XENONnT and Beyond

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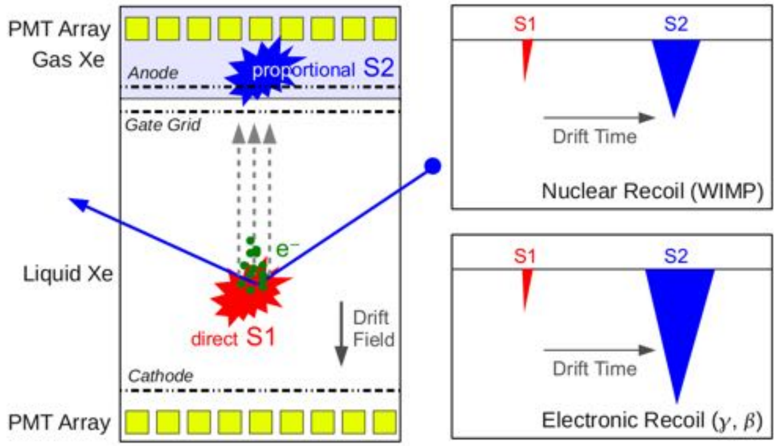
WIN 2015 – MPIK Heidelberg

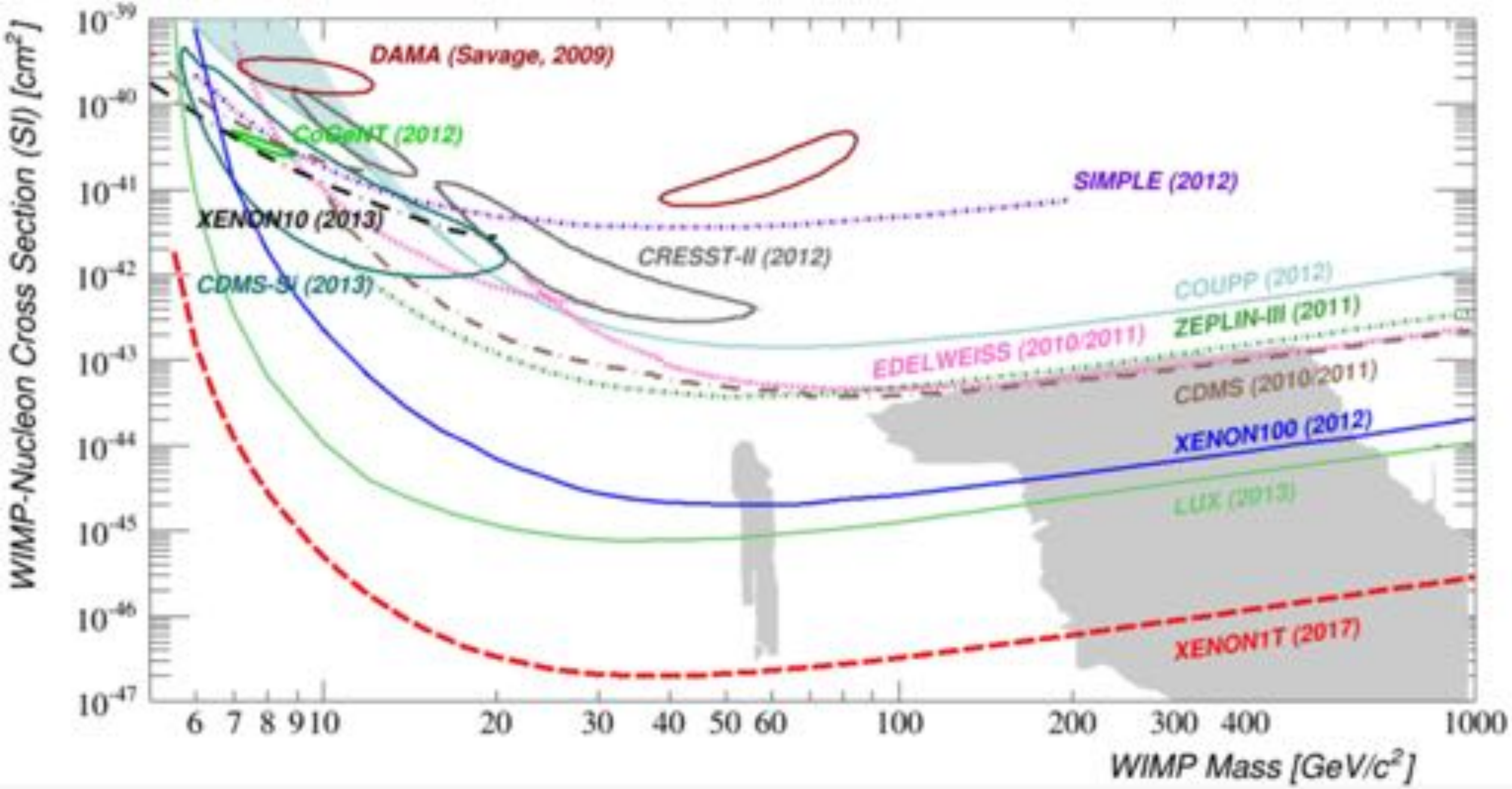
The XENON program for direct Dark Matter Search

THE PRESENT: XENON1T

- LXe TPC under construction at Gran Sasso.
- 1st ton-scale experiment for direct DM detection.
- 3t of LXe, 1t target.
- Commissioning in summer, start data taking end of 2015.



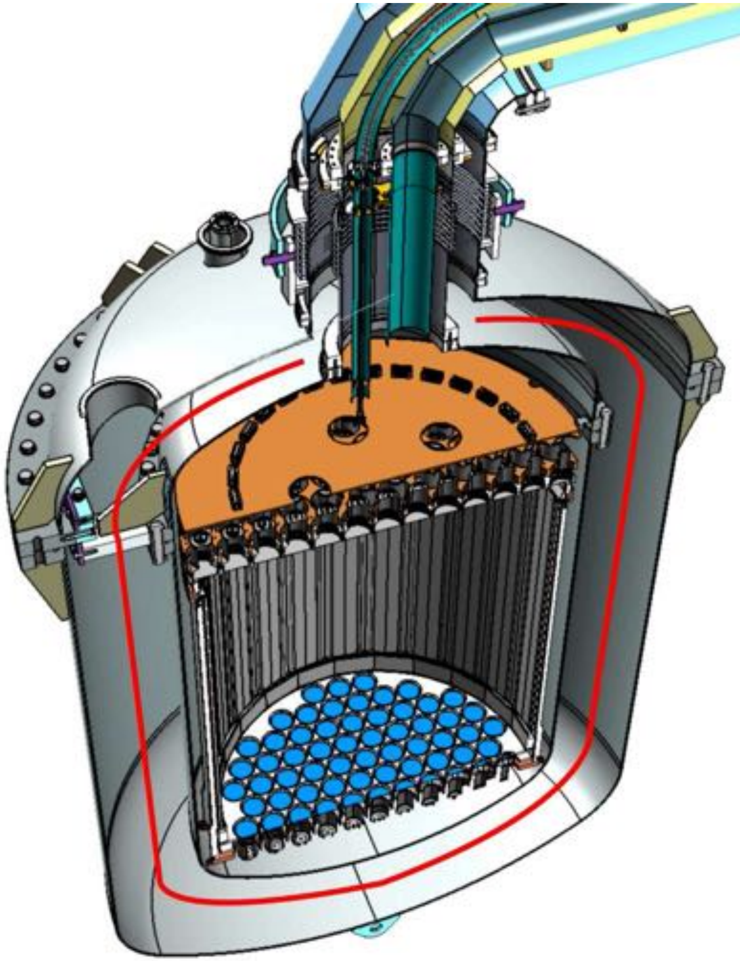
XENON1T SENSITIVITY



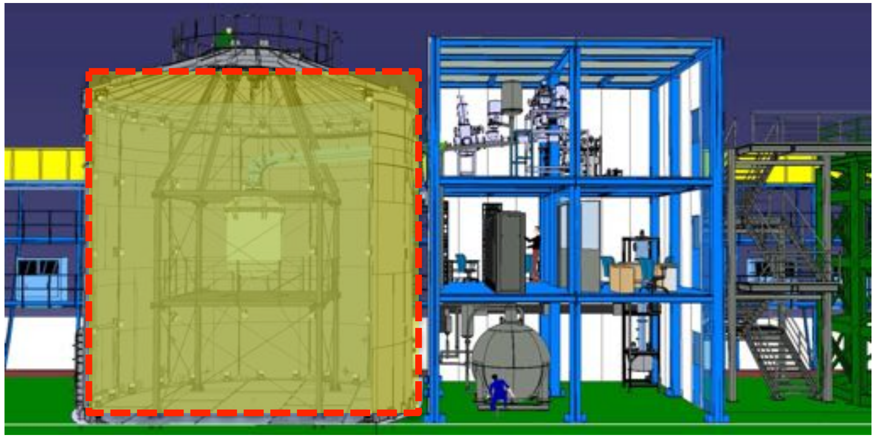
Sensitivity for Spin-independent WIMP-nucleon cross section:
2×10^{-47} cm^2 for 50 GeV WIMP

THE FUTUTRE: XENONNT

- Rapid upgrade of XENON1T.
- ~7 tons of liquid xenon
- New inner vessel and TPC.
- ~200 additional PMTs and electronics channels.
- Sensitivity to spin-independent WIMP-nucleon cross sections of 3×10^{-48} cm^2.

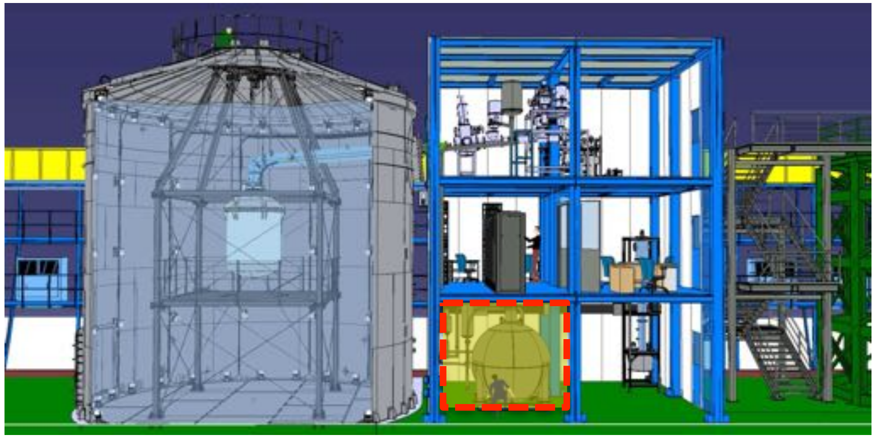


WATER TANK (MUON VETO SYSTEM)



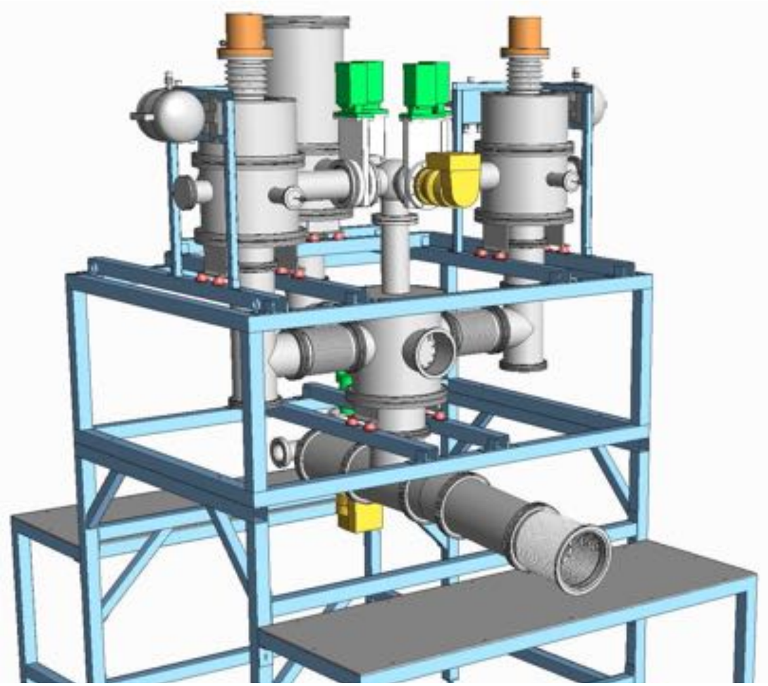
- 10m high, 9.6m diameter.
- Covered with 3M reflector foil.
- 84 8" PMTs (type Hamamatsu R5912).
- μ -induced background <0.01 evt/yr.
- Sufficient for XENONnT.

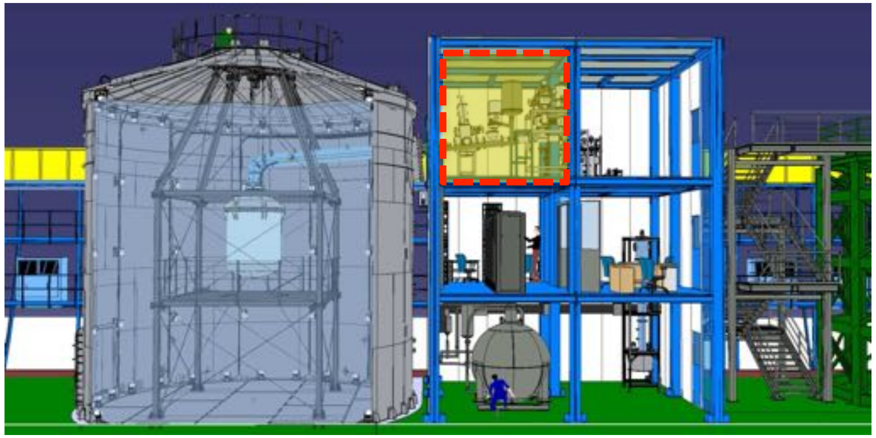
XENON STORAGE TANK



- Double-walled high pressure vessel (70 bar).
- Xe-storage in liquid phase or gaseous phase.
- Rapid emergency recovery.
- 7 tons capacity: Sufficient for XENONnT.

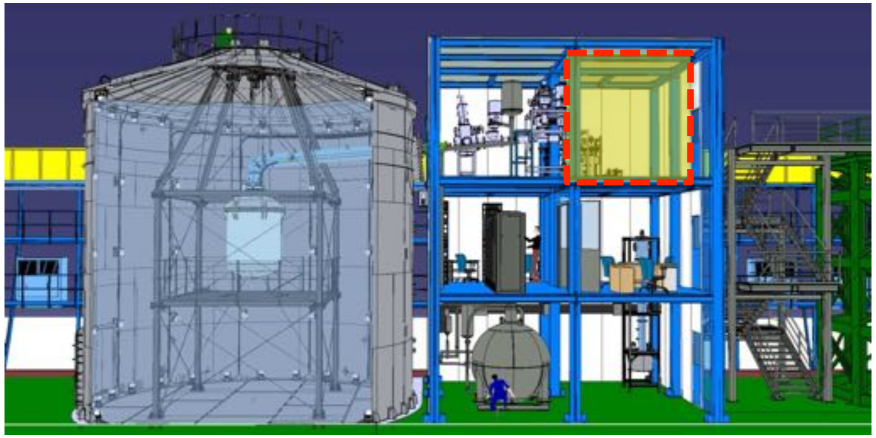
Cryogenic System

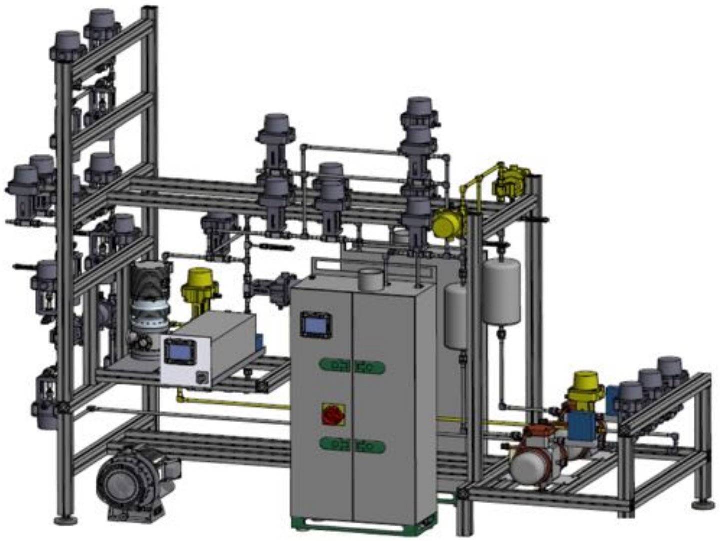




- 200 W cooling power by 3 PTRs (Pulse Tube Refrigerators).
- PTR maintenance during operation.
- Emergency LN_2 cooling.
- Sufficient for XENONnT.

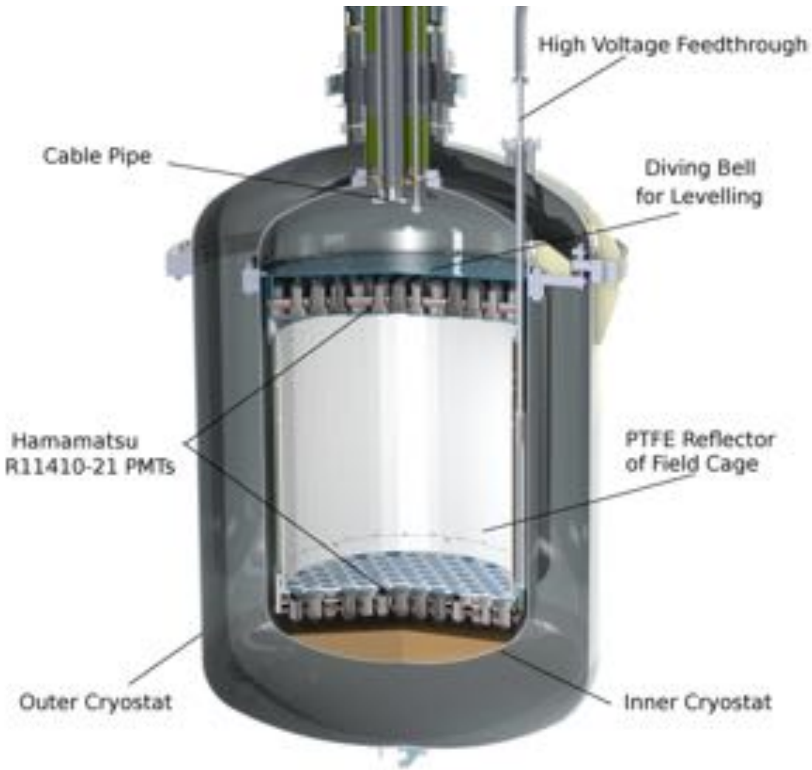
PURIFICATION SYSTEM FOR GASEOUS XE

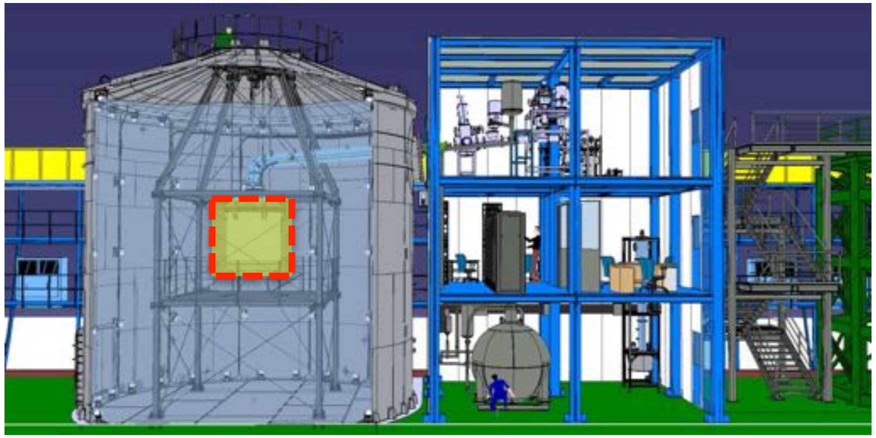




- GXe circulation up to 100 slpm.
- Hot getter purification.
- In-situ monitoring of H_2O-concentration.
- Sufficient for XENONnT.

Cryostat and Cryogenic Pipes





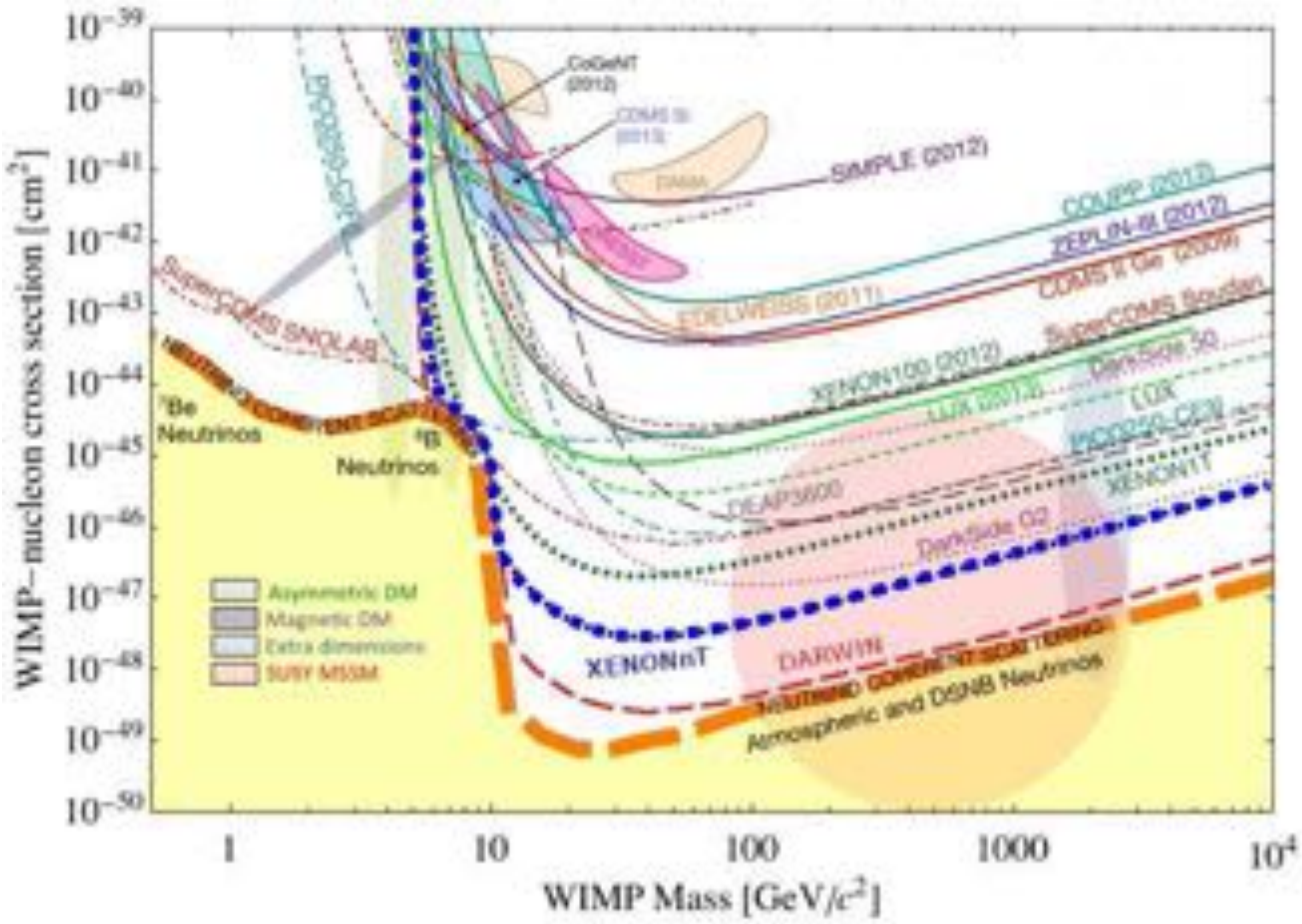
- Double-wall vacuum cryostat made from stainless steel.
- Larger outer vessel. May host XENONnT inner vessel.
- Cables for all XENONnT channels already installed.

FROM XENON1T TO XENONNT

- Commissioning of XENON1T will start in 2015
- Infrastructure ready for rapid upgrade
- Xenon purchase ongoing: 3.7 tons delivered, 0.5 tons more ordered → Already more than 50% for XENONnT available.
- 1-2 years of physics data taking with XENON1T.

- Preparation for XENONnT in 2017 (New inner vessel and TPC).

Sensitivity of XENONnT



Achievable sensitivity: 3×10^{-48} cm^2

The far Future: Beyond XENONnT

- XENONnT will not cover completely experimentally accessible parameter space (limited by coherent neutrino scattering).

- Ultimate LXe experiment would need
  - 100 t × y exposure (→ ~20 t LXe target).
  - to be free of radioactive background, i.e. background is neutrino – domianted.

    → Neutrino as new physics channel.

- DARWIN-LXe: Future large observatory for dark matter and neutrinos.

CHALLENGES: ELECTRON / NUCLEAR RECOIL (ER/NR) DISCRIMINATION

- Irreducible ER background from solar ν-e elastic scattering (JCAP01 (2014) 044).
  - 30 ev./t/y in 2–10 keV window form solar ν's.
  - 6 ev./t/y in same window from 2νββ.
- Requires excellent ER/NR discrimination (>99.9 %).

→ Optimize light yield
  - New photo sensors (High QE PMTs, SiPMs, GEMs).
  - 4π coverage.
  - Single phase TPC (?).

- Field uniformity.

Challenges: Drift Field, HV, Mechanical Stability

- 1 kV/cm + 2 m drift lengt → 200 kV on cathode.
- Operation at lower drift field?
  - LUX: 0.18 kV/cm.
  - XENON100: 0.5 kV/cm.
  - More S1 light, less S2 signal: Discrimination?
- Flatness of large surface electrodes.
  - S2 depends on gap size, field strength.
  - Variations influences ER/NR discrimination.
  - Single phase TPC (?)
- Shrinking during cool-down (tensions).
- Large TPC becomes heavy (> 1 ton)
  - Strength of PTFE?

CHALLENGES: XENON LIQUID TARGET

- One annual world production needed (~50 tons)
  - Procurement.
  - Cost.
  - Storage.
  - Cooling.
  - Purification (at high speed).
  - Maintaining purity.
  - Fast emergency recuperation (by gravity?).

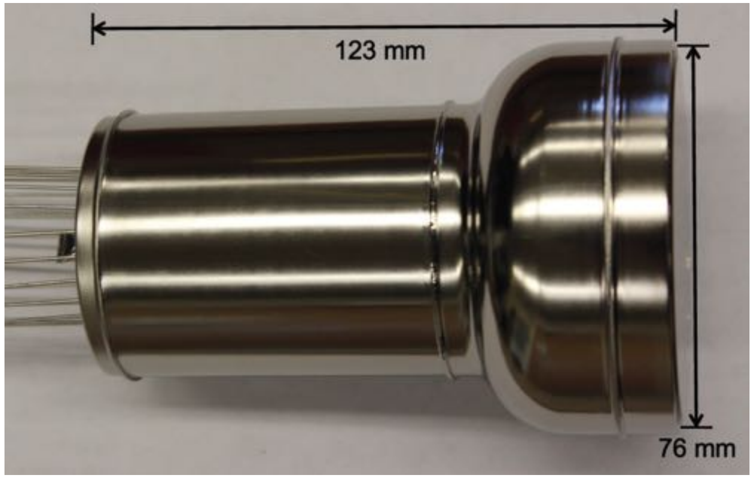
CHALLENGES: EXTERNAL BACKGROUND

- Goal: 0.001 events/t/y
- Cosmogenic neutrons:
  - 10× better muon veto performance than XENON1T.
  - larger water tank (14 m diameter to fit in Gran Sasso).

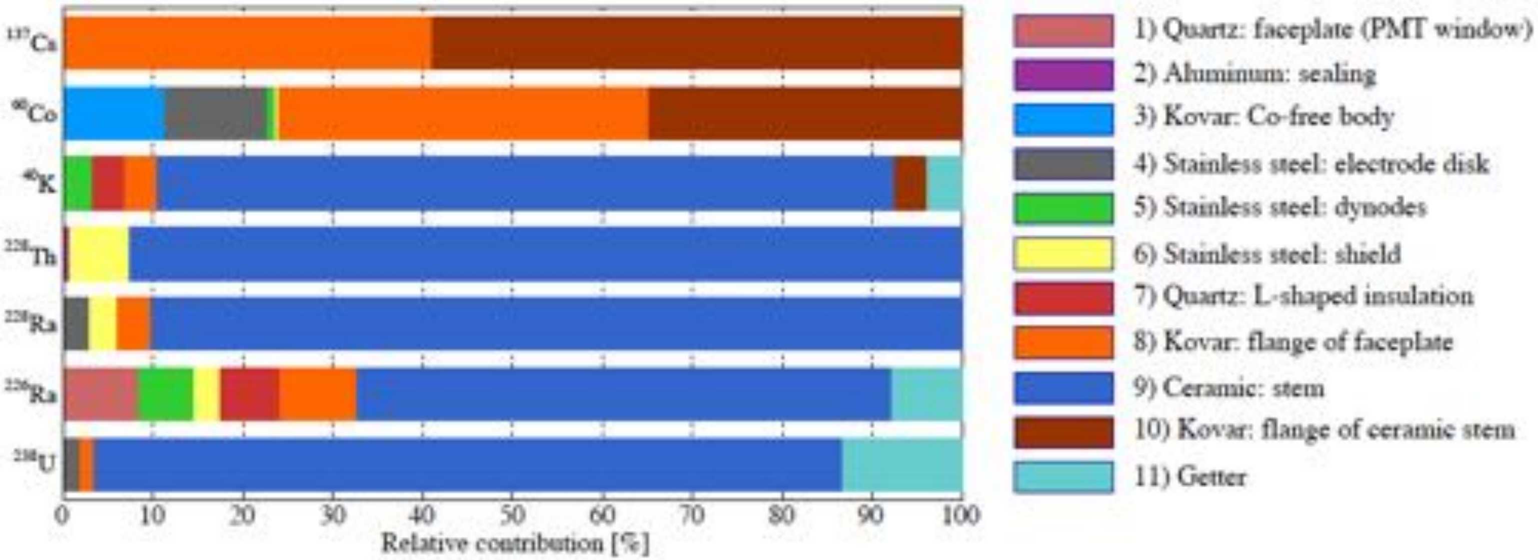
    or
  - line experimental hall with muon veto system.

- Radiogenic neutrons:
  - (α/n) reactions in construction materials.
  - Liquid scintillator veto around cryostat (Darkside).
  - Reducing radioactivity (Screening).

REDUCING RADIOACTIVITY IN R11410 PMT FOR XENON1T

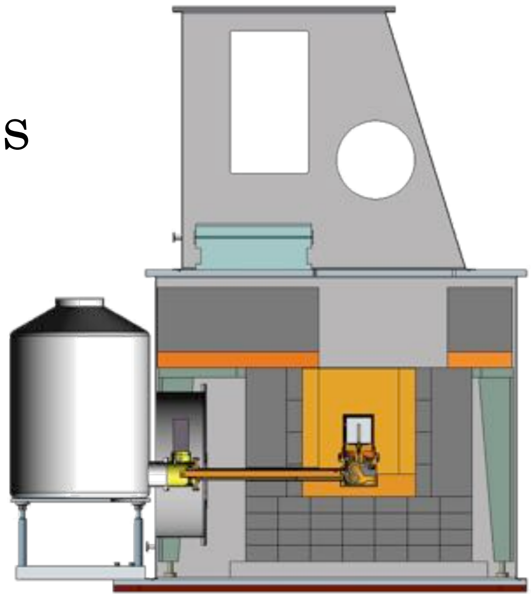


- Individual components screened and replaced.
- Radioactivity reduced 10× to 12 mBq/PMT.
- Resdiual contamination mostly in ceramics.
- see arXiv: 1503.07698.

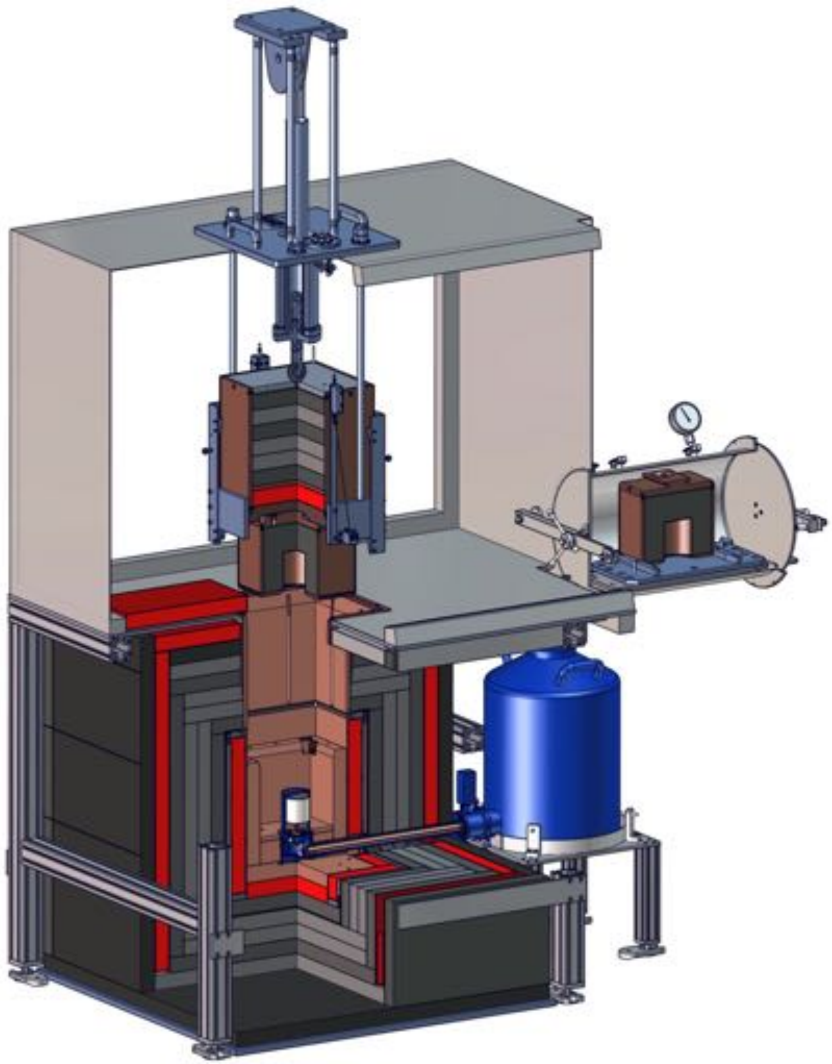


New Developments in Gamma-Ray Screening

- Ultralow background deep underground HPGe spectrometers
- Best sensitivity achieved by GeMPIs
  developed at MPIK
  operated at Gran Sasso
  - ^{226}Ra: 16 μBq/kg, ^{228}Th :19 μBq/kg
- Issues:
  - Long queues
  - Long screening times
  - Only few deep underground locations available
- Need for local screening facilities with competitive sensitivity.



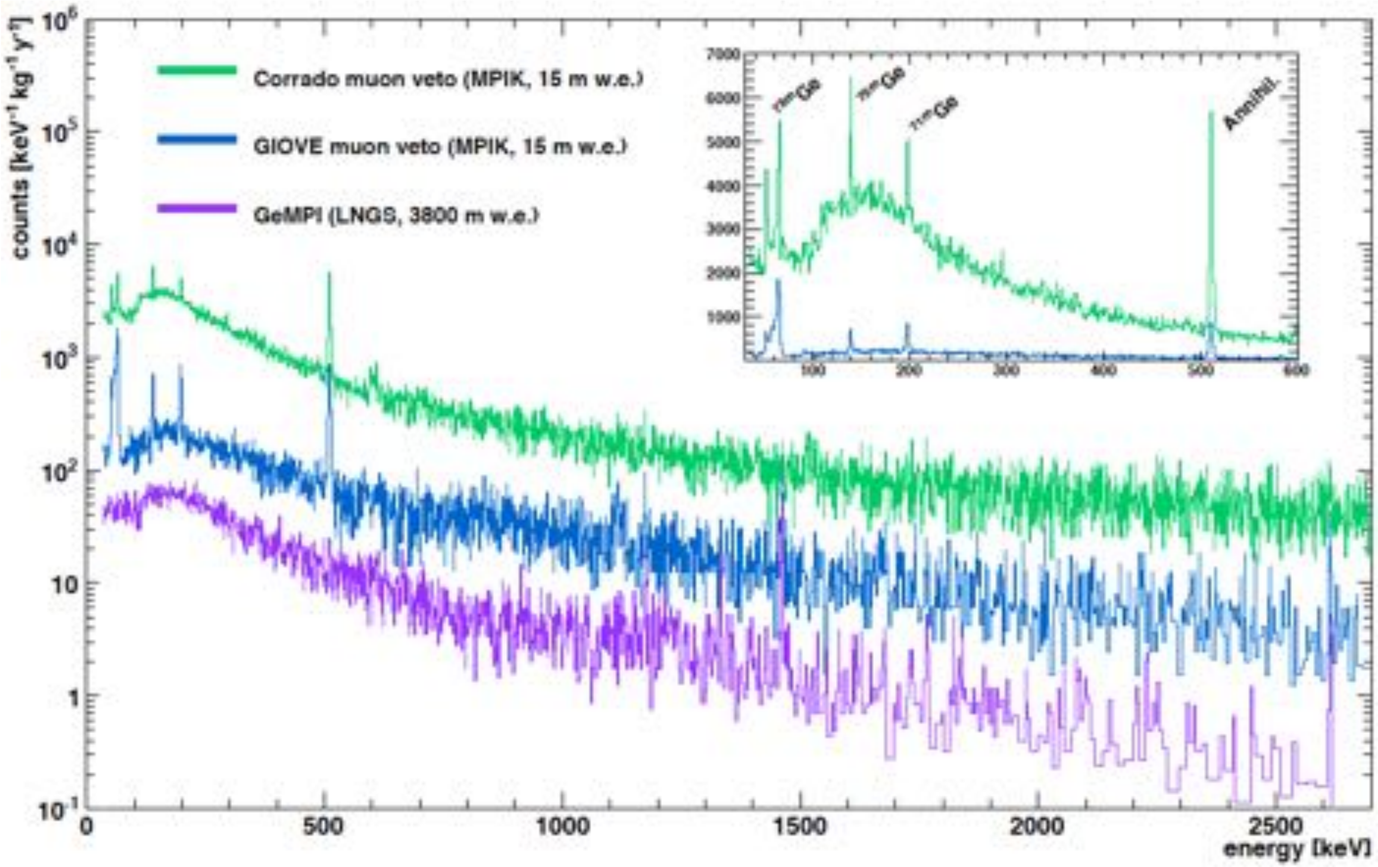
The GIOVE HPGe Spectrometer



Gerd Heusser

- Highly optimized shield design employing
  - Passive gamma shield (Cu/Pb)
  - Neutron moderator and absorber.
  - Inner muon veto.
  - Outer muon veto.
  - Glove-box and air lock.
  - High purity materials.
- Operated at MPIK only few meters below surface at 15 m w.e.

PERFORMANCE OF GIOVE



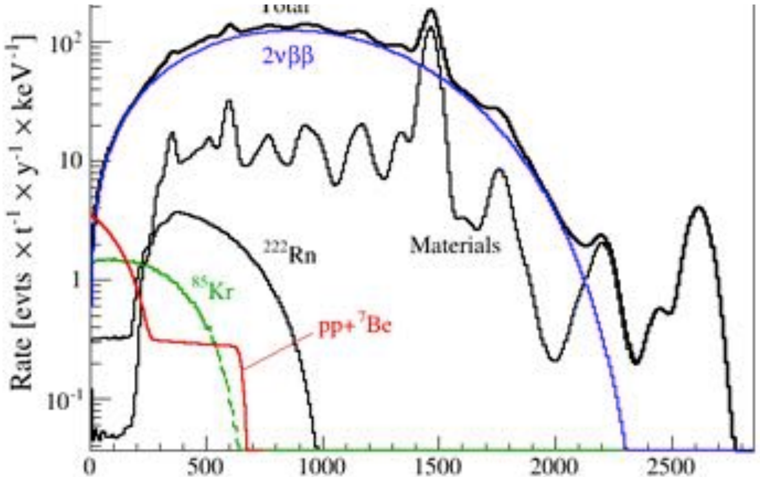
- Achieved sensitivity:

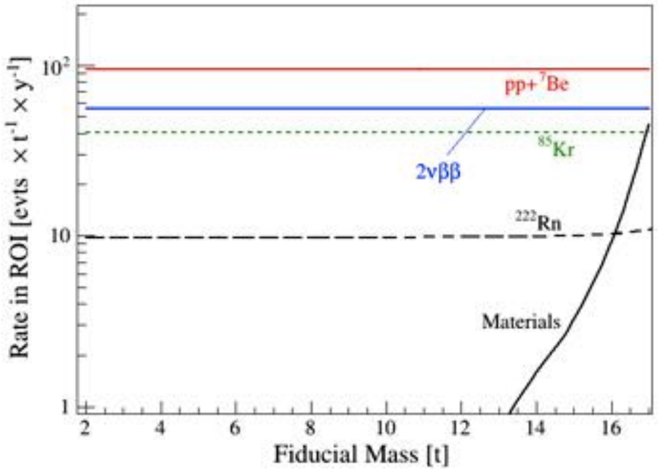
  ^{226}Ra: <68 μBq/kg , ^{228}Th: <49 μBq/kg

- Closed gap to deep underground spectrometers.

Paper close to submission.

CHALLENGES: INTERNAL BACKGROUND



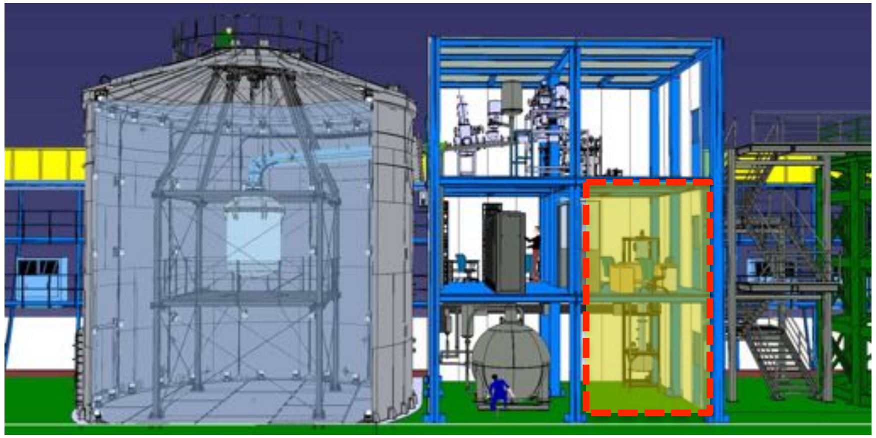


- Internal contaminations must be below neutrino background.

  → Kr/Xe < 0.1 ppt.

  → ^{222}Rn in Xe: < 1 μBq/kg (lower for neutrino physics).

REMOVING KRYPTON FROM XENON



- Commercial Xe contains Kr at 1 ppm – 10 ppb level.
- XENON1T: Dedicated xenon distillation column developed by Muenster group.
- High throughput: 3.8 kg/h.

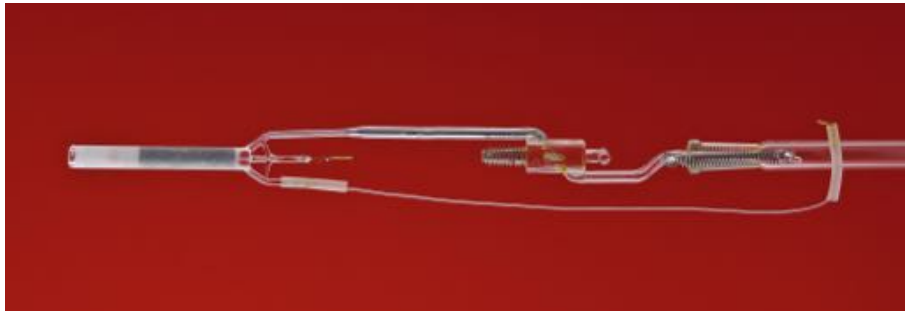
Measurement of Kr in Xe with sub-ppt Sensitivity

- Challenge: Remove bulk Xe before analysis
- By cryo-trapping (NIM A 665, 1 (2011)), optical methods (Rev. Sci. Inst. 84, 093105 (2013)) or gas chromatography.

- Gas chromatography + Mass spectrometry → 8 ppq detection limit (EPJC 74, 2746 (2014))
- Measurement of XENON1T distilled Xe: <28 ppq (!)

^{85}Kr problem solved even for ultimate LXe detector.

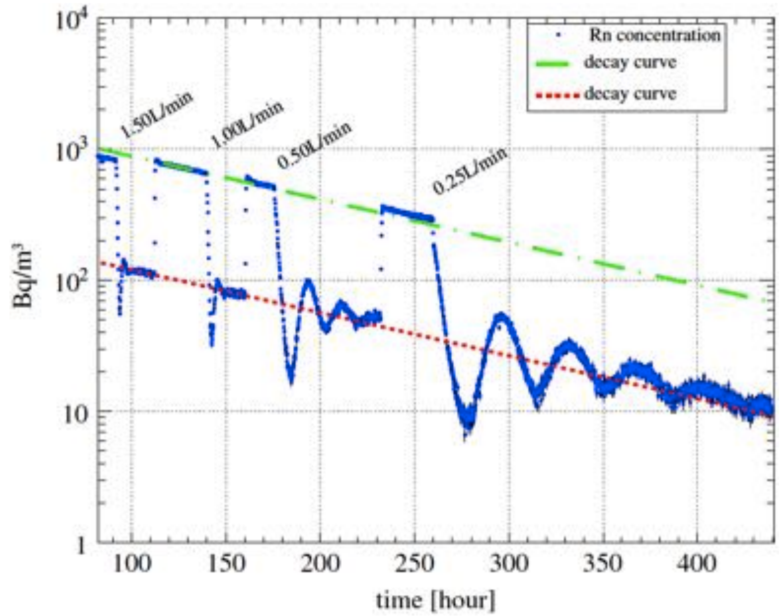
Material Screening: The Radon Emanation Technique

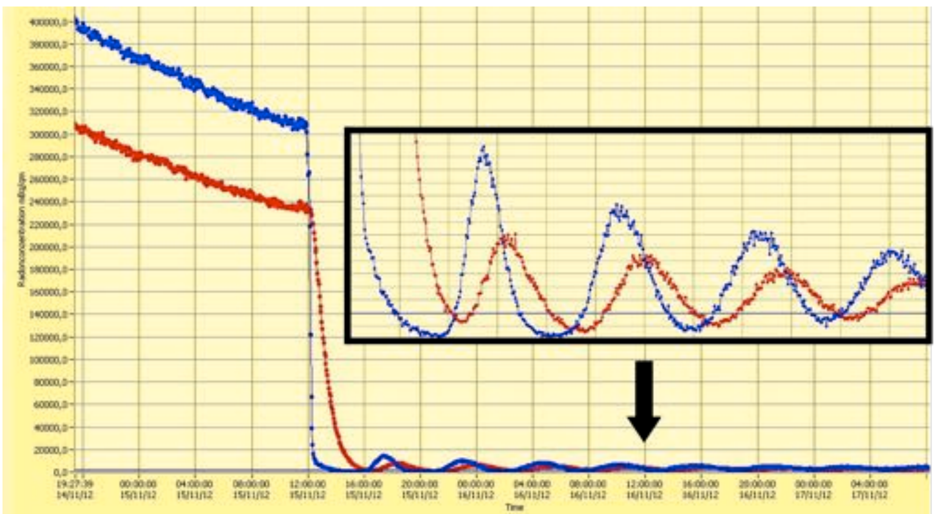


- Direct measurement of emanated ^{222}Rn.
- Sensitivity: 30 µBq.
- Complementary to γ-ray screening.
- Automated system for high sample throughput.
- Systematic investigation of origin of ^{222}Rn sources.

R&D FOR RN REMOVAL FROM XE

- Rn/Xe separation is challenging (similar noble gases).
- Pioneering work by XMASS: NIM A 661, 50 (2012).
- Rn slowed down in adsober until decay.
- Purification efficiency not yet sufficient.





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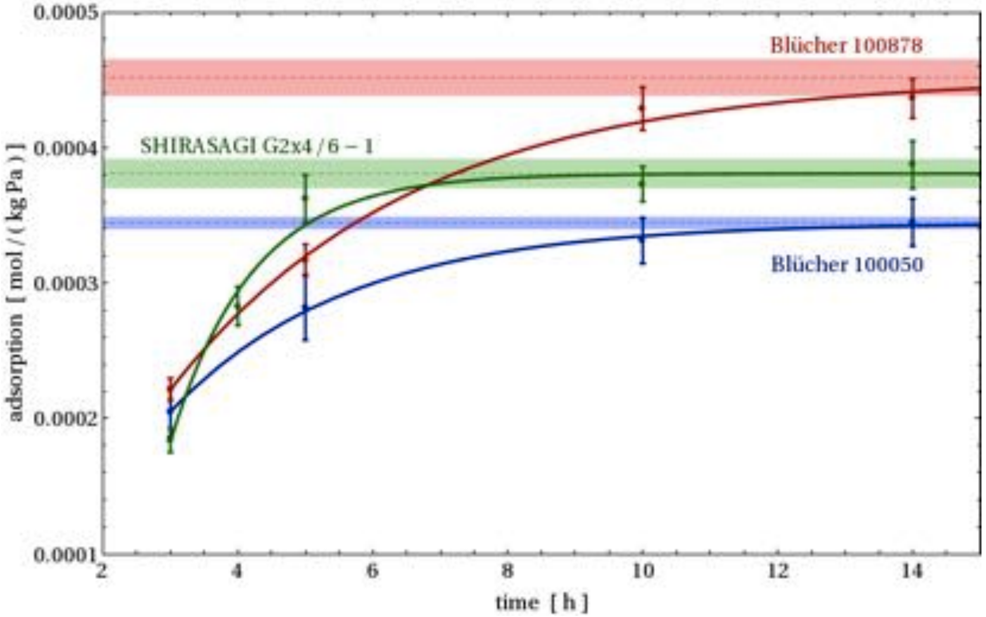

- Selection of adsorber material with highest Xe/Rn separation coefficient.
- Issues:
  - Lot of adsorbed xenon.
  - ^{222}Rn release from adsorber.
  - High speed purification!

- Alternative approach: Separation of Rn/Xe by "vapor pressure" (boil-off purification / distillation).
- Boil-off purification: Lower "vapor pressure" of Rn w.r.t. Xe experimentally demonstrated.
- Distillation: Reduction of radon level in xenon experimentally demonstrated.
- Desin studies for Rn removal plant ongoing.

CONCLUSION

- XENON1T will be the 1st ton-scale direct DM detection experiment online.
- Rapid upgrade to XENONnT (possibly in 2017): Will reach 10^{-48} cm^2 sensitivity.
- Ultimate LXe experiment requires 100 t × y exposure.
- Several big challenges:
  - NR/ER discrimination
  - Light yield
  - Drift field
  - LXe procurement and handling
  - External and internal backgrounds

The XENON Collaboration

~120 scientists from 18 institutions