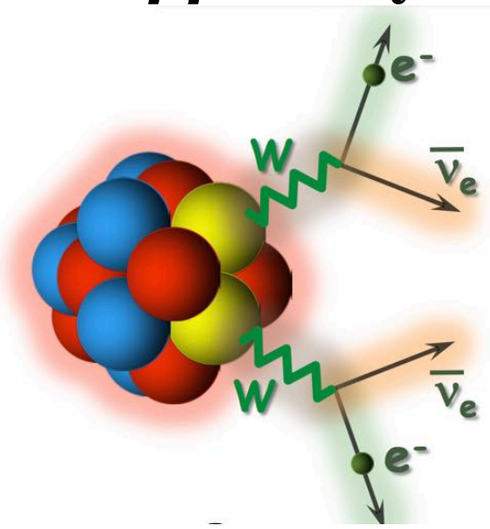
CANDLES Experiment
Current Status and Future Plan

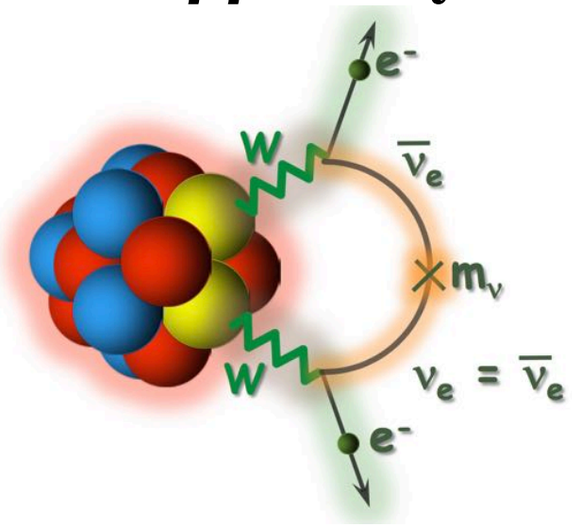
X. Li
for the CANDLES Collaboration

Neutrinoless Double Beta Decay (0νββ)

2νββ decay



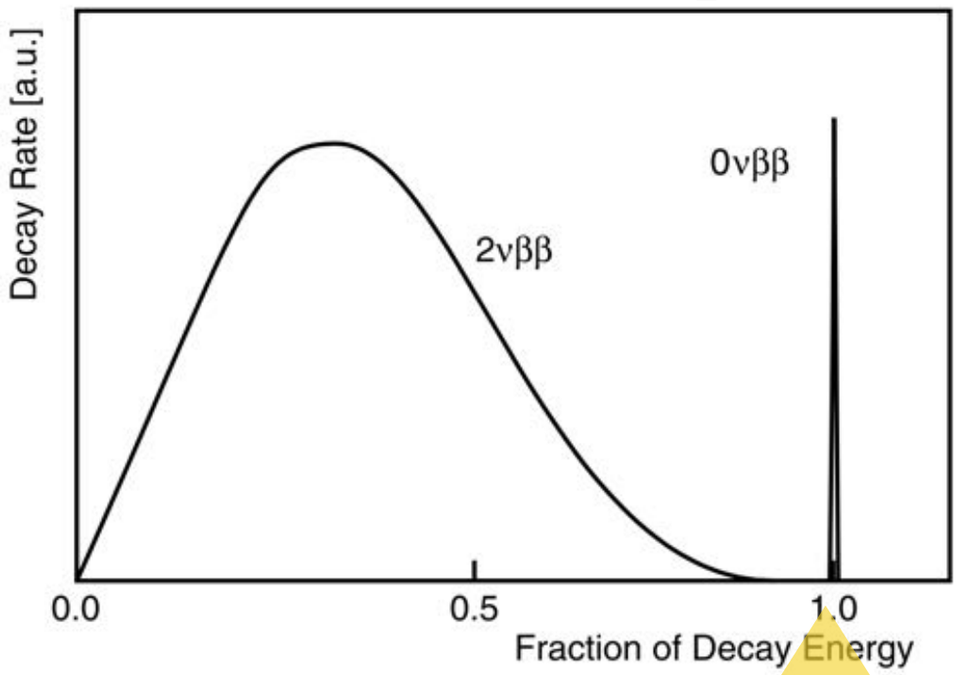
0νββ decay



(A, Z) => (A, Z+2) + 2e⁻

- process beyond Standard Model
  - Lepton number violation
  - Majorana particle
  - none-zero neutrino mass
- not observed yet
- predicted lifetime: $T_{1/2} > 10^{26}$ year

Detection Principle



normalized $Q_{\beta\beta}$ value

- 2νββ decay target: ^{76}Ge, ^{136}Xe, …, ^{48}Ca etc
- detect sum energy of two β rays

  2νββ: spectrum is continuous up to $Q_{\beta\beta}$ value

  0νββ: a single peak at $Q_{\beta\beta}$ value
- reduce background
- improve energy resolution to separate 2νββ and 0νββ

CANDLES Experiment

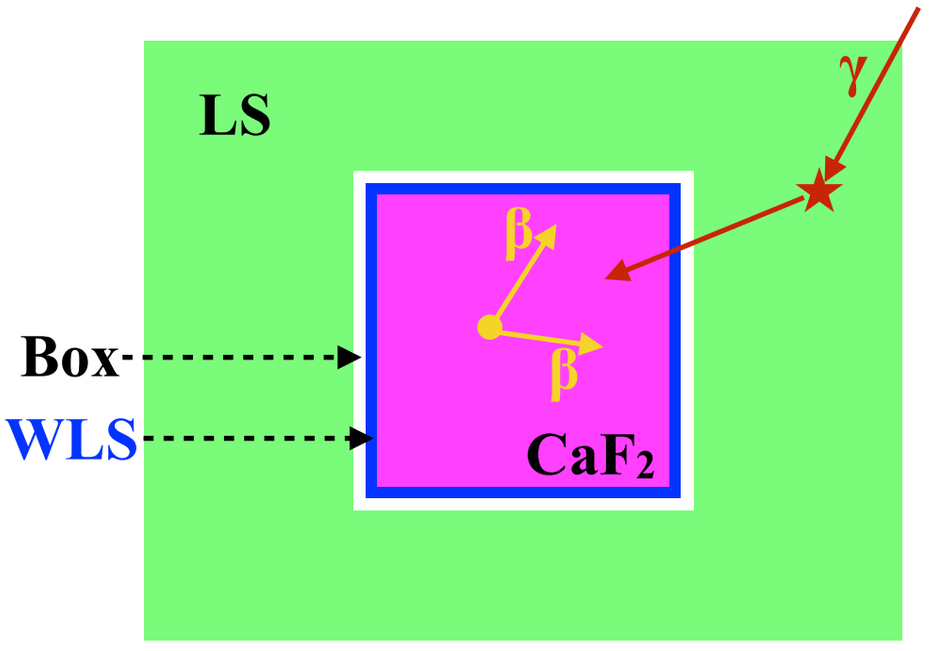
Choosing a 2νββ source isotope

candidate	$Q_{\beta\beta}$(MeV)	NA(%)
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

- ^{48}Ca isotope
  - largest $Q_{\beta\beta}$ value in all the candidates
    - less environment radiation, e.g. ^{208}Tl
    - potential to achieve BG free environment
    - large phase space factor that the decay rate is faster than other isotopes
  - natural abundance is low
    - some enrichment methods are under development

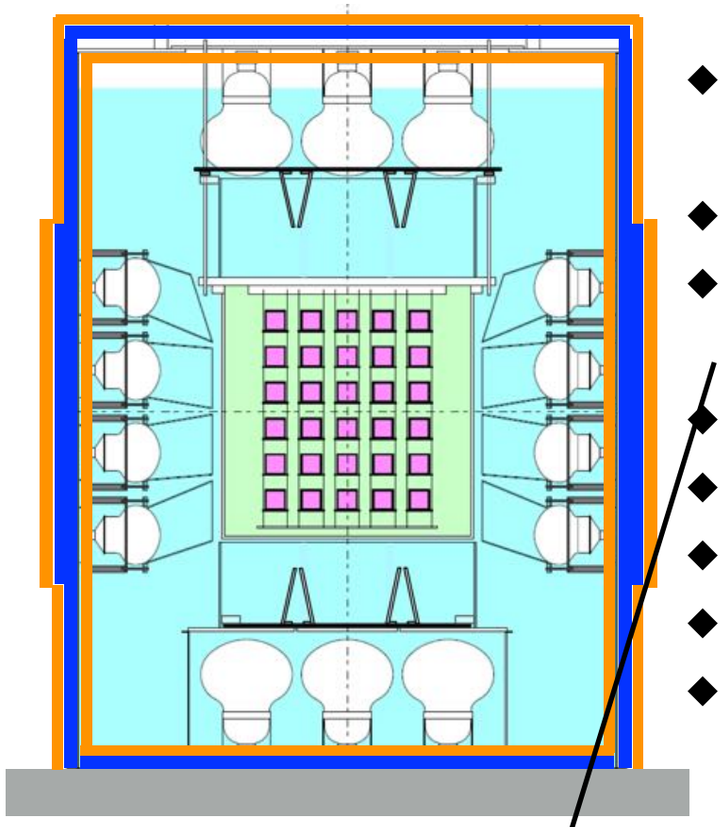
CANDLES's idea

- use CaF_2 crystal scintillator and PMT to make a calorimeter
- develop a 4π active veto with liquid scintillator (LS) to reduce external gamma background by PSD (p.5)



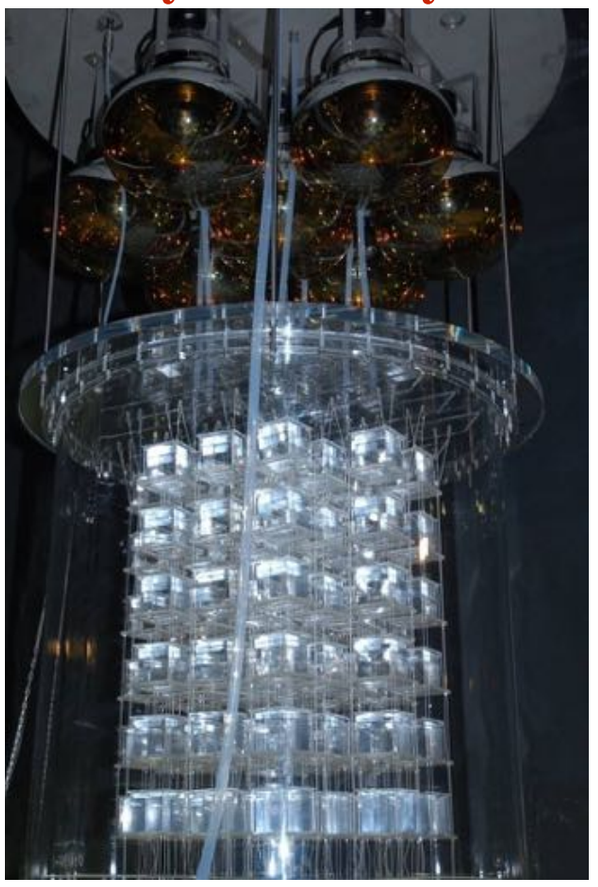
Detector Structure

CANDLES Detector

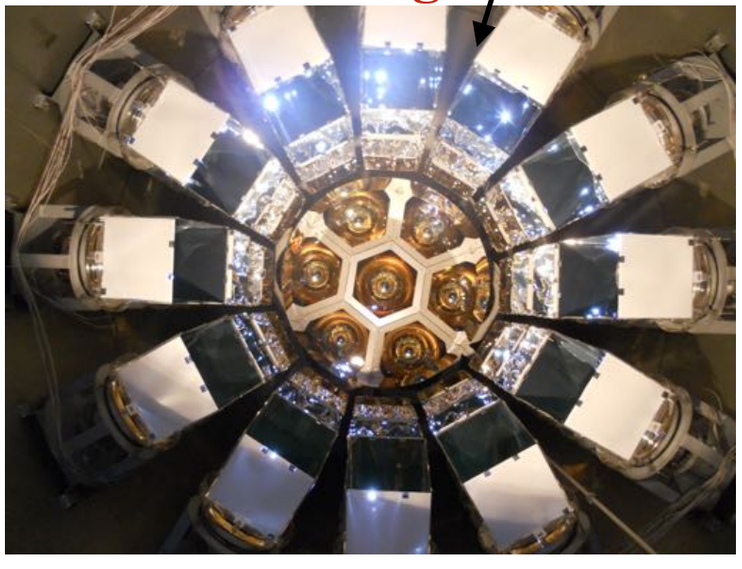


- CaF_2 crystals (96, 300kg)
- LS
- light guide (R_{Al}>93%)
- PMTs (62)
- pure water
- tank (Φ:3m, H:4m)
- boron shield (5mm)
- lead shield (10cm)

Crystal Array



PMT and Light Guide

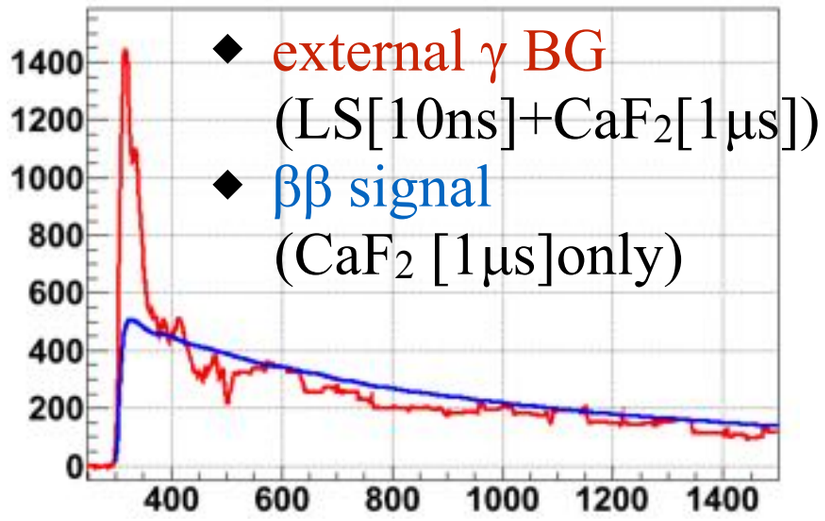


(n,γ) Shielding

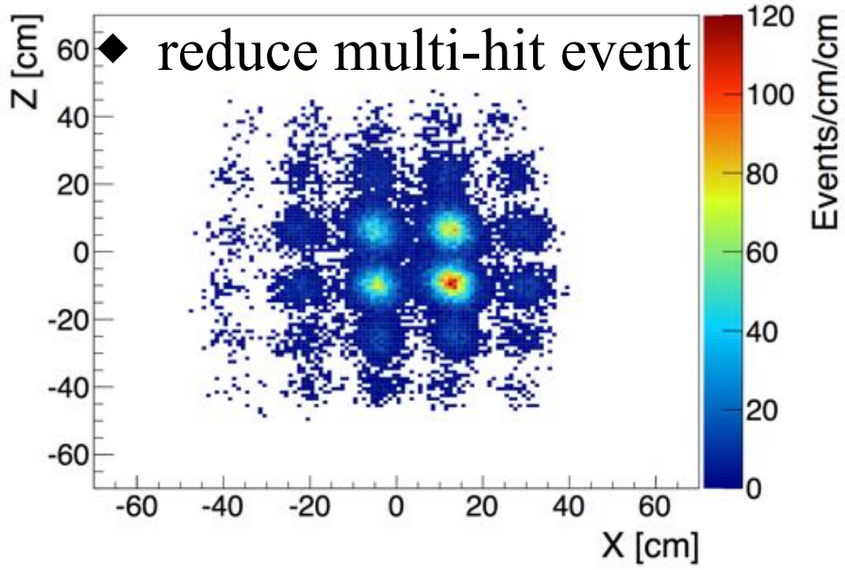
Background Reduction

- DAQ records waveform and time information => Analysis calculates position, energy, Particle ID information of γ/β and α to reduce BG

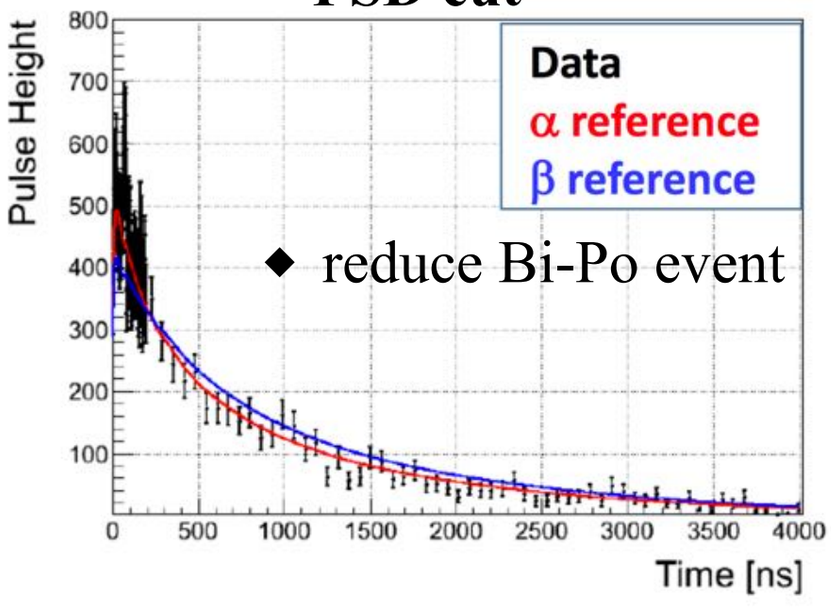
LS cut



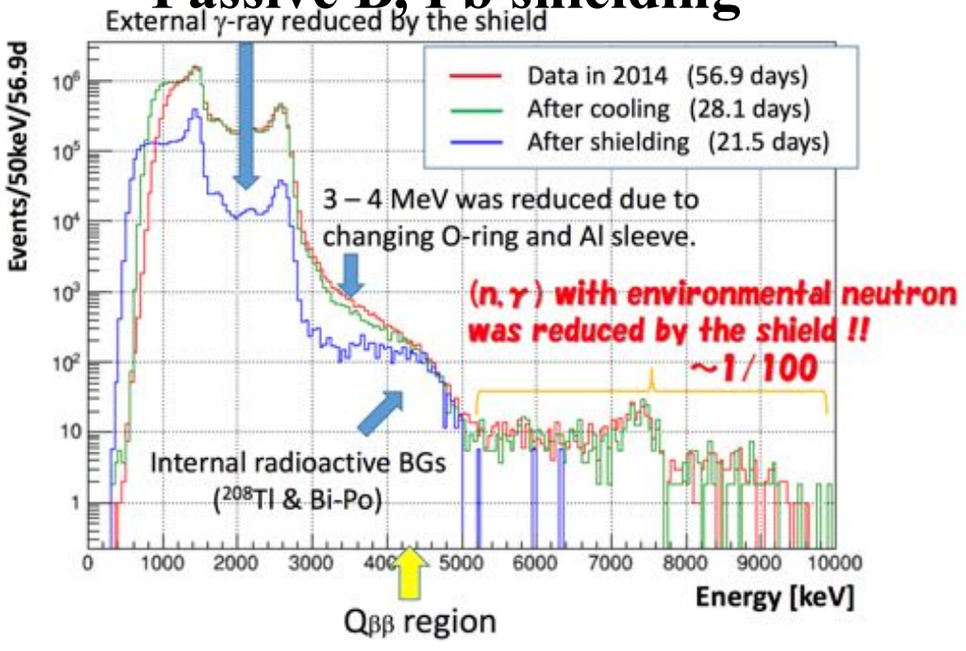
Position cut



PSD cut



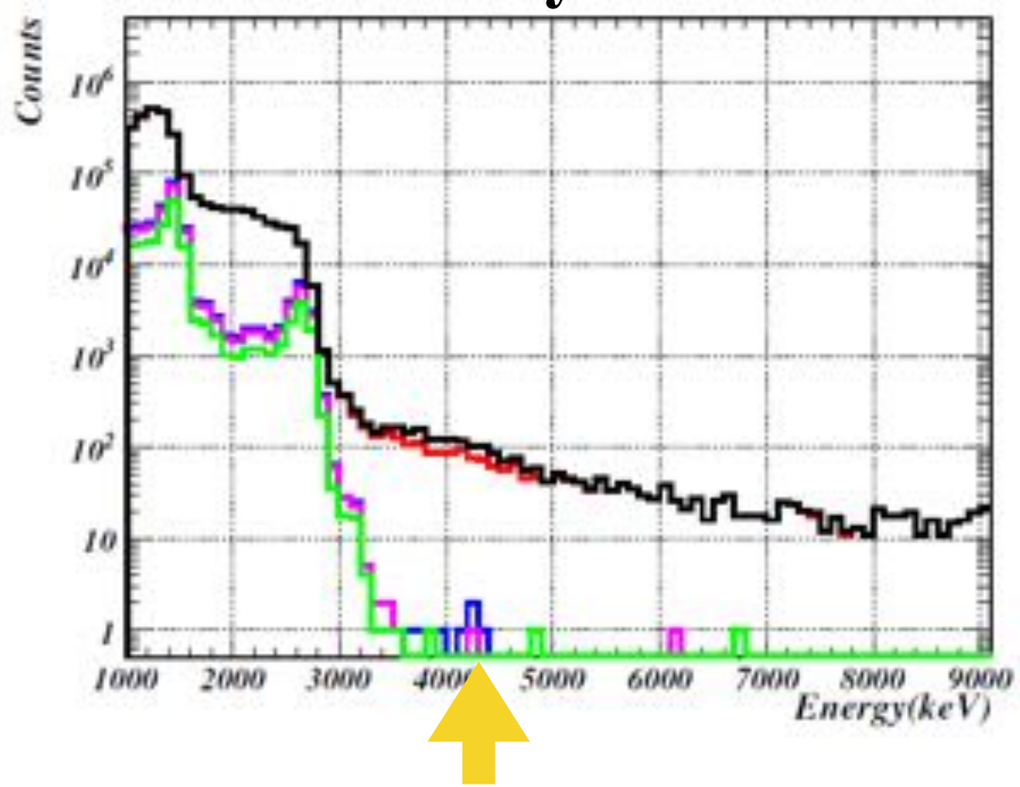
Passive B, Pb shielding



Background Spectrum

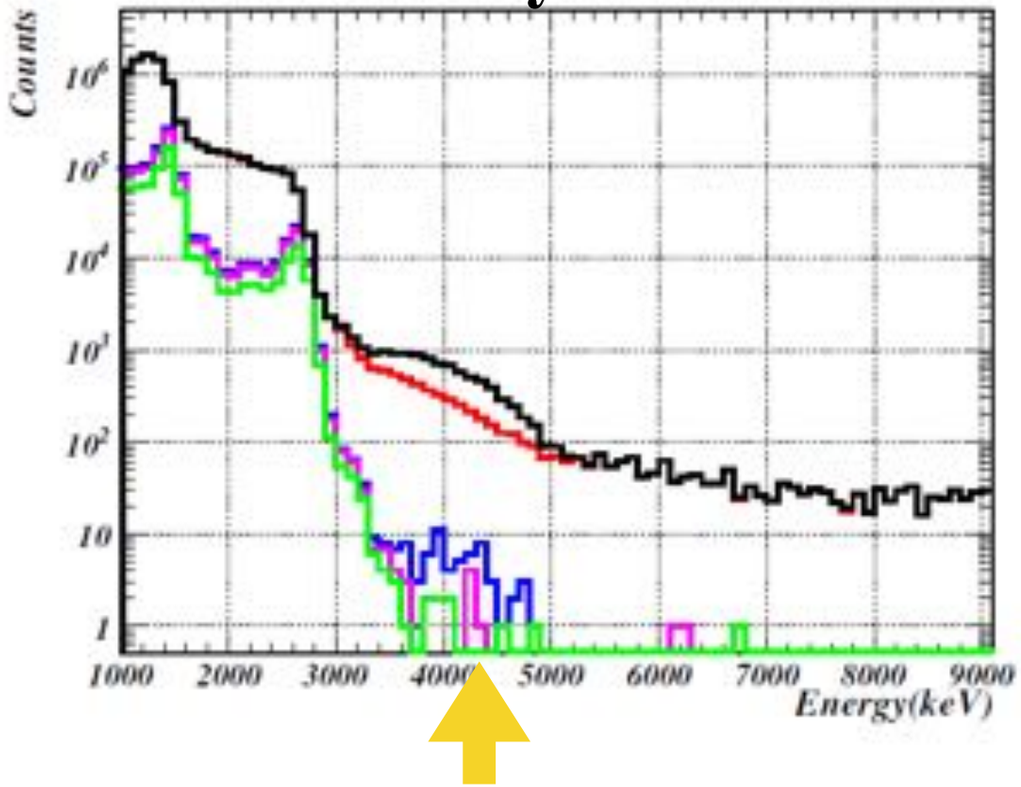
- 27 clean crystals (Th contamination < 10μBq/kg) from all 96 crystals are selected. The result is compared with the one of all crystals.

27 Crystals



$Q_{\beta\beta}$

All Crystals



$Q_{\beta\beta}$

- no cut
- Bi-Po cut
- LS cut (PSD)
- ^{208}Tl cut
- Multi-hit cut

Sensitivity of CANDLES

- Sensitivity for $0\nu\beta\beta$ in 1 year is calculated from expected backgrounds
  - data set: 21.5 days after shielding
  - $Q_{\beta\beta}$ region: 4170 ~ 4480 keV ($Q_{\beta\beta}$ -1σ +2σ)

	without multi-hit cut		with multi-hit cut	
	27 crystals	all crystals	27 crystals	all crystal
events at $Q_{\beta\beta}$ region	1	5	0	0
expected ^{208}Tl	0.22	2.2	0.14	1.4
expected (n, γ)	0.01	0.04	0.01	0.04
detection efficiency	46%		30%	
sensitivity for 1 year	0.7×10^{23}yr	1.0×10^{23}yr	0.5×10^{23}yr	0.9×10^{23}yr

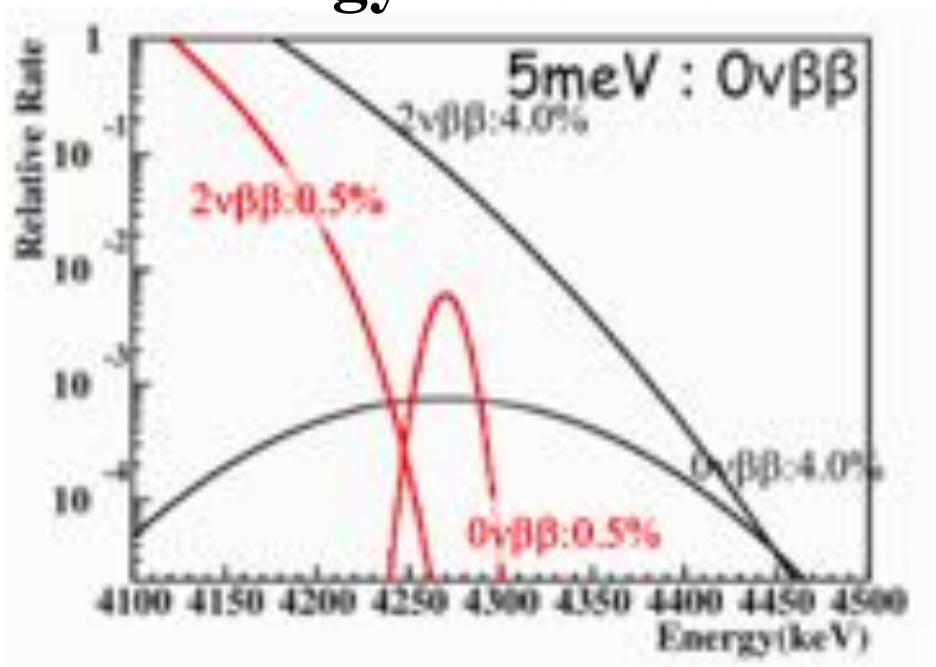
Sensitivity of CANDLES experiment for $0\nu\beta\beta$ using 1 year data is $0.5 \sim 1.0\times10^{23}$ year

Future Plan of CANDLES Experiment

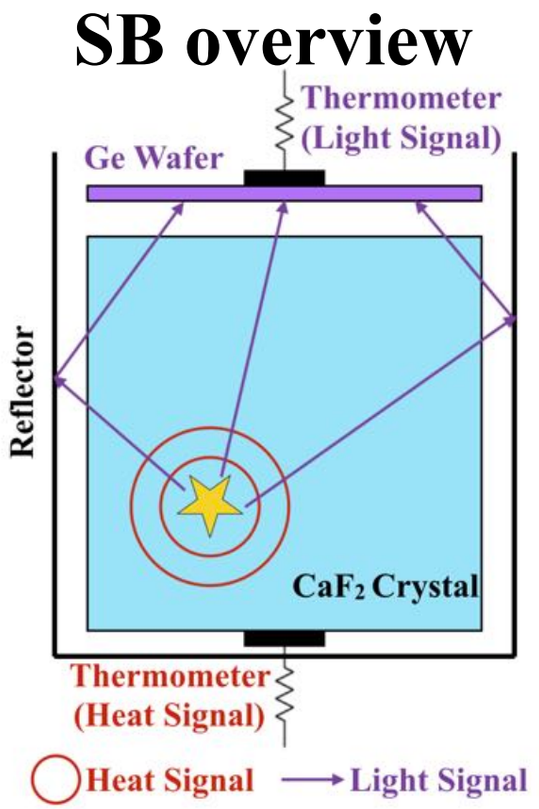
- The key to challenge 0νββ decay up to higher sensitivity is the enrichment of ^{48}Ca isotope
  - natural abundance 0.187% => Max ×500 enrichment factor is possible
  - four enrichment methods are being developed at below facilities
    - crown ether resin + chromatography (Osaka Univ, TIT, …)
    - crown ether + micro reactor (Osaka Sangyo Univ)
    - laser seperation (Fukui Univ)
    - multi-channel counter current electrophoresis (Osaka Univ)

- The ultimate BG will be 2νββ decay after enrichment
  - apply high energy resolution (0.5%FWHM) technology to CANDLES
    - bolometer method
      - phonon statistics, better than photon statistics
    - bolometer experiment group
      - CUORE: 0.2% (^{130}Te)
      - AMoRE (^{100}Mo)
      - CRESST (dark matter)

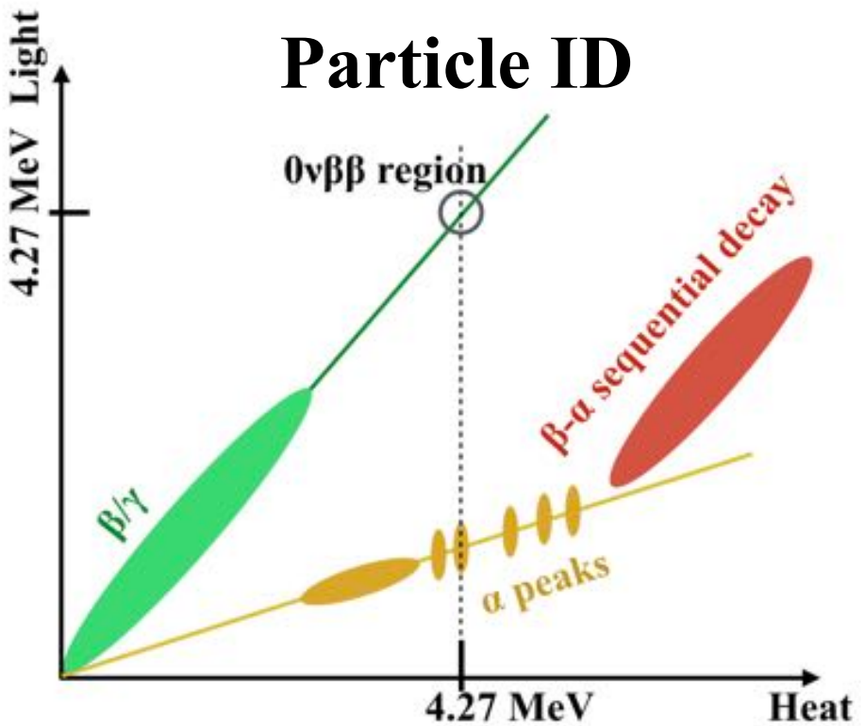
Energy Resolution



Next Generation: Scintillating Bolometer



- Heat detector (CaF_2) + Light detector (Ge)
  - simultaneously measuring heat and light by neutron transmutation doped germanium (NTD-Ge) sensor
  - heat detector => CaF_2 crystal: 20×20×20 mm^3
  - light detector => Ge wafer: 22mmΦ×200μm
  - heat detector => energy calculation
    light detector => background reduction



- Quenching effect used for BG reduction
  - light outputs of same energy γ/β and α are different

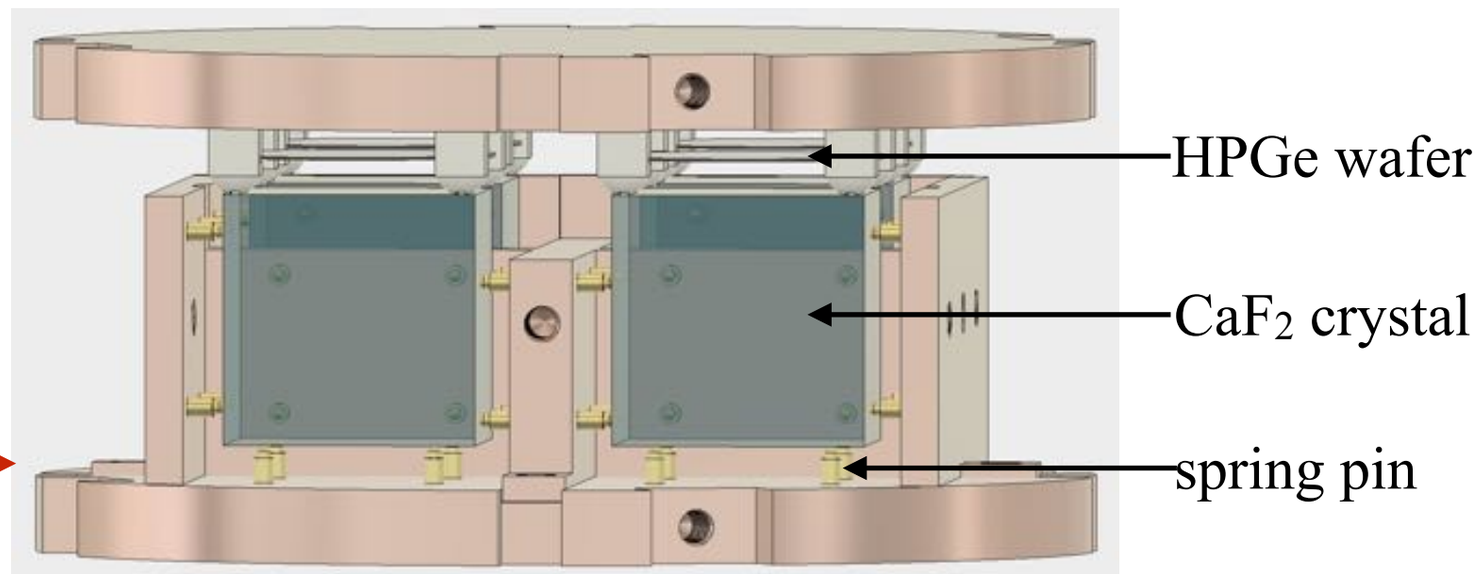
Future prospect is good, but at first 10mK

Development Status

Dilution Refrigerator

- Dilution refrigerator made by Tokyo Univ
  - developed for dark matter research, so customized to low BG measurement
  - we apply it to 0νββ decay search
- Cooling system reconstruction
  - have made a new circulation pipeline for costly ^{3}He without any leakage
  - have achieved 4K, 1K and will challenge 10mK in April this year

CaF_2 Detector modules



Summary

- CANDLES is a project to search for neutrinoless double beta decay using ^{48}Ca isotope in 300 kg CaF_2 scintillator, running at Kamioka underground laboratory.

- The sensitivity of CANDLES detector is 0.5 ~ 1.0×10^{23} year with 1 year data.

- The next generation detector “Scintillating Bolometer” with high energy resolution is being developed.

Thank you