The COBRA Experiment

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On behalf of the COBRA Collaboration

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COBRA – the Concept

Cadmium Telluride $0$-neutrino Beta Decay Research Apparatus

★ Build up a large array of CdZnTe semiconductor detectors

$\nu\beta\beta$ Candidate Isotopes

★ CdZnTe contains 9 $\beta\beta$ Isotopes

$^{116}\text{Cd}$, $^{130}\text{Te}$, $^{114}\text{Cd}$, $^{70}\text{Zn}$, $^{128}\text{Te}$ ($\beta^-\beta^-$), $^{64}\text{Zn}$, $^{106}\text{Cd}$, $^{108}\text{Cd}$, $^{120}\text{Te}$ ($\beta^+\beta^+, \beta^+\text{EC}, \text{EC/EC}$)

★ Main $\nu\beta\beta$ candidate: $^{116}\text{Cd}$

- Endpoint = 2805 keV
- Enrichment to 90%
- Favourable $G_{0\nu}|M_{0\nu}|^2 \rightarrow T_{1/2} \sim 10^{26}$ years for 50meV $\nu$

★ Also interesting: $^{106}\text{Cd}$

- Endpoint = 2771 keV
- EC(EC), $\beta^+/\text{EC}$ and $\beta^+\beta^+$ modes
- $\beta^+/\text{EC}$ - enhanced sensitivity to RH weak currents

Experimental Requirements

\[ T^{0\nu}_{1/2} \propto a \varepsilon \sqrt{\frac{M_t}{\Delta E B}} \]

- 64,000 1cm\(^3\) crystals = 418 kg
- 90% enriched in \(^{116}\text{Cd}\)
- Backgrounds < 0.001 count keV\(^{-1}\)kg\(^{-1}\)year\(^{-1}\)
- Energy Resolution < 2%
Energy Resolution

- Only electron signal read out (CPG technology)
- Possible improvements: cooling, new grids
- Better detectors are available

ΔE = 1.9% @ 2.8MeV
=2.9% @ 662keV
Background Sources - 1

★ 2νββ decays

\[ T_{1/2}^{(116\text{Cd})} = 2.7 \times 10^{19} \text{ y} \]

For \( \Delta E = 2\% \), fraction of 2νββ events in 0νββ window ≈ 3 \times 10^{-9}

\[ F = \frac{8Q}{m_e} \left( \frac{\Delta E}{Q} \right)^6 \]

Background Sources - II

★ Muons and Neutrons

- $^{113}$Cd thermal neutron capture $\sigma = 20,647$ barns

Spectrum from activation with 18.5 GBq Am/Be source:

★ Detailed MCNP simulations to optimise shielding.
Background Sources - III

★ $\alpha, \beta, \gamma$ sources

- Intrinsic and surface contaminants
- Cosmogenics

**Gas**

$^{222}\text{Rn}$ gas

**Delrin Holder**

$^{238}\text{U}, ^{232}\text{Th}$ decay chain

$^{40}\text{K}$

$^{137}\text{Cs}$

**Crystals**

$^{238}\text{U}, ^{232}\text{Th}$ decay chains

$^{40}\text{K}$

$^{137}\text{Cs}$

$^{210}\text{Po}$

$^{210}\text{Pb}$ on surface

Cosmogenic isotopes

**Chamber walls**

$^{210}\text{Pb}$ on surface
Simulations

★ Determine material requirements through simulation
VENOM – Geant4 based Monte Carlo package
implements the DECAY0 decay generator
Experimental Status

★ Surface Labs
  • Tests of individual crystals

★ LNGS (~3500 mwe)
  • 2×2 proto-type
  • 4×4×4 array installed
Physics Results

★ 4.34 kg.days of 2×2 proto-type data
★ Measurement of 4-fold forbidden $^{113}\text{Cd}$ $\beta$ decay


$T_{1/2} = (8.2 \pm 0.2 \text{ (stat.)} \pm 1.0 \text{ (sys)}) \times 10^{15} \text{ yrs}$

★ New $T_{1/2}$ limits on $0\nu\beta^+/EC$ and $0\nu\text{EC/EC}$ modes

- $^{64}\text{Zn}$ $0\nu\text{EC/EC}$: $T_{1/2} > 9.7 \times 10^{16}$
- $^{120}\text{Te}$ $0\nu\text{EC/EC}$: $T_{1/2} > 2.2 \times 10^{15}$
- $^{120}\text{Te}$ $0\nu\beta^+/EC$: $T_{1/2} > 6.4 \times 10^{16}$
Coincidences

★ Intrinsic $^{238}$U and $^{232}$Th could be major backgrounds

★ Reject multiple-crystal events
  • $\beta\beta$ is normally single crystal event
  • Reduce $^{232}$Th chain events from crystals by >50%

Simulated $^{238}$U chain events inside detectors
No Energy smearing
Timing Coincidences

- The major contribution to $^{238}\text{U}$ spectrum at 2–3MeV is the fast $\beta-\alpha$ decay:

$$^{214}\text{Bi} \rightarrow ^{214}\text{Po} \rightarrow ^{210}\text{Pb}$$

- Endpoint 3.3MeV, accounts for >70% events in 2-3MeV region from $^{238}\text{U}$ chain

- 7.7MeV alpha half-life = $164.3\mu\text{s}$

- >40% efficiency for tagging $^{214}\text{Bi}$ events originating inside the crystals
Observation of $^{214}$Bi events

★ Surface coating $\rightarrow$ self calibrating device!
  • small dead volume
  • Measure of “paint” activity

$T_{1/2} = 162 \pm 19\mu$s
Pixellisation - I

★ Extra information on events with signal energy. 200μm pixels (example simulations):

★ eg. Could achieve nearly 100% identification of $^{214}$Bi events.
Pixellisation - II

- Tests of 16×16 1.6mm pixel detectors

Single Pixel $^{57}$Co spectrum

Crystal

ASIC readout

122keV

137keV
Shielding and Veto

★ Optimise shielding design for neutrons

Size = 18.4 m³, Mass = 64964 kg

★ **Active scintillator** component for inner layer
  - Veto any residual external background components
  - Veto $\gamma$s from internal backgrounds
  - Enhance sensitivity to $\beta\beta$ decays with high energy $\gamma$s
Working design of 64K 1cm³ enriched CZT detectors gives sensitivity to ¹¹⁶Cd $T_{1/2} \approx 10^{26}$ y.

New 64-crystal prototype installation in LNGS.

Resolution $\leq 2\%$.

Background reduction:
- Material selection
- Timing and spatial coincidences
- Comprehensive shielding with active veto
- Pixellated detectors under investigation

Work in progress:
- Much has been achieved but lots of work to do…

Summary

Ssssssummary

Ssssssummary
Join the party!

★ New collaborators would be welcomed!