3D сегментированный сцинтилляционный детектор нейтрино для осцилляционных экспериментов

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Physics motivation

HyperK, 750 kW -10 years, 1.3 kW – 6 years

LBL oscillation experiments
T2K-II, T2HK, DUNE
Search for CP violation, MH measurement
$\nu_\mu \rightarrow \nu_e$ $10^3 – 10^4$ events

Issues:
→ systematic uncertainties $\leq 2\%$
→ anti-nu cross sections
→ $\sigma(\nu e)/\sigma(\nu\mu) < 2\%$
→ CCQE $4\pi$ high acceptance
→ $\nu$ CC low threshold of protons $\sim 45$ MeV, cross sections, nuclear models
→ $e$/gamma separation

Relatively small detector of reactor antineutrinos
- $4\pi$ uniform detector
- positron detection with high spatial and energy resolution
  direction of positrons from anti-nu interactions
- efficient neutron detection
3D neutrino target/detector

3D Segmented Scintillator neutrino Detector (3D SSD)
Mass ~ few tons
Scintillator cubes $1\text{cm}^3 \geq 10^6$
Readout: three $X,Y,Z$ WLS fibers per cube $\rightarrow$ ~100 k channels
Photosensor: SiPM’s
Integration in near detectors

Possible integration of 3D segmented detector in ND complex

3D segmented detector
e/\gamma \text{ separation}

Monte Carlo simulations

\begin{align*}
\text{e Sample} & \quad \text{\textbf{B}=0.2 \ T} \\
\text{\gamma Sample} & \quad \text{\textbf{B}=0.2 \ T}
\end{align*}
ν interactions

Monte Carlo simulations

CCQE

CC1π
Scintillator cubes

Cubes: 10x10x10 mm³
Material: extruded polystyrene + p-terphenyl
White chemical reflector, thickness ~ 50 mkm
3 holes: each of 1.5 mm diameter
WLS fibers: Kuraray Y11, double clad 1.0 mm diameter

Produced by Uniplast, Vladimir

ArXiv:1707.01785
Prototype for test at CERN

- 125 cubes of 1 cm$^3$ were tested
  75 WLS fibers with 75 SiPM readout → 75 readout channels
- Length of Kuraray 1 mm Y11 WLS fibers 130 cm
- 3 fibers inserted in one cube, no glue
- Distance between MPPC and cube in each fiber 100 cm
- Reflectors at far end of the fiber - white paint Silver Shine
- Trigger counters 3x3 mm$^2$

MPPC:
S12571-025C, pixel size 25 microns,
PDE about 33% for green light.

Electronics
- Amplitude 75 ADC channels CITIROC ASICs (from Baby-MIND)
- Timing and amplitude 15 channels, digitizer CAEN DT5742 5 GHz
Beam test at T10 (CERN) : 28 October - 1 November 2017
p (π, μ) = 6 GeV/c
Beam spot ~3 cm (horiz)x 6 cm (vert)
Trigger counters (in front/behind prototype) 3 x 3 mm2
Veto counter : beam hole 9 mm diameter
Installation at T10
Light Yield (1)

Digitizer  CAEN DT5742

Light yield /fiber  ~ 38-49 p.e
Light Yield (2)

1 cube – readout sum of 2 fibers

1 cube – readout sum of 2 fibers

Sum of 2 cubes, readout sum of 4 fibers

L.Y. ~ number of readout fibers of fired cubes
Timing (1)

Signal from 1 fiber

$\sigma_t \sim 800-900$ ps for one fiber

Digitizer CAEN DT5742

Preliminary
Timing (2)

Signal sum of 2 cubes: 2 fibers from each cube → 4 fibers
\[ \sigma_t = 470 \text{ ps} \]

Very good performance:
- ~ 40-45 p.e./MIP for one fiber → 120-130 per/MIP/cube
- detection threshold ~ 30-40 keV
- 800-900 ps/fiber → ≤ 500ps/4fibers
- Cross-talk ~3%
Accuracy of manufacturing

100 cubes
- measurement of 2 sides after cutting \( \sigma = 27 \, \mu m \)
- measurement of 1 side (extrusion thickness) \( \sigma \sim 100 \, \mu m \)

R&D to improve precision: 1- extrusion + machining
or 2- injection molding
Aim to develop and make a pilot detector in 2018-2019

Full scale prototype  0.5 x 0.5 x 1.0 m³
250000 detectors of 1 cm³ each
12500 readout channels  WLS fibers/SiPM
Electronics – 1-5 GHz digitizers
Mechanics – thin strong box
Optical connectors
Assembly
Quality tests, calibration

- R&D: extrusion, injection molding, precision, quality control…. electronics, mechanics….
- Beam test in 2018
International collaboration

Proto-collaboration to make 3D SSD is formed

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<thead>
<tr>
<th>Country</th>
<th>Institution</th>
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<tr>
<td>Russia</td>
<td>INR</td>
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<tr>
<td>France</td>
<td>CEA/DAPNIA Saclay, Ecole Politechnique, LPNHE -Paris</td>
</tr>
<tr>
<td>Switzerland</td>
<td>University of Geneva, CERN (Neutrino platform)</td>
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<tr>
<td>Italy</td>
<td>INFN/ University Roma, Padova</td>
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<td>Poland</td>
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<td>Japan</td>
<td>KEK, Tokyo University, Kyoto University</td>
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Strong support from CERN Neutrino Platform

Great interest from LBL experiment DUNE
UK: Oxford, Imperial
Reactor experiments
Oxford (Solid experiment)
Mass production: stage 1

10000 cubes manufactured by Uniplast, Vladimir
Summary/Plan

- Novel 3D SSD neutrino detector is under development
- Small prototype demonstrates good performance
- International proto-collaboration formed
- Next step: 2018-2019 development, construction and test of large scale prototype/pilot detector
- Beam test in 2018

Our plan: 5 x 5 x 5 cm$^3$ $\rightarrow$ 50 x 50 x 100 cm$^3$ (pilot) $\rightarrow$ full scale (≥ 1 t) detectors