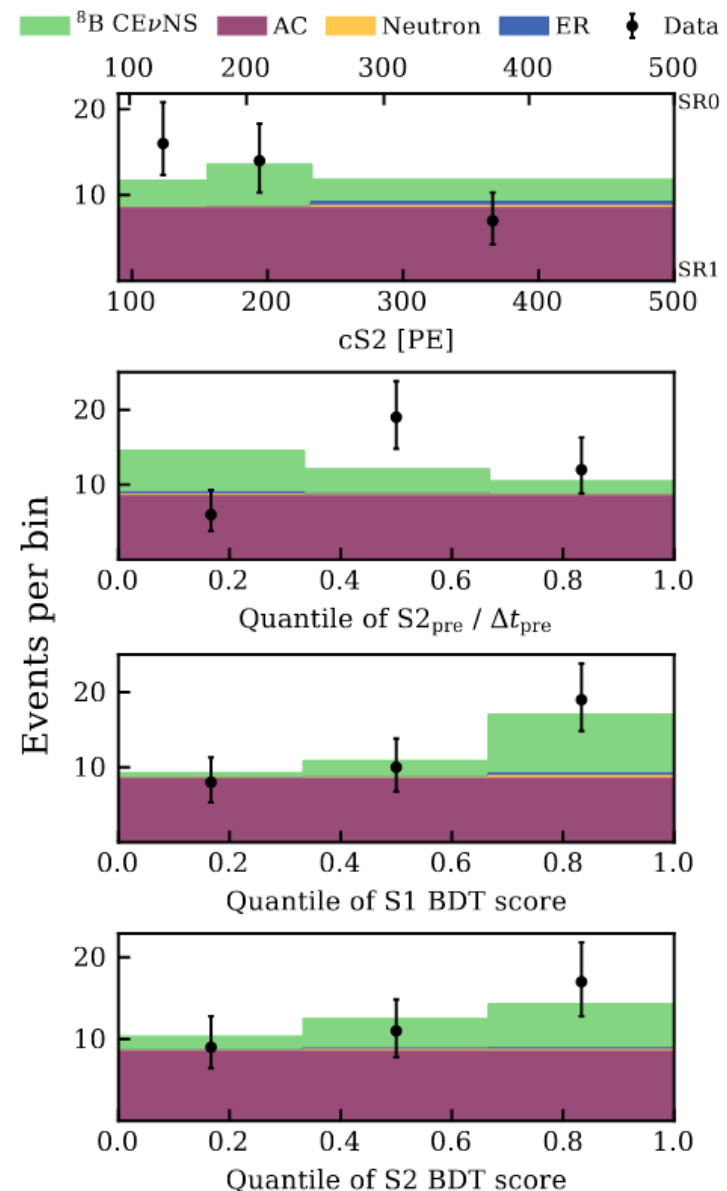
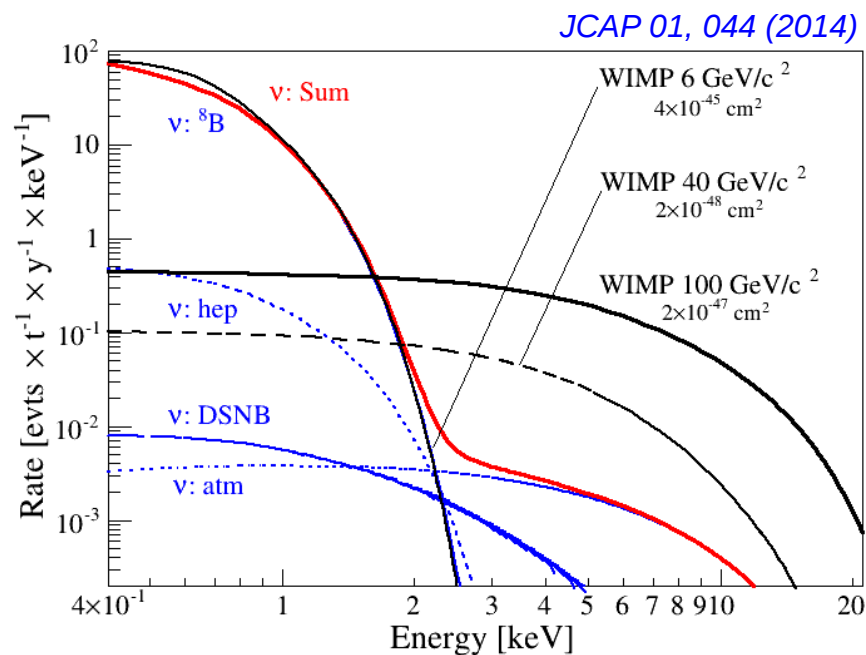


Reduce all other backgrounds by

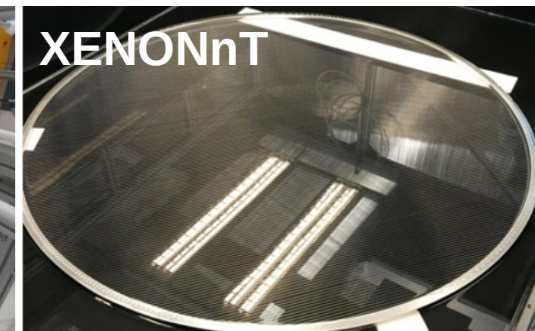
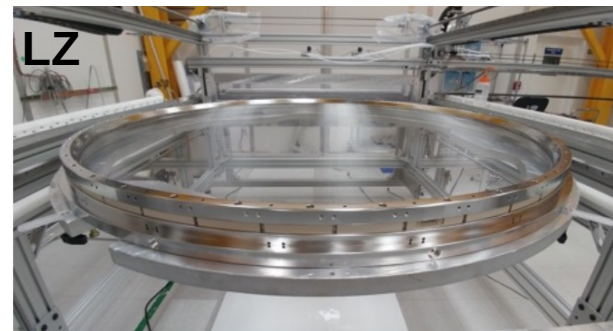
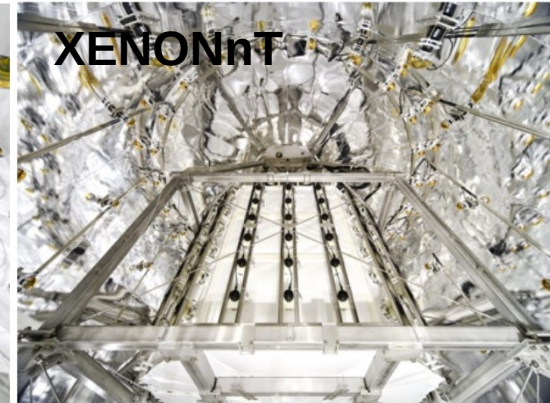
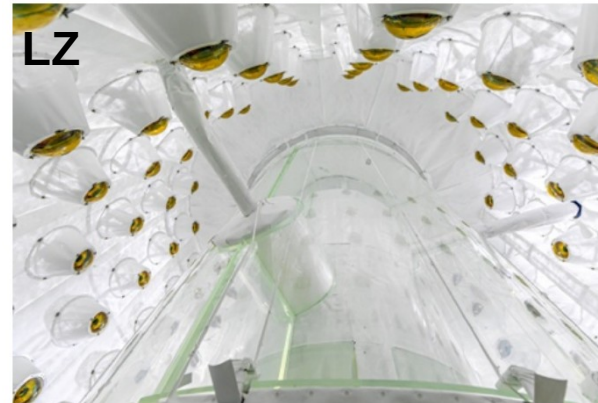
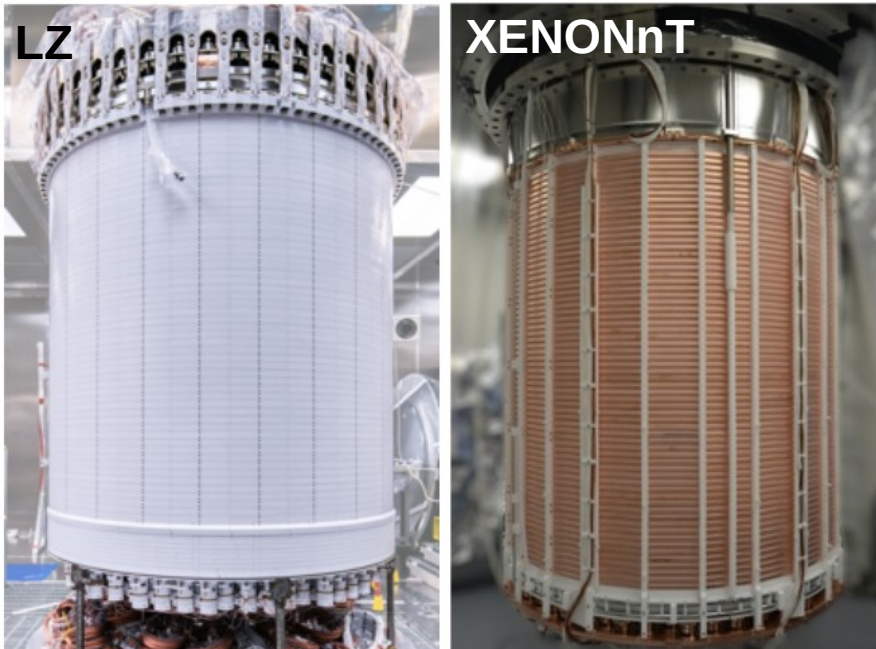
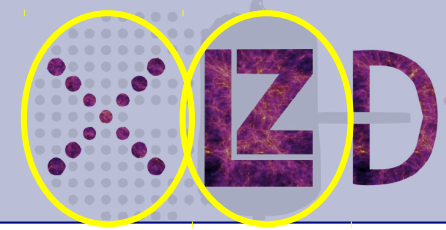
- Low-background materials, shielding
- Detector design, surface treatment
- Active vetoes (LXe, n, μ)
- ${}^{85}\text{Kr}$ removal (cryogenic distillation)
- Online ${}^{222}\text{Rn}$ removal (cryogenic distillation)
- Precautions against ${}^3\text{H}$ contamination
- Optimized HV system → avoid accidentals



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



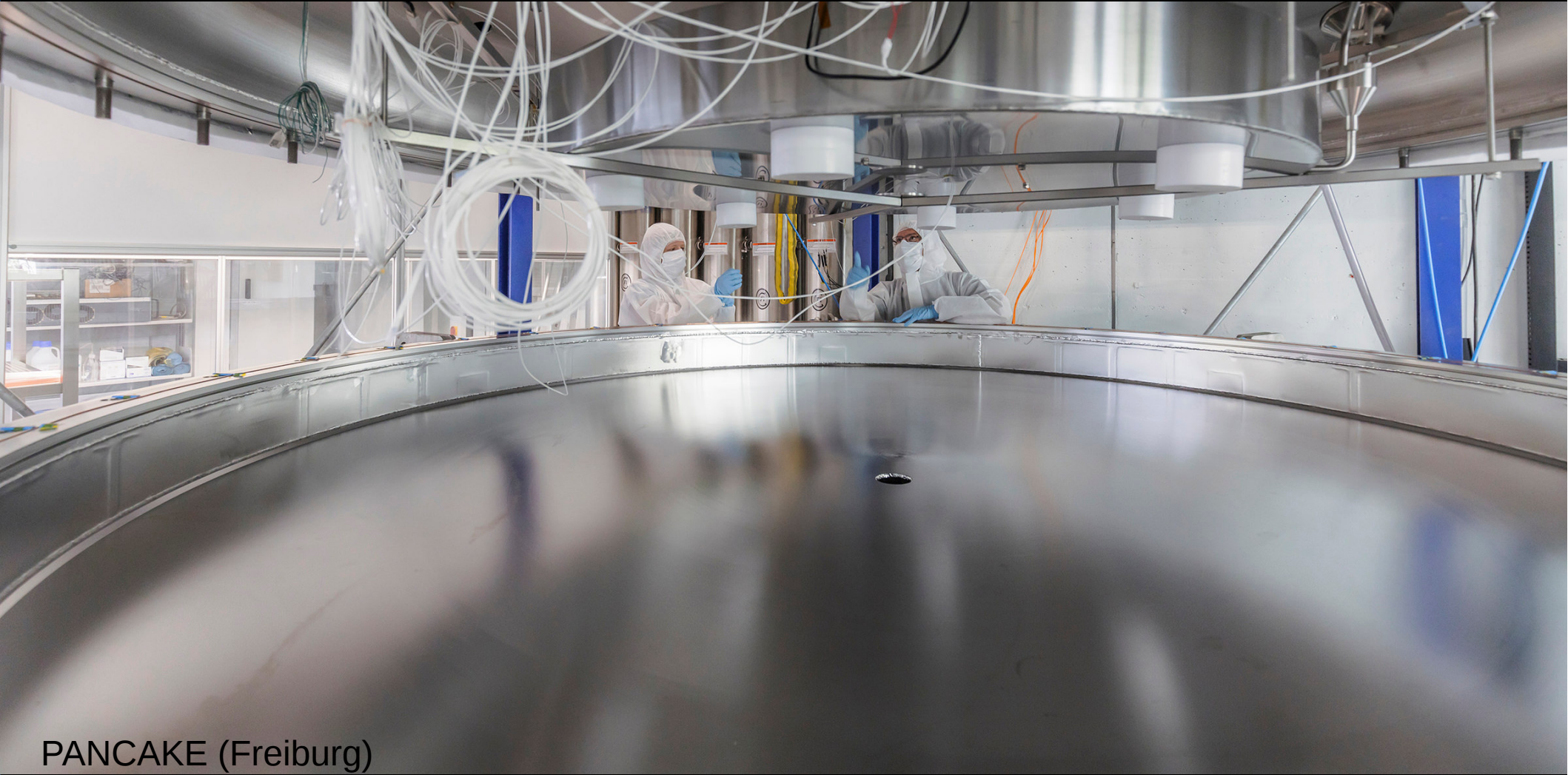
Two world-class demonstrators



- 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)

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



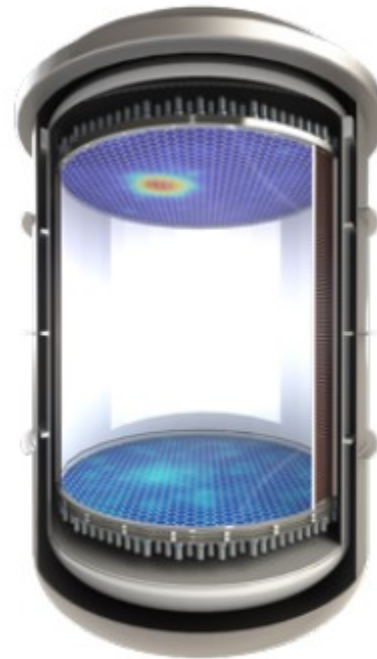
Supernovae

Early alert
Supernova neutrinos
Multi-messenger
astrophysics



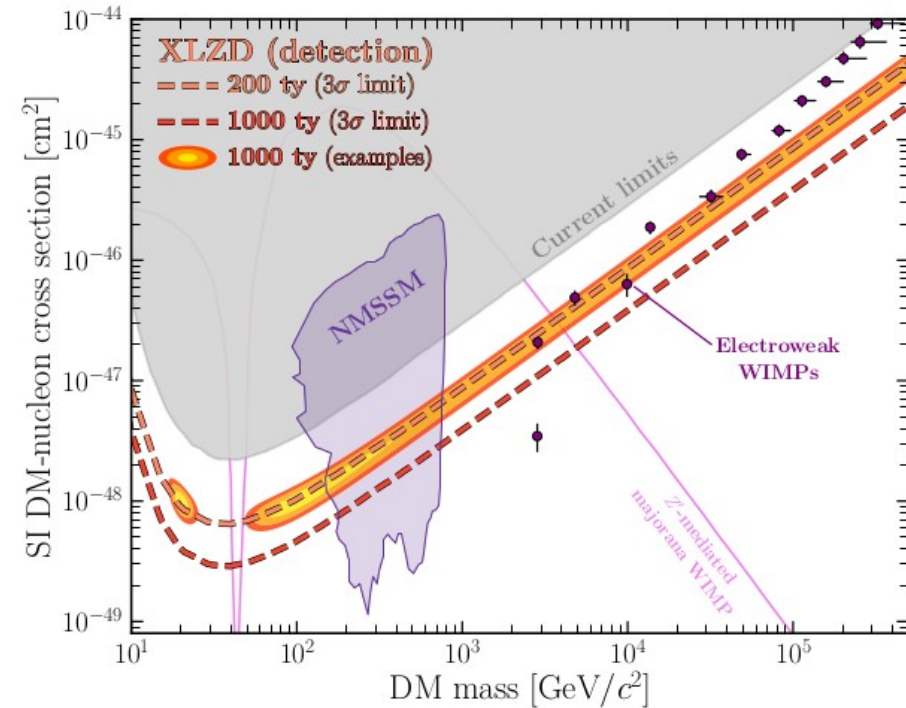
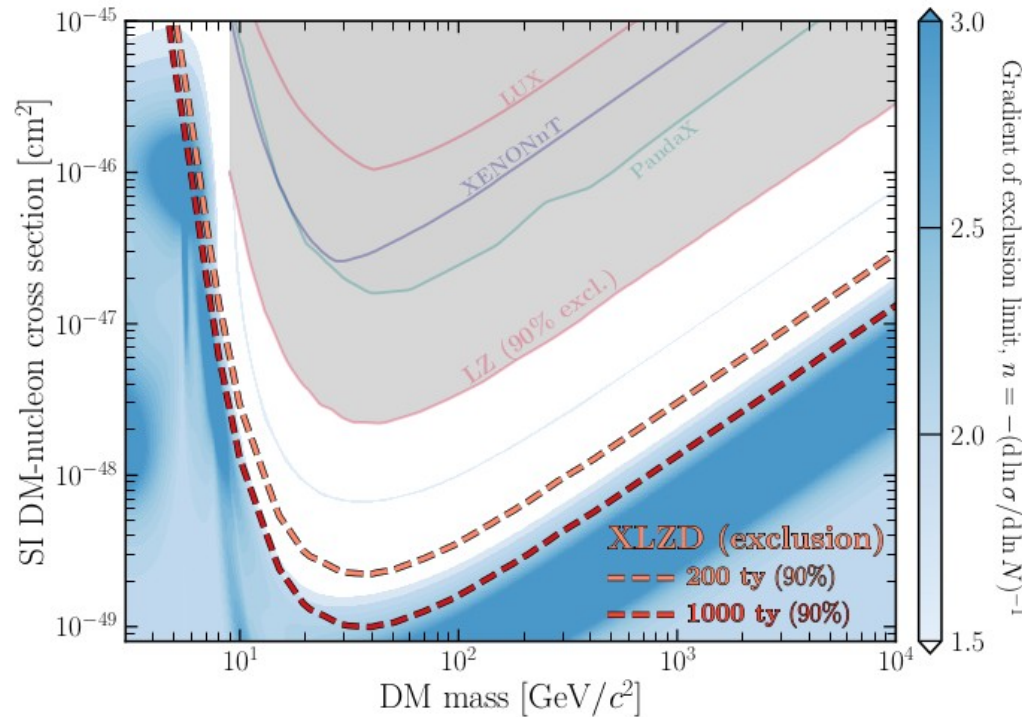
Sun

pp neutrinos
Solar metallicity
 ${}^7\text{Be}$, ${}^8\text{B}$, hep



A xenon-based low-background observatory for astroparticle physics

Science I: Dark Matter

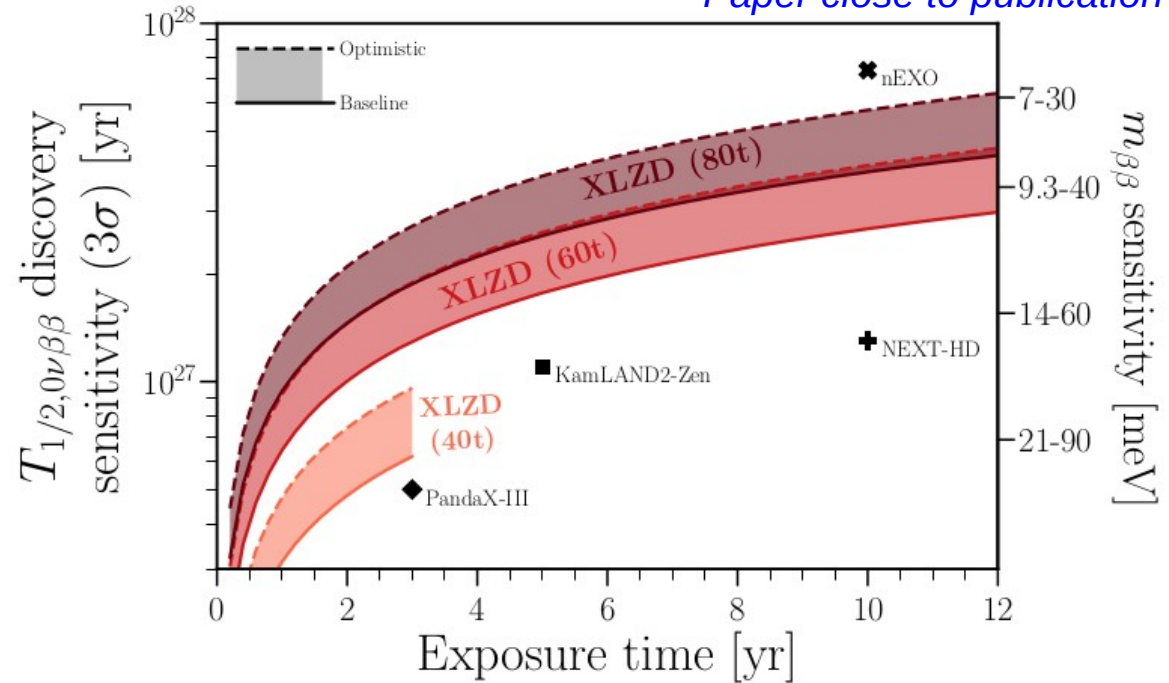
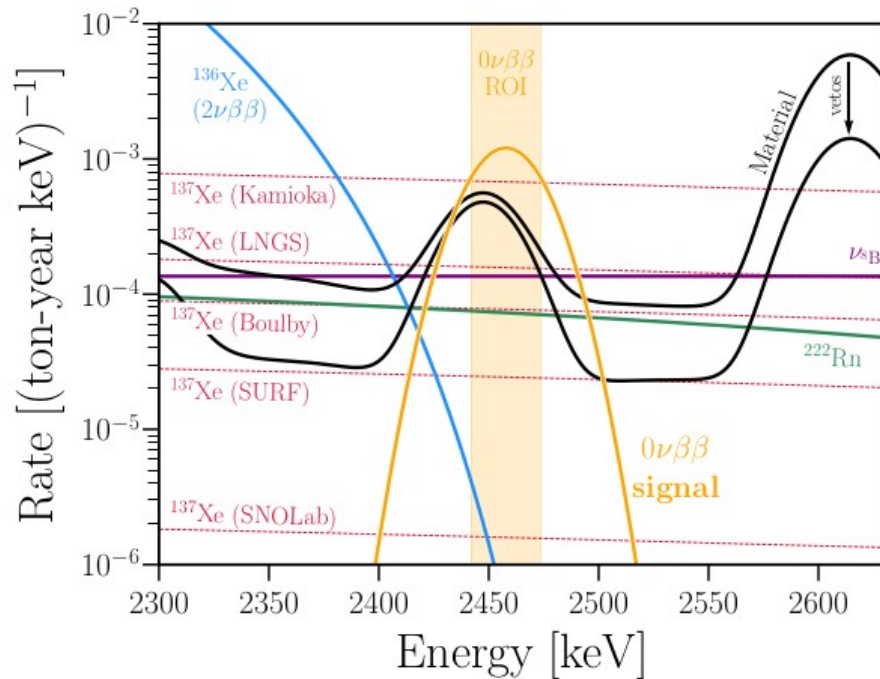


- Excellent sensitivity for spin-independent and spin-dependent WIMP-nucleon scattering
- Covers parameter space into the neutrino fog
- Minimum exposure: 200 t \times y, aim for \sim 500 t \times y
- Definite detector: up to 1000 t \times y in case hint of signal is seen earlier

Science II: $0\nu\beta\beta$

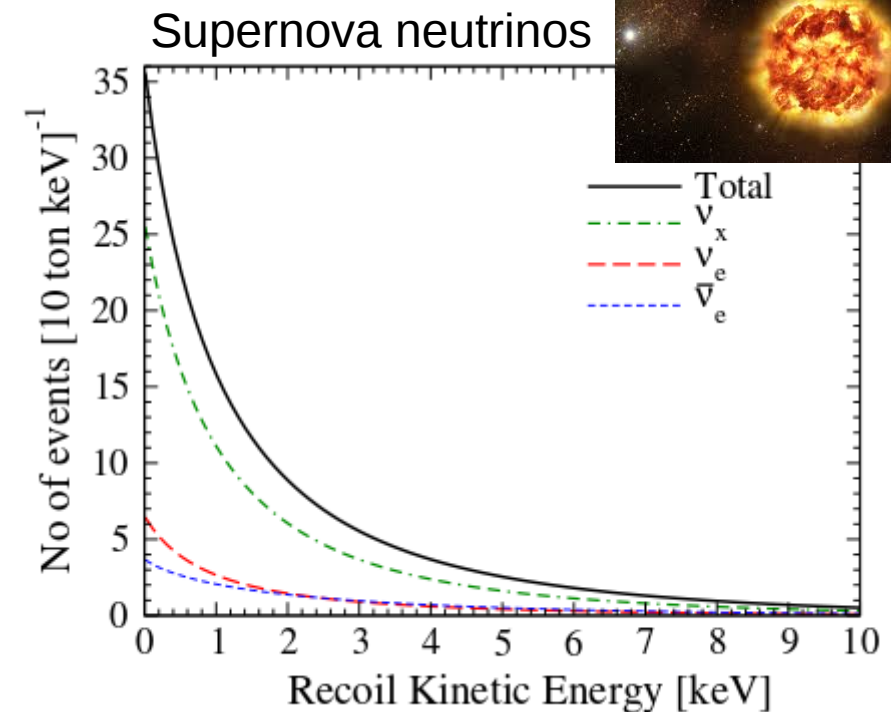
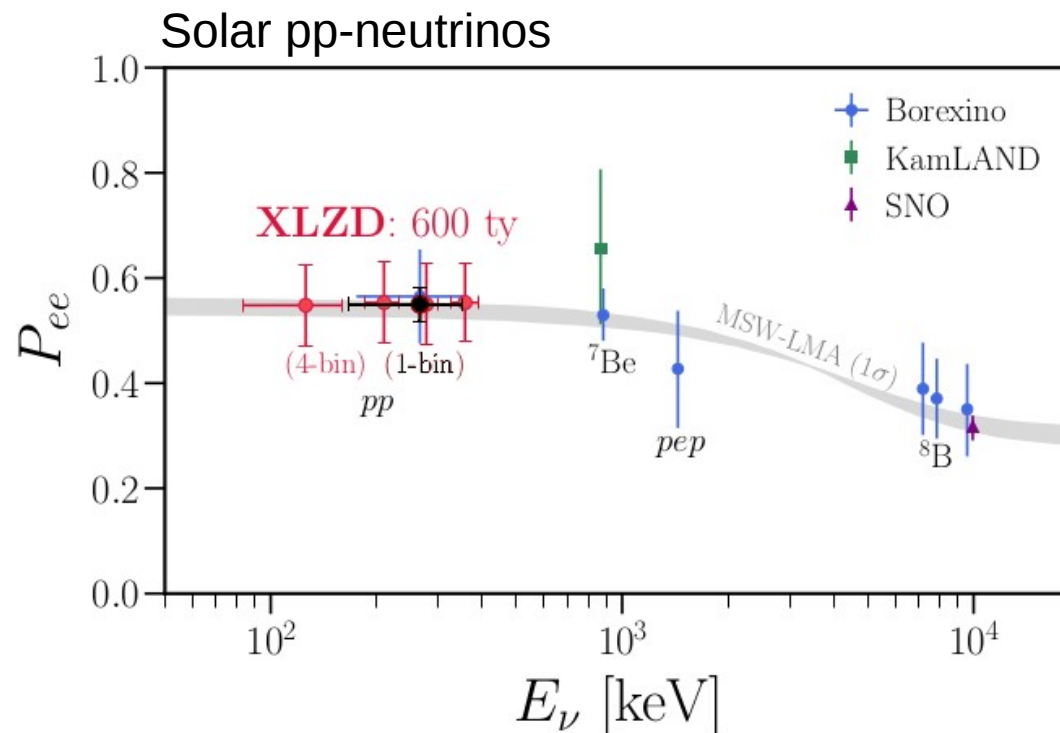


Paper close to publication



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

Science III: 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)

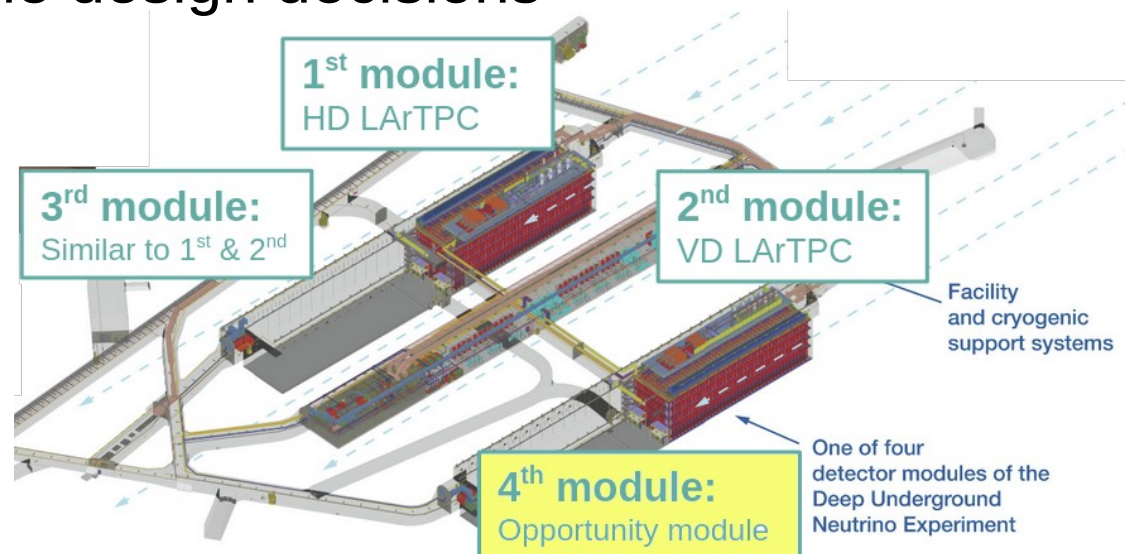
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Covers (probably) all science channels you can think of...

- Host laboratory not yet defined
- Minimal lab-depth driven by $0\nu\beta\beta$
- 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

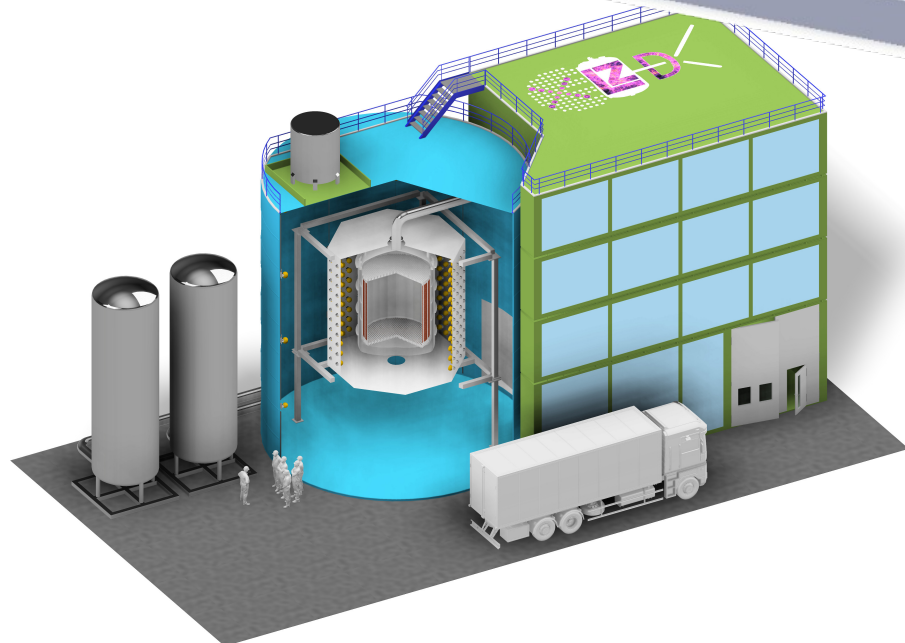
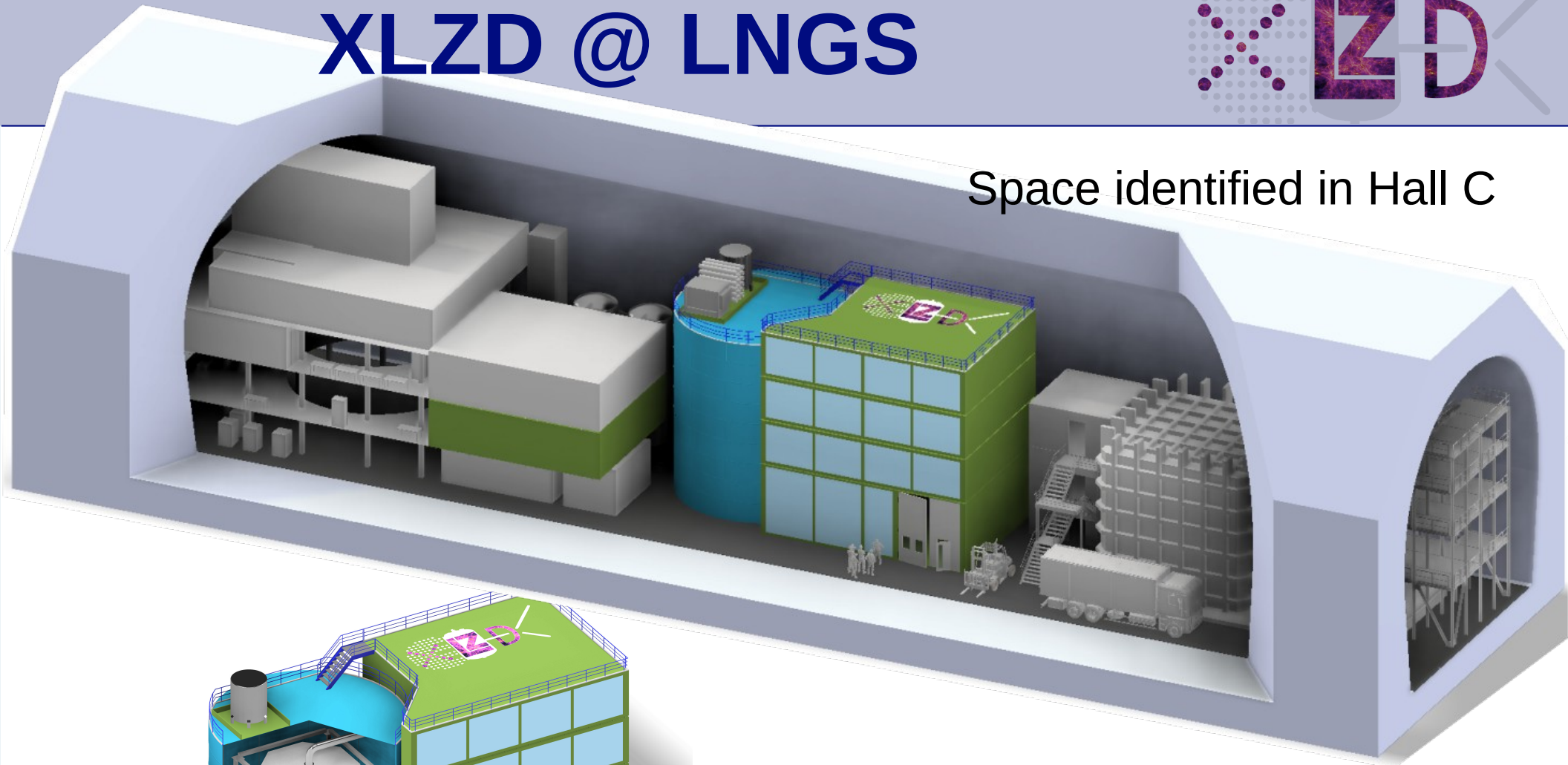
SURF option:



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

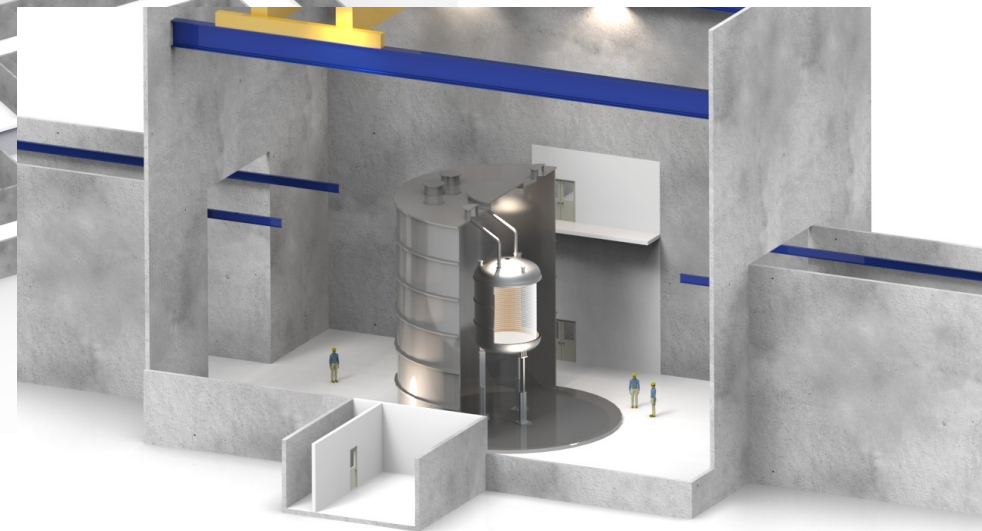
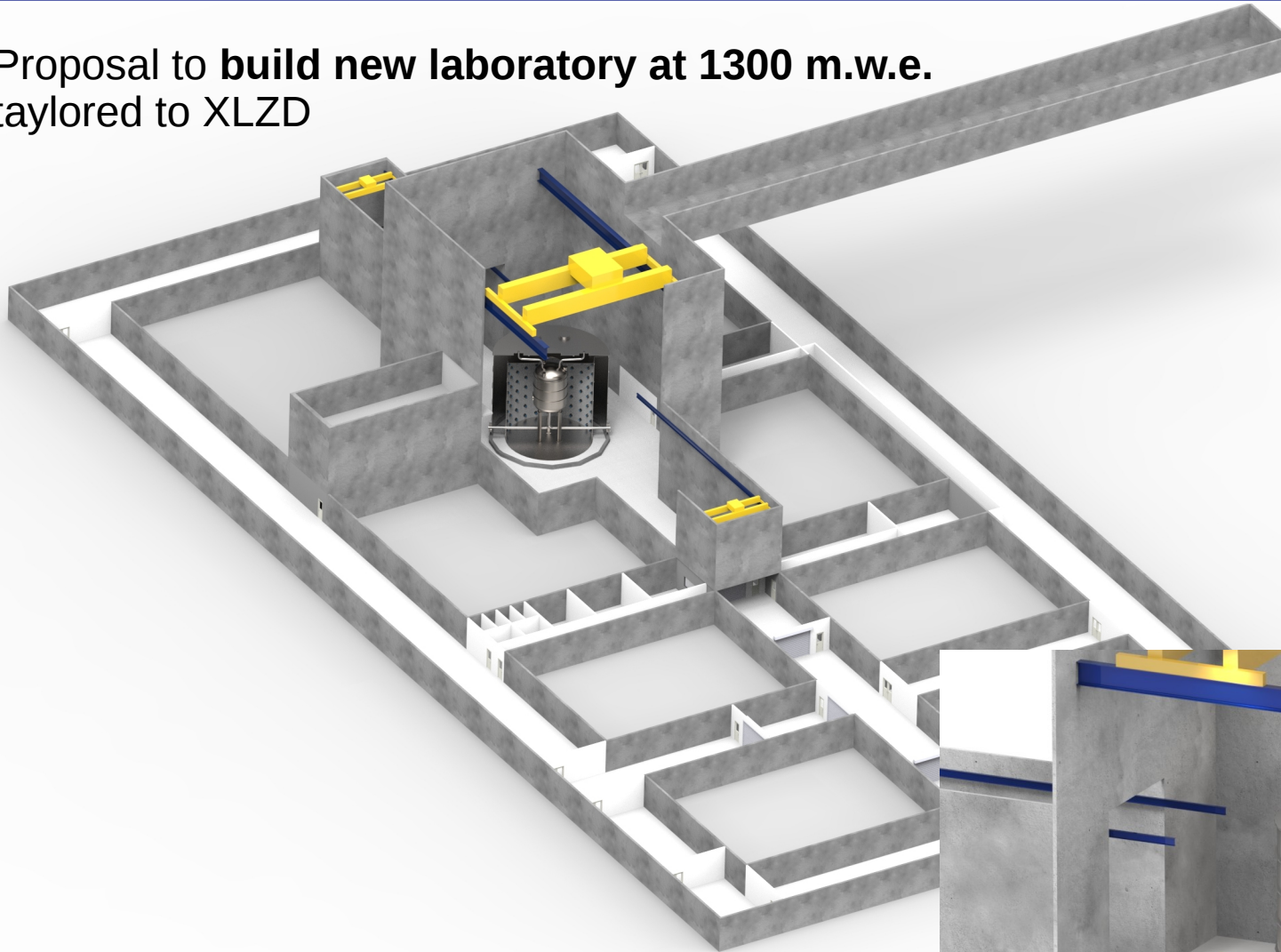
XLZD @ LNGS



XLZD @ Boulby (UK)



Proposal to **build new laboratory at 1300 m.w.e.**
tailored 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)




XLZD Meeting @ Rutherford Lab (UK), April 2024

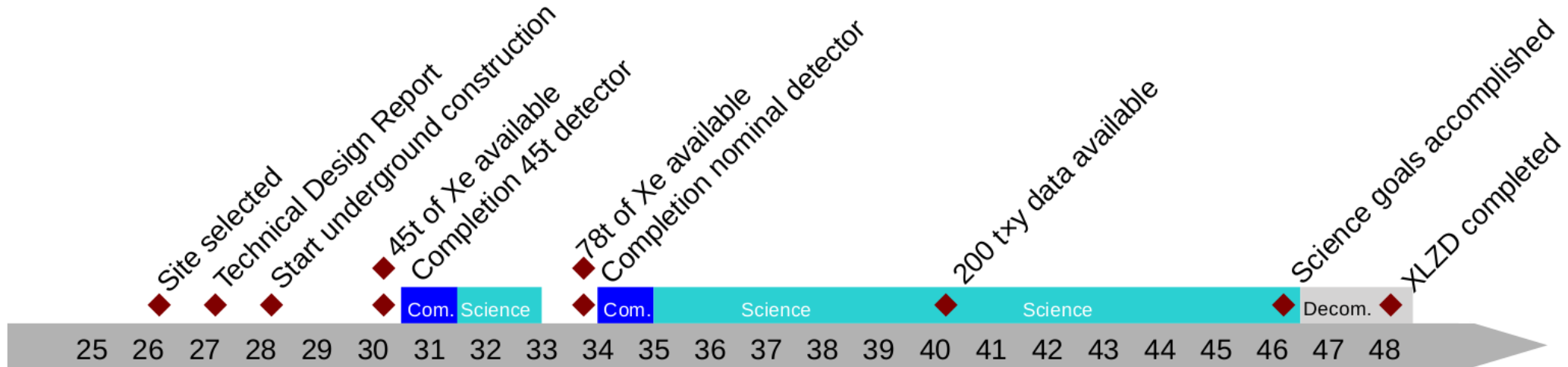


FIS Proposal: XLZD Project



- **XLZD: a xenon-based low-background observatory for astroparticle physics**
- Responsible Institution: KIT (Kathrin Valerius)  KIT
Karlsruher Institut für Technologie
- 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 decommissioning: 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

