EOS
Testbed for Hybrid Neutrino Detection Technology

Tanner Kaptanoglu
for the EOS collaboration
UC Berkeley and LBNL

Snowmass Early Career
7/24/2022
Motivation

- Hybrid detectors distinguish Cherenkov & scintillation light for:
  - Improved energy / vertex resolution
  - Dir. reconstruction using Cher. light
  - Improved signal sensitivity & bkg. rejection
  - Additional particle ID

- Future ktonne-scale detectors, such as THEIA, would leverage hybrid detection to provide broad physics program

*SNOWMASS 20O, G. D. Orebi Gann: Theia*

- Utilize hybrid detector technology to enhance program for far-field reactor monitoring (nonproliferation) [1]

[1] T. Akindele et al., SNOWMASS white paper: A Call to Arms Control: Synergies between Nonproliferation Applications of Neutrino Detectors and Large-Scale Fundamental Neutrino Physics Experiments
Motivation

THEIA physics program [1]:

→ Long baseline oscillations

SNOWMASS 20H, L. Pickard: High energy physics program at Theia

→ Low energy solar neutrinos [2]

→ Geo & reactor neutrinos [3]

SNOWMASS 20H, Z. Bagdasarian: Low-energy neutrino physics at Theia

→ $0\nu\beta\beta$, supernova neutrinos, and more!

Motivation

- THEIA physics program [1]:
  - Long baseline oscillations
  - Low energy solar neutrinos [2]
  - Geo & reactor neutrinos [3]
  - $0\nu\beta\beta$, supernova neutrinos, and more!

- Goal: discrimination of Cherenkov and scintillation signals
THEIA physics program [1]:

- Long baseline oscillations
- Low energy solar neutrinos [2]
- Geo & reactor neutrinos [3]
- $0\nu\beta\beta$, supernova neutrinos, and more!

Goal: discrimination of Cherenkov and scintillation signals

Novel target mediums (such as WbLS) provide many benefits

Motivation

SNOWMASS 30R, M. Yeh: Development and production of high-performance water based liquid scintillators for particle physics experiments

Motivation

- THEIA physics program [1]:
  - Long baseline oscillations
  - Low energy solar neutrinos [2]
  - Geo & reactor neutrinos [3]
  - $0\nu\beta\beta$, supernova neutrinos, and more!

- Goal: discrimination of Cherenkov and scintillation signals

- Novel target mediums (such as WbLS) provide many benefits

- On the path to large hybrid detectors significant R&D is needed!

---

Motivation

- **THEIA physics program [1]:**
  - Long baseline oscillations
  - Low energy solar neutrinos [2]
  - Geo & reactor neutrinos [3]
  - $0\nu\beta\beta$, supernova neutrinos, and more!

- **Goal:** discrimination of Cherenkov and scintillation signals

- **Novel target mediums (such as WbLS)** provide many benefits

- **On the path to large hybrid detectors** significant R&D is needed!

---

Motivation

- THEIA physics program [1]:
  → Long baseline oscillations
  → Low energy solar neutrinos [2]
  → Geo & reactor neutrinos [3]
  → 0νββ, supernova neutrinos, and more!

- Goal: discrimination of Cherenkov and scintillation signals

- Novel target mediums (such as WbLS) provide many benefits

- On the path to large hybrid detectors significant R&D is needed!

Motivation

- THEIA physics program [1]:
  - Long baseline oscillations
  - Low energy solar neutrinos [2]
  - Geo & reactor neutrinos [3]
  - \(0\nu\beta\beta\), supernova neutrinos, and more!

- Goal: discrimination of Cherenkov and scintillation signals

- Novel target mediums (such as WbLS) provide many benefits

- On the path to large hybrid detectors significant R&D is needed!

---

Hybrid Detector R&D Program


>80% Cherenkov

Fast timing with LAPPDs

Spectral sorting with dichroicons

α/β light yields

Proton light yield

WbLS Synthesization

T. Kaptanoglu
Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley
Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley

Advanced PMT testing facility for fast ex-situ characterization of:
- PMT gain
- SPE timing/charge
- Dark rate, after-pulsing rate
- Magnetic shielding effects

Stainless steel tank

Acrylic Vessel

Water Buffer

~200x R14688 Hamamatsu HQE 8” state-of-the-art PMTs

Charge Peak-to-Valley ~ 6

TTS ~ 900ps (FWHM)
Introducing EOS

EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley

- 20x R11780
- HQE 12” PMTs
- Acrylic Vessel
- Water Buffer
- ~200x R14688
- Hamamatsu HQE
- 8” state-of-the-art PMTs
- Stainless steel tank

T. Kaptanoglu
Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley

~20x R11780 HQE 12" PMTs

Stainless steel tank

~200x R14688 Hamamatsu HQE 8” state-of-the-art PMTs

Dichroicons + PMTs at bottom of detector

Acrylic Vessel

Water Buffer

Dichroicon module
Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley

EOS Diagram:
- Pulsed light source
- Acrylic Vessel
- Water Buffer
- Port for calibration sources
- ~20x R11780 HQE 12'' PMTs
- ~200x R14688 Hamamatsu HQE 8'' state-of-the-art PMTs
- Dichroicons + PMTs at bottom of detector
- Stainless steel tank

T. Kaptanoglu
Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley

- ~20x R11780 HQE 12” PMTs
- Stainless steel tank
- Acrylic Vessel
- Water Buffer
- Pulsed light source
- Port for calibration sources
- ~200x R14688 Hamamatsu HQE 8” state-of-the-art PMTs
- Dichroicons + PMTs at bottom of detector

→ 16 channels
→ 500 MS/s
→ No deadtime
→ 14-bit ADC

CAEN V1730S digitizers
Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley

- EOS is a flexible testbed for hybrid detector technology!
  - Novel target mediums
  - Fast-timing, high QE PMTs
  - Spectral sorting
  - Novel readout solutions
  - Advanced recon. algorithms

~20x R11780 HQE 12'' PMTs

Port for calibration sources

Pulsed light source

Acrylic Vessel

Water Buffer

~200x R14688 Hamamatsu HQE 8'' state-of-the-art PMTs

Dichroicons + PMTs at bottom of detector

CAEN V1730S digitizers

Stainless steel tank

WbLS

T. Kaptanoglu
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale

- Fast timing PMTs
- Slow WbLS

- Dichroicons

- WbLS
- Improved recon. methods
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
  → Using deployed (directional) calibration source
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:
  - Use Cherenkov light to perform direction reconstruction against scint. background
  - Show improved position resolution (better than water Cherenkov detector)
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:
  - Use Cherenkov light to perform direction reconstruction against scint. background
  - Show improved position resolution (better than water Cherenkov detector)
- Validate a detailed WbLS optical model at a large scale

→ Light yield, quenching
→ Emission timing
→ Absorption and scattering

PMT hit-times

#PE detected
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale

- Develop reconstruction algorithms to:
  - Use Cherenkov light to perform direction reconstruction against scint. background
  - Show improved position resolution (better than water Cherenkov detector)

- Validate a detailed WbLS optical model at a large scale

- Performance testing for range of detector configurations
  - Vary WbLS concentration, change/add photodetectors, utilize spectral sorting, etc.
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:
  → Use Cherenkov light to perform direction reconstruction against scint. background
  → Show improved position resolution (better than water Cherenkov detector)
- Validate a detailed WbLS optical model at a large scale
- Performance testing for range of detector configurations
- Stretch goal: particle ID (neutron / γ / β / α)

β/α discrimination [1]

Lack of Cherenkov light gives clear β/α discrimination

n/γ discrimination [2]

20J, T. Akindele, Enhanced Particle Identification in Water-based Liquid Scintillator

Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale

- Develop reconstruction algorithms to:
  - Use Cherenkov light to perform direction reconstruction against scint. background
  - Show improved position resolution (better than water Cherenkov detector)

- Validate a detailed WbLS optical model at a large scale

- Performance testing for range of detector configurations

- Stretch goal: particle ID (neutron / γ / β / α)

- Ultimately, enable broad, world-leading nonproliferation + physics program!
Future Goals

- EOS will be transportable for possible deployments:
  - Close (few-m to few-100m) to a reactor core, for hybrid neutrino event reconstruction demonstration
  - In a particle test beam, e.g. FNAL, CERN, SNS for characterization of high-energy events

https://www.prisma.uni-mainz.de/facilities/triga-reactor-and-neutron-source/
3 Year Timeline

- 2022: Design optimization and purchasing of key equipment
- 2023: Construction, PMT and WbLS deployment
- 2024: Data-taking with deployed radioactive source
International Collaboration:
More than 20 institutions in 6 countries!
Conclusions

- Tonne-scale demonstration of WbLS is a key step toward THEIA
- EOS will provide a flexible test-bed for developing technologies: fast photodetectors, WbLS, dichroicons, and more
- EOS construction will begin soon in 2023!
Acknowledgements

- Gabriel Orebi Gann
- Orebi Gann group
- DOE for support for R&D work
- NNSA for support for EOS