A search for low mass dark matter candidates produced in the T2K neutrino beam and detected by off-timing NCQE deexcitation gammas in Super-K
T2K is a long baseline neutrino oscillation experiment

- electron neutrino appearance
- muon neutrino disappearance
- neutrino cross section measurements
- sterile neutrino searches

near detector

J-PARC

Super-K far detector

Tokai, Ibaraki

Kamioka Observatory

295 km
T2K … can be used to produce and then detect DM

Technique proposed to detect accelerator-produced, relativistic DM in Super-K
Dark sector connected to Standard Model through vector portal

Kinetic mixing between Standard Model $\gamma$ and vector mediator $A'$

$m_{A'} > 2 \, m_\chi$

$A' \rightarrow \bar{\chi} + \chi$

direct production

$p + p(n) \rightarrow A' \rightarrow \bar{\chi} \chi$

indirect production

$p + p(n) \rightarrow \pi^0, \eta \rightarrow A'\gamma \rightarrow \bar{\chi} \chi \gamma$

30 GeV protons

graphite target

295 km

50 kt water Cherenkov detector
Theorist estimate of T2K Super-K sensitivity
A. Ritz and P. deNiverville, private communication.

Some model-dependent constraints:
- Monojet (CDF)
- $\mu (g - 2)$

CRESST (2002)
XENON10 (2011)

$WIMP$-nucleon cross section (cm$^2$)

T2K Super-K projected sensitivity for 1 event

$m_{\Lambda'} = 1 \text{ GeV}$ $\alpha' = \alpha$ $\text{POT} = 5 \times 10^{21}$
The same sensitivity would also look like this:

Some model-dependent constraints:
- $J/\psi \rightarrow \text{invisible}$
- Monojet (CDF)
- $e^+e^-$
- $(g - 2)\mu$
- $\pi^0 \rightarrow \gamma + \text{invisible}$
- $K^+ \rightarrow \pi^+ + \text{invisible}$

$(g - 2)\mu$ anomaly resolved

$m_\chi = 100$ MeV
$\alpha' = \alpha$
$5 \times 10^{21}$ POT
Super-K water Cherenkov detector is well understood

50 kilotonne (22.5 kilotonne fiducial)
11,000 inward-facing PMTs
2,000 outward facing PMTs
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DM signature may be similar to neutrino neutral current on oxygen, detect nuclear deexcitation γ

1000 m
2700 m.w.e.
Time of flight to separate DM from neutrino

- J-PARC near detector
- SK
- 295 km
- 1 ms for neutrino

**Diagram**

- **Profile**
  - **J-PARC** near detector
  - **SK**
  - **295 km**
  - **1 ms for neutrino**

**Graph**

- **$m_{\chi}$**
  - **Direct production** $m_{A'} = 1$ GeV
  - **$1 \frac{d\sigma}{dE_dE_d\theta}$** (nb/(GeV°))
  - **$10^2$** to **$10^6$**

**Table**

<table>
<thead>
<tr>
<th>$m_{\chi}$</th>
<th>TOF delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 MeV</td>
<td>3 µs</td>
</tr>
<tr>
<td>300 MeV</td>
<td>400 ns</td>
</tr>
<tr>
<td>100 MeV</td>
<td>30 ns</td>
</tr>
</tbody>
</table>

**References**

- **PRD 86 035022 (2012)**, data from author
Time of flight to separate DM from neutrino

Gaussian neutrino pulses

Beam structure
- 8 bunches per spill
- bunch is 24 ns wide
- separated by 581 ns
- (spill delivered every 3 s)
The production of vectors via e.g.

The same for

rest frame,

FIG. 5.

 domicile. The aforementioned NA61

for the T2K target configuration, and found

against existing data published by NA61 

in Fig. 6. We have also tested this distribution

 experiments of interest. Example distributions

scaled to cover the target materials for the ex-

data for (averaged

and

relative small DM velo-

cities (e.g. in the limit that the DM is produced at the threshold,

pp

450 MeV

near detector

Time of flight to separate DM from neutrino

collisions at T2K ND280 at

and

†

and

V

Cambridge,

applied

and

the beam direction in the lab frame,

f

BMPT

4

0.25

E

0

2

500

2000

3000

1000

0

2

4

6

8

10

12

14

E_\chi \ (\text{GeV})

10^6

10^5

10^4

10^3

10^2

 Gaussi an neutrino pulses, followed by DM distributions

3 \mu s

10^{-6}

10^{-5}

10^{-4}

10^{-3}

10^{-2}

10^{-1}

1

arbitrary counts

tof delay (\mu s)
Time of flight to separate DM from neutrino

J-PARC near detector

SK

295 km

1 ms for neutrino

Gaussian neutrino pulses, followed by DM distributions

400 ns

\[ E_\chi \ (\text{GeV}) \]

\[ \text{arbitrary counts} \]

\[ \text{tof delay (\mu s)} \]
which we exclude in the analysis.

Pseudoscalar meson production distributions for MINOS and T2K configurations are shown for MINOS and T2K experiments of interest. Example distributions for (averaged

Corina Nantais

Dark Sectors 2016, 30 April 2016
Nuclear deexcitation gammas after the neutrino-oxygen neutral-current quasielastic (NCQE) interaction

\[ ^{16}\text{O} \]

\[ \nu \rightarrow \gamma \]

600 MeV, single nucleon emission is dominant mechanism

excited nucleus decays by emitting gammas

contribution of \( p_{3/2} \) is overwhelming:
6.32 MeV from \( (p_{3/2})_p \)
6.18 MeV from \( (p_{3/2})_n \)

87% branching ratio for \( \sim 6 \) MeV from \( p_{3/2} \)
Analysis of neutrino-oxygen NCQE events in T2K Super-K

Selection cuts
- 4 – 30 MeV reconstructed energy
- > 34° Cherenkov angle to remove muons
- ±100 ns of beam timing
- fiducial volume
- reconstruction quality cuts
Conclusion

Search for low mass dark matter candidate produced in T2K neutrino beam

- understand detection of deexcitation gammas in Super-K after neutrino-oxygen NCQE
- plan to apply to DM search
- DM/neutrino discrimination using time of flight
- compare ratio of neutrino and DM for model-independent cross section