# miniTimeCube

# Building the world's smallest neutrino detector



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### mTC: Compact collaboration

A mrc

- University of Hawaii: Ryan Dorrill, Mark Duvall, Andrew Druetzler, John Koblanski, John Learned, Viacheslav Li, Luca Macchiarulo, Shigenobu Matsuno, Sergey Negrashov, Kurtis Nishimura, Marc Rosen, Gary Varner
- Ultralytics LLC: Glenn Jocher
- University of Maryland: Kristi Engel, William McDonough, Scott Wipperfurth
- National Institute of Standards and Technology: Pieter Mumm
- National Geospatial-Intelligence Agency: Shawn Usman



#### Google trend of "neutrino"





#### Google trend of "neutrino"









• miniTimeCube

• Contributions

• Future/Summary





### Why build another neutrino experiment?



- Neutrino oscillations at very short baselines are not well understood.
- Only a couple of detectors were directional.
- Paving road to geo-neutrino detection (better understanding of the Earth's interior)



Potential applications:

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Non-proliferation of nuclear weapons

SNM detection (neutron detection)

*Reactor fuel monitoring* 



#### mTC: John's idea





Charged particle moving in a scintillator, first photon arrival times.



#### mTC: Inverse $\beta$ decay in the mTC





#### mTC: Scintillator EJ-254





mTC scintillator cube inside Delrin frame



Blue laser illuminating the scintillator

Note: ignore the scintillation decay time, the key to directionality is to detect first photons.



#### mTC: Micro-Channel-Plate PMT 8x8 anode









Quantum efficiency of MCP-PMT

MCP-PMT

24 in total = 4 PMTs x 6 mTC faces



### mTC: Gary Varner's oscilloscope on a chip





#### (Electronics is similar to iTOP Belle project at KEK)



#### mTC: Readout module





#### mTC: Assembly





CAD only top/bottom chiller plates shown

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mTC opened enclosure (active cooling of 300 W electronics)

4/20/18

miniTimeCube: Building The World's Smallest Neutrino Detector



#### mTC: Assembly





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University of Hawai'i



#### mTC: Assembly



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#### mTC: two racks 11U and 21U







#### mTC: Trigger 1.0 vs 2.0





- Three-level trigger system (L0, L1, L2) : Limitation by the firmware not physics
- Two-level trigger system (L0, L1) : Easier to implement neutrino trigger

#### (similar to SuperK multiplicity trigger)



#### mTC: cosmic muons









#### mTC: Neutrino trigger





One channel ring buffer (512 windows)



#### mTC: Data structure



Unix Time	Event	S	R	C	CH	ref	win	trgbit	64 voltage values
1467893327085081	2723	1	0	0	0	383	42	0	$2329 \ 2342 \ 2400 \ldots$
1467893327085081	2723	1	0	0	0	383	43	1	$2264 \ 2309 \ 2335 \ \dots$
1467893327085081	2723	1	0	0	0	383	44	1	$2182 \ 2183 \ 2186 \ \dots$
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### mTC: how many nu's to expect at NIST reactor



 $N_{235} = 0.93 \times 6\bar{\nu}_e / \text{fission} \times 20 \text{ MW} / (201.7 \text{ MeV/fission}) = 3.45 \times 10^{18} \bar{\nu}_e / s$  $N_{238} = 0.07 \times 6\bar{\nu}_e / \text{fission} \times 20 \text{ MW} / (205.0 \text{ MeV/fission}) = 2.55 \times 10^{17} \bar{\nu}_e / s$ 

$$N_{\bar{\nu}_e} = \frac{1}{4} n_{\rm H} \ V \ \sigma \ \frac{dN_{\bar{\nu}_e}}{dt} \ \frac{1}{4\pi L^2} \ t_{\rm day}$$

$$N_{\bar{\nu}_e} = \frac{1}{4} \frac{5.16 \times 10^{22}}{\text{cm}^3} \ 13^3 \text{cm}^3 \ 5 \times 10^{-43} \text{cm}^2 \ \frac{1.6 \times 10^{12} \ \bar{\nu}_e}{\text{cm}^2 s} \ 86400 s = 2 \ \bar{\nu}_e/\text{day}$$

 $2 \times .40 \approx 1 \bar{\nu}_e / \text{day}$ 



### mTC: shielding by UMD



	Material	Dimension (cm)
1	Borated polyethylene	10
2	A36 steel	1
3	Steel shot & paraffin wax	15
4	A36 steel	1
5	Borated polyethylene	10

Polyethylene layer used is doped with 5% boron.

Steel layer and steel shot is A36 steel.

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Steel shot & paraffin wax mixture comprised of 75% steel, 25% wax.





#### mTC: Shielding







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#### mTC: Installation by reactor





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### mTC: Shielding adds space constraints



#### Detector is less accessible







### mTC: Shortcomings



• Electronics timing hasn't reached the desired sub-100 ps level

• Half of the MCP-PMTs burned out (shortly before the deployment by the reactor)

• Background rates were unexpectedly high and unpredictable

• MCP-PMTs had a major issue with ion-feedback and charge sharing effect



#### Contributions: Data analysis



#### Waveform and pedestal



Waveform corresponds to a single photon (laser data)

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After pedestal is subtracted



#### Contributions: Noise analysis



Waveform corresponds to a single photon. Noise affects timing substantially at this level.



#### Contributions: Data analysis



One of the ~850,000 neutrino candidates collected.



#### Contributions: Laser calibration system





#### (similar to the device Shige Matsuno built for SuperK)

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#### Contributions: Laser calibration system





Laser fiber in between four MCP-PMTs



Needle connector tip

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#### Contributions: Cross-talk 1.0





#### Contributions: Cross-talk 1.0





#### Contributions: Cross-talk 1.0





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#### Contributions: Cross-talk 1.0 solution







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#### Contributions: Cross-talk 1.0 solution



• Install the copper frame on every face

• Get rid of small ground PMT wires



#### Copper frame top face







#### Contributions: Cross-talk 2.0







#### Contributions: Cross-talk 2.0







#### Contributions: 2-fiber test



0 40 60 90 100

20 40 60 103120

0 20 40 MO HD 100 120

20 40 60 80



MCP Test Event 6135



#### Contributions: 2-fiber test







#### Contributions: Electronics cooling system



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#### Contributions: Network for remote operations



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#### Contributions: Neutron tests





# Multiple tests with Pu-240, Cf-252, DT and DD neutron generators at NIST







### Contributions: Installation by the nuclear reactor









### Contributions: High rates and extra shielding







#### **Contributions: Remote operations**



#### Control from Hawaii of the detector in Maryland

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### My contributions

- Mechanical assembly, including machining parts
- Cooling system assembly and different coolant tests
- Laser calibrations
- Cross-talk 1.0 discovery and reductions
- Copper RF frame design and fabrication
- MCP-PMT cross talk 2.0 studies
- MCP-PMT recovery studies after the overheating accident
- Neutron and gamma tests
- MCP-PMT gain calibrations
- Data taking and processing, optimizing trigger parameters
- Installation of the mTC at NIST (CNIF, guide hall, lab, reactor) and UH lab
- Shift work, remote operations, maintaining elogs, online data, and website
- Publishing 1st mTC paper as RSI invited article
- Electronics upgrade, including heat sink installation
- Everyday detector maintenance, including electronics tests, fixing/adjusting power supplies, software, network, shielding, cooling, ordering parts
- Packing/shipping the mTC
- Meetings and decision making







#### Summary

- Invaluable experience for mTC collaboration and future particle detectors
- miniTimeCube has been an excellent prototype overall
- First really compact and low-power integrated neutrino detector
- Wide range of components/methods have been evaluated
- mTC electronics can be used in new experiments (NTC and NuLat)
- Shielding cave was constructed (reusable, for NuLat)
- Prototype for homeland security applications (SNM detection)
- Good to detect muons, neutrons and perform MCP-PMT laser tests
- Solid compact non-flammable target (not unique but only a few used it)
- First use of Boron-doped scintillator in a neutrino detector





- First attempt to employ first-photon analysis to beat slow decay times in vertex location (factor of ten). Note that decay rise time is a few times the 13 cm dimension of the cube, and our studies indicated mm scale resolution
- Highest ever density of channels of waveform photon detector on neutrino target (1536 total, ~5mm square pixels)
- Designed and built our own moveable (adjust distance to reactor by 2m) walk-in radiation cave with 1000x attenuation of neutrons and gammas.
- Achieved reliable automated operations and swiftly activated remote operation capability, even to NIST in DC from Hawaii
- Though the program failed to achieve its goals, largely due to failed PMTs, we set a precedent in the field of a dozen competitors, for a new approach now being carried forward in the NuLat experiment
- We have been a training ground for new experimental physicists who have gained a full experience with creating, building, and operating an experiment, unlike the experience in a huge project where students have narrow exposure to the whole process
- Stay tuned for more updates -- mTC is not over yet

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ありがとう Mahalo Thank you Dziękuję bardzo Спасибо Merci beaucoup Grazie Дякую Danke Хвала Баярлаа 谢谢 고맙습니다



תודה