CURRENT STATUS & FUTURE PROSPECTS OF KAMLAND-ZEN

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On behalf of the KamLAND-Zen Collaboration

7/31/2019

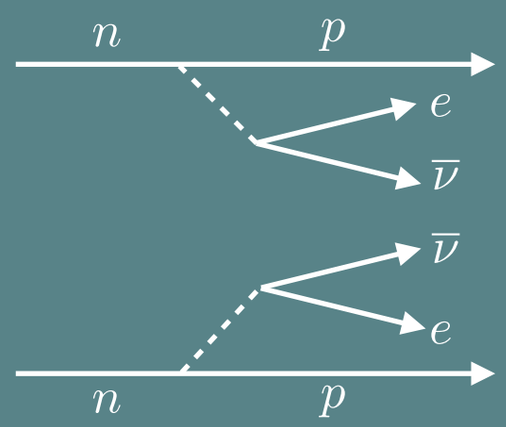
DPF 2019, Northeastern University

NEUTRINOS

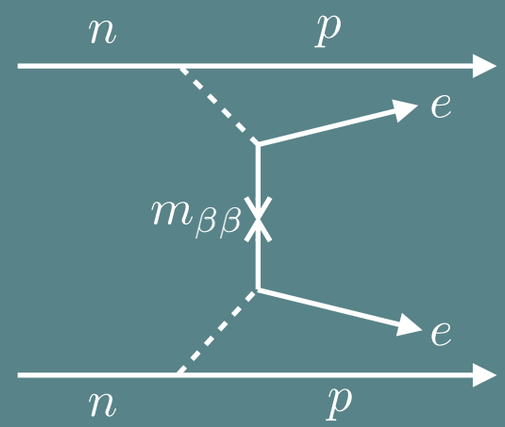
- Seesaw Mechanism explain the low mass of neutrinos:
  Combine Dirac and Majorana masses

$$\mathcal{L} \sim -\frac{1}{2}\begin{pmatrix}\overline{\nu_L} & \overline{\nu_R^c}\end{pmatrix}\begin{pmatrix}0 & m_D \\ m_D & m_M\end{pmatrix}\begin{pmatrix}\nu_L^c \\ \nu_R\end{pmatrix} \Rightarrow m_\nu = \frac{m_D^2}{m_M}, m_N = m_M$$

- Search for double beta decay



SM process

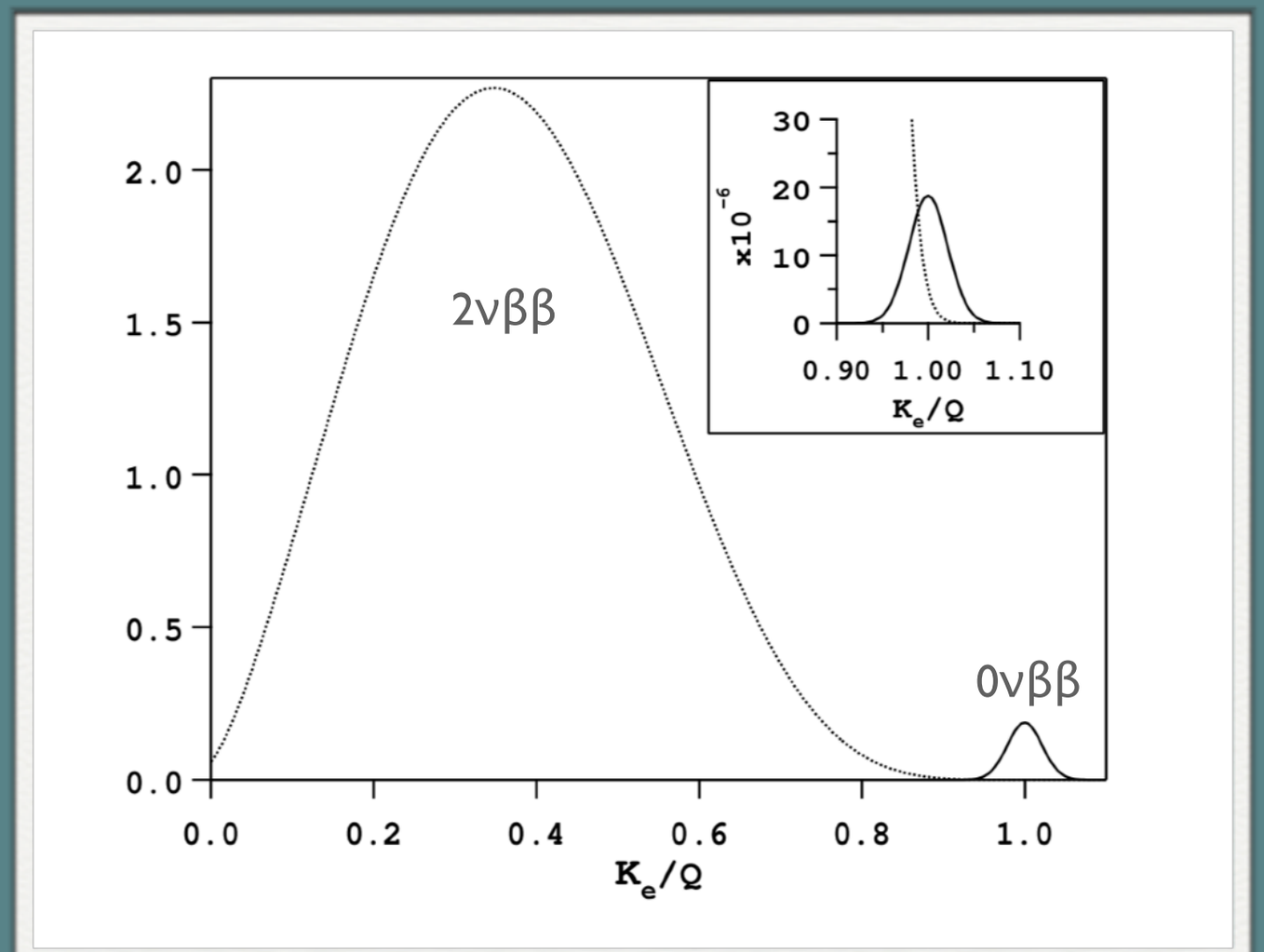


BSM process

DOUBLE BETA DECAY SPECTRUM

- Schematic view of energy spectrum of 2νββ and 0νββ

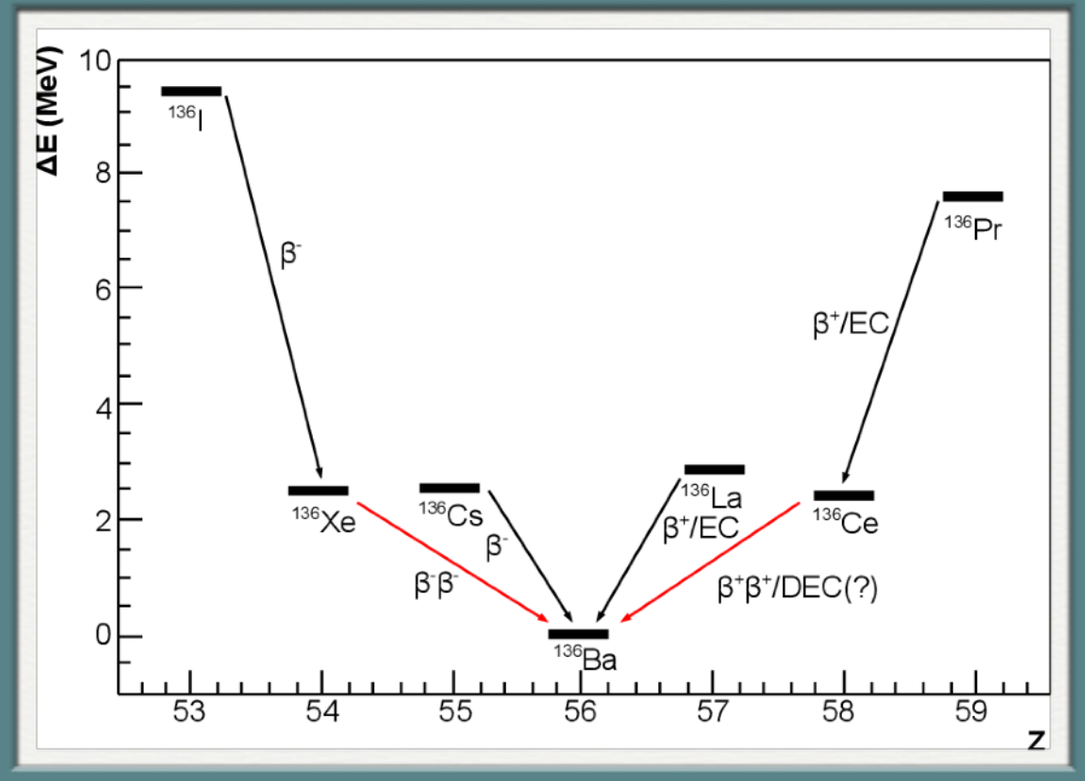
- 0νββ only creates a mono-energetic peak at the Q-value of the nuclei



MOTIVATION

- Lepton Number Violation explains Leptogenesis
  0νββ's introduce Lepton Number Violation
  Explain matter-antimatter asymmetry

- Multiple choices for possible isotopes
  KamLAND is using ^{136}Xe:
  (1) Noble gas
  (2) High Q-value, Q = 2459 keV
  (3) Centrifugal enrichment possible
  (4) Easy to scale, loaded 3% by weight

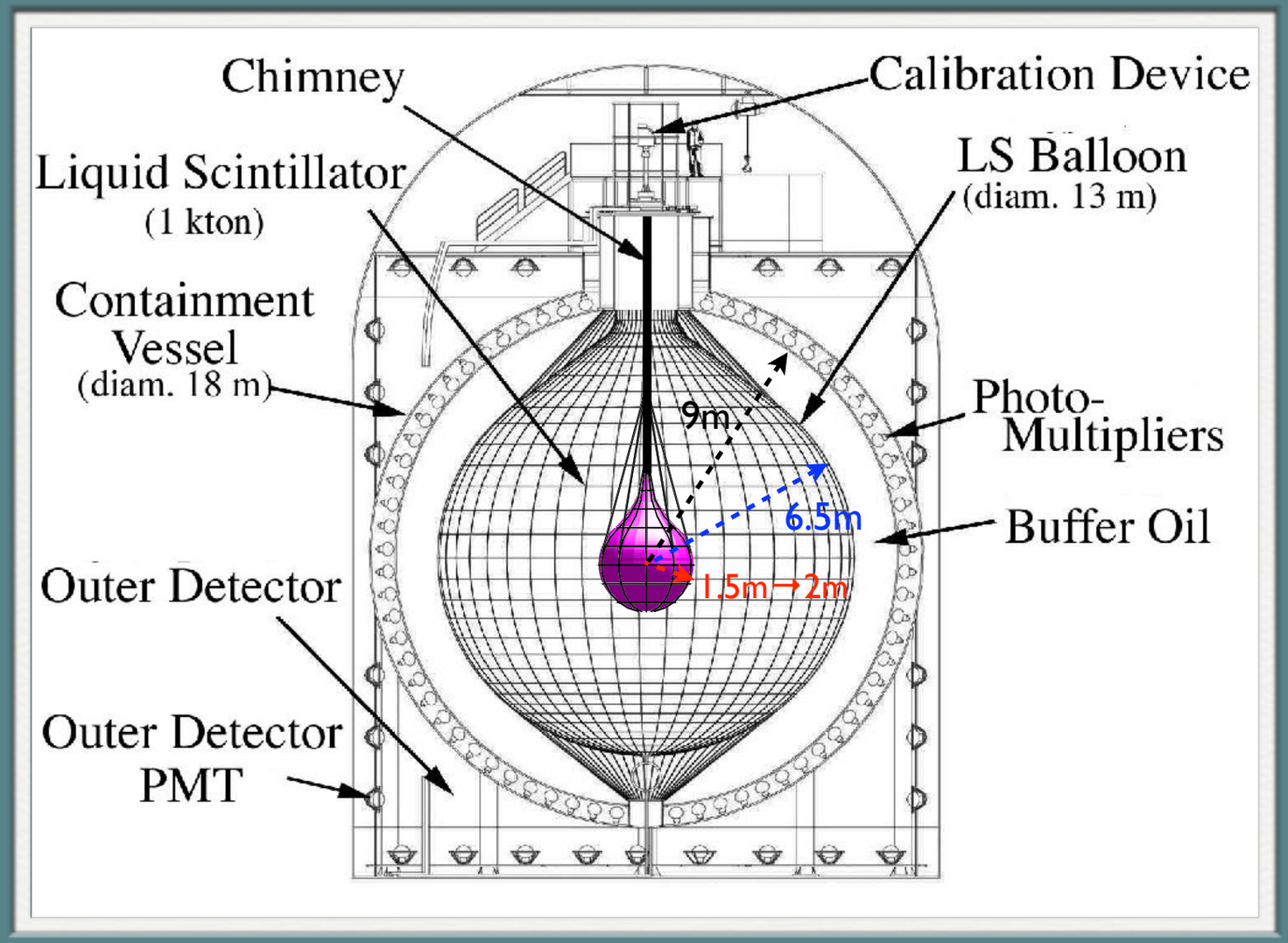


KAMLAND-ZEN APPARATUS

- LS mini-balloon is added 90% enriched ^{136}Xe

- Zen-400
  Period 1: 320kg started at 2012
  Period 2: 380kg started at 2014

- Zen-800
  745 kg started in Jan, 2019
  Data taking in progress

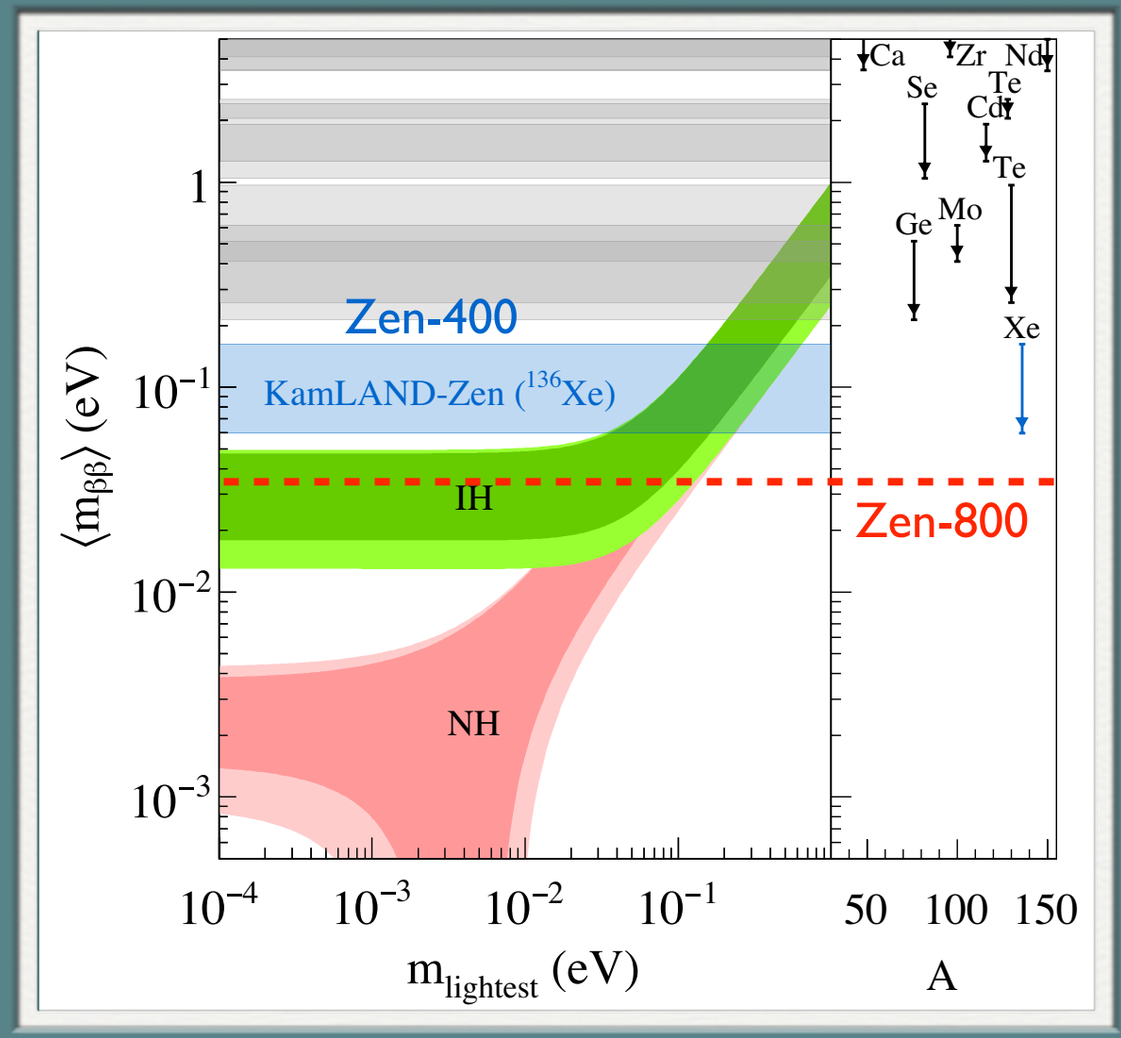


CURRENT RESULT

- Zen-400 conclusion:
  (1) No signal for 0vbb
  (2) Approaching the Inverted Hierarchy region
  (3) First experiment to reach (corresponding to 61-165 meV)

$$T_{1/2}^{0\nu\beta\beta} > 1.07 \times 10^{26} yrs$$

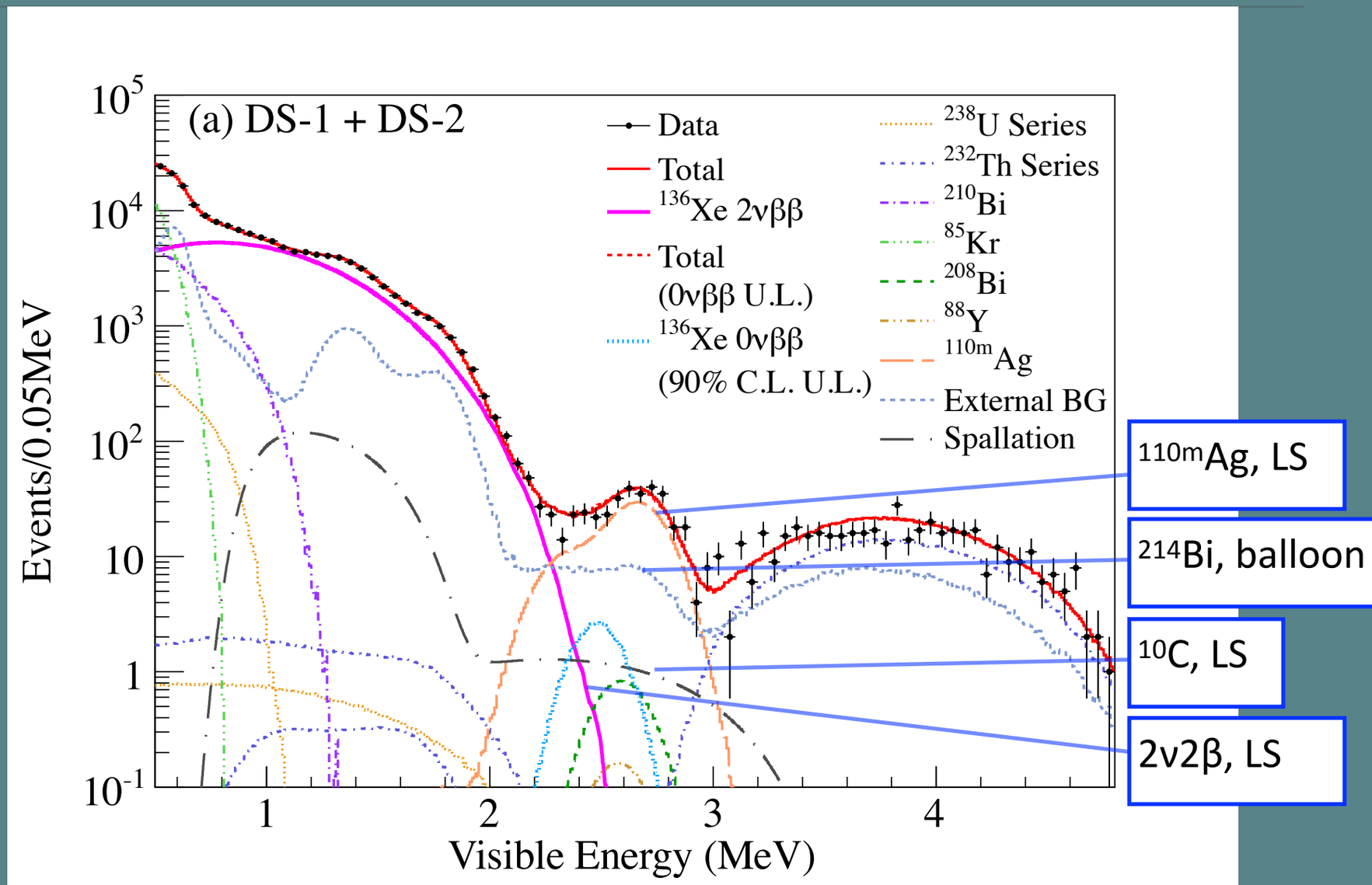
- Zen-800 goal:
  (1) Begin probing the Inverted Hierarchy region
  (2) Target sensitivity of 40 meV



PRL117, 082503 (2016)

ANALYSIS OF ZEN-400

- All data of 2νββ & major backgrounds
- Expect 0νββ shown with 90% C.L.
- Significant ^{110m}Ag contamination
- Large external background



BACKGROUND SUMMARY

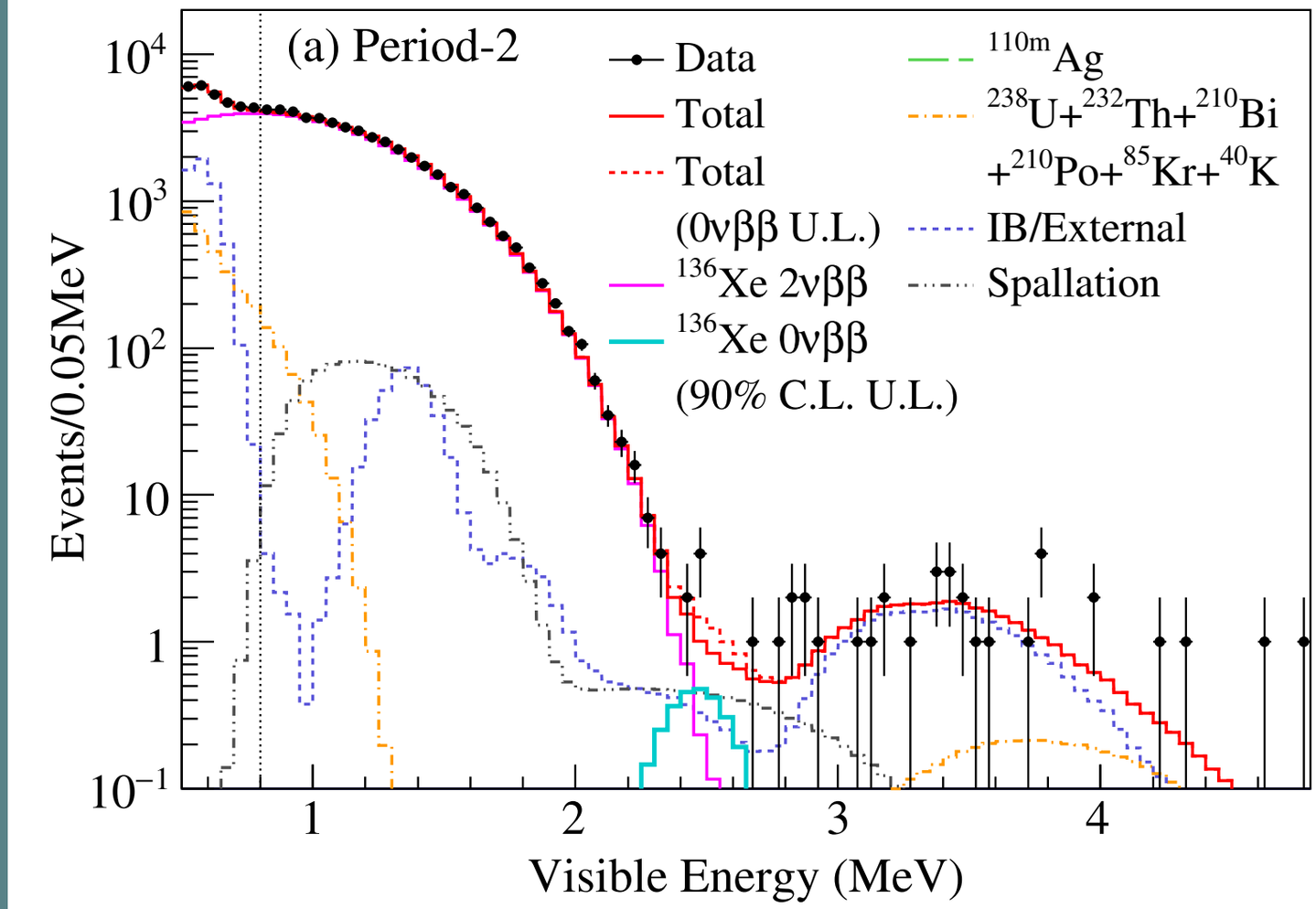
- Backgrounds in region of interest 2.3 ~ 2.7 MeV
- Within 1m-radius spherical volume

	Period-1 (270.7 days)		Period-2 (263.8 days)	
Observed events	22		11	
Background	Estimated	Best-fit	Estimated	Best-fit
^{136}Xe $2\nu\beta\beta$	-	5.48	-	5.29
Residual radioactivity in Xe-LS				
^{214}Bi (^{238}U series)	0.23 ± 0.04	0.25	0.028 ± 0.005	0.03
^{208}Tl (^{232}Th series)	-	0.001	-	0.001
^{110m}Ag	-	8.5	-	0.0
External (Radioactivity in IB)				
^{214}Bi (^{238}U series)	-	2.56	-	2.45
^{208}Tl (^{232}Th series)	-	0.02	-	0.03
^{110m}Ag	-	0.003	-	0.002
Spallation products				
^{10}C	2.7 ± 0.7	3.3	2.6 ± 0.7	2.8
^{6}He	0.07 ± 0.18	0.08	0.07 ± 0.18	0.08
^{12}B	0.15 ± 0.04	0.16	0.14 ± 0.04	0.15
^{137}Xe	0.5 ± 0.2	0.5	0.5 ± 0.2	0.4

Phys.Rev.Lett. 117 (2016) no.8, 082503

REDUCTION OF ^{110M}AG

- After 1.5 years purification
- 95% reduction of ^{110m}Ag



BACKGROUND ^{214}BI

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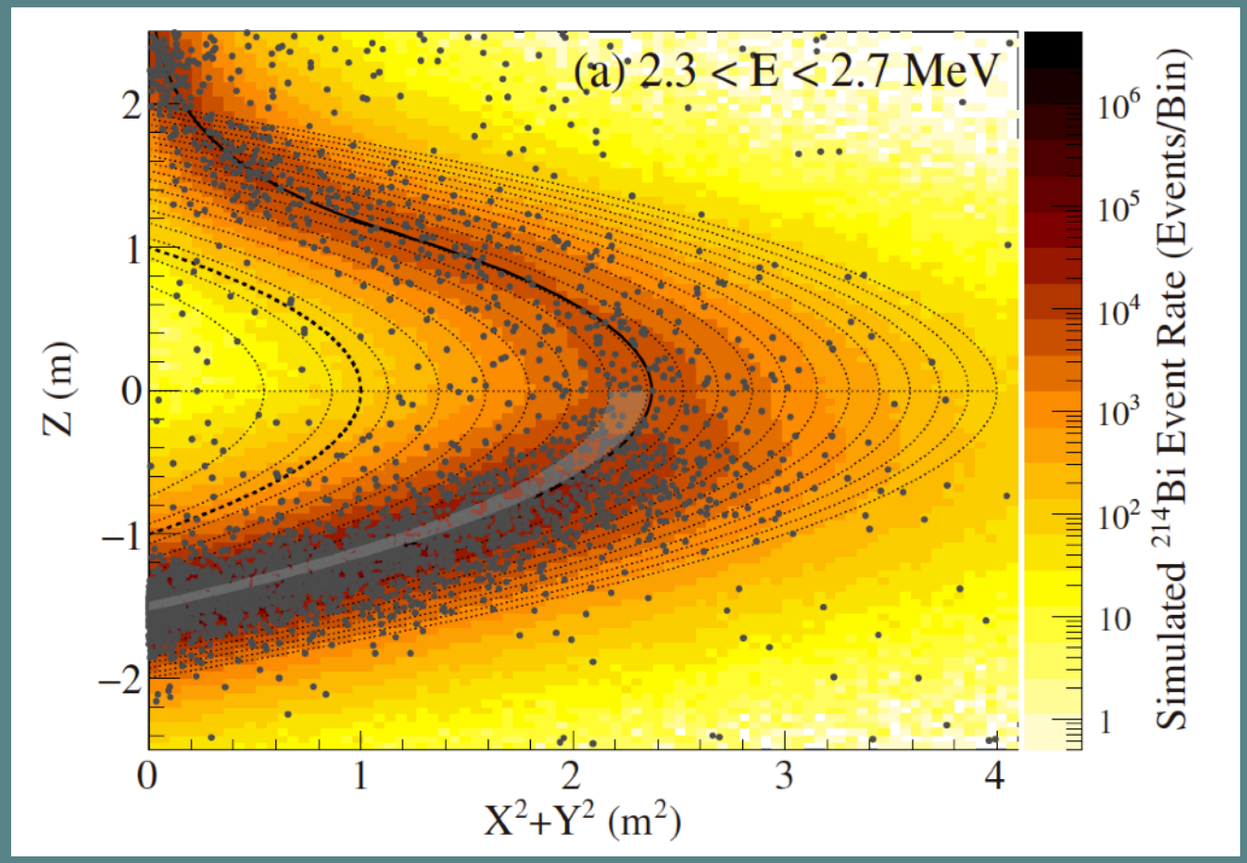
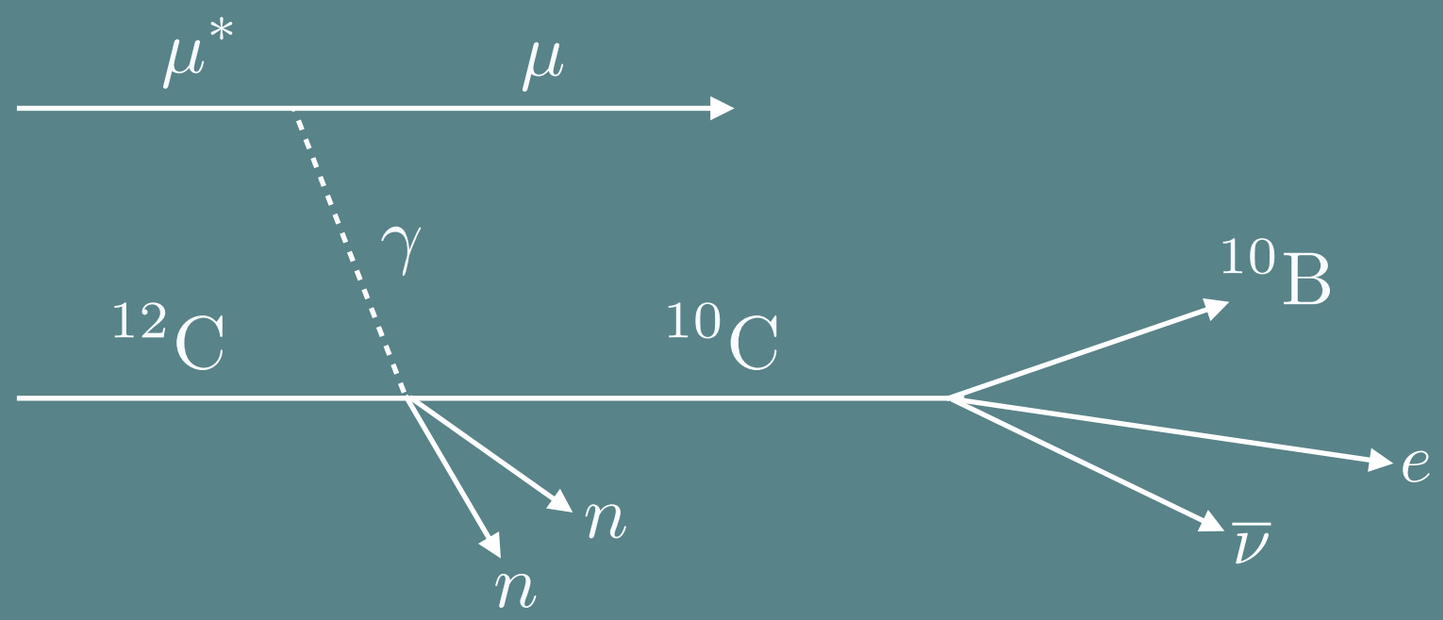
CUT ^{214}BI-^{214}PO DECAYS

- ^{214}Bi-^{214}Po is vetoed by a delayed coincidence tag.
  This cut removes (99.95±0.01)% of ^{214}Bi-^{214}Po decays.
- Major background at bottom of balloon
- Zen-800 is bigger and cleaner



SPALLATION

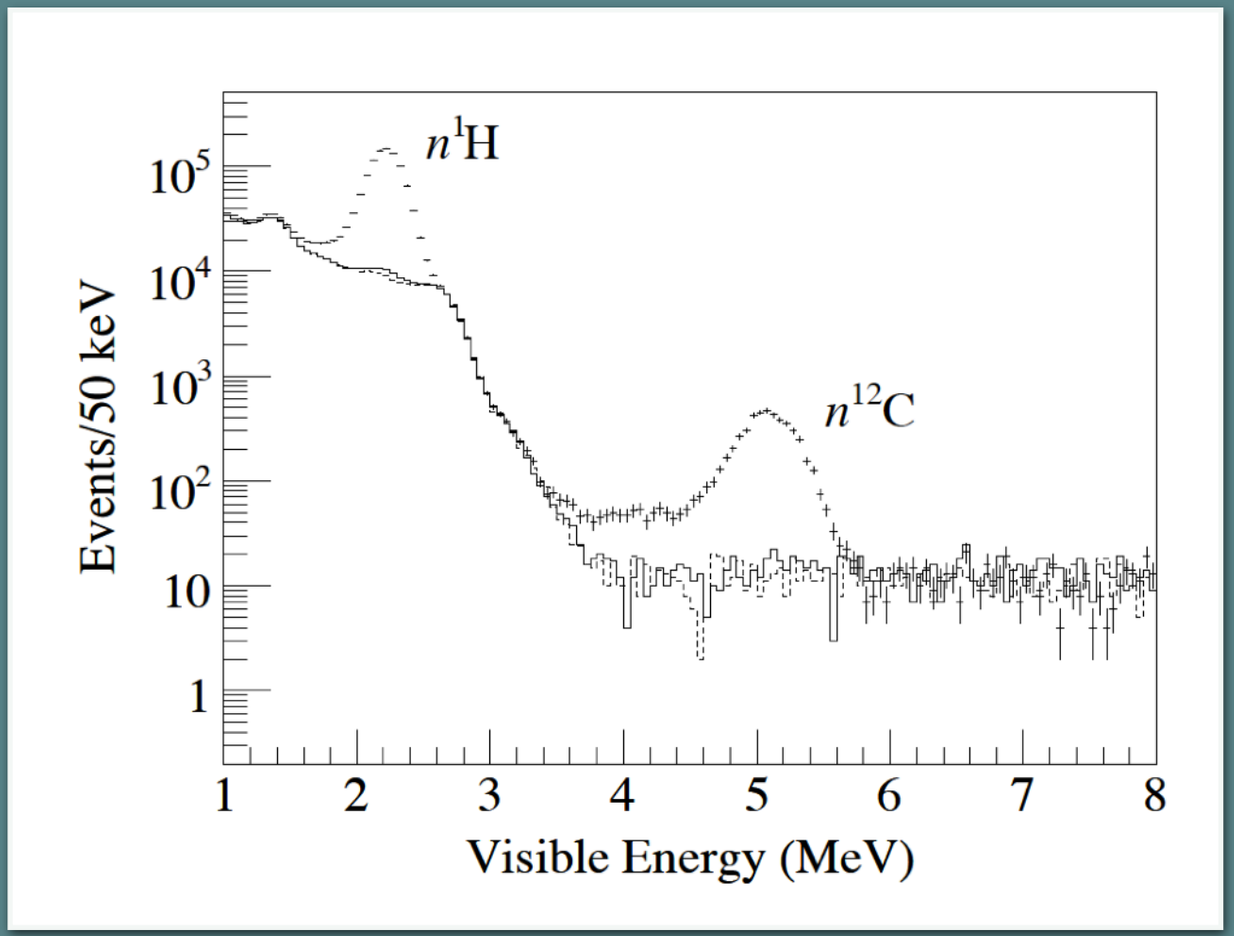
- Cosmic muons and their spallation products are potential backgrounds
- Muon rate ~ 0.333Hz



SPALLATION NEUTRONS

- Spallation Neutrons
  Capture time = 220 μs
  Use coincidence cut to reduce neutrons

- Spectra of the events following muons in
  150 ≤ T < 1000μs
  & 4150 ≤ T < 5000μs



BACKGROUND ^{10}C

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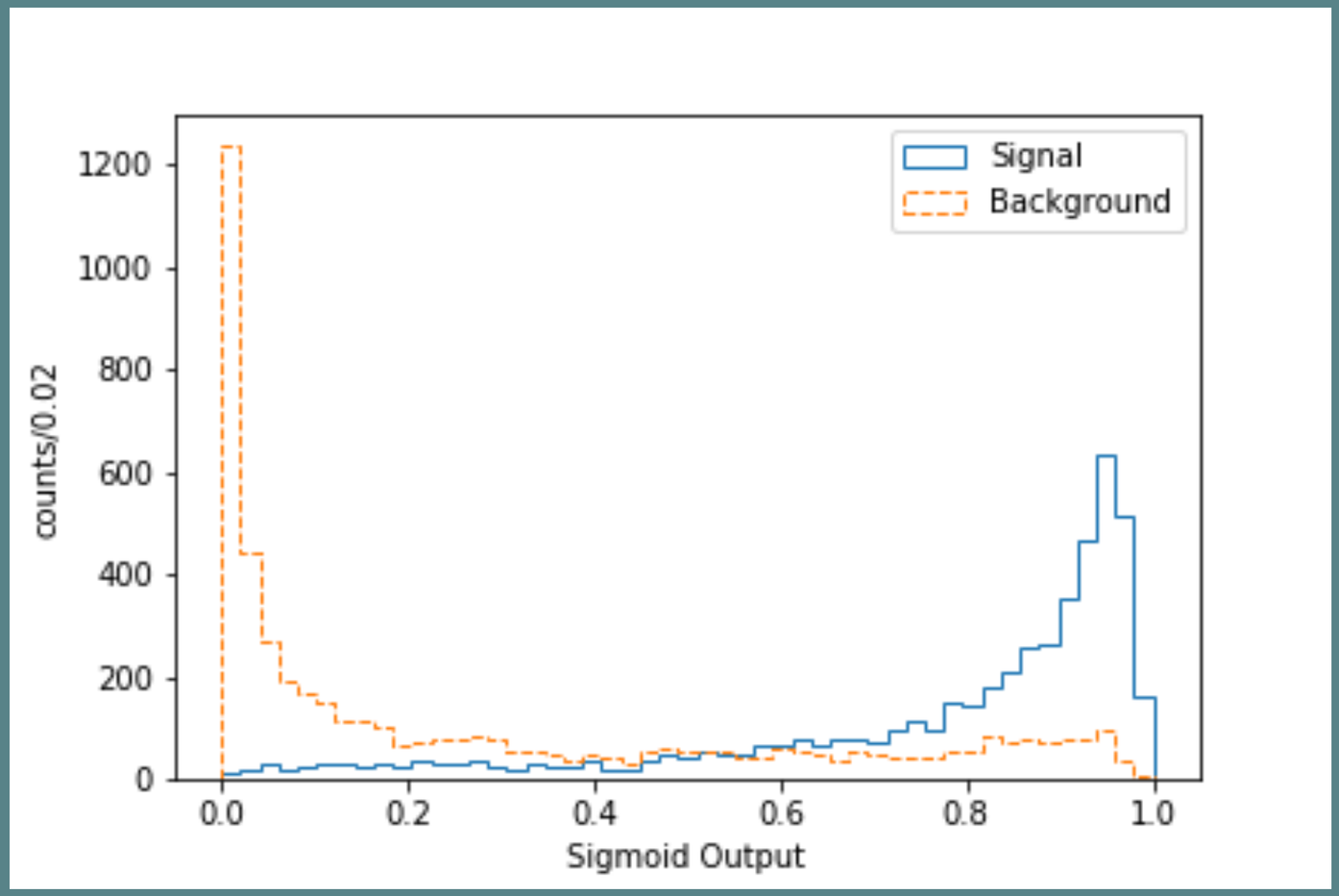
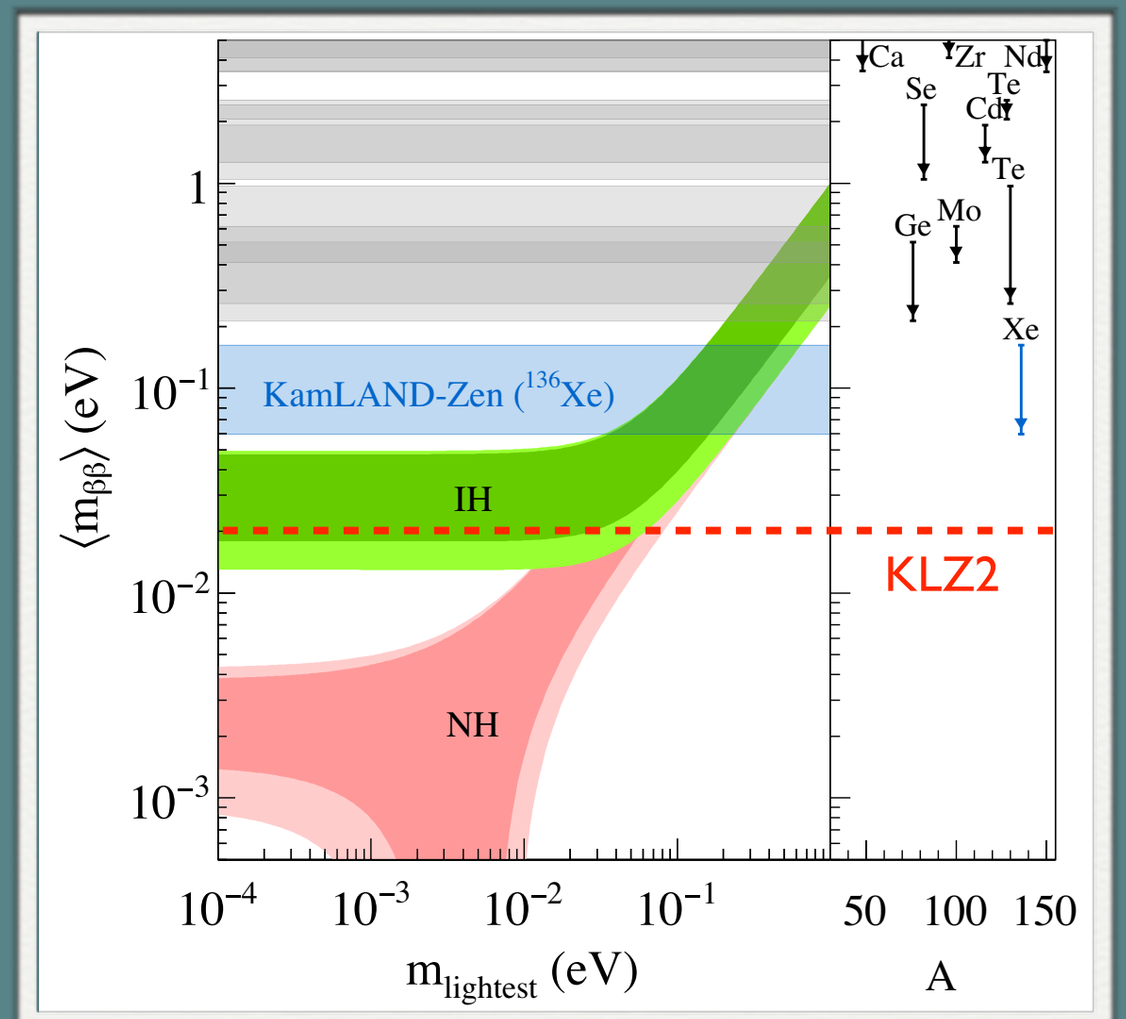
SPALLATION ISOTOPES

- Spallation Isotopes
  Major problem ^{10}C, with lifetime T~20s
  Use machine learning to separate from signal events
  (More details in Aobo's talk)



FUTURE PLAN - KLZ2

- Winston Cones
- Better PMT & More transparent LS => Light collection resolution 4% to 2%
- New electronics in progress
- Goal: (almost) finish probing the IH region



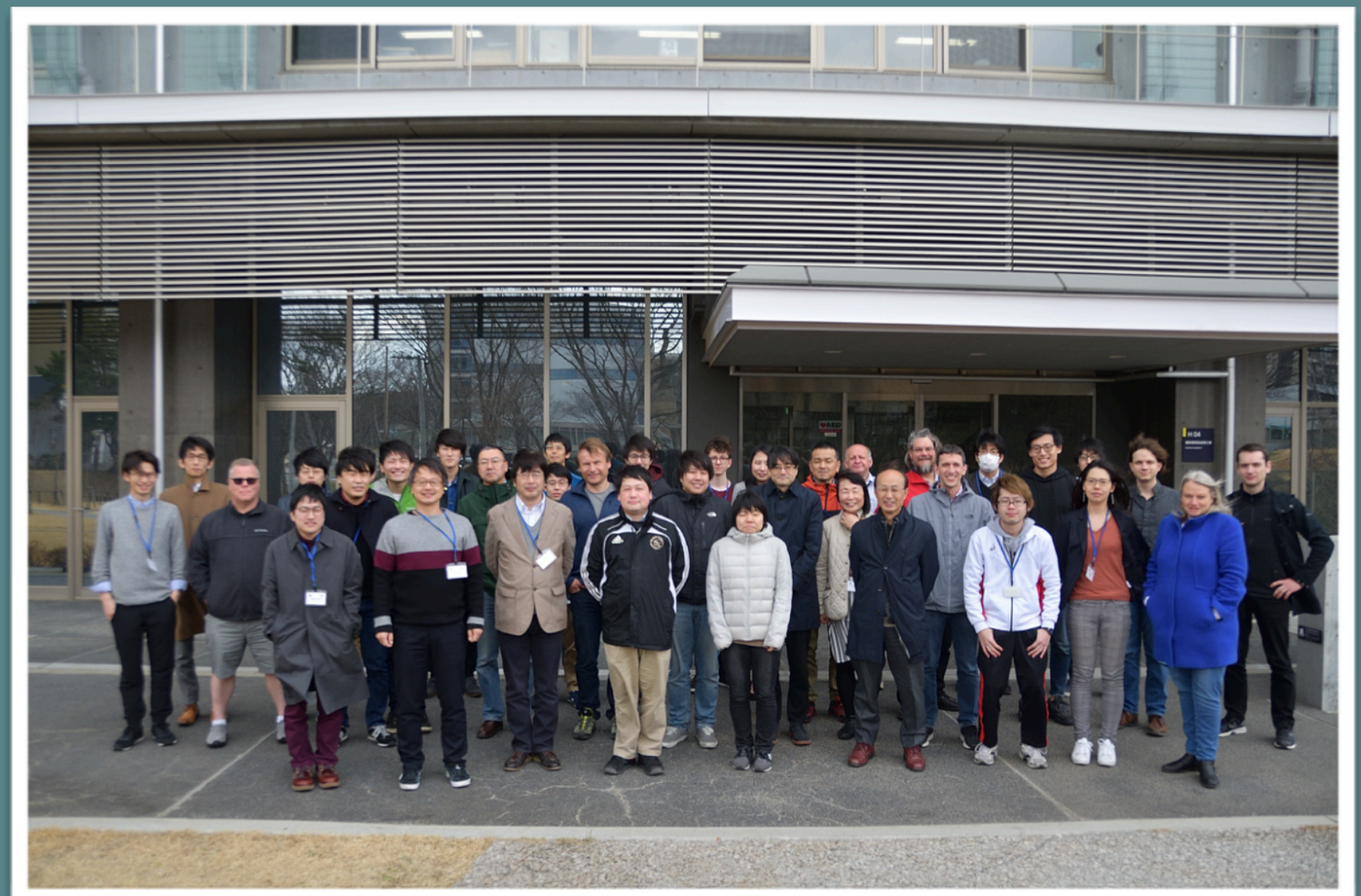
COLLABORATION

- Japan
  Tohoku University, RCNS
  University of Tokyo, Kavli IPMU
  Osaka University
  Tokushima University
  Kyoto University

- US
  Massachusetts Institute of Technology
  Boston University
  University of Washington
  University of California Berkeley
  University of Tennessee
  Triangle University Nuclear Laboratory
  Virginia Polytechnic Institute
  Virginia State University
  University of Hawaii

- Netherland
  Nikhef, University of Amsterdam

- ※ Second affiliation is not listed.



- Timeline of KamLAND-Zen from 2011 to present