Results and status from KamLAND-Zen

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Rencontres de Moriond EW 2014

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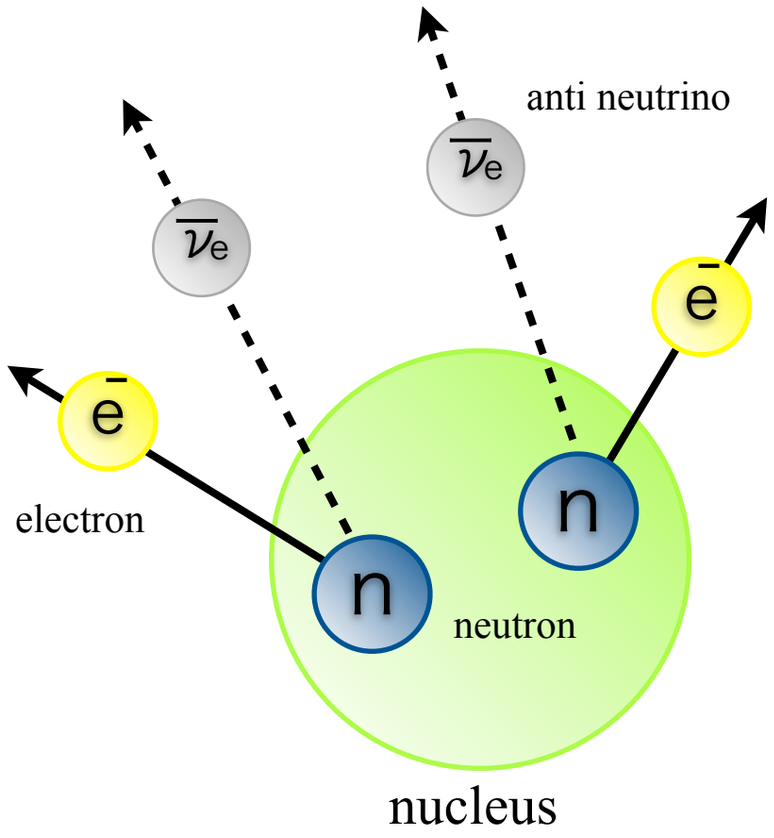
Outline

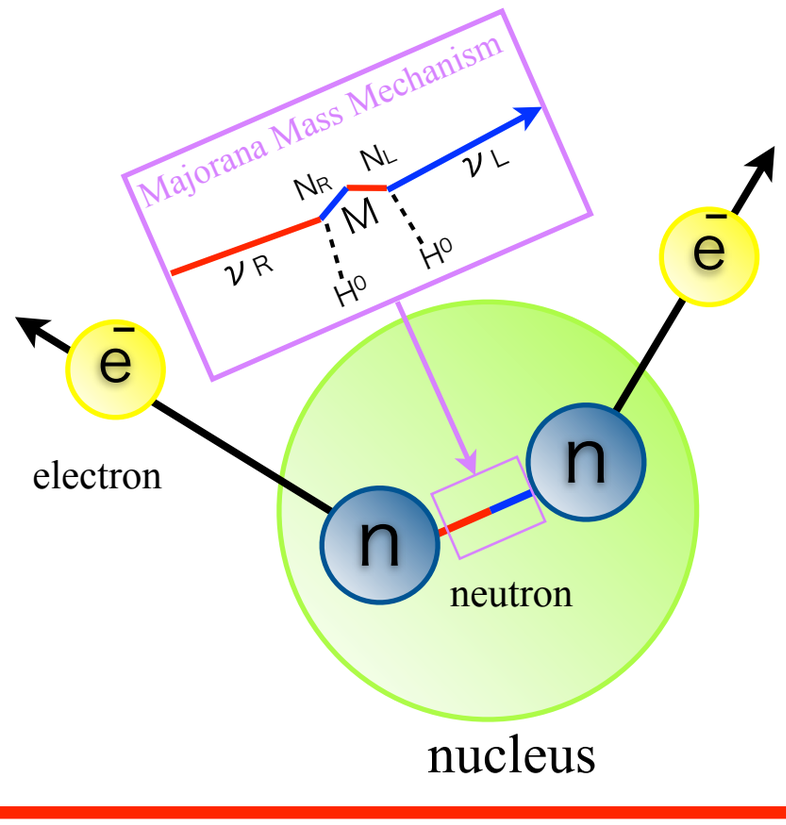
1. Introduction (double beta decay)
2. KamLAND-Zen 1st Phase
3. Result from KamLAND-Zen
4. Purification Campaign
5. Current Status
6. Future Prospects for KamLAND-Zen
7. Summary

Neutrinoless Double Beta Decay

$2n \rightarrow 2p + 2e^- + 2\overline{\nu}$



$2n \rightarrow 2p + 2e^-$



If we found neutrinoless double beta decay ($0\nu\beta\beta$)...

- neutrino is Majorana particle ! i.e. $\nu = \overline{\nu}$
- Majorana neutrino mass can be measured with the half-life

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}|M^{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

phase space factor

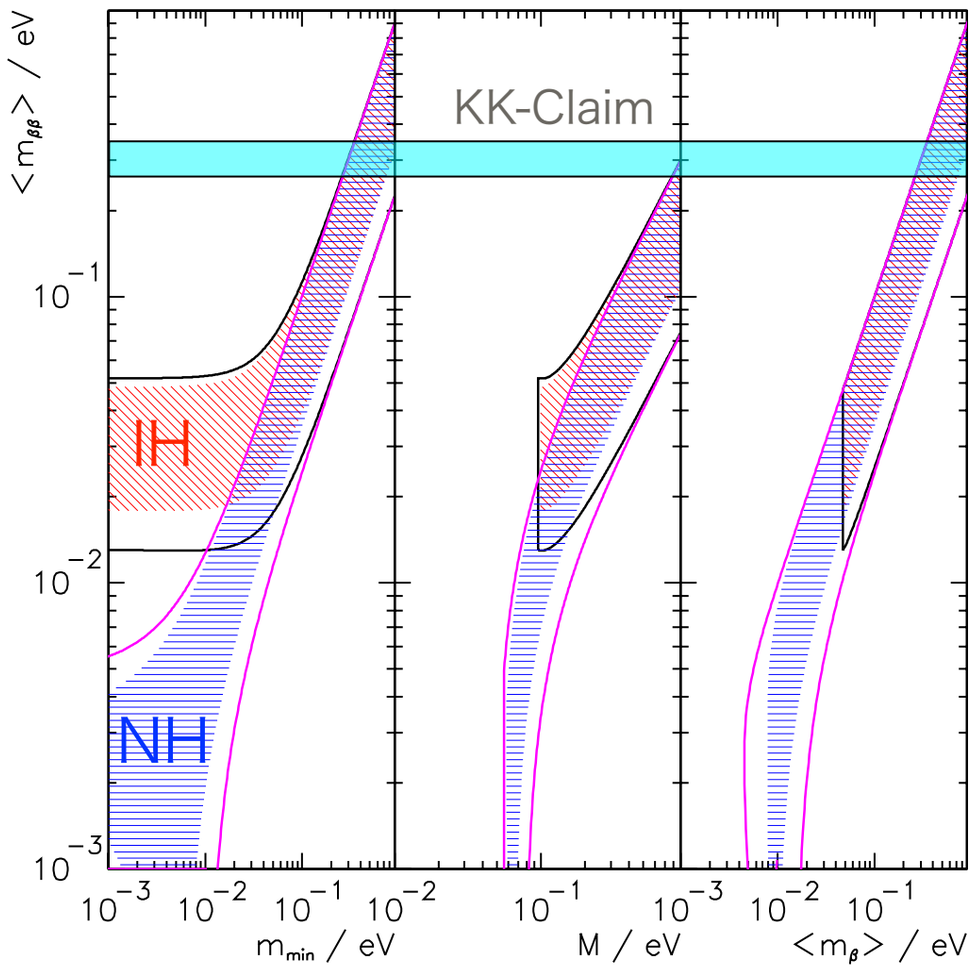
nuclear matrix element (nucl. physics)

Majorana neutrino mass

Majorana Neutrino Mass

effective Majorana neutrino mass : $\langle m_{\beta\beta} \rangle \equiv \left| \sum_{i=1}^{3} U_{ei}^2 \, m_i \right|$

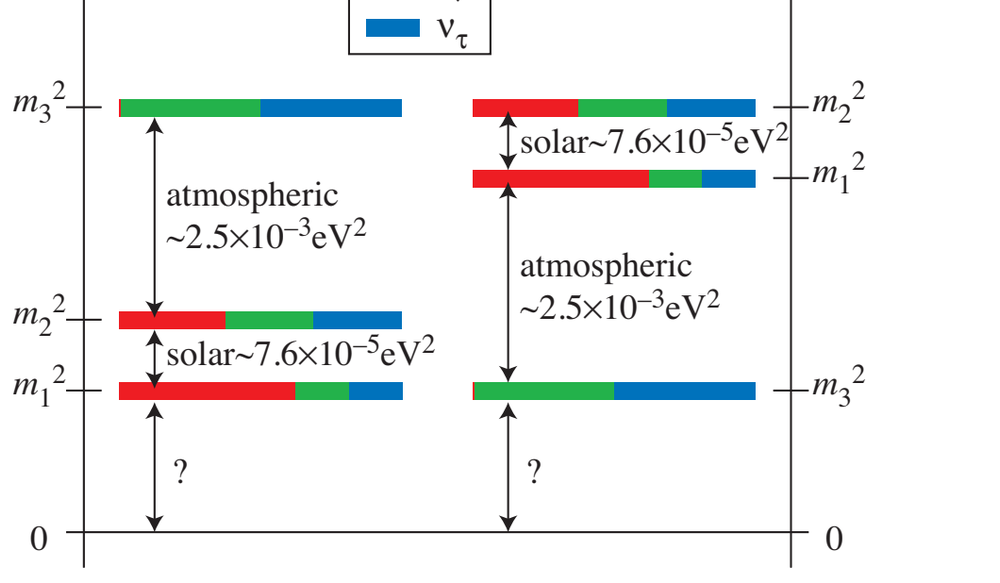
Allowed region of $<m_{\beta\beta}>$



$m_{\min}$ $M \equiv \sum_{i=1}^{3} m_i$ m_β

Measurements of neutrino oscillation

provide $\Delta m_{ij}^2 = |m_i^2 - m_j^2|$



Normal Hierarchy(NH) Inverted Hierarchy(IH)

$<m_{\beta\beta}>$ may mention to

- absolute mass scale of neutrinos
- neutrino mass hierarchy (ordering)

KamLAND

KamLAND detector

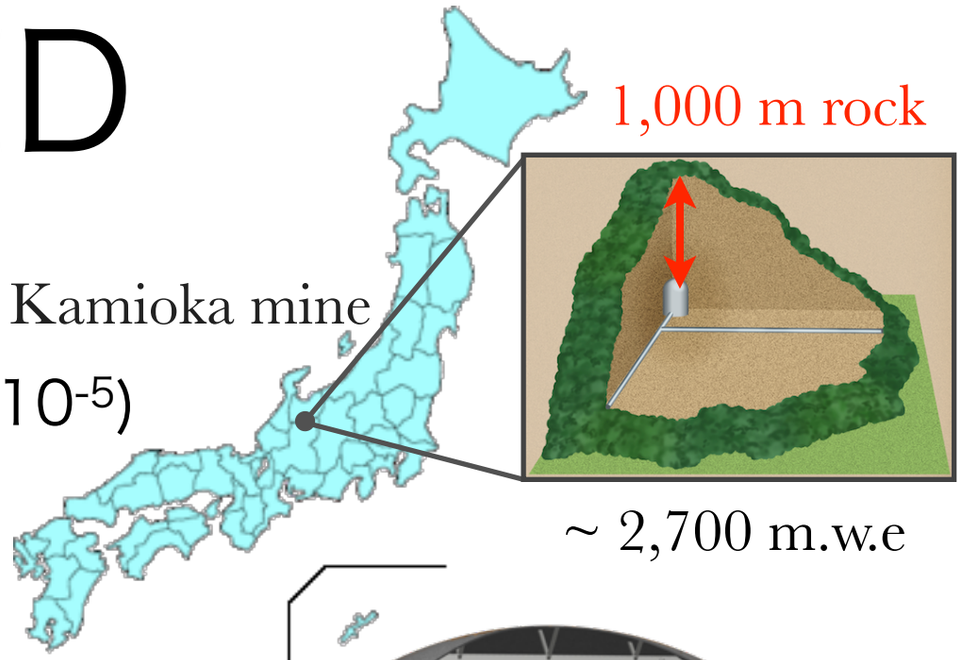
- Kamioka mine underground (muon intensity ~ 10^{-5})
- 1,000 ton of ultra-pure liquid scintillator (LS)
- 17 and 20 inch PMT 1879 channels
- original DAQ system developed for KamLAND
- anti-neutrino detection with inverse beta decay using delayed coincidence technique
- energy resolution ~6.6%/√E[MeV]
- cylindrical outer Cherenkov detector for muon veto
- ultra low background environment
- KamLAND has been running since 2002

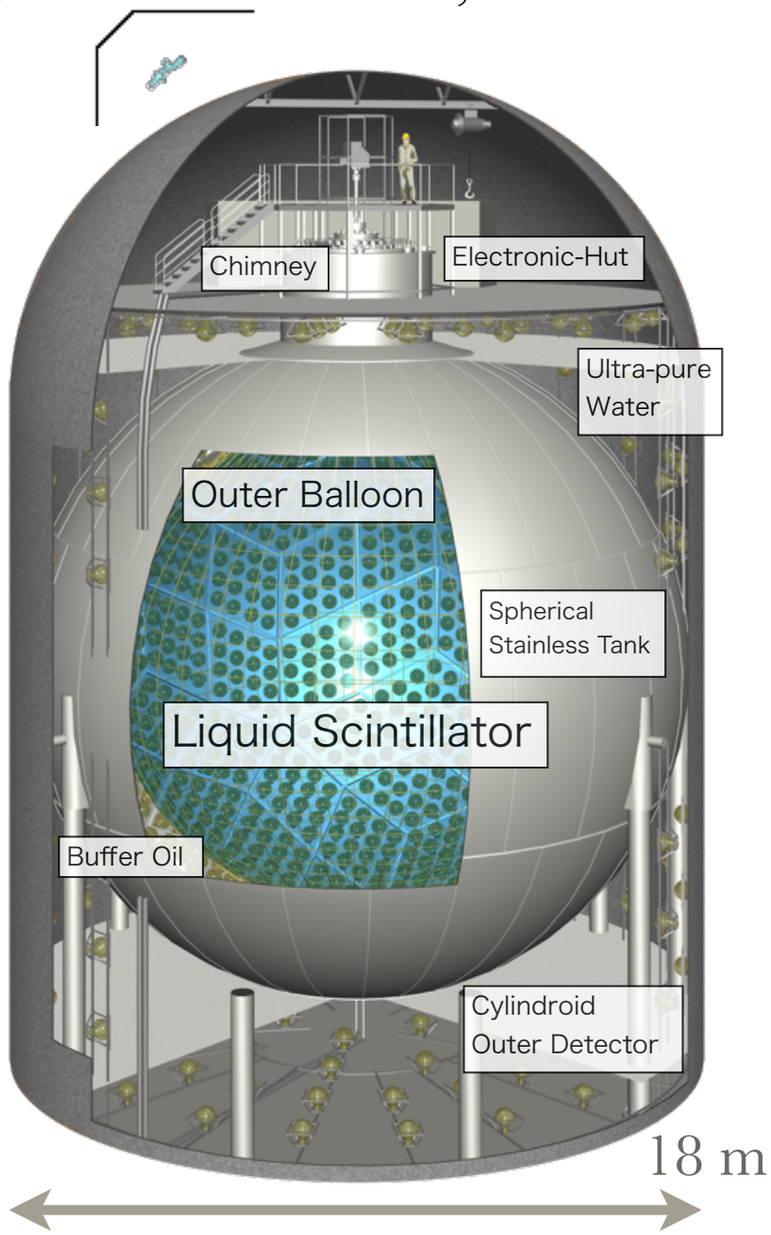
→ well-known detector response and background

What KamLAND achieved

- neutrino oscillation found with reactor
- observation of geo-neutrino
- solar neutrino measurement

and so on...



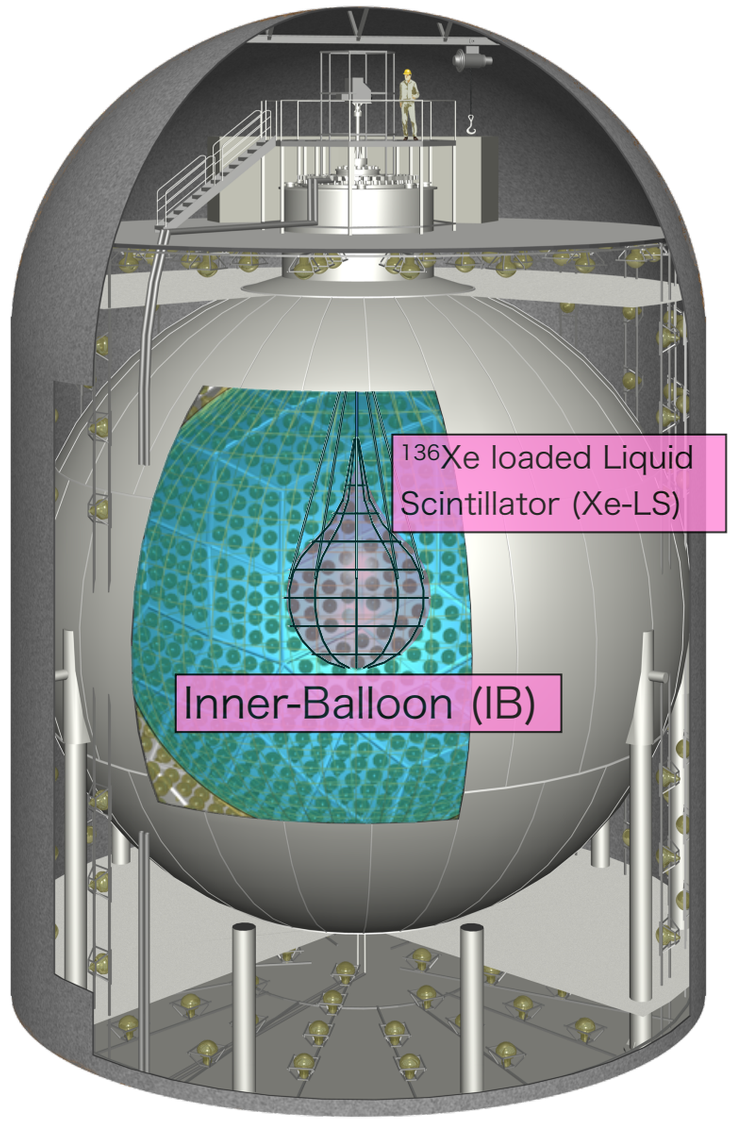


KamLAND-Zen

- **Ze**ro **n**eutrino double beta decay search
- Xenon (zi:nɑn) ・禅
- then (after KamLAND)

KamLAND-Zen

- new generation of double beta decay experiment with enriched ^{136}Xe ~ 300 kg
- low background Inner Balloon (IB)
- Xe gas is dissolved to LS, and loaded to IB
- with existing low background detector
- expecting quick start by modification of KamLAND
- high scalability for the future (ton scale is OK)
- possible to continue the other measurement in the outer region of IB



Why ^{136}Xe ?

- good solubility to LS (3wt%)
- enrichment method is established (>90%)
- chemically stable gas (easy to handle)
- Q-Value is 2.47MeV → low background region in KL
- half-life of $2\nu\beta\beta$ is relatively long
  → so high energy resolution is not needed

KamLAND-Zen Collaboration

- **Research Center for Neutrino Science, Tohoku University**
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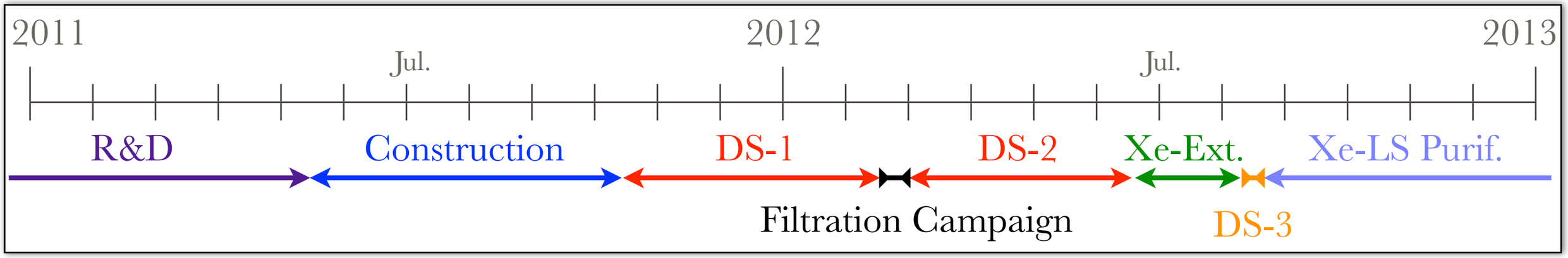
- **IPMU, University of Tokyo** A. Kozlov
- **Osaka University** S. Yoshida
- **University of California, Berkeley and LBNL** B.K. Fujikawa, T. O'Donnell
- **Colorado State University** B.E. Berger
- **University of Tennessee** Y. Efremenko
- **TUNL** H.J. Karwowski, D.M. Markoff, W. Tornow
- **University of Washington** S. Enomoto, J. A. Detwiler
- **NIKHEF and University of Amsterdam** M.P. Decowski

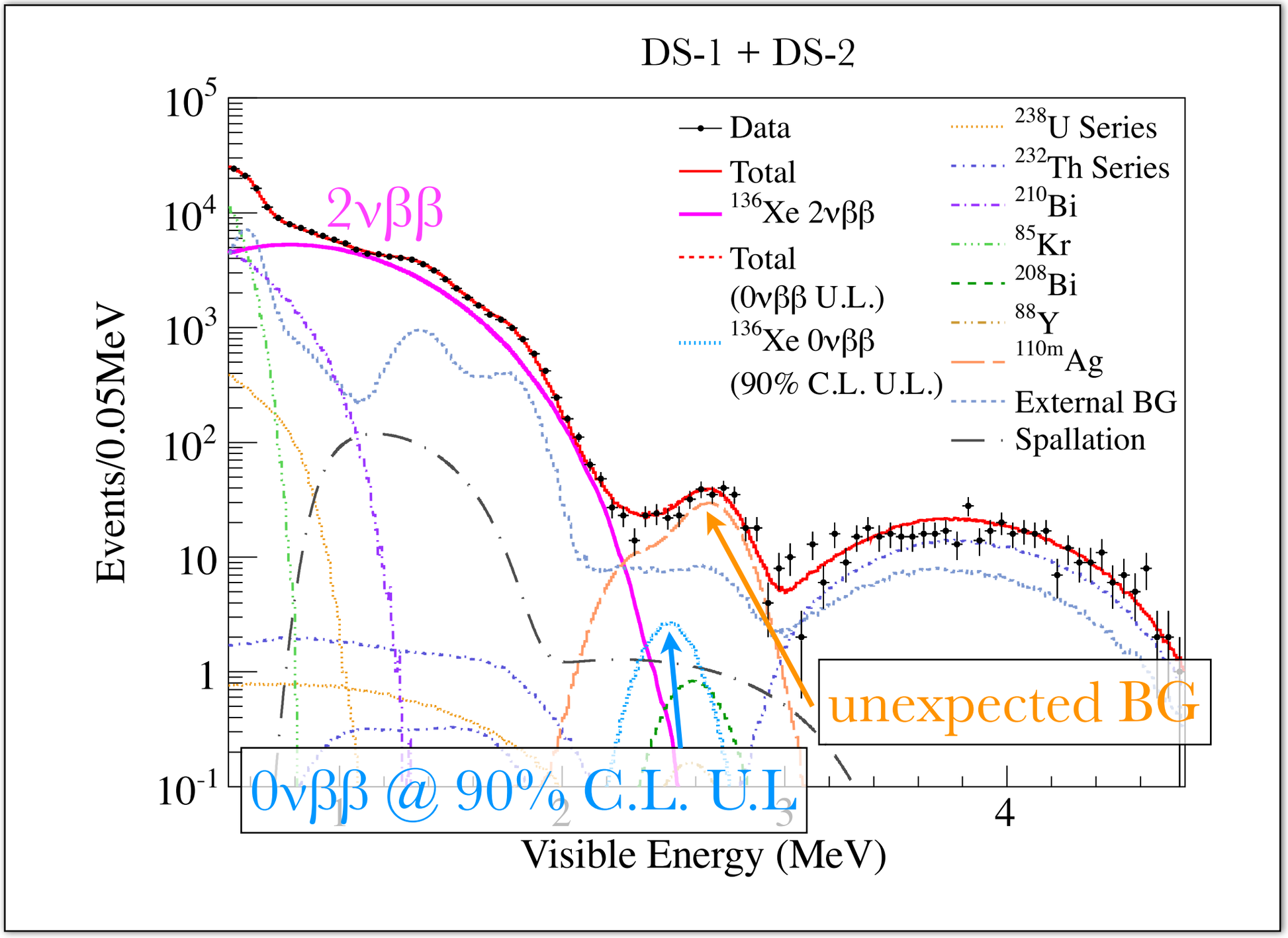
KamLAND-Zen Collaboration (~ 40 people) is a subset of KamLAND Collaboration !

KamLAND-Zen 1st Phase



- The construction started from May 2011, and only 6 months by data taking.
- The first result was reported with data-set of 78 days,
  and the second result was reported with DS-1 (112 days).
- The third result is based on analysis with DS-1 and DS-2 (total 212 days)
  → this is the latest result from KLZ for now. (published in Feb. 2013)
  → the largest exposure of ^{136}Xe (89.5 kg-year) is available
  by improvement of analysis

ES from KLZ 1st Phase



A. Gando, et al., (KamLAND-Zen Collaboration), *Phys. Rev. Lett.* **110**, 062502 (2013).

T. O'Donnell, Recent results from KamLAND-Zen, Rencontre de Moriond EW 2013.

Summary of KamLAND-Zen 1st Phase

KamLAND-Zen 1st Phase obtained the most stringent limit on half-life of ^{136}Xe $0\nu\beta\beta$

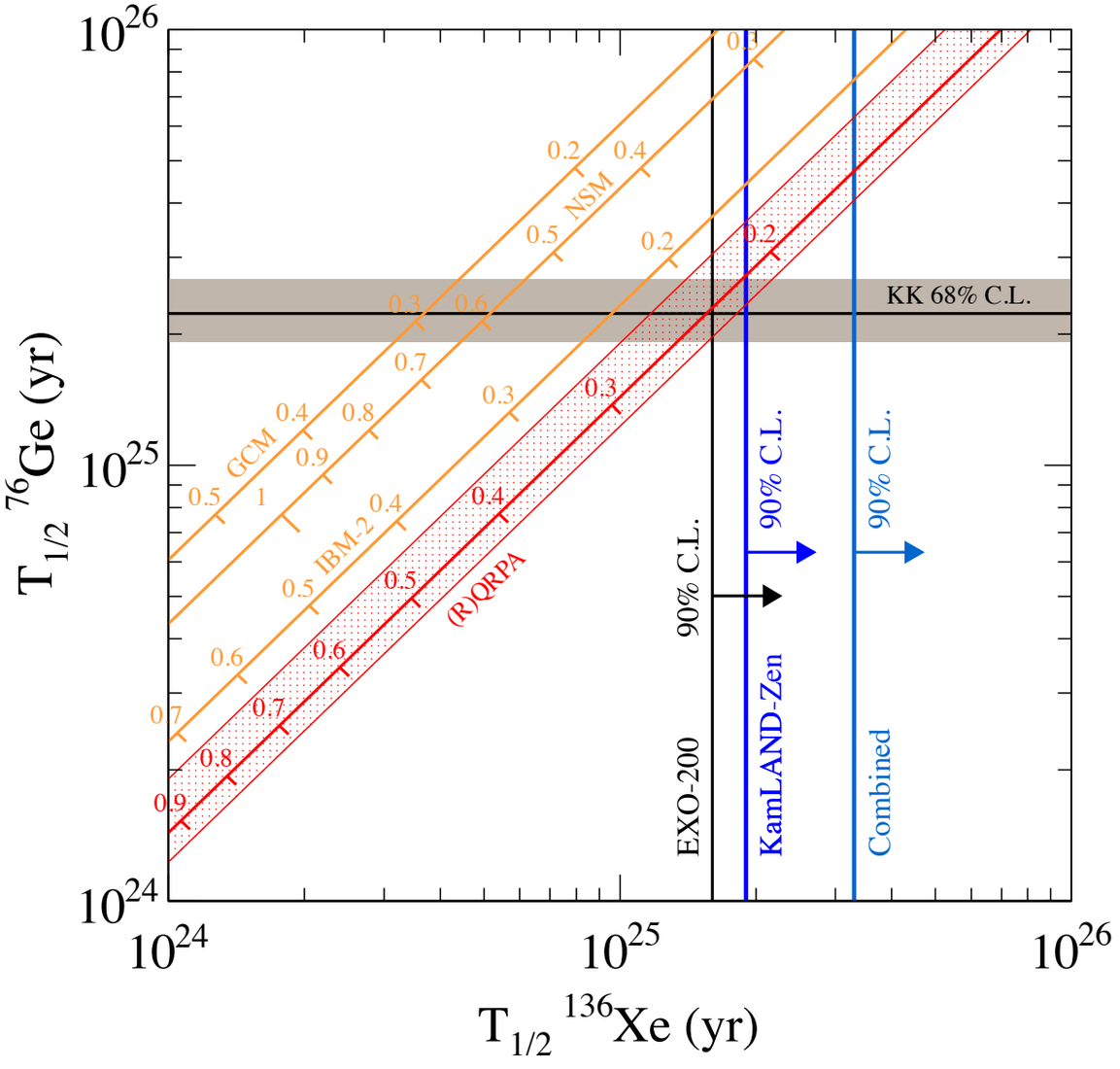
$$T_{1/2}^{0\nu} > 1.9 \times 10^{25}[\mathrm{yr}] \ @\ 90\%\ \mathrm{C.L.}$$

Combined limit with EXO-200 (2012) is

* latest results from EXO-200 (2014) is not considered yet.

$$T_{1/2}^{0\nu} > 3.4 \times 10^{25}[\mathrm{yr}] \ @\ 90\%\ \mathrm{C.L.}$$

→ KK-Claim is excluded at 97.5% C.L. using available NME calculations.

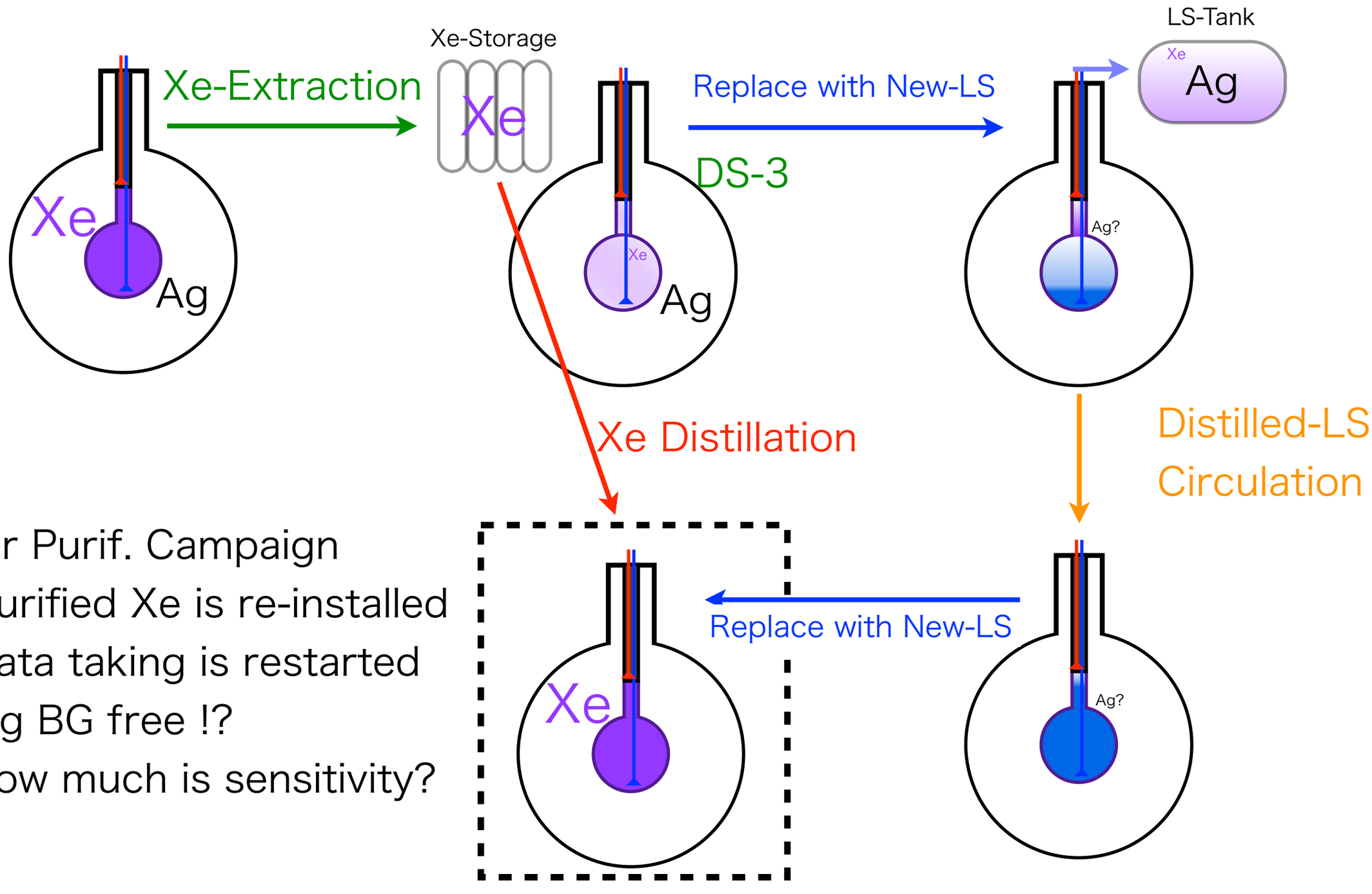


However...

- the sensitivity of KLZ is still limited by the unexpected background at 2.6 MeV which is most likely as ^{110m}Ag.
- the event rate of Ag is too low to evaluate with another detector or techniques
- next task is purification for Ag reduction.

Strategy of Purif. Campaign

Motivation : remove ^{110m}Ag background (~1 events/13ton/day)



After Purif. Campaign

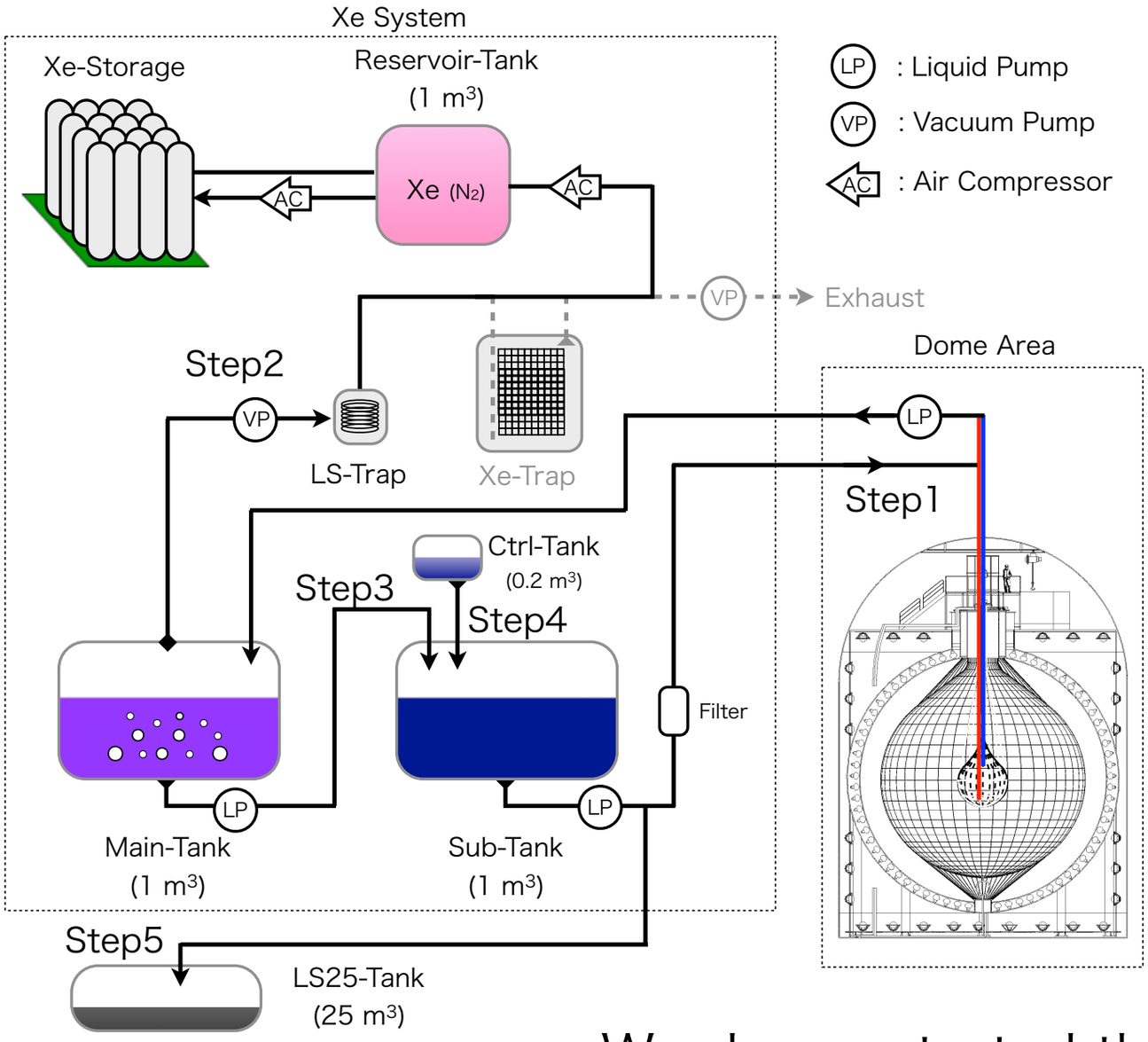
- purified Xe is re-installed
- data taking is restarted
- Ag BG free !?
- how much is sensitivity?

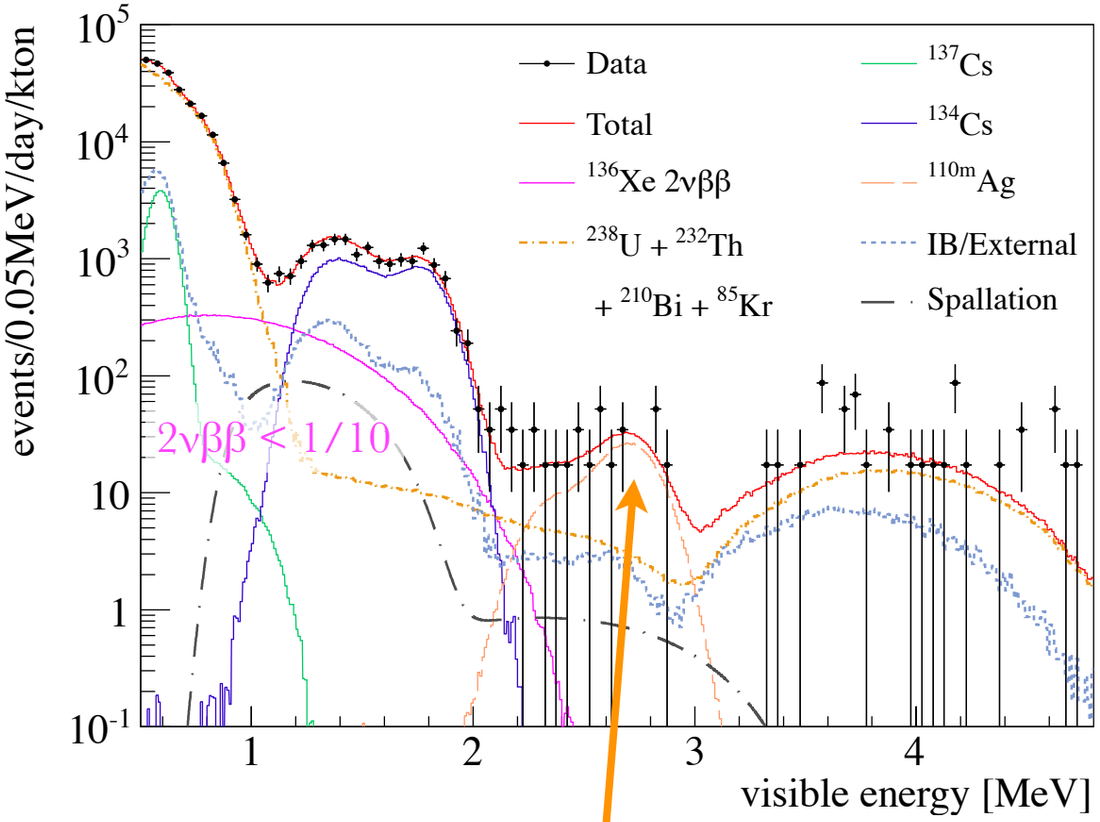
We expects BG reduction ~ better than 1/100.

Xe-Extraction Campaign

At first step of purification campaign, Xe gas is extracted from IB in Jun. 2012.
90% of Xe (~ 290 kg) was successfully collected to the storage tank.

Xe-Extraction Flow



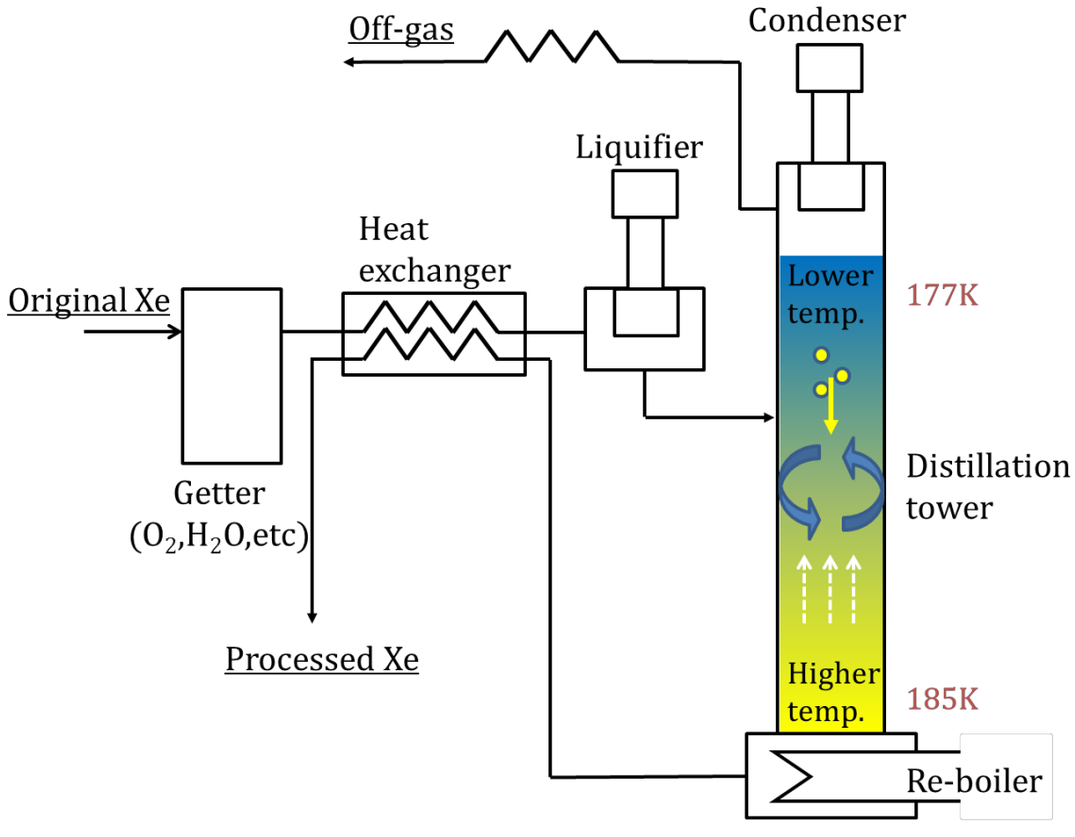


We demonstrated the ability of Xe ON/OFF measurement.

2 Approaches for Purification

Xe Distillation :
2 month and 6 people/day

Xe Distillation Tower borrowed from XMASS

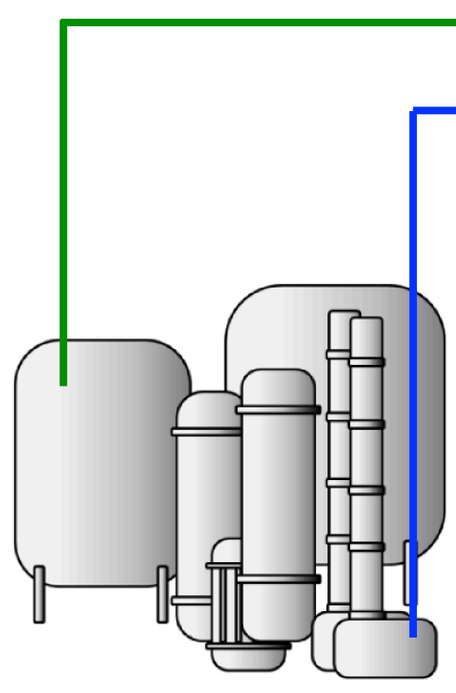


- distillation with collected Xe and newly purchased Xe

complete in summer 2012

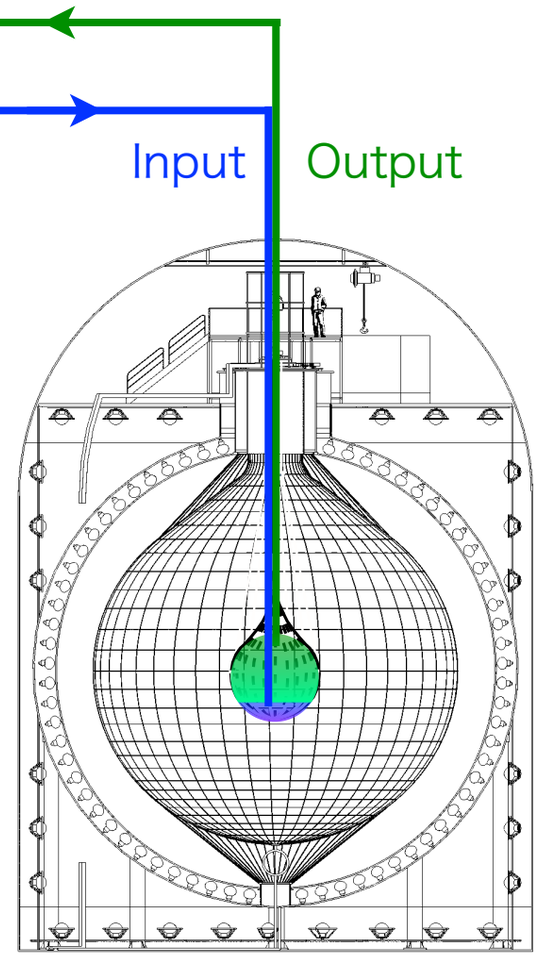
Distilled-LS Circulation :
3 ~ 4 month and 12 people/day

Purification System



- Distillation System
- N_2 Purging System
- density controlling

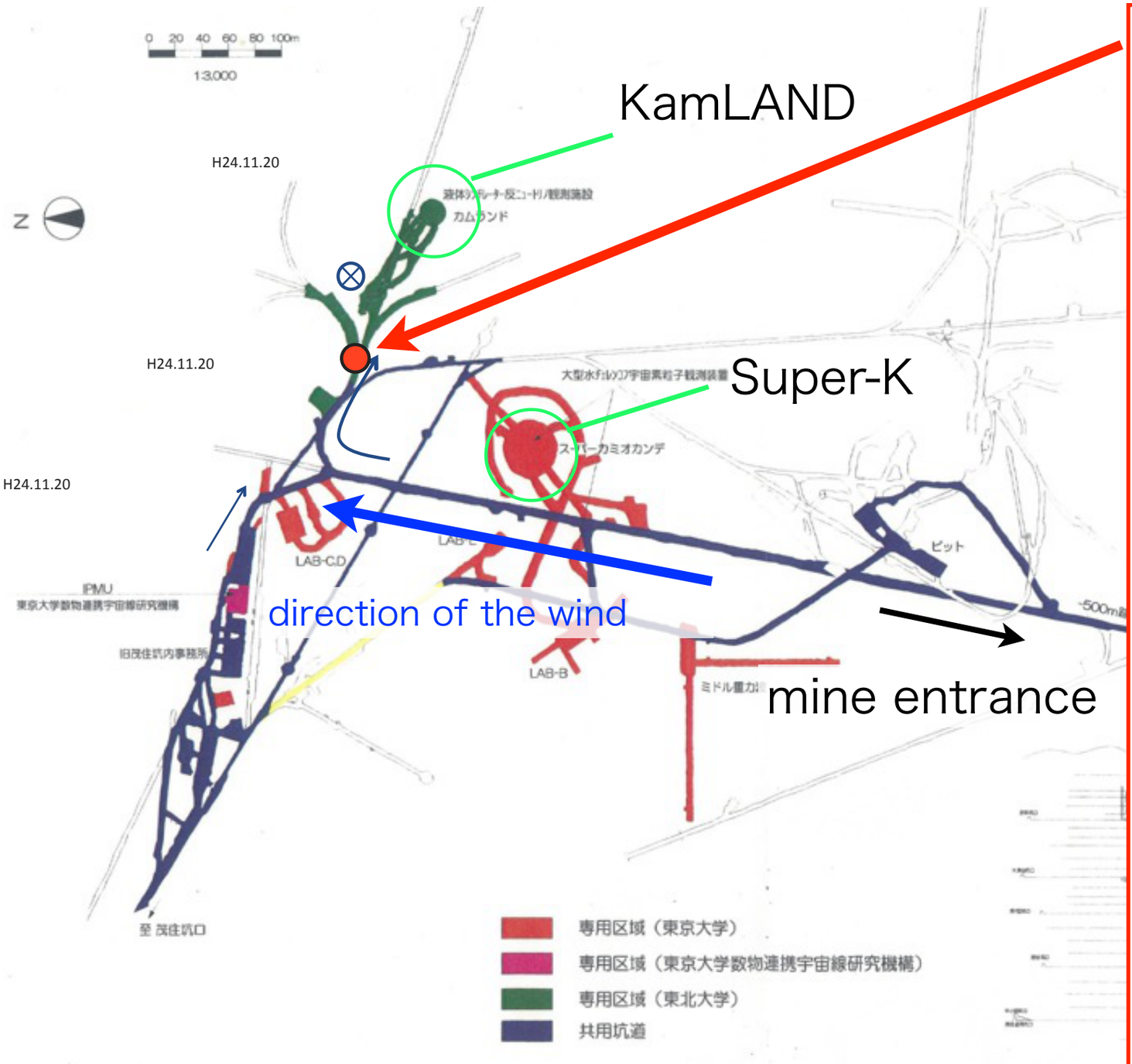
KamLAND-Zen detector



started in autumn 2012

Fire Accident in the mine

On 20th Nov 2012 during Distilled-LS Circulation, an accidental fire broke out at entrance of KamLAND area in Kamioka mine.



Fire Place

Rn Trap Tower

- during dismantle the tower
  → using sander to cut metal
- methanol remaining inside…
  → maybe trigger of fire
- polystyrene form was burned
  → black smoke and dust were delivered to all KL area
- mine workers tried without us

Situation of the accident

・It took over 3 hours to extinguish a fire, because it was the first time for them.
→ fire fighters didn't expect a fire in the mine.

・5 people in Tohoku Univ. were working in KL are at that time.
→ they escaped to dome area of KL where air is rich and far from fire place, and were rescued by fire fighters after several hours since the accident.
→ no serious damage to their body. (but they might feel a fear of death...)

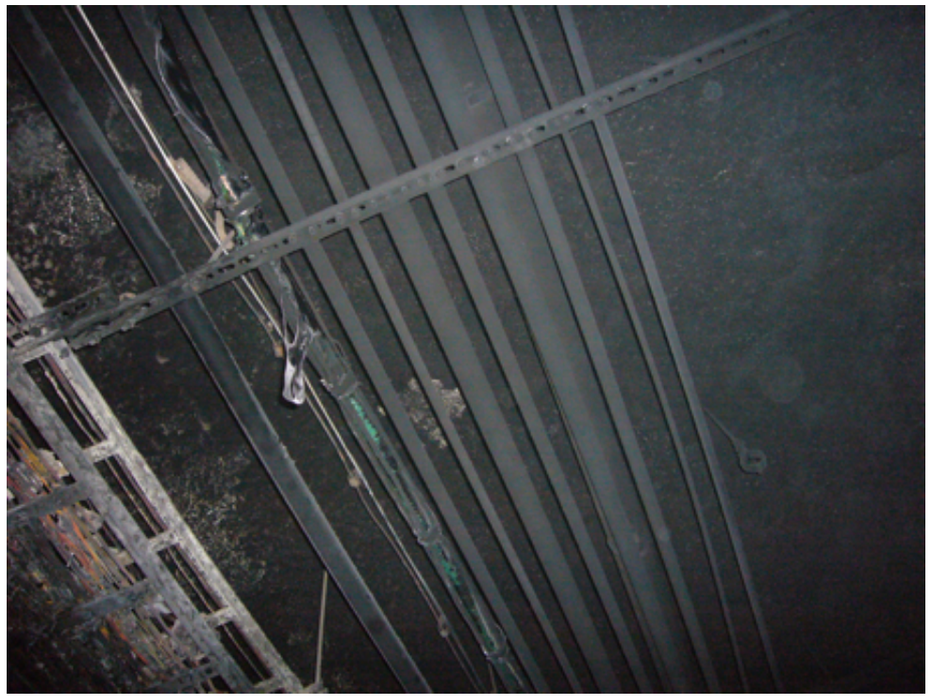
・Many people were working in the mine (for Super-K, XMASS, CANDLESS, etc...), and they could escape out safely from the mine.
・A few people were hurt (a slight burn, damage on throat by smoke), but fortunately, **no one died**.

Pictures after fire

Onsite inspection with people in fire department and police.

Pictures after fire

Many lines (water, electrical wire, LS, network cables) on the ceil and wall were burned, damaged and cut off. Drinking water is spilled out.



Pictures after fire

Everything is soot-blackened, on the ground, wall and ceiling...

Recovery from the Fire

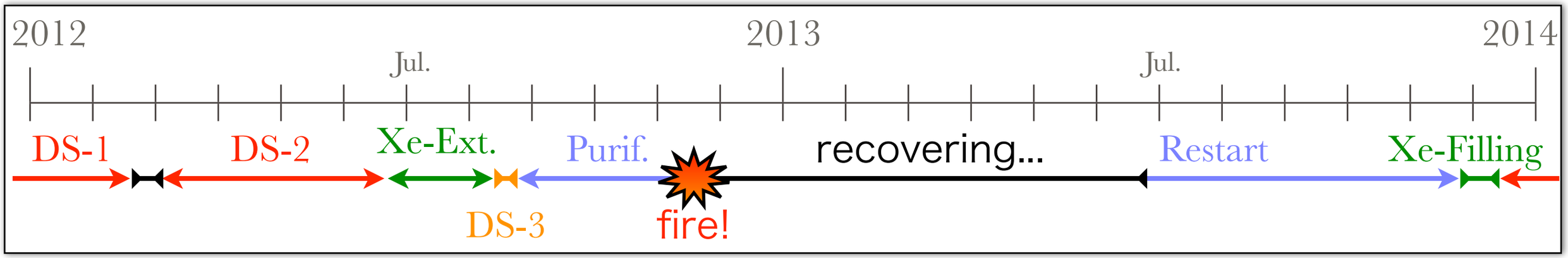
- Thanks to cooperation with University, mine company, fire department and government, the data taking of KamLAND was restarted after only 26 days.
  → KamLAND detector itself was safe and no damaged, fortunately.
  (emergency shut down scheme worked out!)
  → KamLAND experiment (solar, reactor and geo-neutrino measurement) was quickly recovered with some temporary repairs.
  → KamLAND-Zen was suspended because the systems for purification were seriously damaged and got dirty due to smoke and grime.
- Many infrastructure lines, equipments and systems were damaged...
  → cleaning is most high prior work before recovery.
  → we need re-construction or fixing or replacement them.
  → network fiber is also burned out, we tried to transfer data by HDD delivery.
  → LS got dirty and was discarded just in case,
  because we are now working on purification.
  → Tohoku University, Japanese government and Kamioka mine company gave us funds to recover.
- We prepared safety manual and policy not to cause the accident again!

Recovery from Fire

- All of the system in KamLAND area was recovered after a half year from fire.
  → mine road and equipments were cleaned up by our hands
  → damaged devices were replaced to new ones
  → infrastructure lines (electric power, network, LS delivery…) are re-cabled
  → new LS is prepared to resume the purification activities
  → legal inspection was also needed for some systems
  → **finally, we are ready to restart KamLAND-Zen in summer 2013 !**

after a half year… (these pictures were taken in summer 2013)

Resume of Purification Campaign



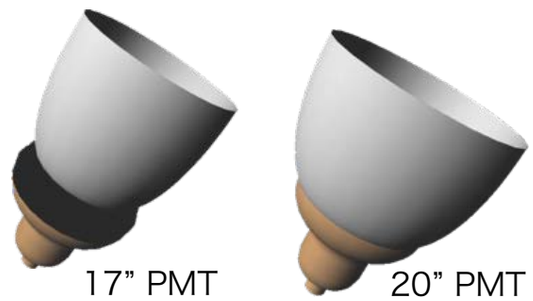
- Distilled-LS Circulation restarted in Jul. 2013, and finished in Nov..
  → the circulation was done by whole 3 volumes
  → twice LS replacement before and after Distilled-LS Circulation
  → we expects a quite better Ag reduction, ideally
  → also, ^{110m}Ag decayed in this 2 years (τ = 365 days)

- Xe was filled in Dec 2013, and data taking started !
  → filling method is improved, and more Xe could be dissolved into LS
  → reduction efficiency is now estimated...
  (it takes a lot of time to estimate it due to the extreme low event rate)
  → the improvement of analysis is on going such as fiducial volume optimization with detailed background estimation from IB

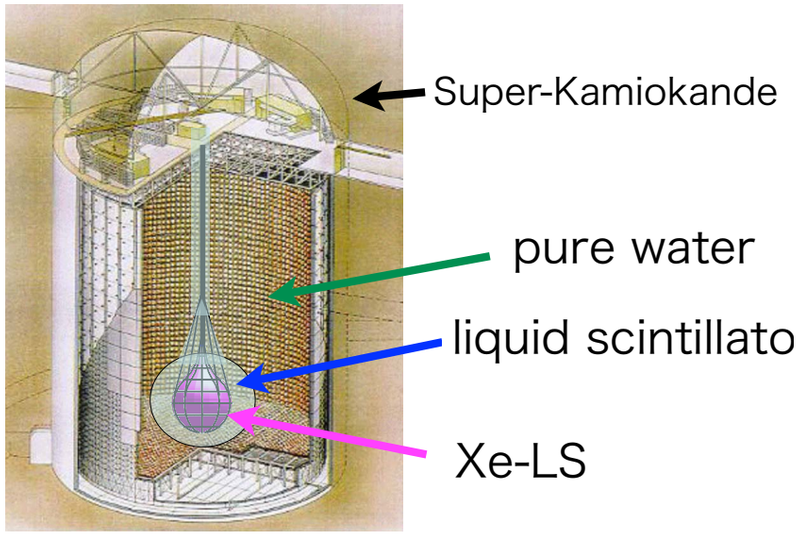
Future Prospects

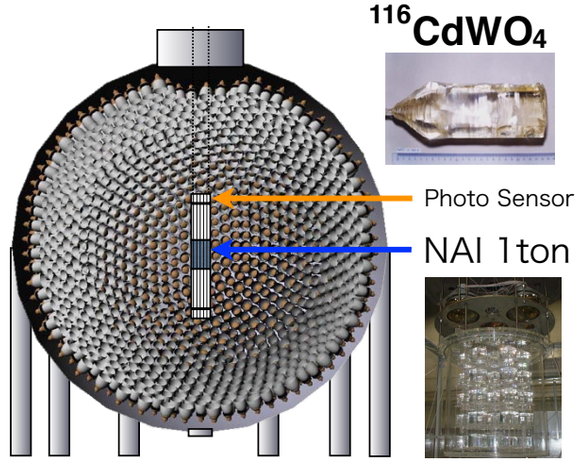
- KamLAND-Zen 1.5th Phase
  - after purification, and data taking is now on going

mirrors for PMT



- KamLAND-Zen 2nd Phase
  - with 600~800 kg of ^{136}Xe and new clean Inner Balloon
- KamLAND2 : Detector Upgrade
  - new liquid scintillator (brighter and heavier to dissolve larger mass of Xe)
  - high QE PMT installation, development of winston-cone mirror for PMT
    → higher energy resolution ~2%/Q-Value
  - enlargement chimney of the detector
    → another isotopes for double beta decay to be installed
- Dream : Super KamLAND-Zen
  - KamLAND-Zen with Super-K
  - huge mass can be available





Summary

- The KamLAND-Zen 1st phase

$$T^{0\nu}_{1/2} > 1.9 \times 10^{25}[\mathrm{yr}] \ @\ 90\%\ \mathrm{C.L.}$$

- Combined result with EXO-200 (2012)

$$T^{0\nu}_{1/2} > 3.4 \times 10^{25}[\mathrm{yr}] \ @\ 90\%\ \mathrm{C.L.}$$

$$\langle m_{\beta\beta} \rangle < (120 - 250)[\mathrm{meV}] \ @\ 90\%\ \mathrm{C.L.}$$

- The KamLAND-Zen 1.5th phase after purification campaign
  - data taking is now on going with lower background level
  - fiducial mass can be increased
  - new EXO-200 results (arXiv:1402.6956) is considerable
  - we expects a limit of 80 meV on Majorana neutrino mass in this year

- Future Prospects
  - detector upgrade for improvement of energy resolution
  - larger mass of ^{136}Xe can be possible with new inner balloon
  - pressurize phase (higher density of ^{136}Xe) is one of candidate
  - R&D for KamLAND-Zen future plan is on going

Backup

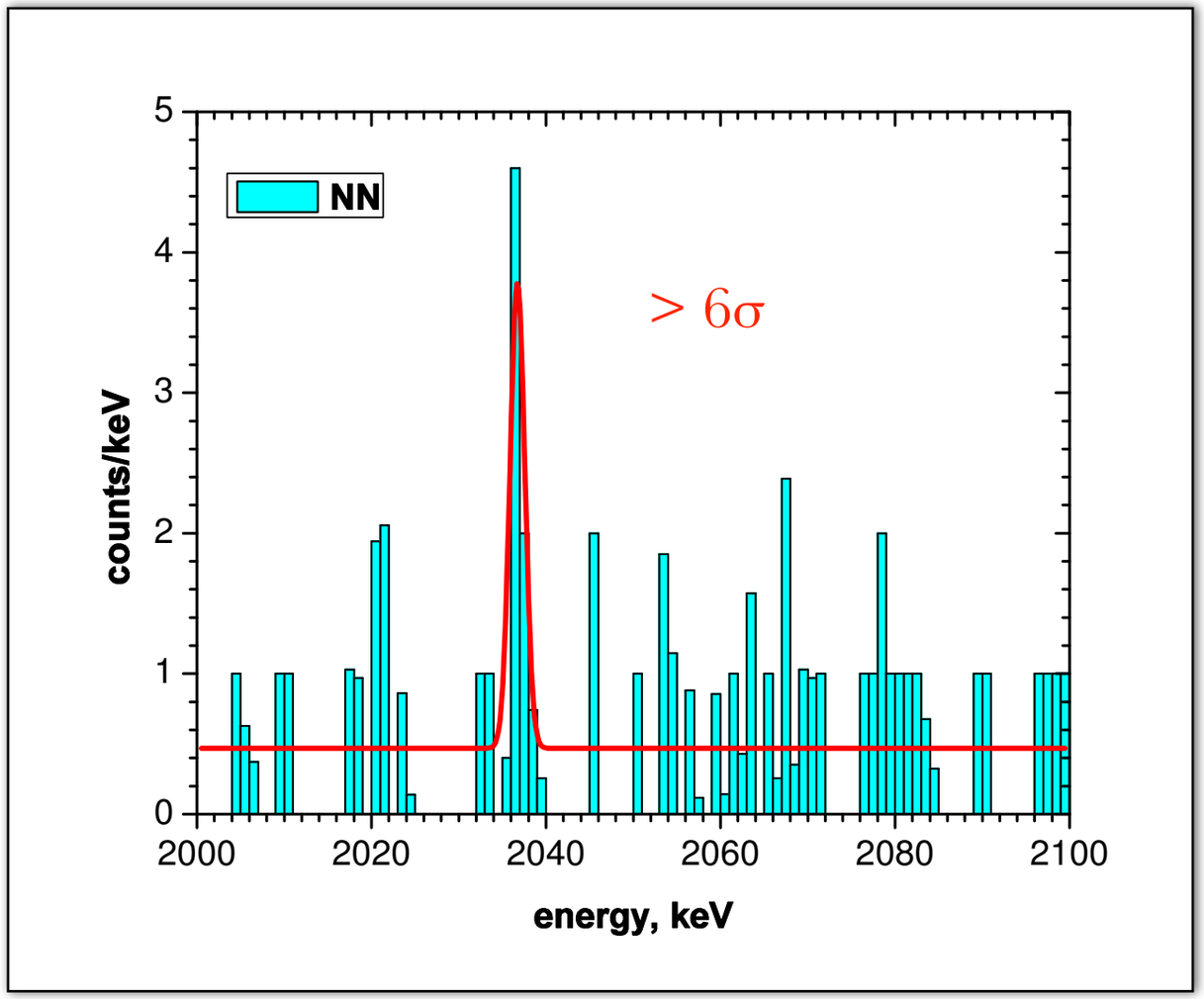
KK-Claim

HEIDELBERG-MOSCOW which is an experiment of search for 0νββ in ^{76}Ge,
and a part of them claimed the detection of 0νββ signal.

KK-Claim in 2006

(also in 2001 and in 2004)

$$T^{0\nu}_{1/2}(^{76}\mathrm{Ge}) = 2.23^{+0.44}_{-0.31} \times 10^{25}[\mathrm{yr}]$$



However...

- Although high statistics,
  questions for background estimation
- result from HEIDELBERG-MOSCOW is
  inconsistent with their claim
- not tested by another experiment yet

→ doubtful in double beta decay community

→ we need to test

Ref. H. V. Klapdor-Kleingrothaus and I. V. Krivosheina, *Mod. Phys. Lett. A* **21**, 1547 (2006).