

NuFact 2022

Salt Lake City, Utah, United States
July 31st – Aug. 6th, 2022

The 23rd International Workshop on Neutrinos from Accelerators

LOCAL ORGANIZING COMMITTEE

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Paolo Gondolo (University of Utah)
Carsten Rott (Co-chair, University of Utah)
Pearl Sandick (University of Utah)
Joshua Spitz (University of Michigan)
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WG1: Neutrino Oscillations

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Mark Scott (Imperial College, UK)
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WG2: Neutrino Scattering Physics

Adi Ashkenazi (Tel Aviv University, Israel)
Tatsuuya Kikawa (Kyoto University, Japan)
Raúl González Jiménez (Complutense University of Madrid, Spain)

WG3: Accelerator Physics

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Tsunayuki Matsubara (J-PARC, KEK)
Kasturya Yonehara (FNAL, USA)

WG4: Muon Physics

Yuki Fujii (University of Tokyo, Japan)
Gavin Hesketh (University of Liverpool, UK)
Yuri Okuzawa (AIST, Japan)

WG5: Neutrinos beyond PMNS

Koun Choi (IBS, CUP, South Korea)
David Ruiz (UC Louvain, Belgium)
Tom Shoemaker (Virginia Tech, USA)

WG6: Detectors

Jonathan Asaadi (University of Texas, USA)
Davide Sgalaberna (CERN, Switzerland)
Nishimura Yasuhiro (Keio University, Japan)

WG7: Inclusion, Diversity, Equity, Education, & Outreach

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Francesca Dordoi (INFN, Cagliari, Italy)
Nagisa Hiroshima (University of Toyama, Japan)

SCIENTIFIC PROGRAM COMMITTEE

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Frederik Wauters (University of Mainz, Germany)

Un-ki Yang (Seoul National University, Korea)

Summary of Working Group 6 (Detectors)

Yasuhiro NISHIMURA (Keio University)

on behalf of WG6 conveners

Davide Sgalaberna (ETH Zurich),

Yasuhiro Nishimura (Keio University),

Jonathan Asaadi (University of Texas Austin)

6/Aug/2022, 23rd NuFact 2022

Overview

- Overview of WG6 parallel talks
 - 4 talks for Photodetectors and Electronics
 - ▶ Hyper-K and IceCube detectors
 - 4 talks about Liquid argon detectors (incl. trigger, readout)
 - ▶ DUNE/SBND/ARIANDE+
 - 4 talks about T2K/DUNE Near detector, Xe TPC
 - 5 talks about Calibration, Reconstruction, etc.
 - ▶ IceCube/MicroBooNE, JUNO, ICARUS, Paleo
- Joint sessions
 - WG1+2+6 : 4 talks for Near detectors, scintillator tracker
 - WG1+6 : 4 talks for Machine Learning
 - WG4+6 : 3 talks for Mu2e Detectors and machine learning

Photosensors and Electronics

14:00	Multi PMTs at the Water Cherenkov Test Experiment/IWCD at Hyper-K <i>Ballroom 3</i>	Ryosuke Akutsu	
			14:00 - 14:20
	Options for PMT electronics at the Hyper-K far detector <i>Ballroom 3</i>	Shota Izumiya	
			14:20 - 14:40
	Time generation and clock distribution for Hyper-Kamiokande <i>Ballroom 3</i>	Lucile Mellet 	
			14:40 - 15:00
15:00	IceCube & SWGO Photodetectors <i>Ballroom 3</i>	Michael DuVernois	
			15:00 - 15:20



ICECUBE
GEN2

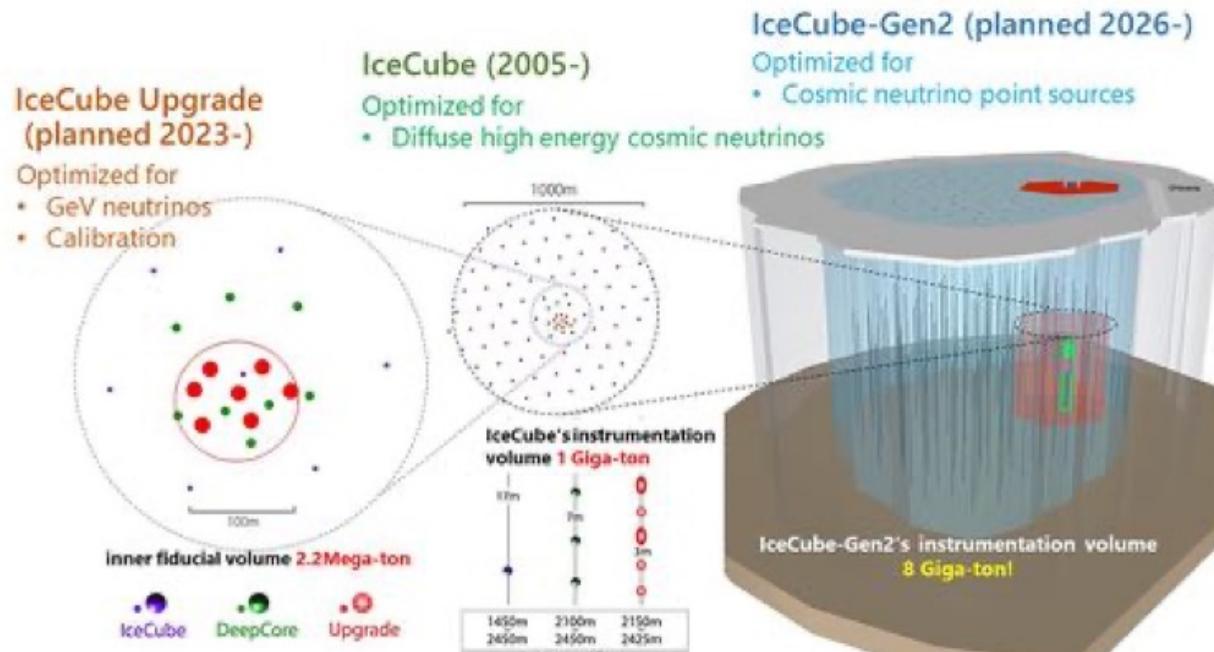


Photodetectors: PMTs/Bases for IceCube & Friends

Mike DuVernois

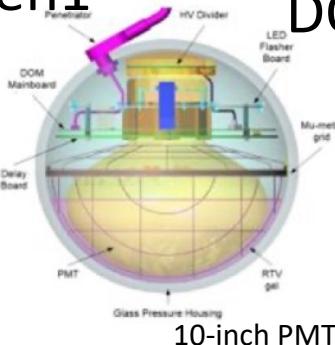
IceCube Upgrade & Gen2 Technical Coordinator

University of Wisconsin-Madison

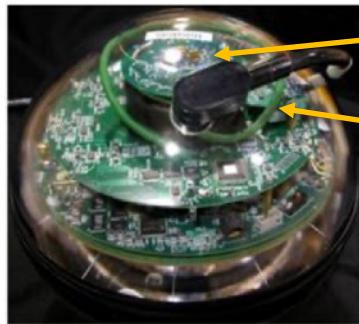


PMT+HV base for IceCubes

Gen1

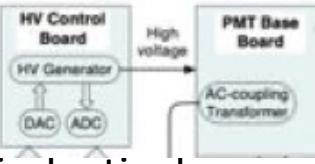
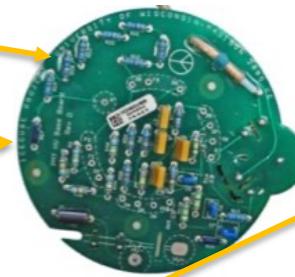


DOM



10" Hamamatsu PMT with base using custom resistive divider, EMCO HV supply,

inductively coupled output



Upgrade



mDOM

WBS 1.3.1
430 mDOMs

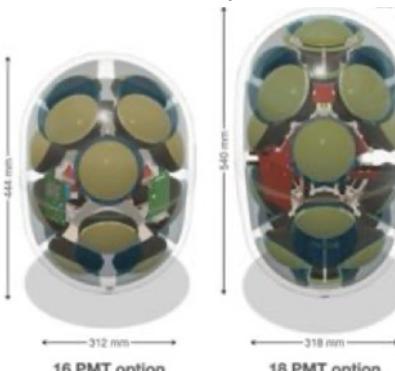
(DESY-Zeuthen, 24x 3" HQE PMTs)

D-Egg

WBS 1.3.2
310 D-Eggs

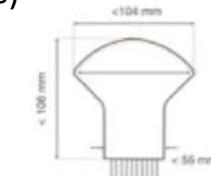
(Japan, 2x 8" HQE PMTs)

Gen2

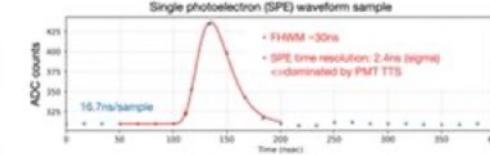
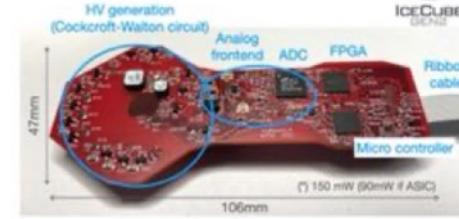


shared these modules with a number of neutrino, CR, and gamma ray groups.

4-inch PMT + Waveform MicroBase (HV+DAQ)



Target numbers	
Parameter	Target value
Gain	5e6 @ <1500V
Transit Time Spread	< 8ns (FWHM)
Peak/Valley	>2
QE	>25% @400nm
Pre/late/after pulses	Less than 1/5/10%



Multi-PMTs at the Water Cherenkov Test Experiment /IWCD at Hyper-K



Hyper-Kamiokande

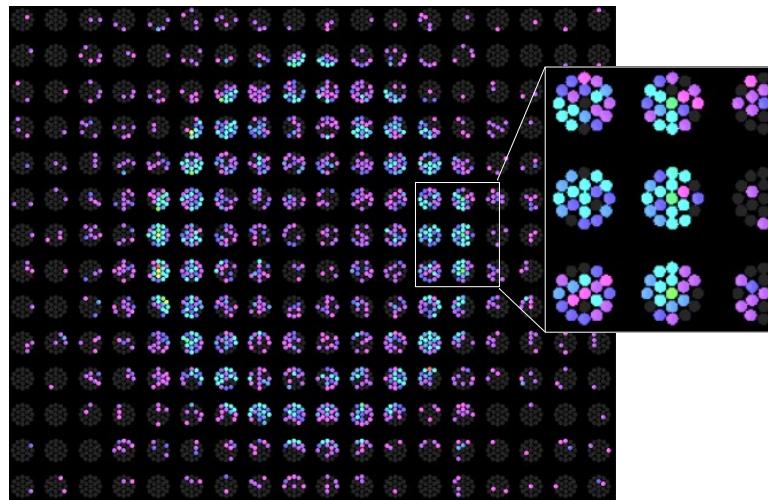
Ryosuke Akutsu (TRIUMF)



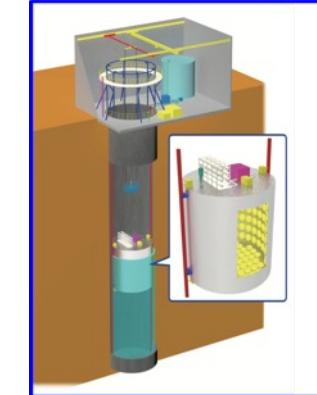
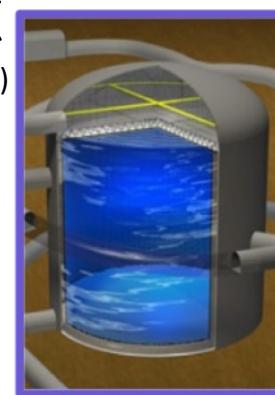
On the behalf of the Hyper-Kamiokande collaboration

Higher granularity and better timing
resolution thanks to 3" PMTs

→ Higher event reconstruction performance
near the detector wall



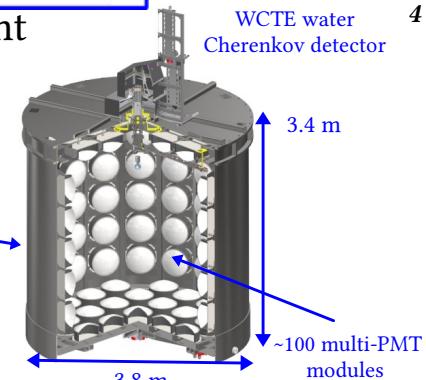
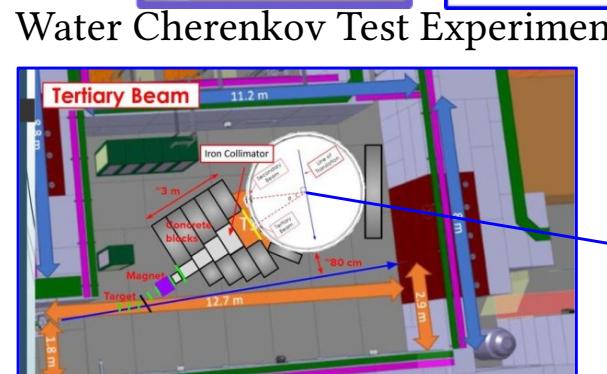
Hyper-K
(Kamioka, Japan)



IWCD
(near to J-PARC,
Japan)

At CERN

WCTE water
Cherenkov detector



https://indico.fnal.gov/event/53004/contributions/246051/attachments/158347/207750/MultiPMTs_WCTEandIWCD_RyosukeAkutsu_02Aug2022_v1.pdf

Multi-PMT (mPMT) module

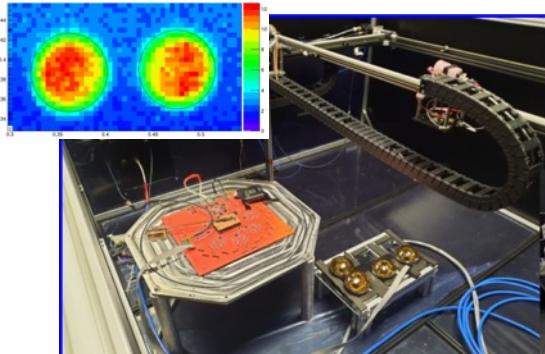
- ◆ 19 x 3" diameter photomultiplier tubes (PMTs) are integrated in a water-tight module



Hamamatsu R14374

5

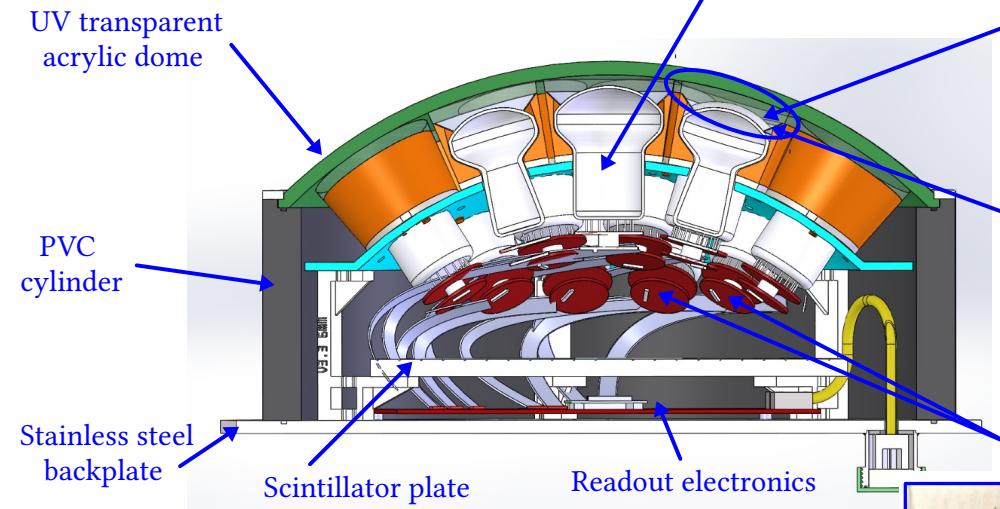
Test stand



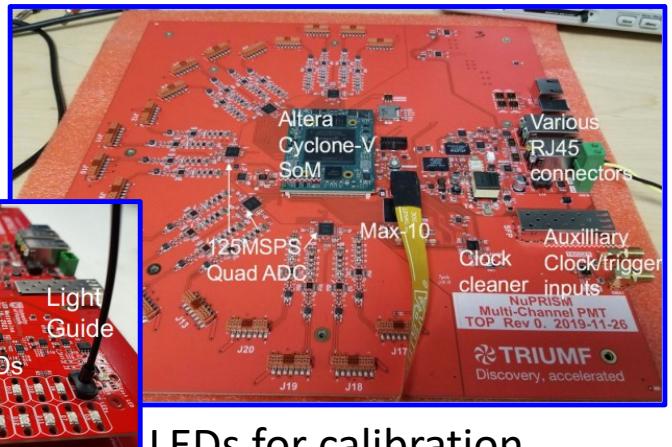
Optical silicone gel



Reflector



20-channel 125 MSPS FADC mainboard with full waveform DAQ



LEDs for calibration



Controller & signal board

Cockroft-Walton circuit



LEDs

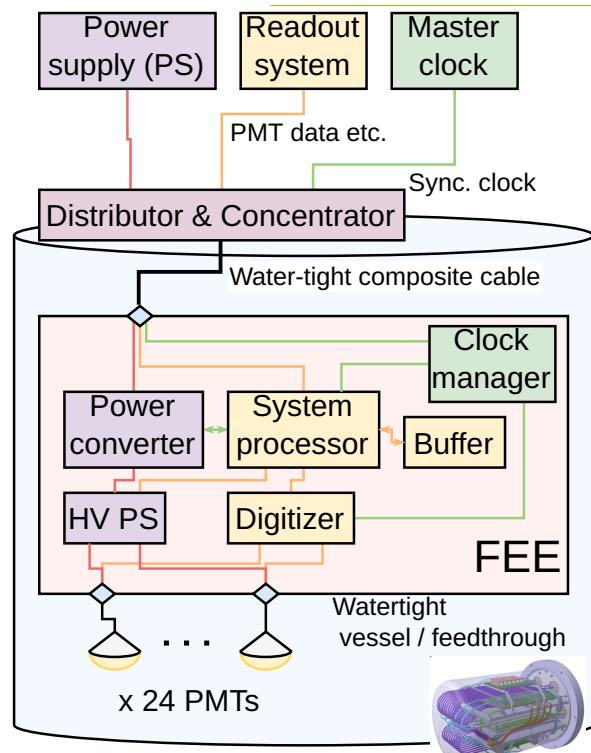


Position markers

Fast pulsed LED (0.6 ns FWHM) for timing and water optical property (230 – 700 nm availability)

Options for PMT Electronics at the Hyper-K Far Detector

Shota Izumiya (Tokyo Inst. of Tech.)



Hyper-Kamiokande: water Cherenkov detector

- FV ~ 190 kt, 20,000 of 20" PMTs + 1,000 mPMTs
- Planning to start operation in 2027

Three options of digitizer for 20" PMTs

- **QTC ASIC + TDC**: experience over 10 yr in SK
- **HKROC**: new waveform-sampling ASIC
- **Discrete type**: tunability & flexibility

24 ch electronics in the water in HK

Prototypes of digitizers for performance evaluation
QTC+TDC



HKROC



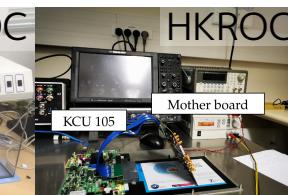
Discrete



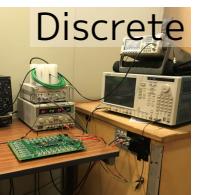
Evaluations
ongoing
for review



QTC+TDC



HKROC

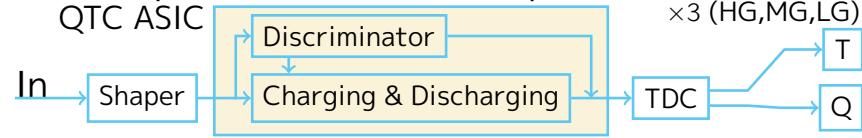


Discrete

Option1: QTC+TDC

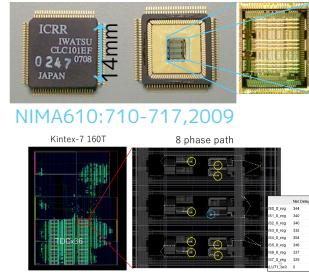
8/15

Reliability based on > 10 yr experience in SK



Hit timing
 $\propto Q$

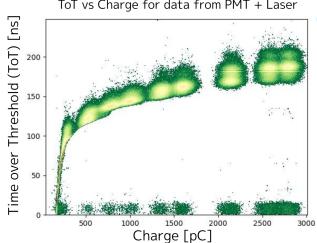
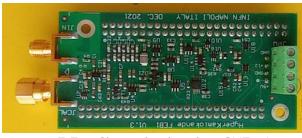
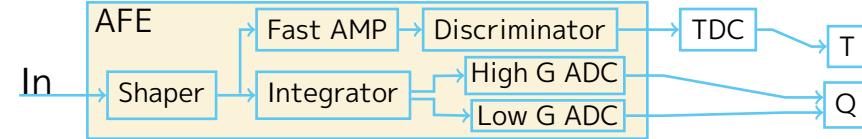
- Charge-to-Time Conv. (QTC)
 - Custom ASIC for SK
 - Established reliability by > 10 yr operation in SK
- Time-to-Digital Conv. (TDC)
 - Newly developed in FPGA for HK



Option3: Discrete Type

10/15

Tunability with discrete components

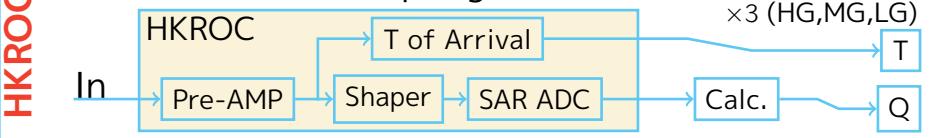


- Highly tunable / flexible circuit with discrete parts
 - Components: op-amp, ADC
 - Time over Threshold (ToT)
 - Complementary information with integrated Q by ADC
- May help to separate noise / pre-pulse / late-pulse

Option2: HKROC

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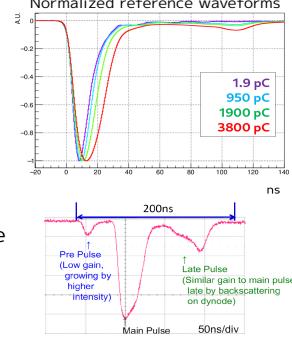
New waveform-sampling ASIC



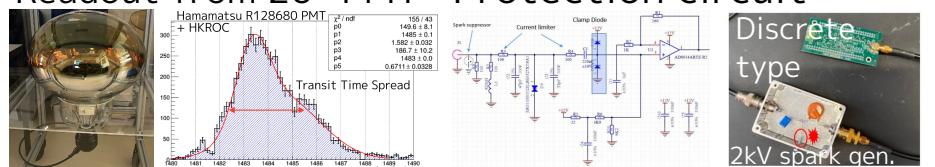
- Waveform sampling ASIC
 - Based on HGCROC (CMS HGCalorimeter)
 - Sampling ADC + Time of Arrival via TDC
 - > 40 MSPS, configurable number of sampling points
- ⇒ Signal separation: $\Delta t > 30$ ns
- Reduced deadtime ⇒ decay-e and nearby SN

Digitizer Evaluation

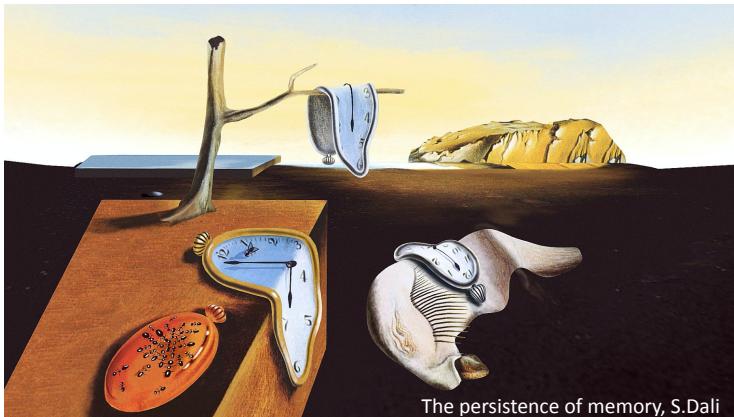
- Basic performance with FG
 - Deterministic signal
 - Stable noise, and configurable pulse timing and amplitude
 - Confirmation with PMT
 - AC coupled system
 - Stochastic signal
 - Noise and pre-/late-/after-pulse
 - Termination and reflections
 - Handling of baseline fluctuation
- ⇒ Important cross validation
- Response to environment: ESD, temperature
 - Circuit simulation: power, heat, reflection etc.



Readout from 20" PMT Protection circuit



Time generation and clock distribution for Hyper-Kamiokande

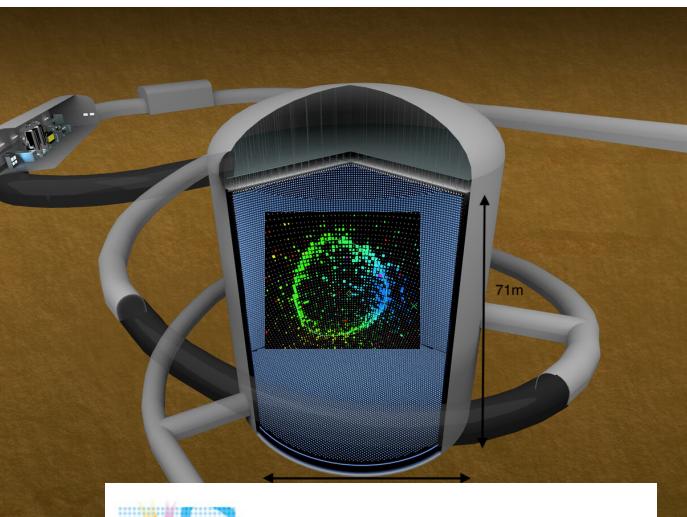
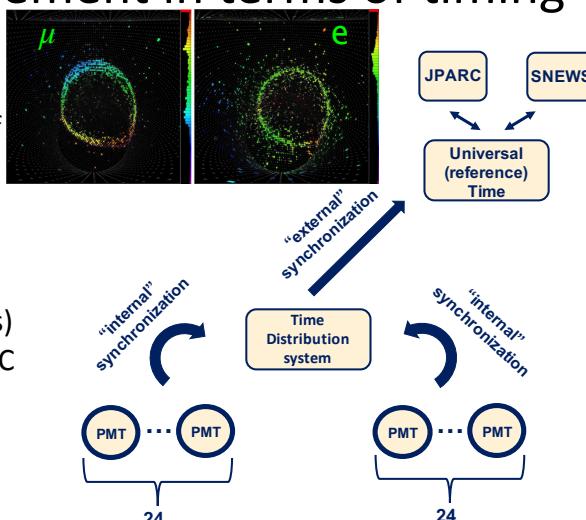


Lucile Mallet on behalf of electronics working group of the Hyper-Kamiokande collaboration



Needs and requirement in terms of timing

- Data : PMTs signal —> coincidence
—> reconstruction and identification of Cherenkov ring patterns
 - ➡ **Internal synchronization** with a stability < 100 ps. (Inter-channel)
- Beam bunches (+ astrophysical events)
 - ➡ **External synchronization** with UTC monitored within 100 ns at least



Hyper-Kamiokande

Rubidium clock



SRS FS725 clock

GNSS = GPS + other satellite constellations



Septentrio PolaRxSTR antenna + receiver

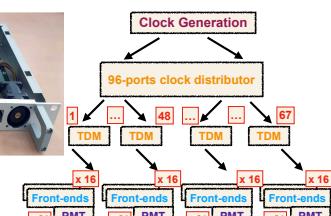
TDM = Time Distribution Module

Distribution of time to the PMTs



- 2 stages

- Electronic boards and cards are being designed and prototyped



Undergoing tests in collaboration between French (CEA, LPNHE) and Italian (INFN) groups

How to measure a frequency stability ?

- Data : Δt between ref pulse and freq under test pulse
- Stability = evolution of Δt over time

$$\sigma_y^2(\tau) = \frac{1}{2} < (y_{n+1}^- - \bar{y}_n)^2 >$$

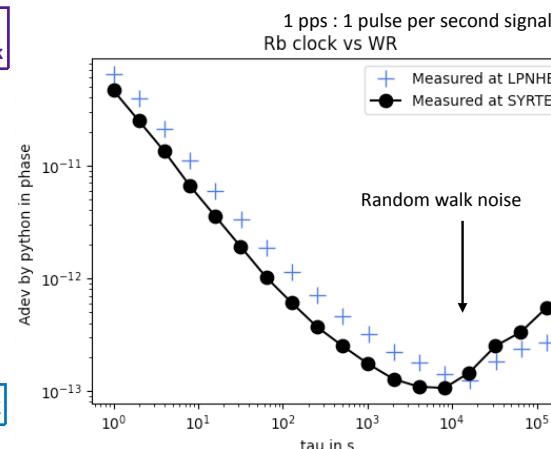
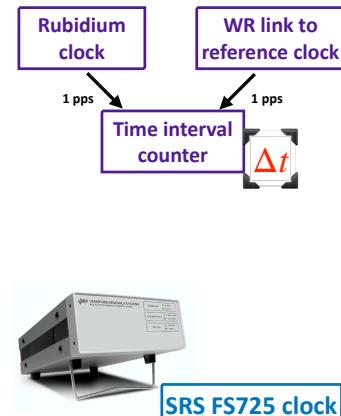
Variance of Δt as a function of interval length

Atomic clock : the most stable at short term

GNSS signal : more stable at long term + link to UTC



Characterization of the rubidium clock

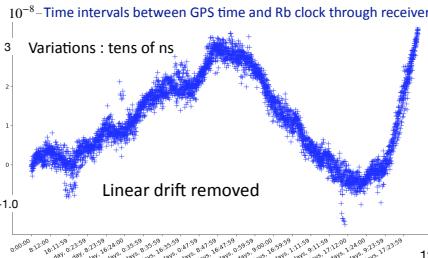
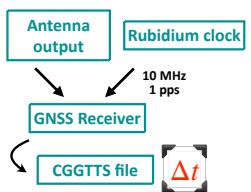


Lucile Mellet Nufact2022 Salt Lake City (UT), US

Proposed solution : Rb as input to receiver

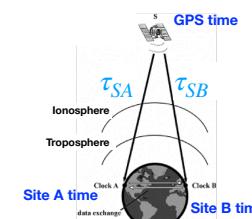
Why :

- Receiver monitors directly the Δt between the clock distributed to the system and the GPS time
- Clock in free-running : total control over applied corrections



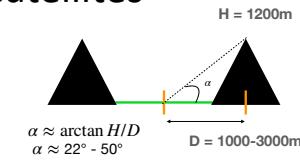
Lucile Mellet Nufact2022 Salt Lake City (UT), US

How to obtain UTC time tags ?



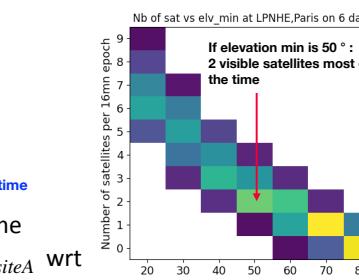
If site B is the reference time keeper : $\rightarrow \tau_{SA} - \tau_{SB} = \Delta t_{siteA}$ wrt UTC (local)

Elevation of satellites



The system has to be robust against :

- Power outage → reboot procedure + calibration
- Limited nb of visible satellites (mountain area)



Liquid Ar Detectors

16:00

The DUNE vertical drift TPC

Oliver Lantwin 

Ballroom 3

16:10 - 16:30

Photon Detection System (PDS) for DUNE low energy physics study and the demonstration of a few nanosecond timing...

Ajib Paudel

SBND Trigger System: General status and the configuration of the Analog Master Trigger Card

Gabriela Vitti Stenico

Ballroom 3

16:50 - 17:10

ARIADNE+: Large Scale Demonstration of Fast Optical Readout for Dual Phase LArTPCs at the CERN Neutrino Platform

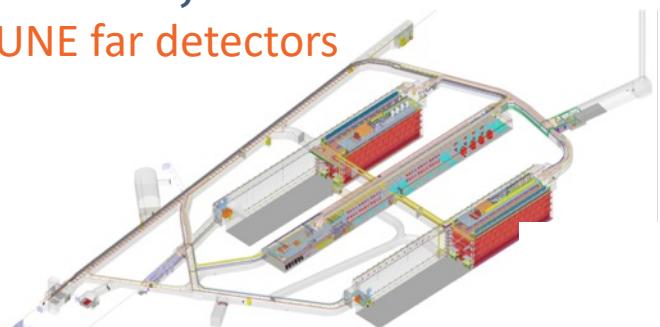
Adam Lowe

The DUNE vertical drift TPC

Oliver Lantwin for the DUNE collaboration

[oliver.lantwin@cern.ch]

The DUNE far detectors

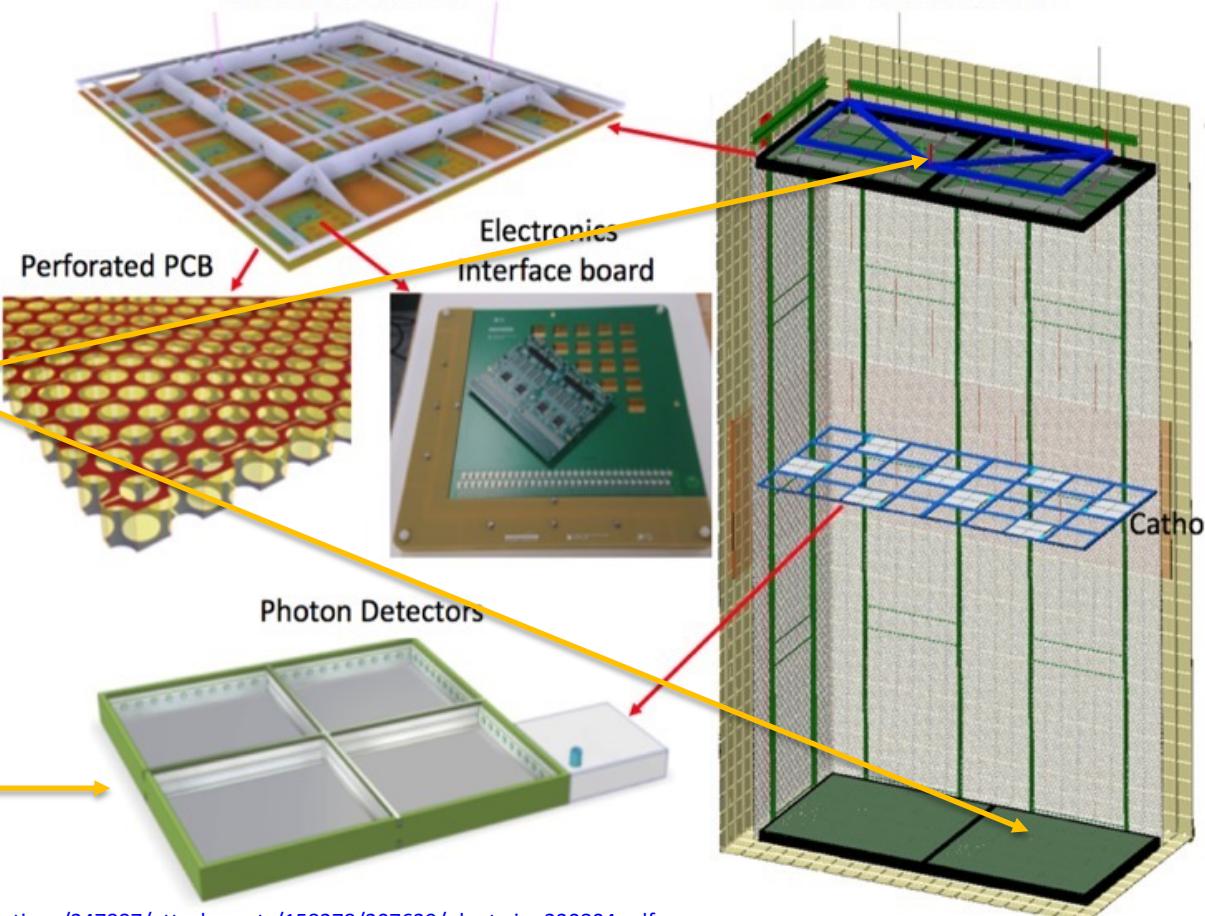


The Vertical Drift concept

with two volumes dimensions
separated by a cathode plane.

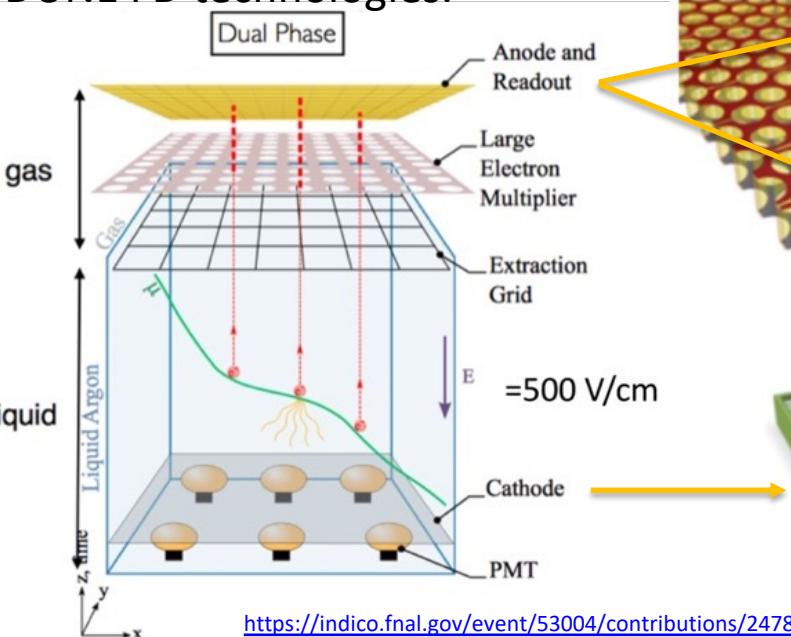
3x3 m² PCB Anode

2 x 6.5-m vertical drift



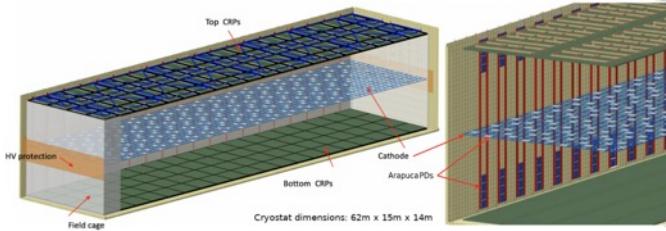
ProtoDUNE detectors

The two ProtoDUNE cryostats (SP/DP) were used to test the DUNE FD technologies.



https://indico.fnal.gov/event/53004/contributions/247887/attachments/158278/207639/olantwin_220804.pdf

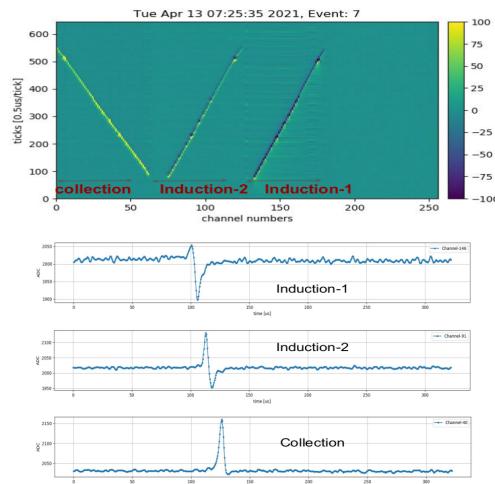
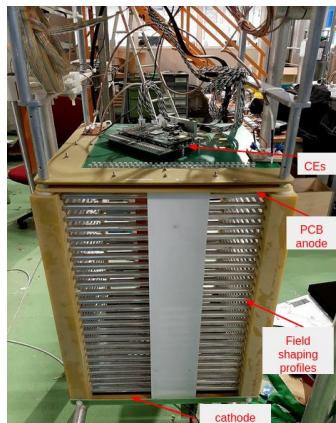
DUNE FD2 VD



- › Final 17kt FD2 VD
2 × 80 (top, bottom) CRPs
- › Component mass production should start in 2024

Successful proof of concept: The 50 l

32×32 cm² prototype TPC built at CERN to test hole-sizes, strip pitch, signal shapes and energy resolution using cosmic muons and a ²⁰⁷Bi source in several runs from 2020 to 2022

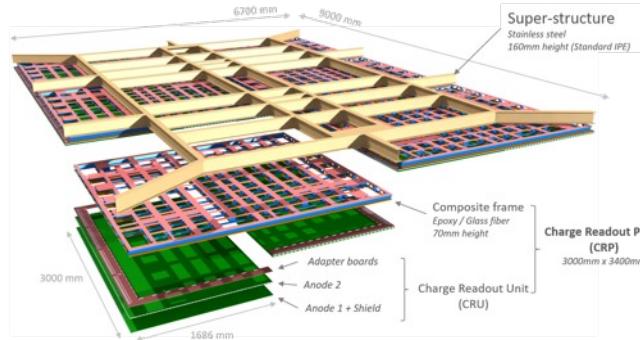


PCB anodes were tested.

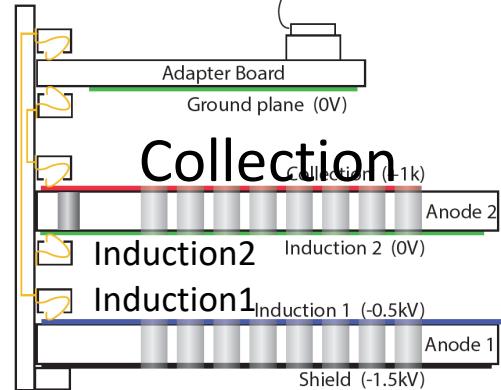
Full Module-0 foreseen for early 2023, on track for DUNE Phase-I

Charge Readout Planes (CRPs)

(top plane configuration, 3.4 m × 3 m each)



Signal cables to FEE in chimney

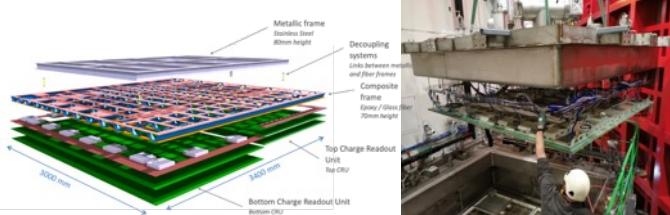


Collection

Full CRP prototype: Cold-box

Test of CRP + electronics

NP02 cold-box (CERN)

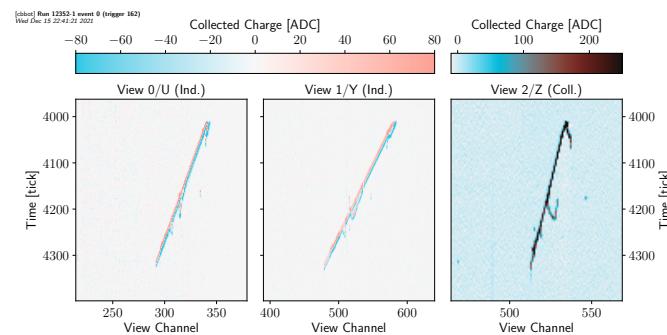


PCB anode



Different PCB configurations tested

- › CRP design validated at cold and gluing/interconnection of segments demonstrated.
- › Two runs with large samples of $\mathcal{O}(10^6)$ triggers each were taken in Nov and Dec 2021, with full analysis in progress, with good tracks seen in both readout systems
- › Excellent signal-to-noise ratio



Photon Detection System for DUNE low energy physics study and the demonstration of a few ns timing resolution using ProtoDUNE-SP PDS

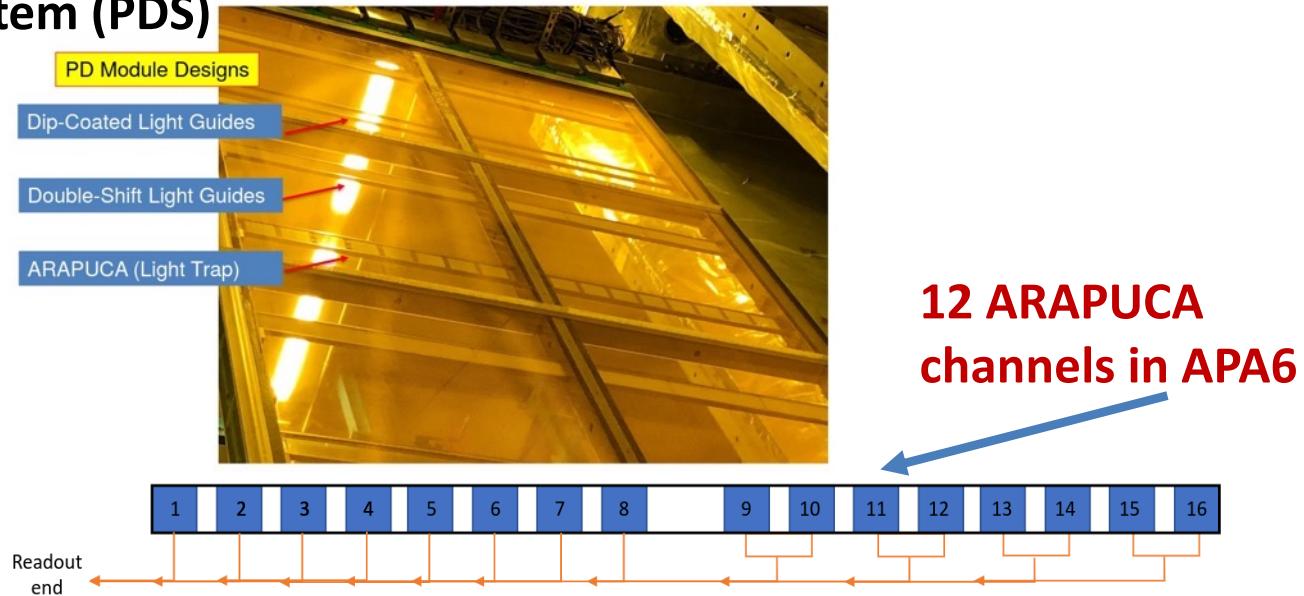
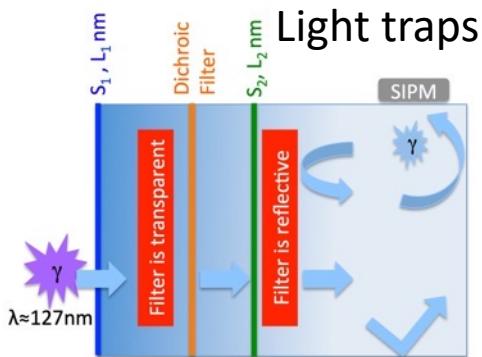
Ajib Paudel (Fermilab)

On behalf of the DUNE collaboration

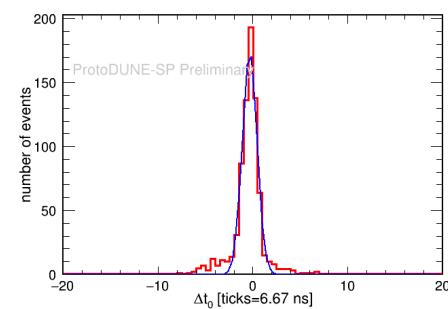
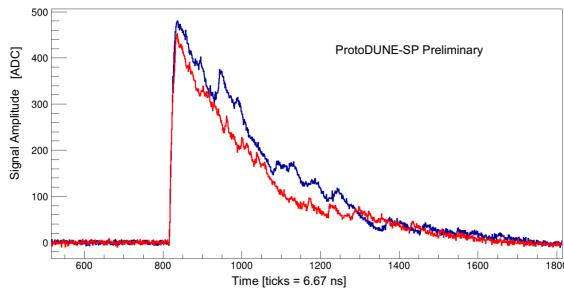
ProtoDUNE-SP

Photon Detection System (PDS)

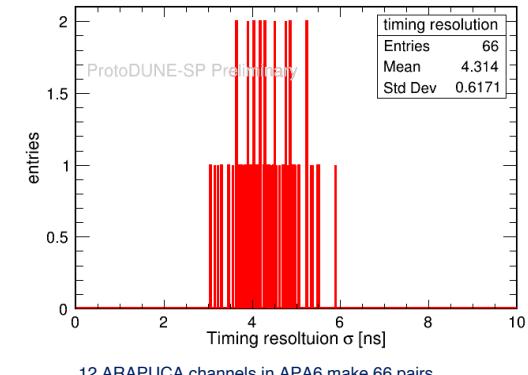
ARAPUCA detector



2 signals (nearby channels)



$$\text{Measured timing resolution} = \sigma_{\text{fit}}/\sqrt{2} \sim 3.7 \text{ ns}$$

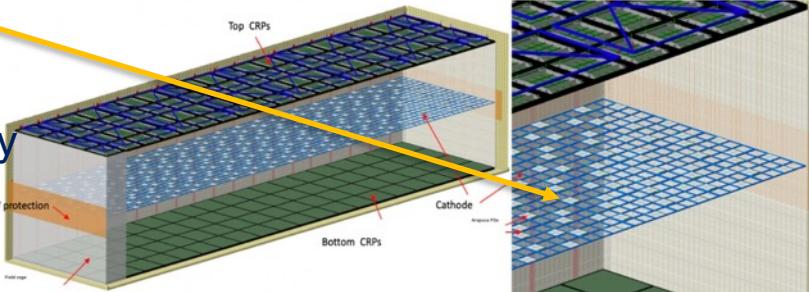


https://indico.fnal.gov/event/53004/contributions/245849/attachments/158471/207932/NuFACT2022_presentation_AjibPaudel.pdf

DUNE-FD2 (VD) PDS

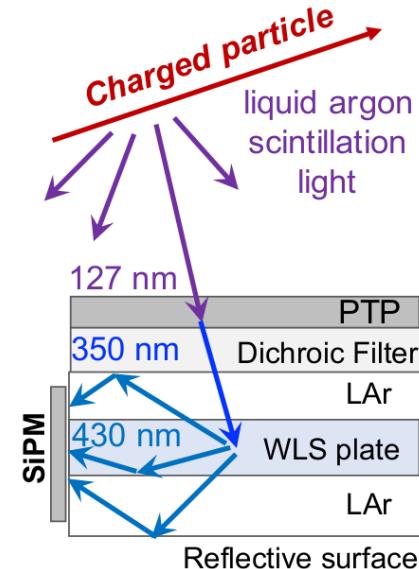
~ 4π PDS coverage is expected to improve energy resolution

DUNE-FD2(VD)



To increase light yield for high resolutions, PDS on top of High Voltage cathode surface as well as behind semi-transparent field cage is planned.

X-ARAPUCA detector

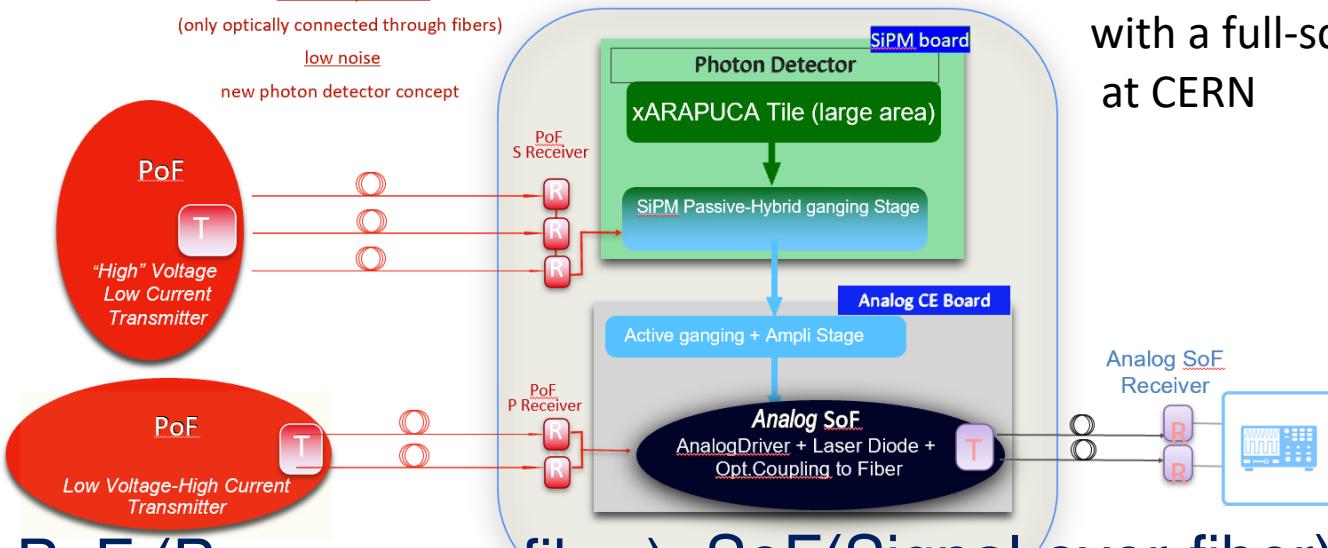


The VD R&D path

An electrically isolated

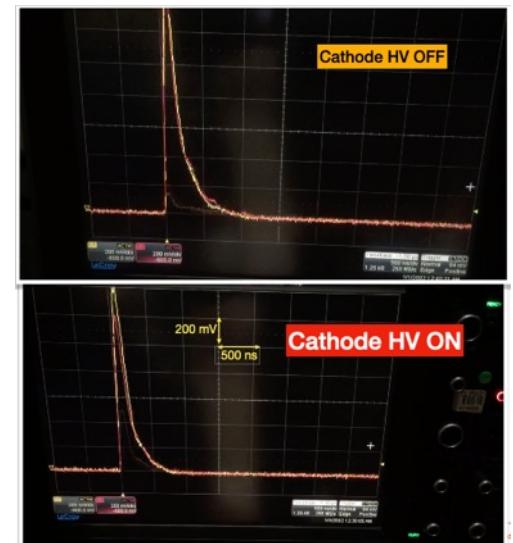
(only optically connected through fibers)
low noise
new photon detector concept

HV Cathode in LAr



Not to scale.

Demonstrated on a prototype with a full-scale components at CERN



PoF (Power-over-fiber) SoF(Signal-over-fiber)

R&D activities to further improve the signal quality and study long term stability (30+ yrs) are ongoing.

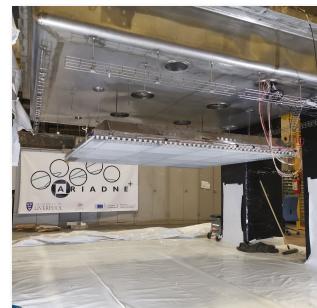
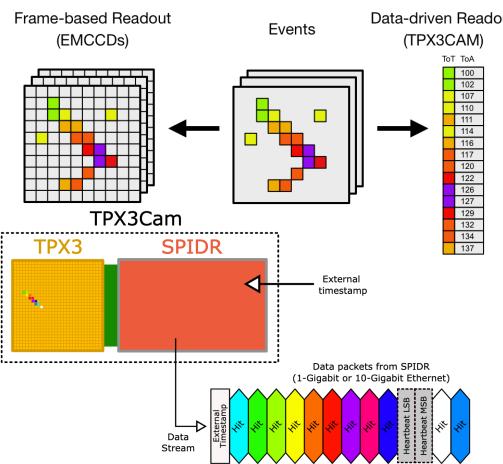
ARIADNE+: Large scale demonstration of fast optical readout for dual-phase LArTPCs at the CERN Neutrino Platform

Adam Lowe (University of Liverpool) on behalf of the ARIADNE+ collaboration

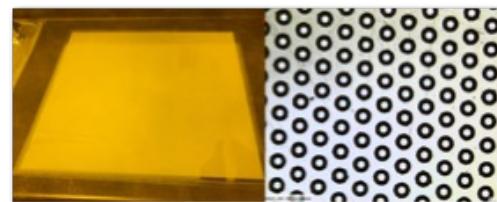
Full 3D optical readout with Timepix3



TPX3 ASIC Chip bump bonded to an optical sensor

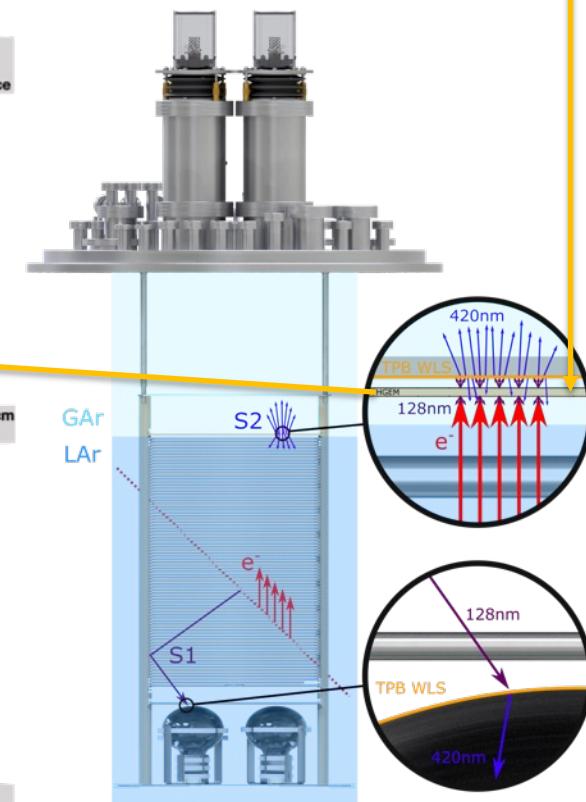
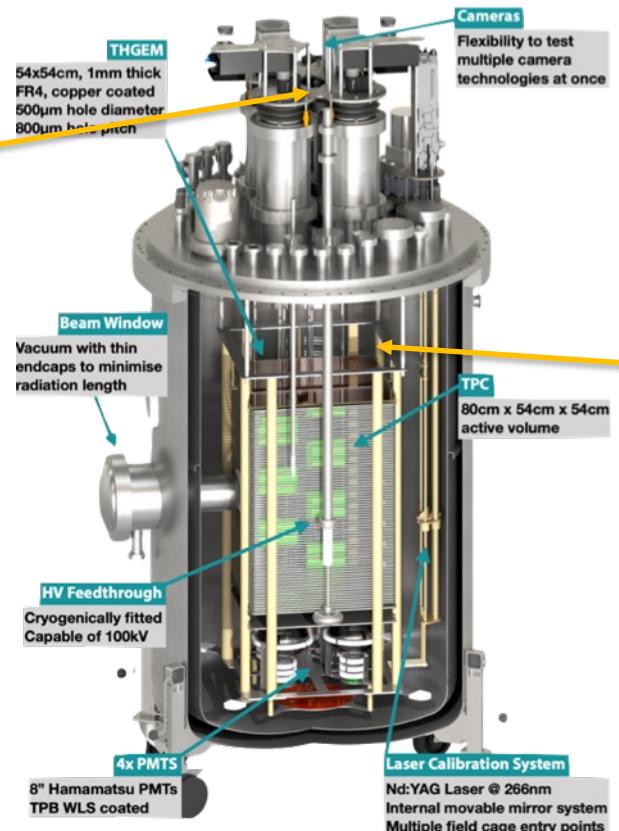


A **THGEM** (THick-Gaseous Electron Multiplier) amplifies drift charge

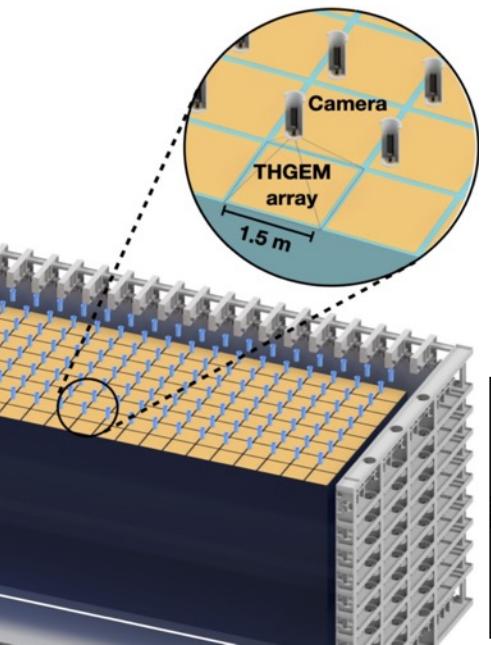


generating **secondary scintillation light (S2)**

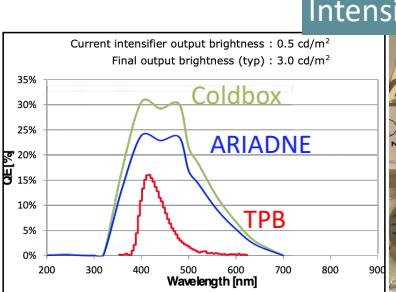
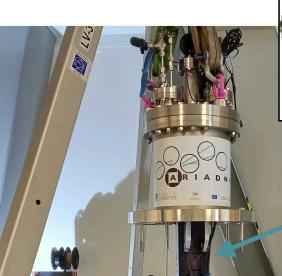
ARIADNE 1-tonne detector



ARIADNE (ARGon ImAGING DetectionN chambEr)



TPX3 Camera Setup



Intensifier

Timepix3
Camera

Relay Lens

Visible (f0.95,
10.5 mm)

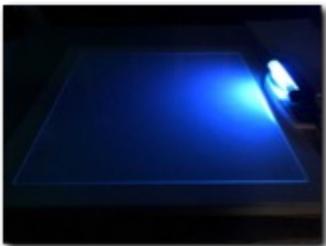


Custom made VUV
 MgF_2 Lens
(f3, 11mm, 5mm
diameter)

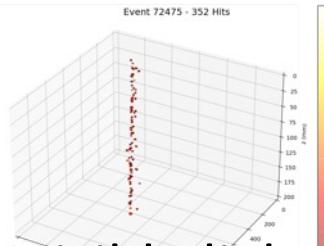


Objective Lens

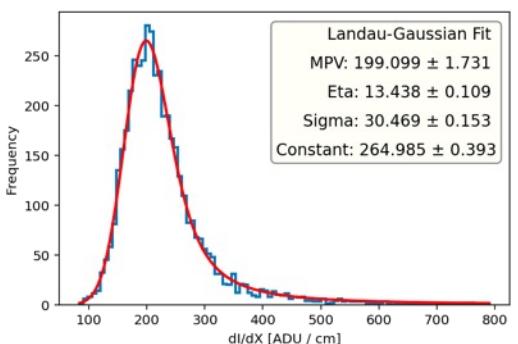
Polyethylene Naphthalate (PEN) Film coated glass panels for Wavelength Shifting (WLS)



VUV intensifier
imaging w/o WLS



Track fitting to
through going muons
(Through THGEM and greater than 19 cm depth)



Energy resolution :
 $16.73 \pm 0.16 \%$

TPX3Cam TPC Benefits



Raw data is natively 3D



Huge readout rates possible (80 MHits/s)



Zero suppressed readout (approx. few kbytes per event)



High resolution with approx. 1 mm per pixel



Easy access for swapping in/out technologies

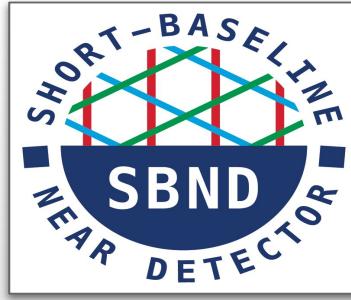


Same readout is possible for dual phase or gas TPCs



Comparatively low cost to other readout methods

SBND Trigger System: Status and MTC/A Configuration



Gabriela Vitti Stenico,

On behalf of [SBND Collaboration](#)

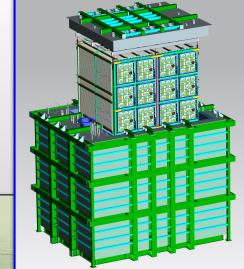
[University of Texas at Arlington](#)

Short-Baseline Near Detector (SBND)

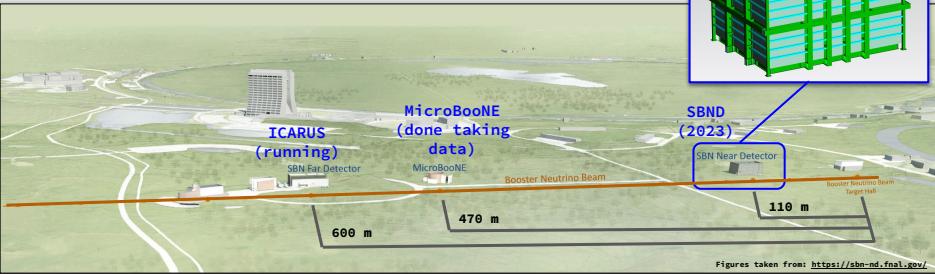
SBND Overview:

Nebot-Guinet and Balasubramanian's talks
on Tuesday (08/02) and Del Tutto's talk today
(08/04)!

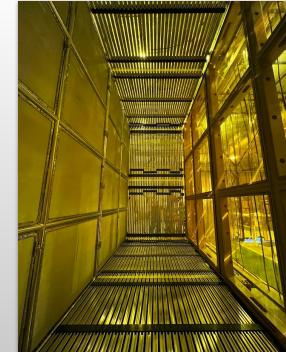
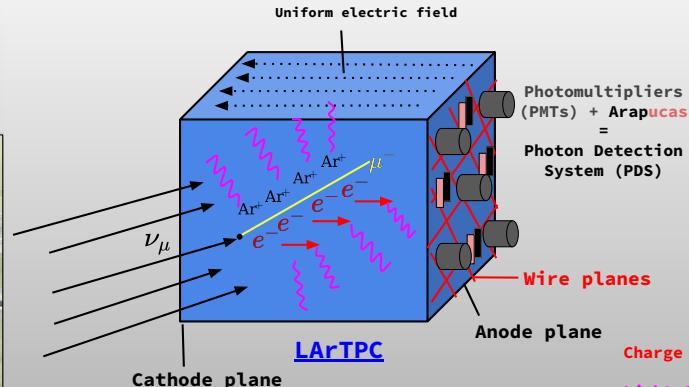
[Active volume: 112 ton liquid argon](#)



- Liquid Argon Time Projection Chamber (LArTPC);
- Sits in the beamline of the Booster Neutrino Beam (BNB) at Fermilab;
- SBND will record around 2 million neutrino events per year;
- Goals: eV-scale sterile neutrino and other Beyond Standard Model searches, neutrino-Argon cross-section measurements!

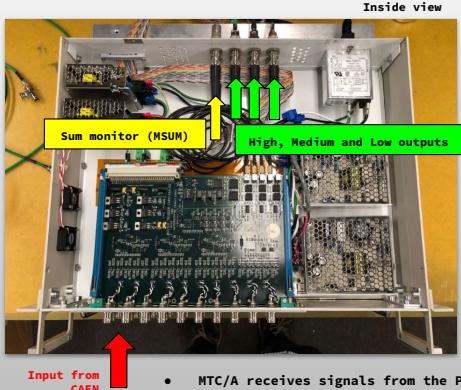


SBND LArTPC:



Inside view of one of SBND's TPCs. Photo by Mônica Nunes.

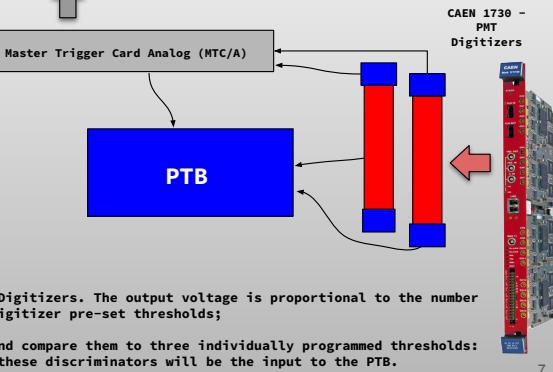
MTC/A:



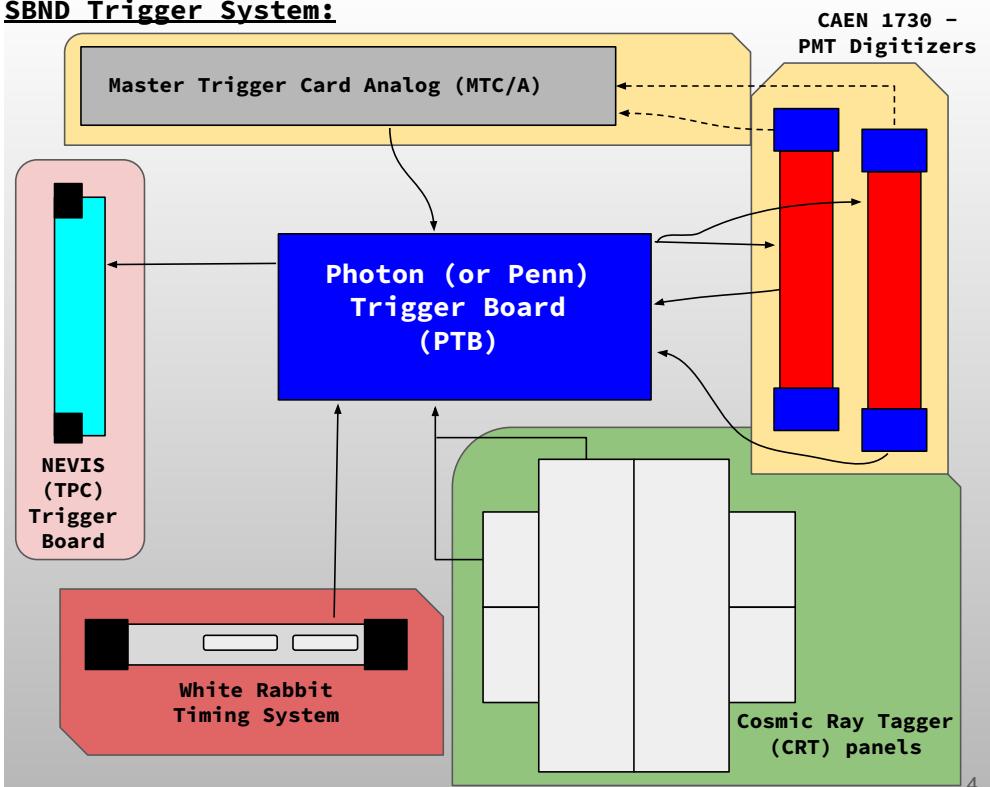
- MTC/A Digital to Analog Converter (DAC) thresholds are configurable with the PTB Linux side.

MTC/A 1

MTC/A 2



SBND Trigger System:

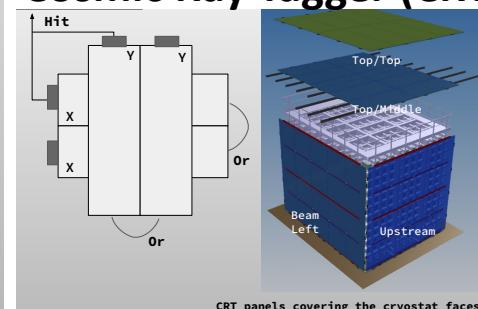


Photon (or Penn) Trigger Board (PTB)



logic operations with the subsystem inputs send the information (timestamp + type of trigger + status) to the DAQ.

Cosmic Ray Tagger (CRT)



Near Detectors

11:00

3D segmented scintillator neutrino detector SuperFGD for T2K experiment	<i>Christopher Mauger</i>
<i>Ballroom 3</i>	11:15 - 11:35
Characterisation of the ERAM detectors for the High Angle TPC of the T2K ND upgrade	<i>Claudio Giganti et al.</i>
<i>Ballroom 3</i>	11:35 - 11:55
Demonstration of a novel, ton-scale, pixel-readout LArTPC for the DUNE Near Detector	<i>Dr Jeremy Wolcott</i>
<i>Ballroom 3</i>	11:55 - 12:15
The search for $\nu\bar{\nu}$ with the NEXT time projection chamber	<i>Krishan Mistry</i>
<i>Ballroom 3</i>	12:15 - 12:35

Demonstration of novel, ton-scale

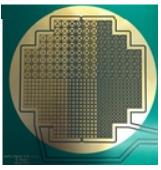
LArTPC for the DUNE ND

Jeremy Wolcott (Tufts University)
for the DUNE collaboration

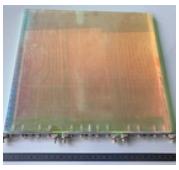
NuFact 2022 • August 5, 2022



New technology demonstrations

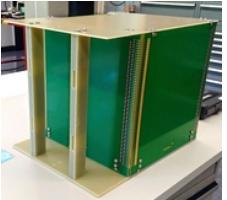


Charge readout



Light readout

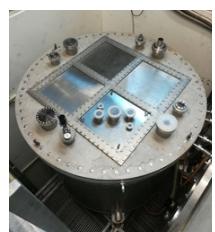
Small-scale integration tests



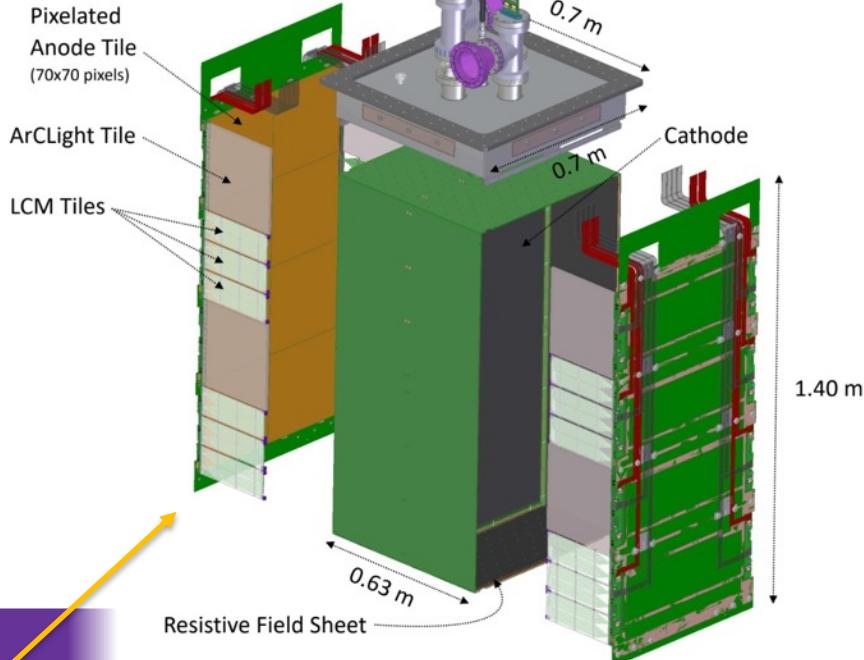
~30x30x30 cm³
"SingleCube"
prototypes



"Module 0"

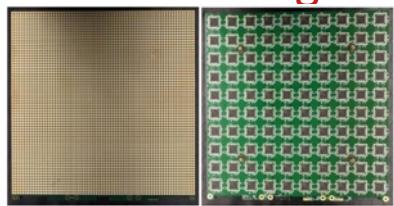


"2x2" cryostat



3 major innovations

1 Pixelated Charge Readout

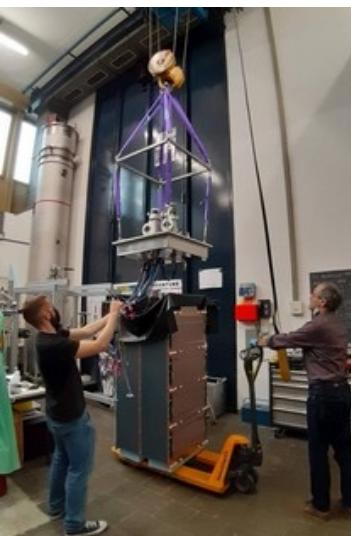


2 Light Readout System

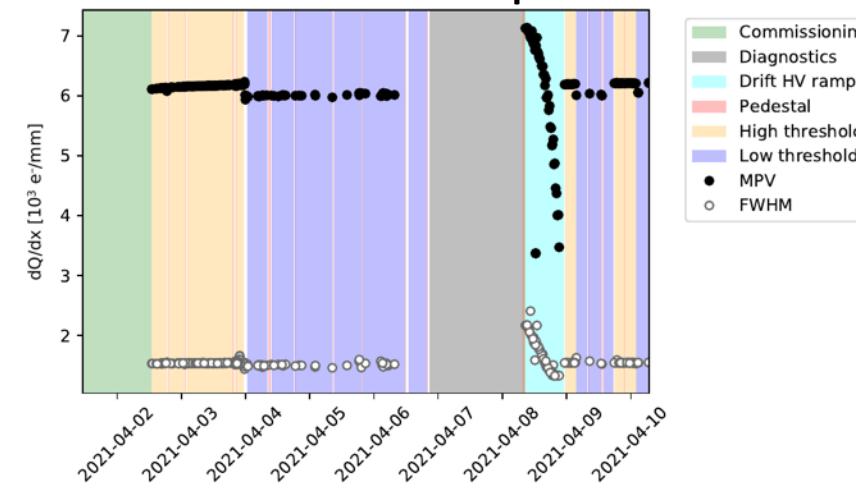


3 Resistive field sheet

First module (“module 0”) was tested with LAr at Bern in 2021

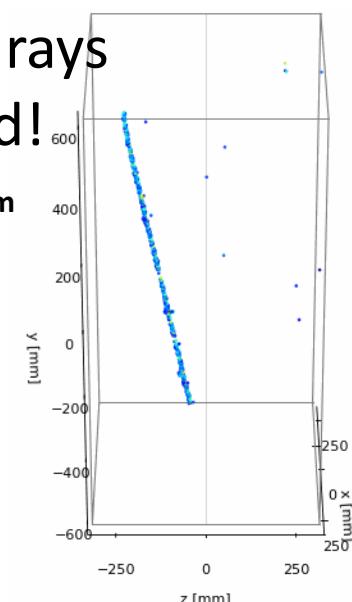
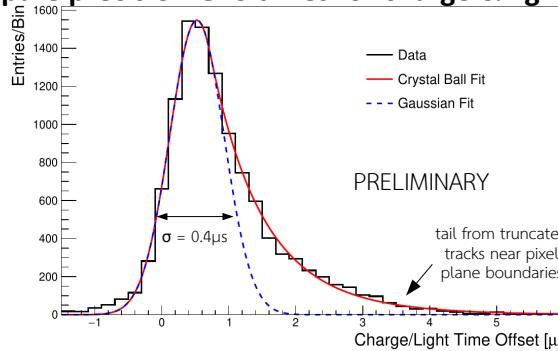


Smooth & stable performance



10s of millions of cosmic rays successfully self-triggered!

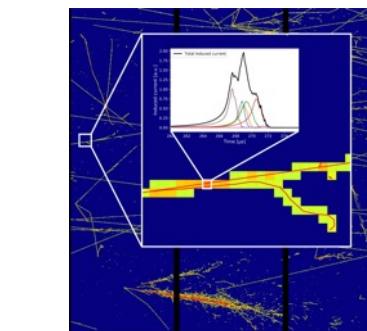
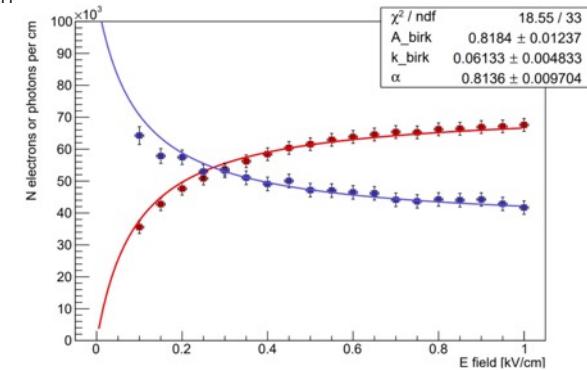
Compare precision GPS times for charge & light system



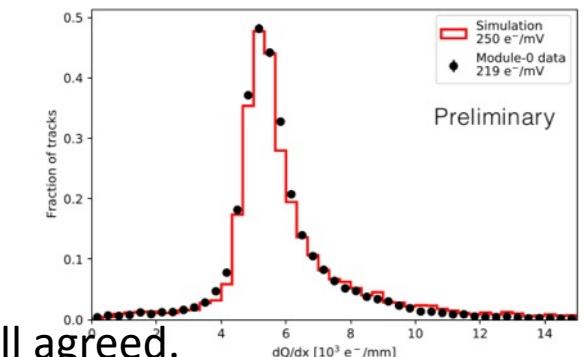
Charge readout timing resolution 0.6mm @ 500 V/cm

(requirement: 1.3mm)

charge and light
over various
field strengths



dQ/dx simulation well agreed.



The search for $0\nu\beta\beta$ with the NEXT time projection chamber

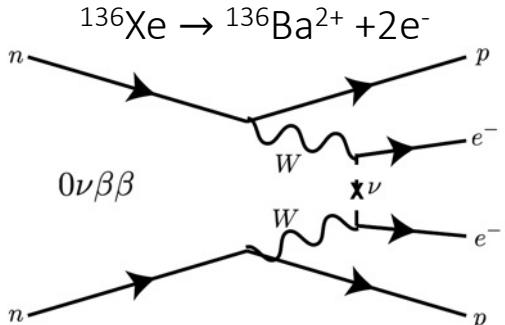
Krishan Mistry on behalf of the NEXT collaboration

5th August 2022

NuFACT 2022

Neutrino Experiment with a Xenon TPC (NEXT)
a high-pressure gaseous time projection chamber

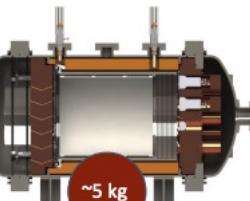
Xenon-136 $2\nu\beta\beta$ isotope



NEXT-White

2015-2021

Background model assessment
 $2\nu\beta\beta$ measurement for ^{136}Xe



NEXT-100

2022-2025

Background model assessment
Neutrinoless double beta decay search in ^{136}Xe



NEXT-HD

2026?

Neutrinoless double beta decay search through inverted neutrino mass ordering

NEXT-BOLD

Barium tagging for background-free experiment

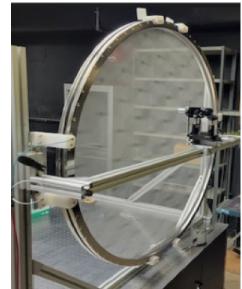


- Many of the TPC components of NEXT-100 have been completed and are ready to be installed

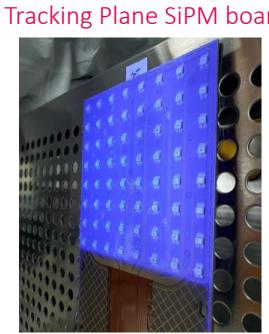
Pressure Vessel



EL Region



Copper Shielding



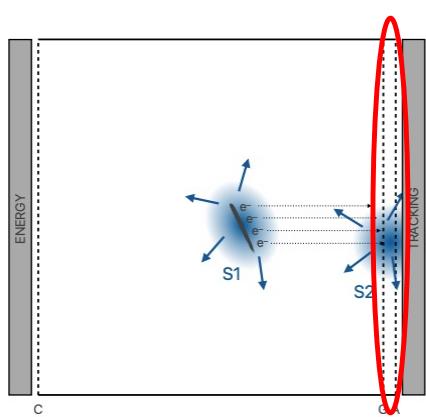
Tracking Plane SiPM boards

Field Cage

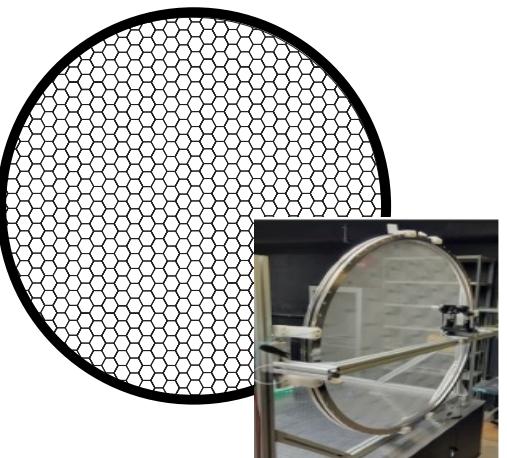


Asymmetric TPC design

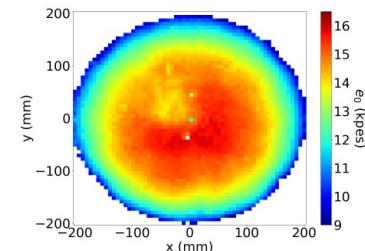
EL Region



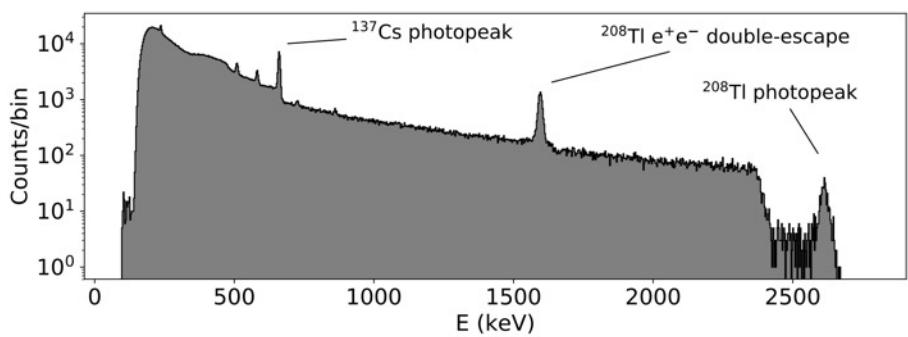
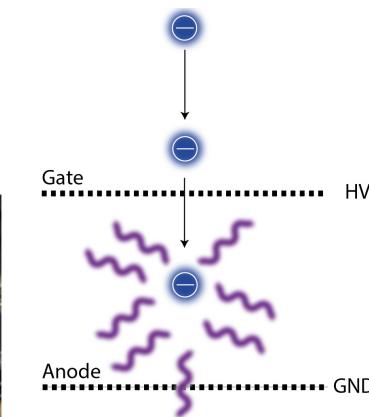
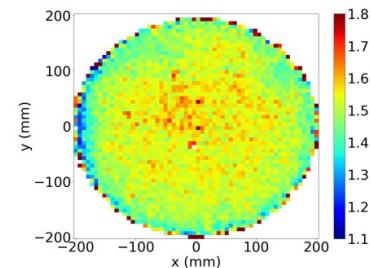
EL Grid



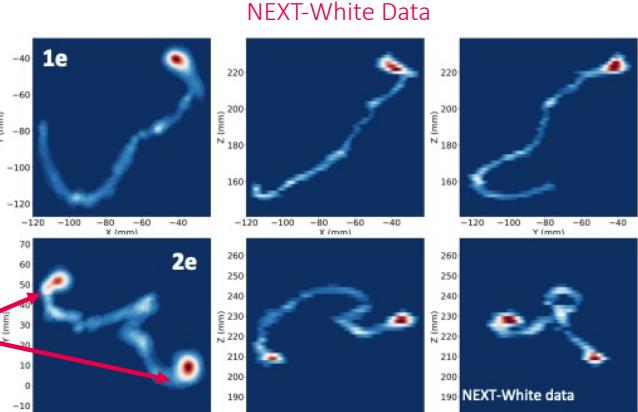
Two tensioned hexagonal meshes Geometric Corrections
with front mesh biased to -HV



Lifetime Corrections



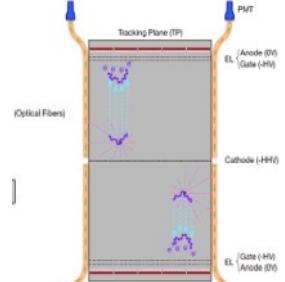
Reconstruction of the topology allows for effective rejection of single electron events



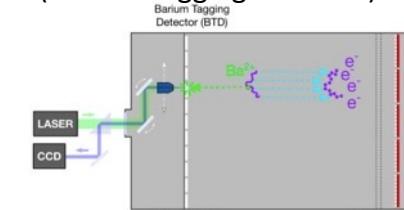
“blobs” at end of tracks used to identify $2e^-$ vs $1e^-$

Futures

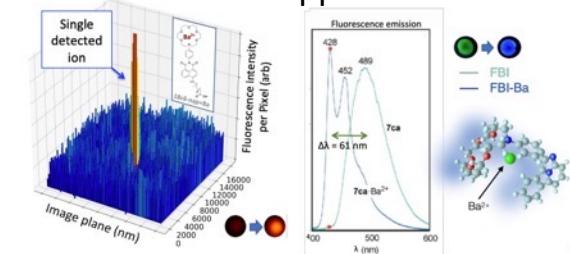
NEXT-HD



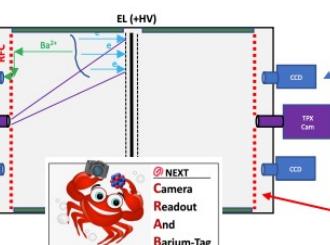
NEXT-BTD (Barium Tagging Detector)



NEXT-BOLD: making barium shine with 2 approaches



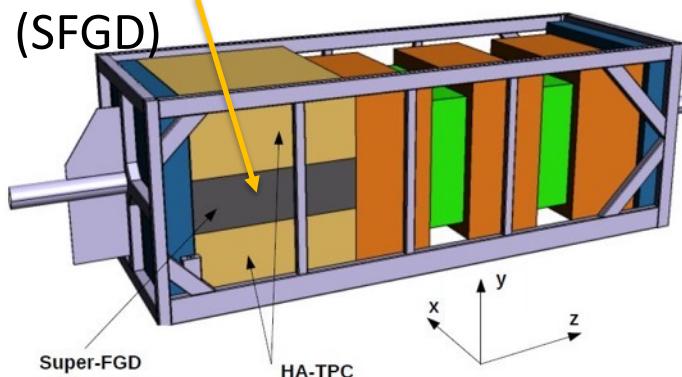
NEXT-CRAB (Camera Readout and Barium Tagging)



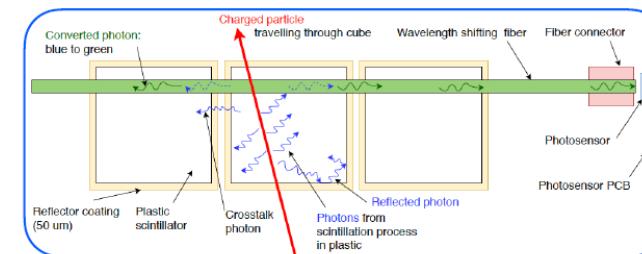
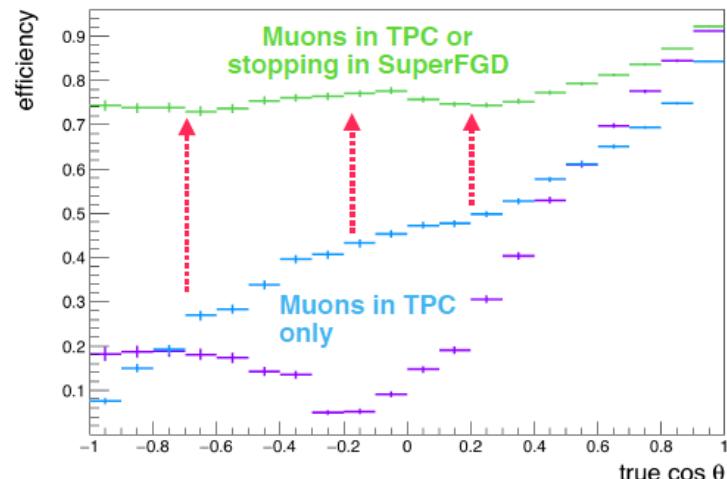
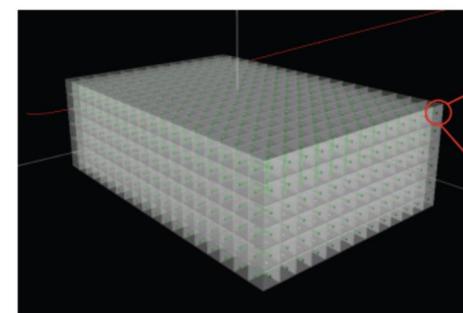
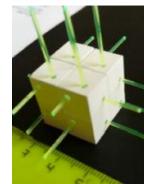
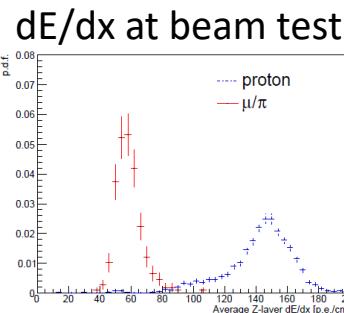
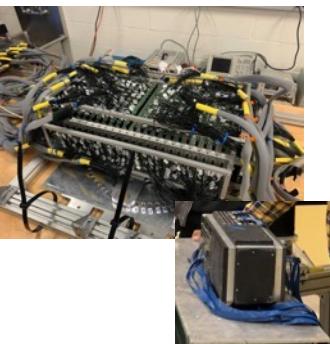
T2K Near Detector Upgrade: Super Fine-Grained Detector

Christopher Mauger for the T2K
collaboration
University of Pennsylvania

Super Fine-Grained Detector



Prototypes



1x1x1 cm³ cubes
Polystyrene scintillator
1.5% paraterphenyl
0.01% POPOP
Chemical etched reflector
WLS fiber Kuraray Y11
2-clad ($\phi=1\text{mm}$)

- 3D-array of 1-cm scintillator cubes (184x192x56)
- Fibers run the length (or width or height) of the detector – 3-fibers in each cube
- Low-occupancy experiment – 3D view of events (4π– like acceptance)

Cube Production/Assembly Completed!

Delivered at J-PARC

First layers

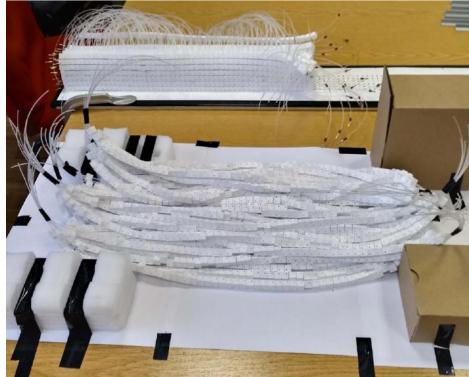
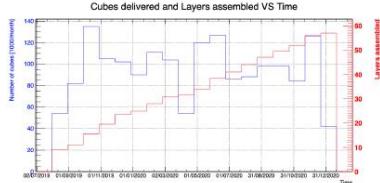


1 Layer = 184 x 192 cubes (baseline design)

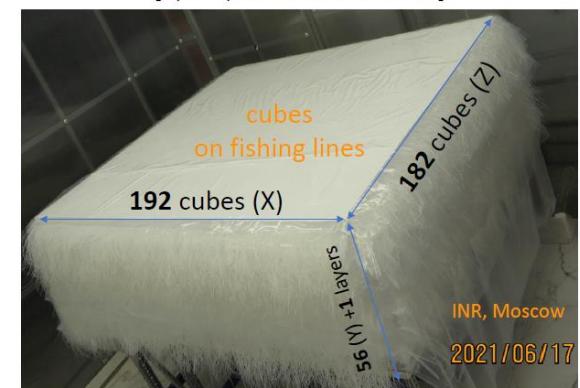
All (56) layers



All cubes have been produced by Uniplast and layers have been assembly at INR

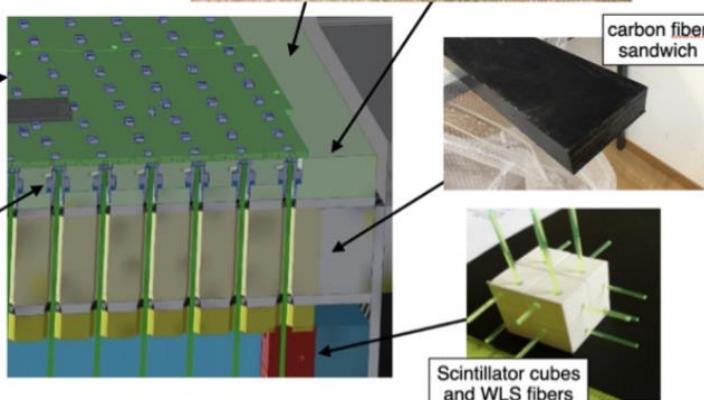


56 (Y) +1 spare layers x 192 cubes (X) x 182 cubes (Z)
[1,991,808 cubes in total]

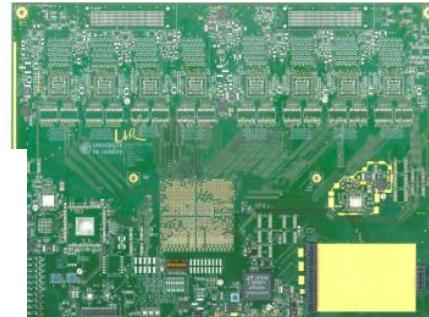
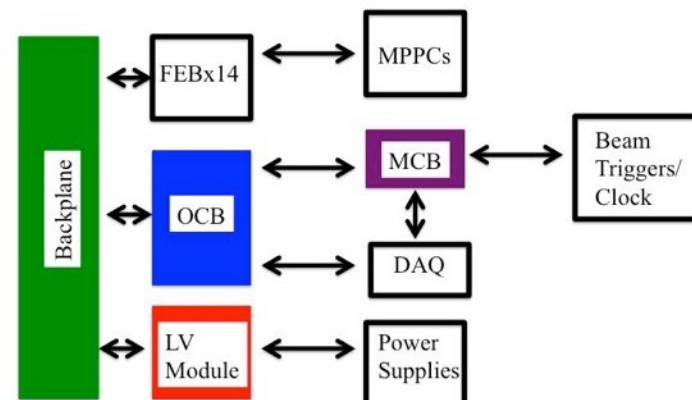


Optical readout

MPPC is surface mounted onto the PCB screwed into the box plate
Fibers glued to optical connectors – total of 56,382 fibers



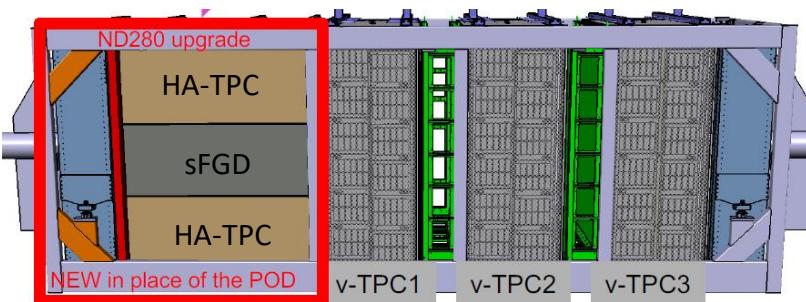
SFGD Electronics Architecture



Front-End Board (14 boards per crate) – analog processing, ADC, bias voltage to the MPPCs
8 CITIROC chips per board – 256 channels

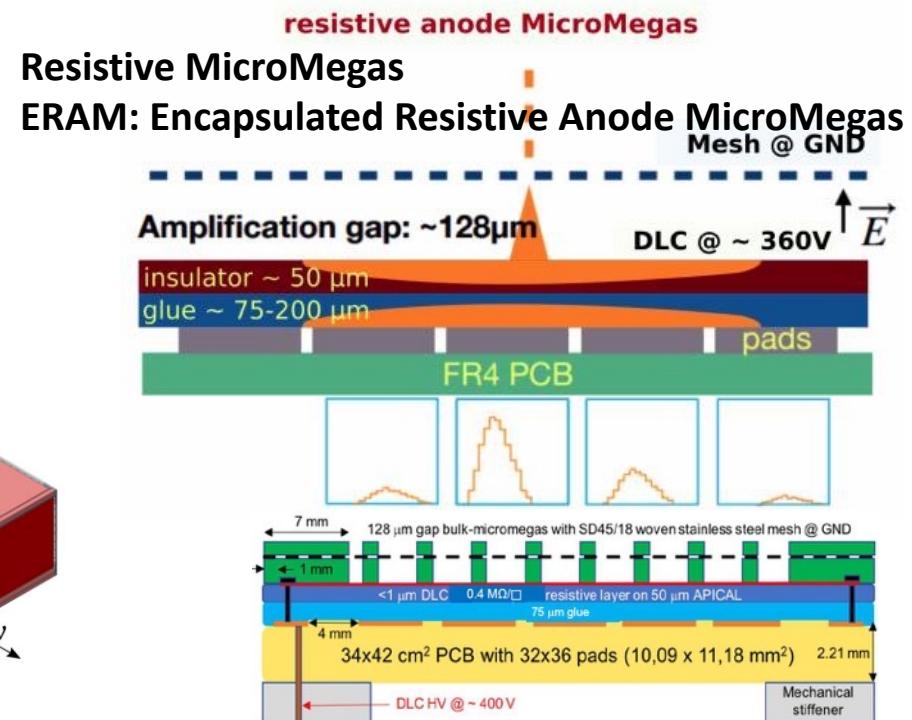
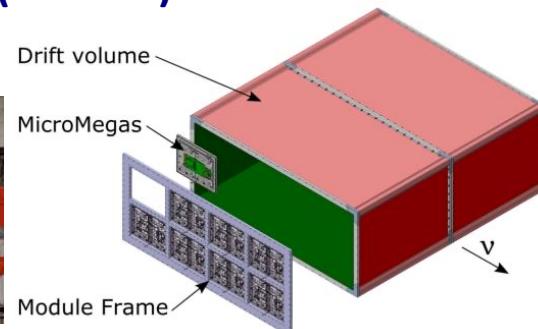
Characterisation of the ERAM detectors for the High Angle TPC of the T2K ND upgrade

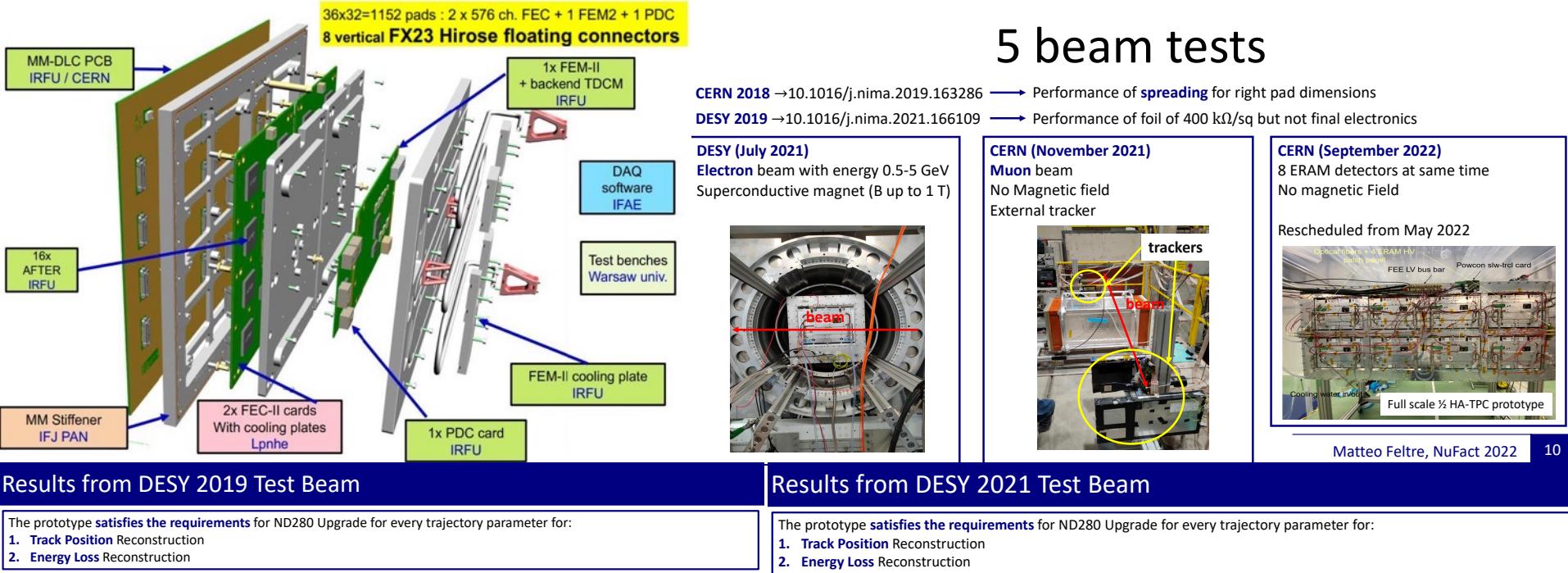
Matteo Feltre, on Behalf of T2K Collaboration
INFN Padova



Two High Angle TPCs (HA-TPC):

Field Cage

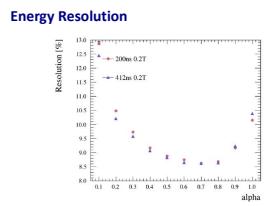
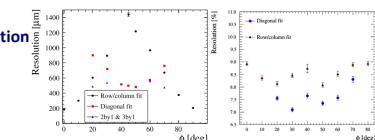
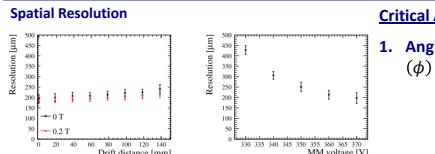




Results from DESY 2019 Test Beam

The prototype **satisfies the requirements** for ND280 Upgrade for every trajectory parameter for:

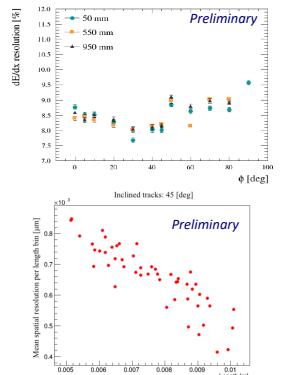
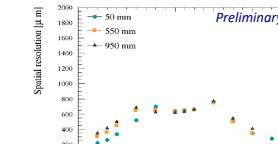
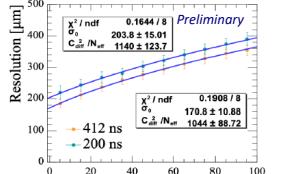
1. Track Position Reconstruction
2. Energy Loss Reconstruction



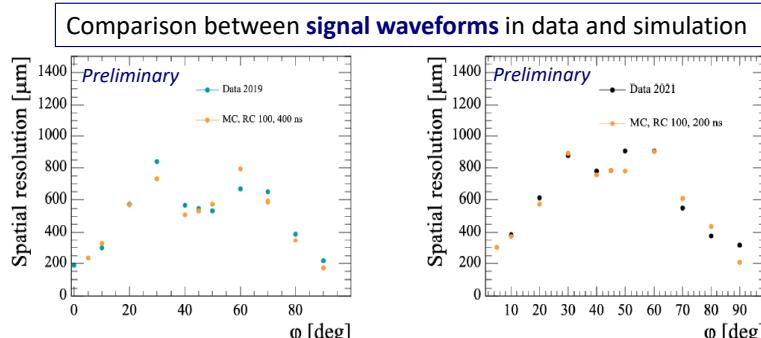
Results from DESY 2021 Test Beam

The prototype **satisfies the requirements** for ND280 Upgrade for every trajectory parameter for:

1. Track Position Reconstruction
2. Energy Loss Reconstruction



Data - Simulation



Future Steps

Test beam in September 2022 with:

- 8 ERAM modules
- Full scale prototype as Field Cage

Complete installation in Fall 2023

Calibration & others

14:00

Measuring solar neutrinos over gigayear timescales with paleo detectors	<i>Dr Natalia Tapia Arellano</i>
<i>Ballroom 3</i>	14:20 - 14:38
The Camera System for the IceCube Upgrade	<i>Woosik Kang</i>
<i>Ballroom 3</i>	14:38 - 14:56
Energy Reconstruction and Calibration of the MicroBooNE LArTPC	<i>Dr Wanwei Wu</i>
<i>Ballroom 3</i>	14:56 - 15:14
Calibration strategy for the JUNO experiment	<i>Dr Davide Basilico</i>
<i>Ballroom 3</i>	15:14 - 15:32
Calibrating for Precision Physics in LArTPCs at ICARUS	<i>Gray Putnam</i>
<i>Ballroom 3</i>	15:32 - 15:50

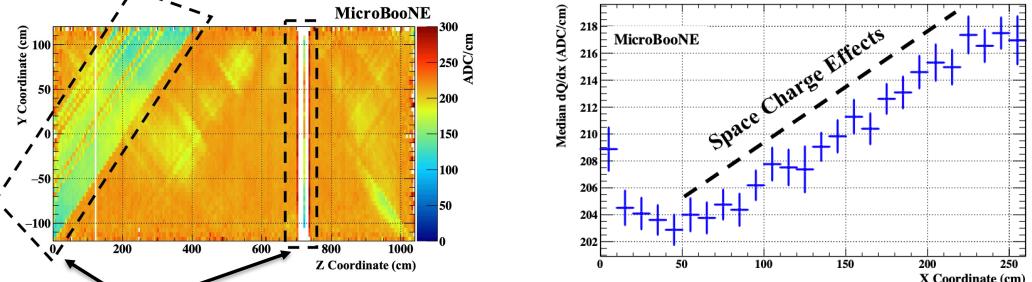
Energy Reconstruction and Calibration of the MicroBooNE LArTPC

Wanwei Wu (wwu@fnal.gov), Fermi National Accelerator Laboratory

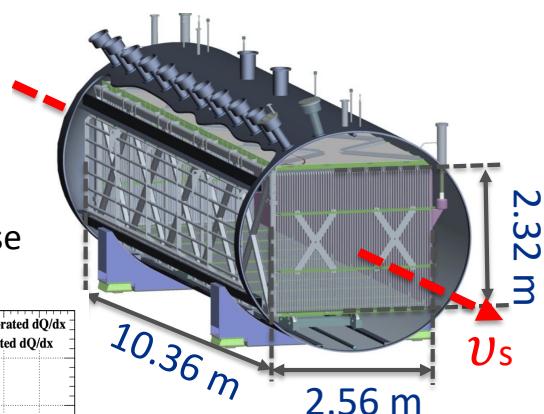
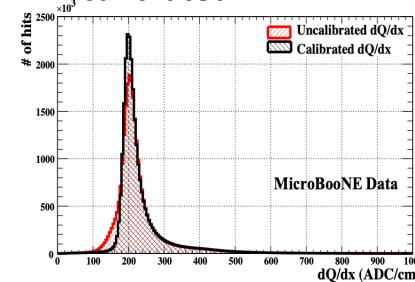
On behalf of the MicroBooNE Collaboration

NuFACT 2022, August 5, 2022

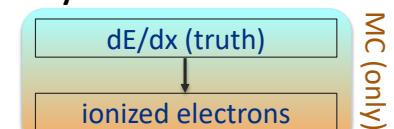
dQ/dx in YZ plane and in the drift direction X



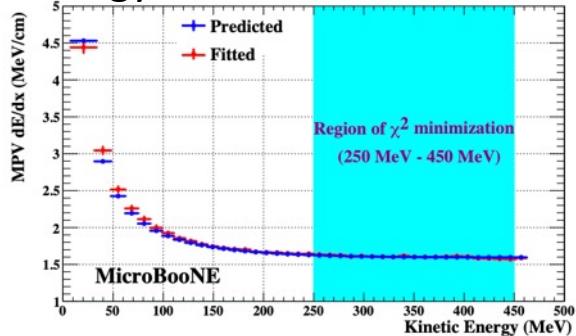
Detector response calibrated



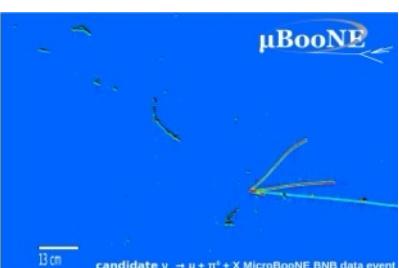
Many effects need to be calibrated



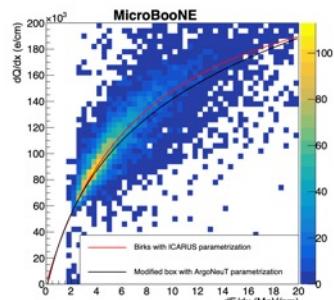
Energy Scale Determination



π^0 mass reconstruction

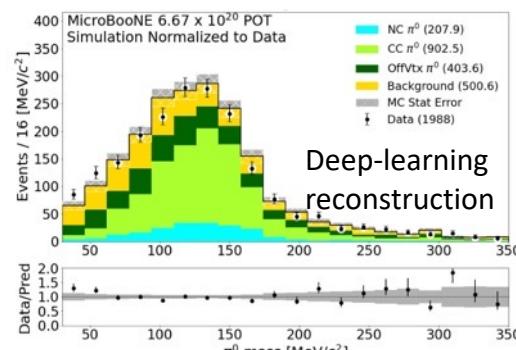
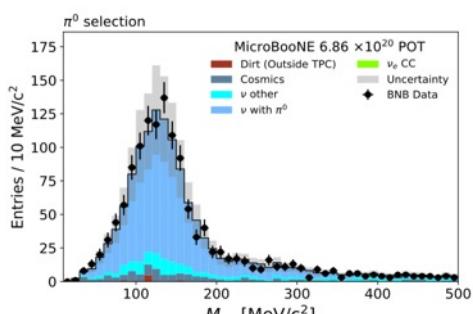


dQ/dx vs. dE/dx —Recombination Effects

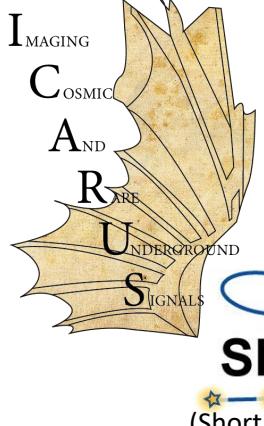


$$\frac{dQ}{dx}(e/cm) = \frac{\ln\left(\frac{dE}{dx} \frac{\beta'}{\rho E} + \alpha\right)}{\frac{\beta'}{\rho E} W_{ion}}$$

$$\frac{dQ}{dx}(e/cm) = \frac{A_B}{W_{ion}} \left(\frac{\frac{dE}{dx}}{1 + \frac{k}{\rho E} \frac{dE}{dx}} \right)$$



Deep-learning reconstruction



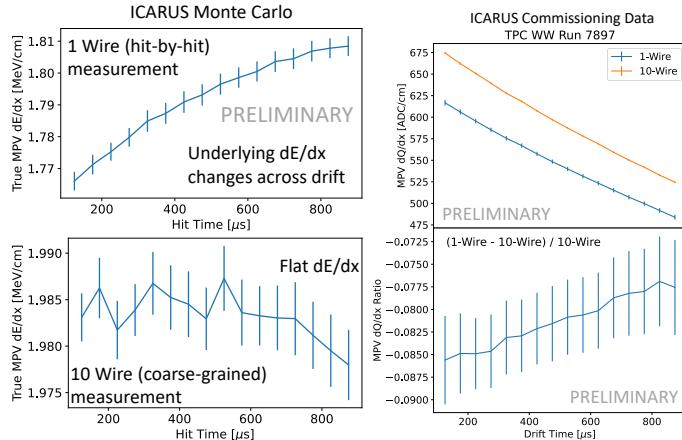
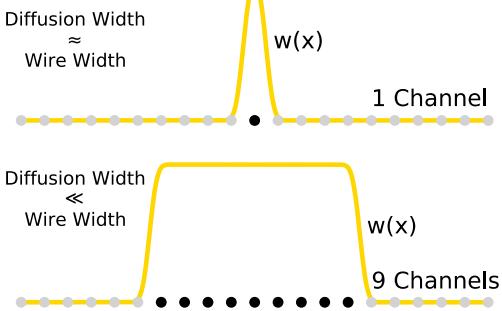
Calibrating for Precision Calorimetry in LArTPCs at ICARUS and SBN

GRAY PUTNAM
UNIVERSITY OF CHICAGO

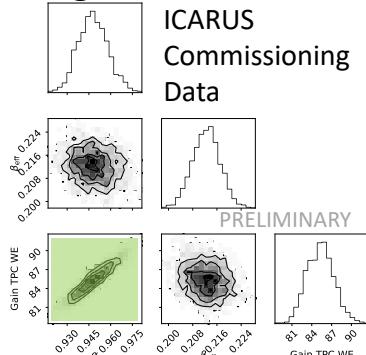


(Short Baseline Neutrino at FermiLab)

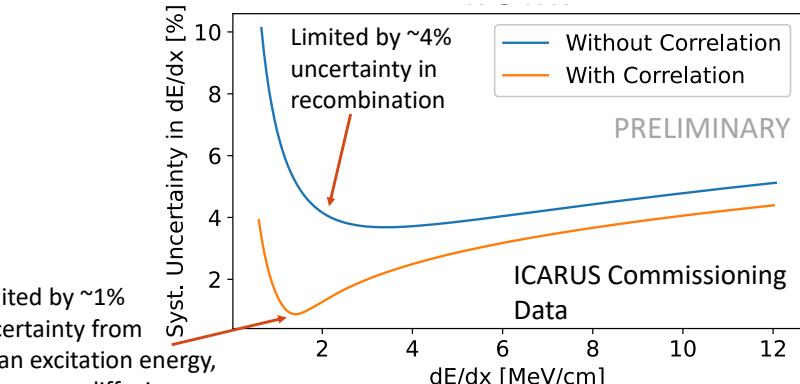
1. Drift Direction Response Normalization with Diffusion



Strong correlation between gain and recombination

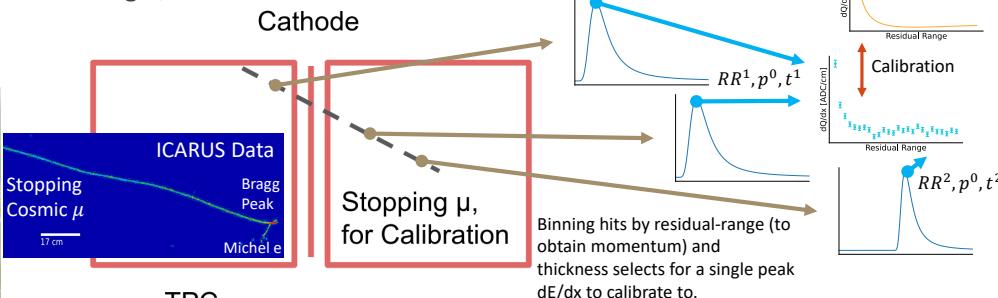


Limited by ~1% uncertainty from mean excitation energy, transverse diffusion

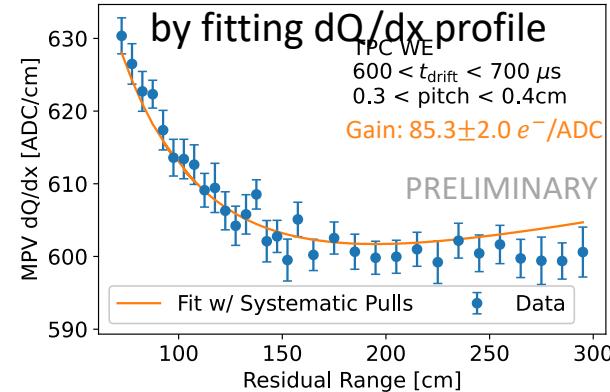


Calibration Procedure

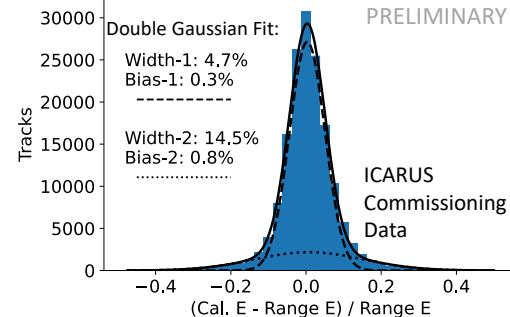
• Bin hits in terms of: residual-range (momentum), track angle, and drift time



2. Energy scale calibration



Energy reconstruction (stop- μ)



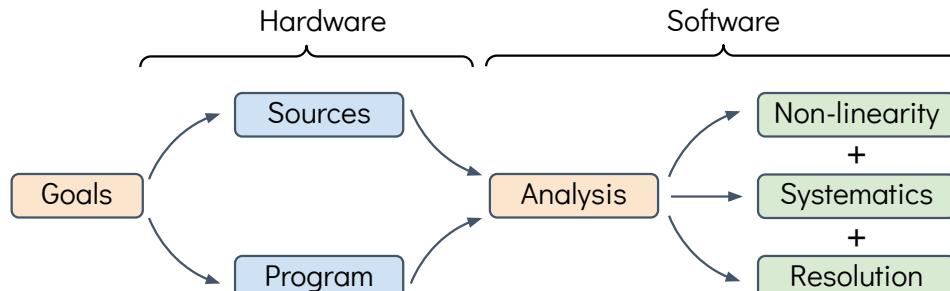
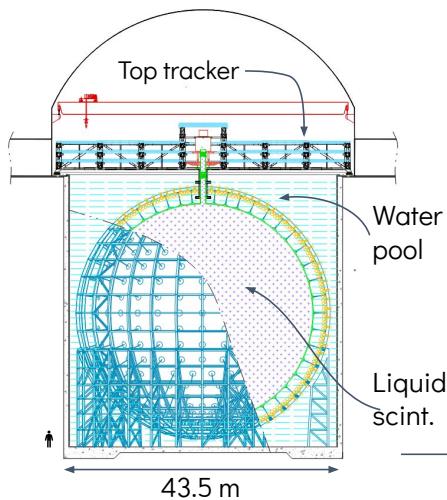
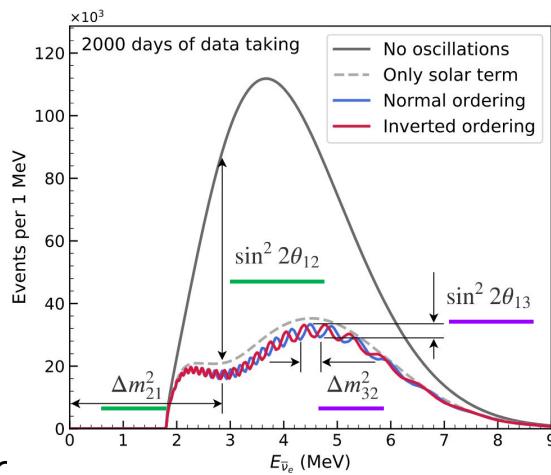
- 4.7% resolution in bulk of distribution (2% intrinsic resolution from range)
- Bias within 1 σ range expected from systematic uncertainties

Calibration strategy for the JUNO experiment

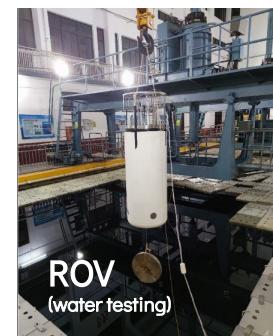
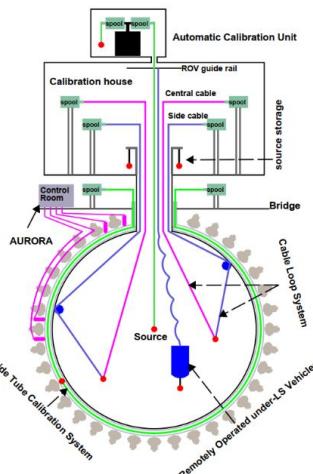
Dr. Davide Basilico on behalf of the JUNO collaboration
University of Milan & INFN Milan

NuFact 2022 - 2022 August 05 - Snowbird

Key requirements: <1% energy linearity and <3% effective energy resolution



Hardware & sources



- 1D: Automatic Calibration Unit (ACU)
- 2D: Cable Loop System (CLS)
- 3D: Remotely Operated under-LS Vē

Calibration of non-linearity

- 1) physics non-linearity → radioactive sources + cosmogenic isotope ^{12}B
- 2) instrum. non-linearity → laser source

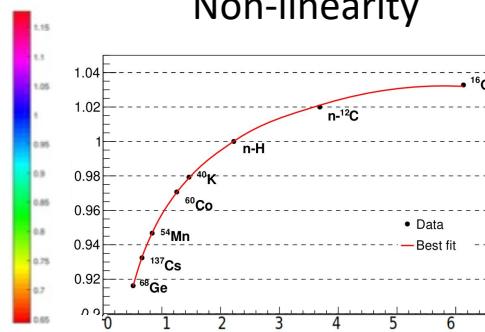
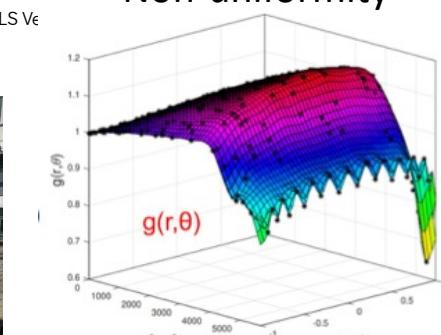
Systematics understanding and control

→ rad. sources syst (shadowing, non uniformity)
→ PMTs syst. (dark noise, non linearity, ...)

Optimization and calibration of energy resolution

→ position non-uniformity: source in multiple positions

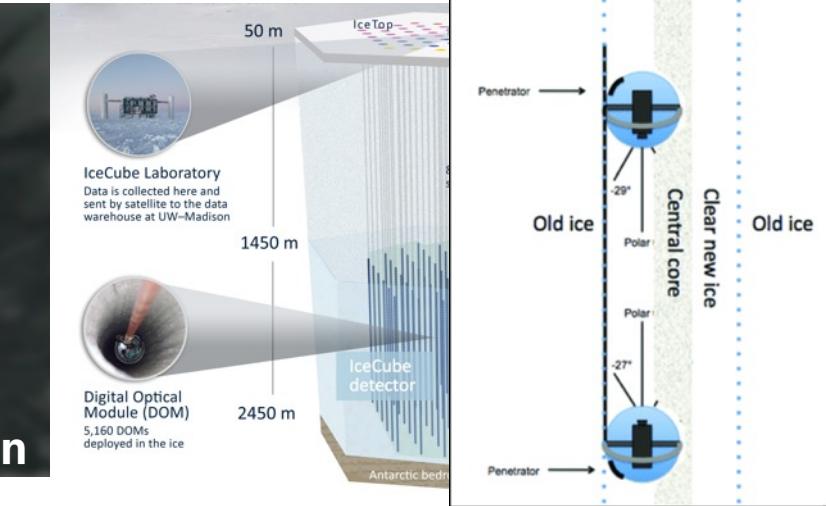
Non-uniformity



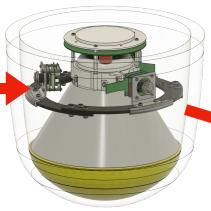
+ Instrumental nonlinearity, stability monitoring

The Camera System for the IceCube Upgrade

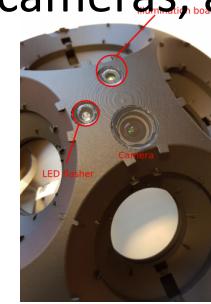
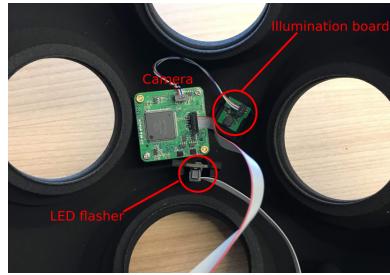
Woosik Kang on behalf of the IceCube Collaboration



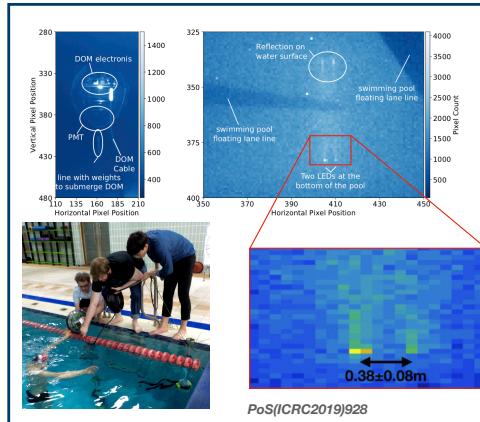
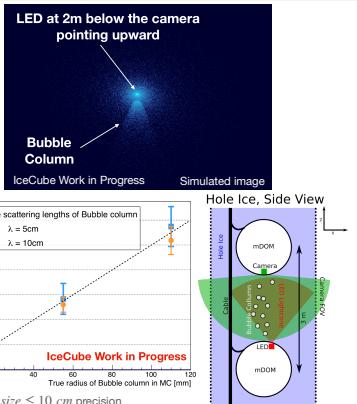
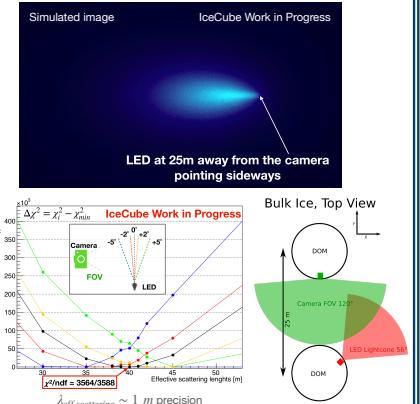
D-Egg : 3 outward facing cameras



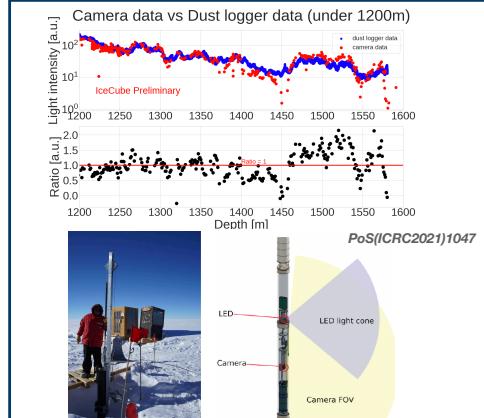
mDOM : 2 ↑+ 1 ↓ cameras, and 1 LED ↑



Simulation



Field tests



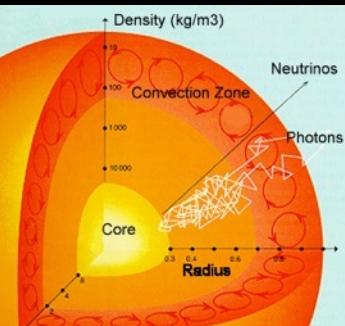
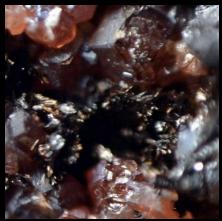
Measuring solar neutrinos over Gigayear timescales with Paleo Detectors

ArXiv: 2102.01755

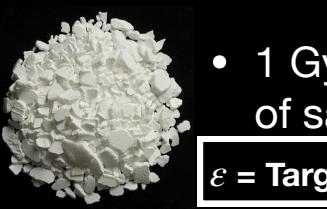
Shunsaku Horiuchi, Natalia Tapia
Paleo Detectors

- Alternative to conventional Detectors
(Solid state track detectors, SSTD)
- DM Searches
- Instead of a large target mass experiment
- Examine rocks!!

Billion year $\sim 10^9$ y



For Paleo Detectors:

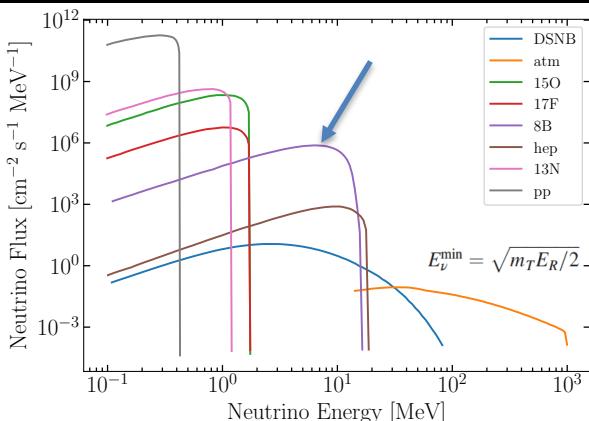


- 1 Gyr old sample and $O(10)$ mg of sample

$$\varepsilon = \text{Target Mass} * \text{Integration Time}$$

$$\bullet \quad \varepsilon = 0.01 \text{ kg Myr}$$

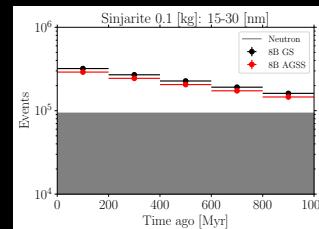
S. Baum, A. K. Drucker, K. Freese, M. Gorski, P. Stengel, T. D. P. Edwards, B. J. Kavanagh, C. Weniger



Results

Different Scenarios

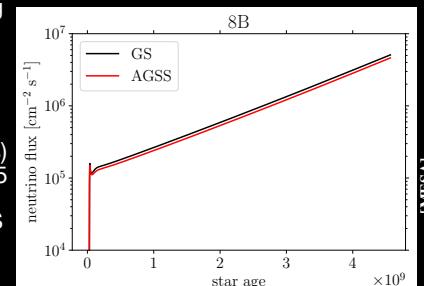
- We examined in details the track length range of 15-30 nm
- We use a sample mass of 0.1 kg
- Time window of time variation: 200 Myr and 500 Myr



Metallicity Models:

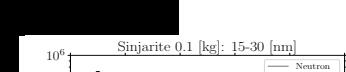
- 8B Neutrinos strong dependence on Solar Core T°
- MESA (Modules for Experiments in Stellar Astrophysics) code version r12115
- Z/X = 0.0229 for GS
- Z/X = 0.0181 for AGSS

8B : T^{24}



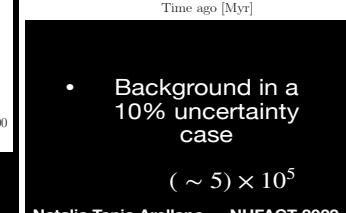
[Farag et al. 2020]

- Discrepancy in results from Sun's **Metallicity** (anything beyond helium)
- Inconsistency between **photosphere abundances AGSS09** and **helioseismic data in GS98** sensitive to interior composition.



Metallicity sensitivity

- GS98 1Gyr: $(1.63 \pm 0.05) \times 10^6$
- AGSS09 1Gyr: $(1.52 \pm 0.05) \times 10^6$



- Background in a 10% uncertainty case ($\sim 5 \times 10^5$)

Natalia Tapia Arellano — NUFACt 2022

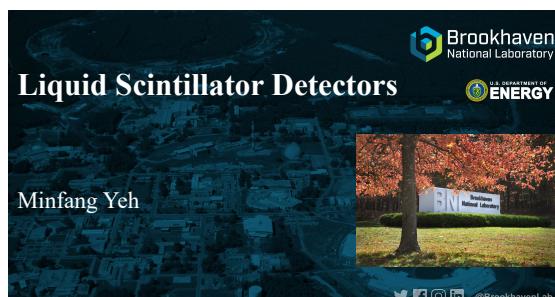
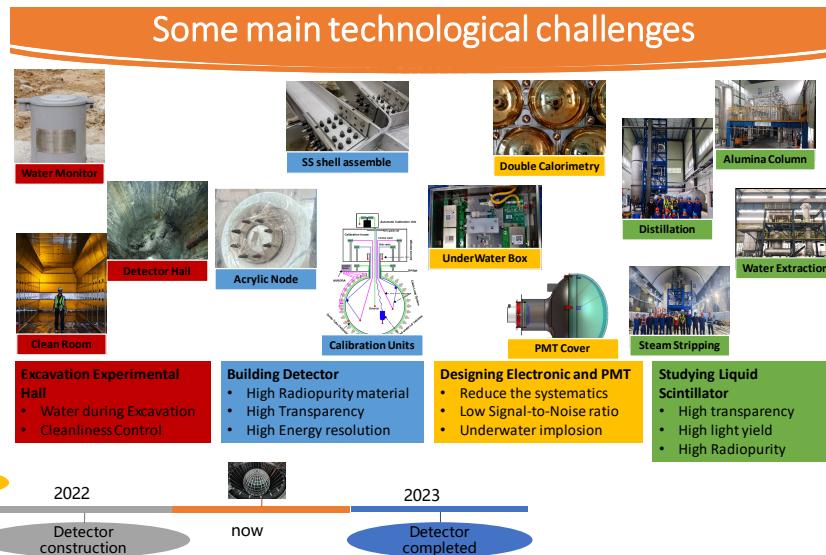
Plenary talks

- Focused on coming experiment and machine learning.

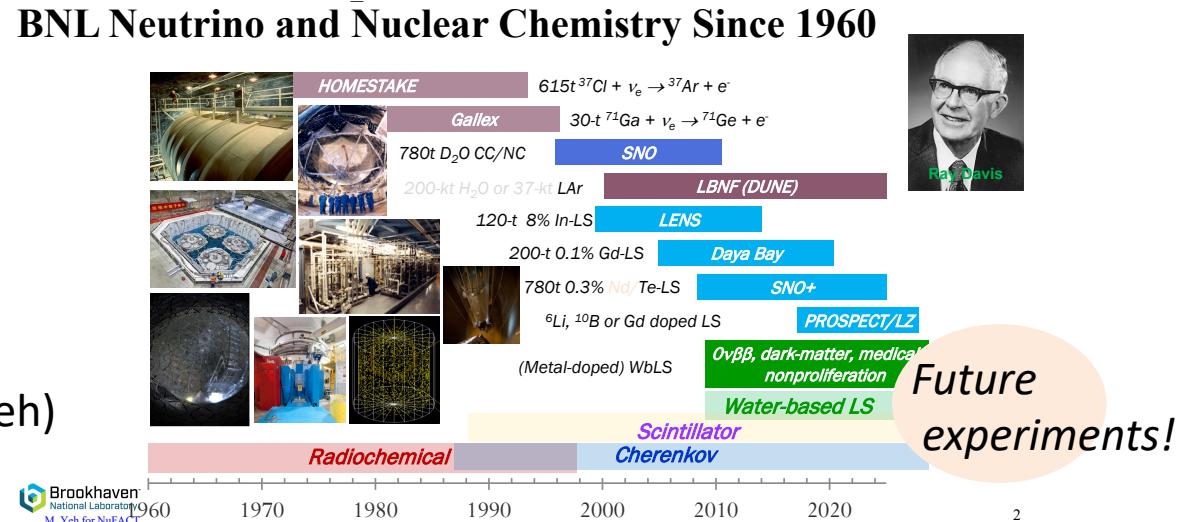
Challenges in the construction of large neutrino detectors:
the JUNO case

Michele Montuschi

On behalf of JUNO collaboration



(By Minfang Yeh)

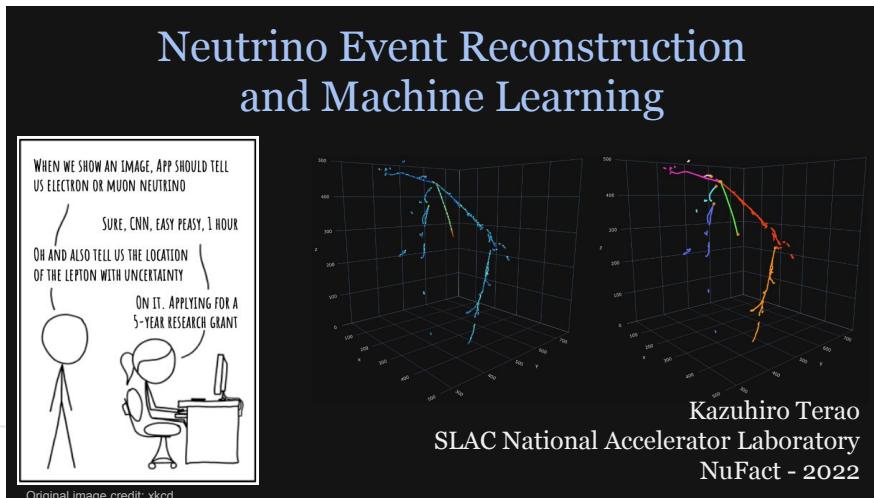


Machine Learning at WG1+6 Joint session (ν osc. & Detectors)

Plenary talk

14:00

4 parallel talks



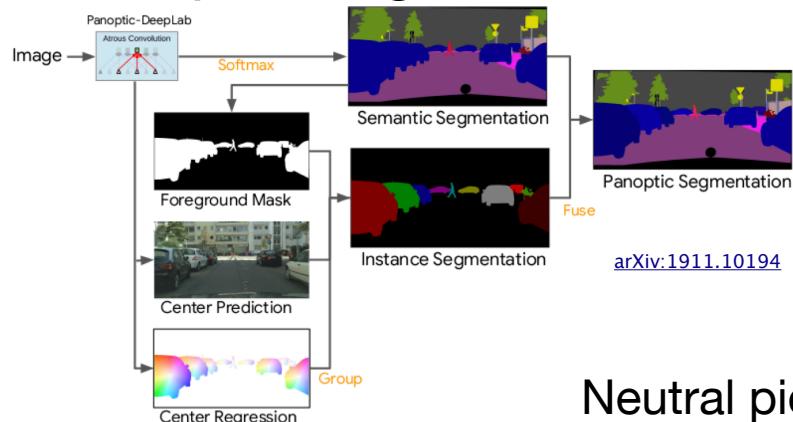
15:00

Machine Learning Techniques to Enhance Event Reconstruction in Water Cherenkov Detectors	Nick Prouse
Ballroom 2&3	14:20 - 14:42
Measurement of Atmospheric Muon Neutrino Disappearance using CNN Reconstructions with IceCube	Shiqi Yu
Ballroom 2&3	14:42 - 15:04
Machine Learning Methods for Solar Neutrino Classification	Alejandro Yankelevich
Ballroom 2&3	15:04 - 15:26
Panoptic Segmentation for Particle Identification in ProtoDUNE-SP	Carlos Sarasty
Ballroom 2&3	15:26 - 15:48

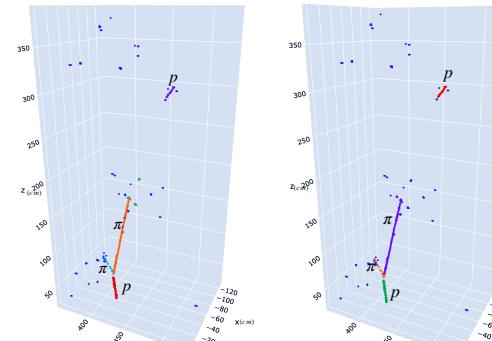
Panoptic Segmentation for Particle ID in ProtoDUNE

Carlos Sarasty-Segura on behalf of the DUNE Collaboration

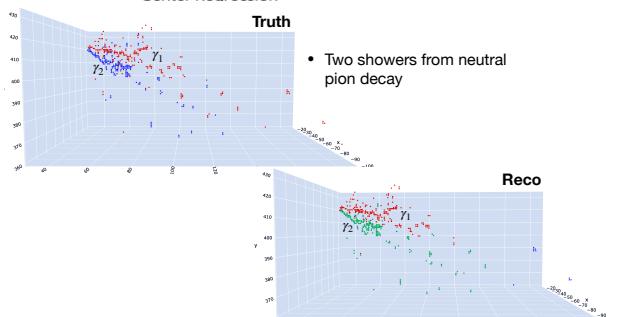
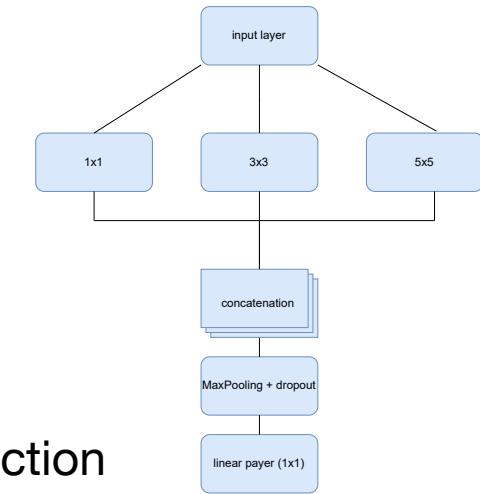
Panoptic segmentation



[arXiv:1911.10194](https://arxiv.org/abs/1911.10194)

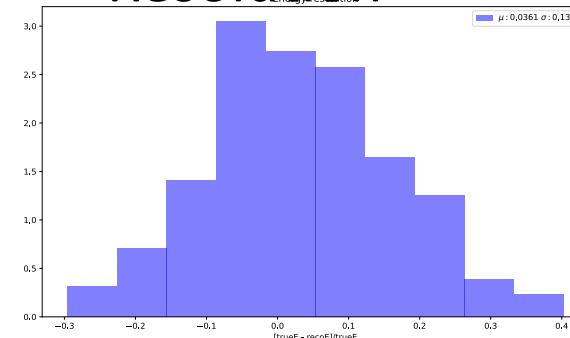


Neutral pion invariant mass reconstruction

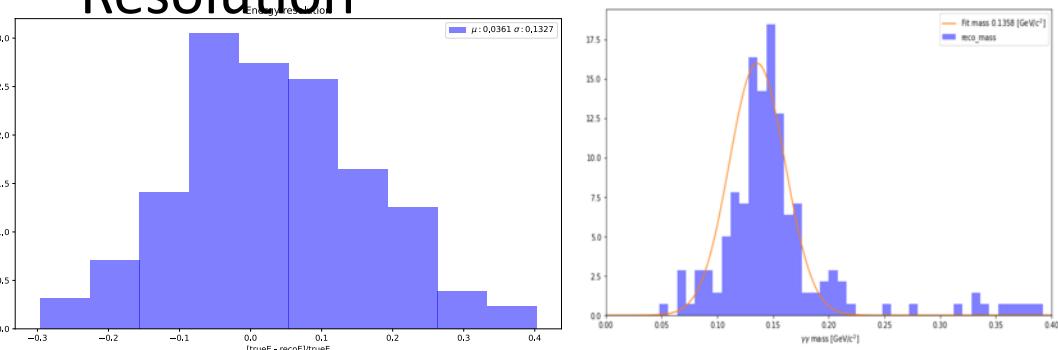


- Principal Component Analysis is used to find direction of showers
 - Find direction that maximize the variance of the projected data
 - Compute covariance matrix
 - Compute eigenvectors, eigenvalues

Resolution



π^0 mass



A very preliminary result of neutral pion mass reconstruction using panoptic segmentation network looks promising.

Measurement of Atmospheric Muon Neutrino Disappearance using CNN Reconstructions with IceCube

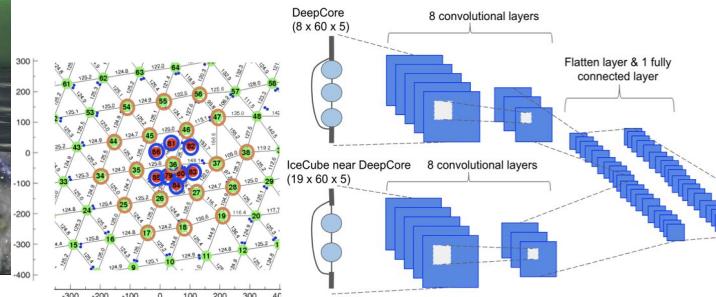
Shiqi Yu
Michigan State University

NuFact 2022



GeV-Scale CNN Architecture

- Only use DeepCore & nearby IceCube strings
- Five CNNs trained & optimized separately



Inputs: 5 summarized variables

- sum of charges
- time of first (last) pulse
- charge weighted mean (std.) of times of pulses

Regression:

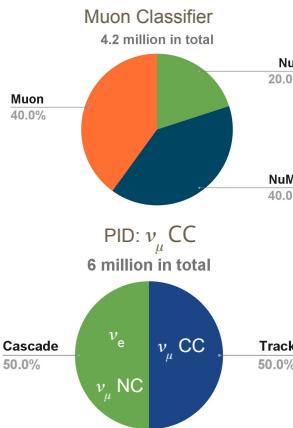
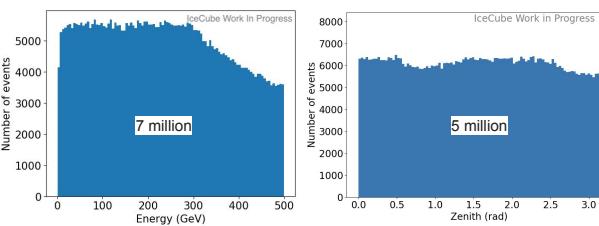
- Energy, direction, interaction vertex

Classification:

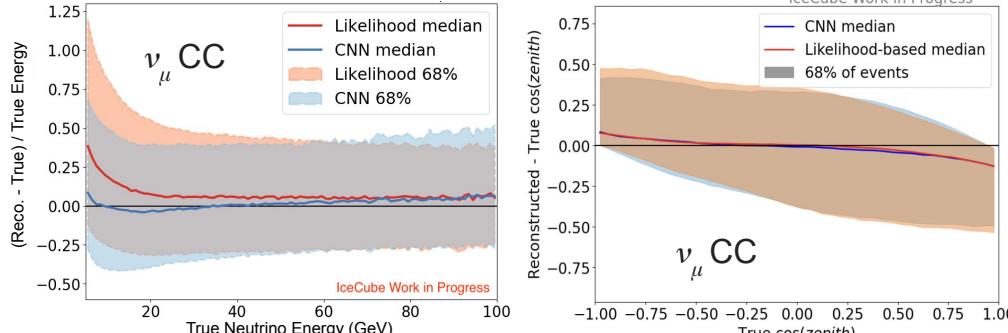
- PID, muon classifier

Training Samples

- Balanced MC samples;
- Energy, direction, interaction vertex are trained on ν_μ CC events (signal);
- PID and muon classifiers are trained on balanced samples.



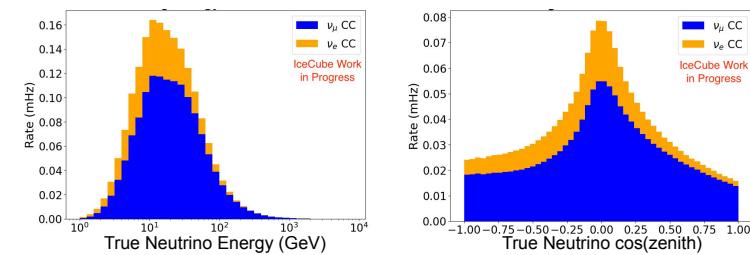
Reconstruction performance



Testing Samples

- Nominal MC sample with flux, xsec, and oscillation weights applied;
- Testing on signal (ν_μ CC) and major background (ν_e CC);
- Baseline: current reconstruction method (likelihood-based)

[K. Leonard IceCube plenary talk](#)



Computing speed

	Second per file (~3k events)	Time for full sample assuming 1000 cores
CNN on GPU	21	~ 13 minutes
CNN on CPU	45	~ 7.5 hours
Current Likelihood-based method (CPU only)	120,000	~ 46 days

- CNN runtime improvement: ~6,000 times faster;

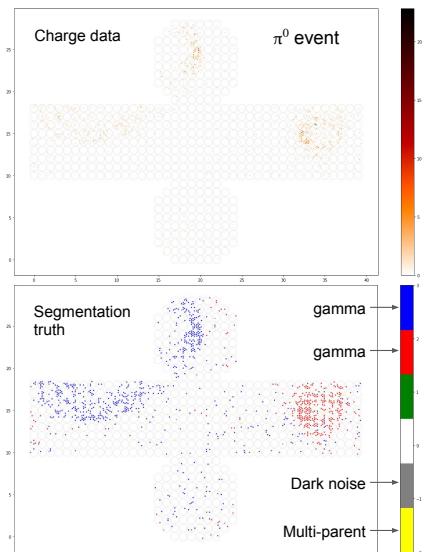
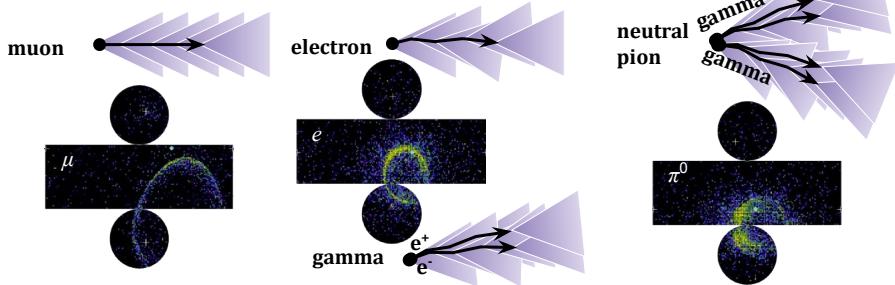
Machine Learning Techniques to Enhance Event Reconstruction in Water Cherenkov Detectors

Nick Prouse

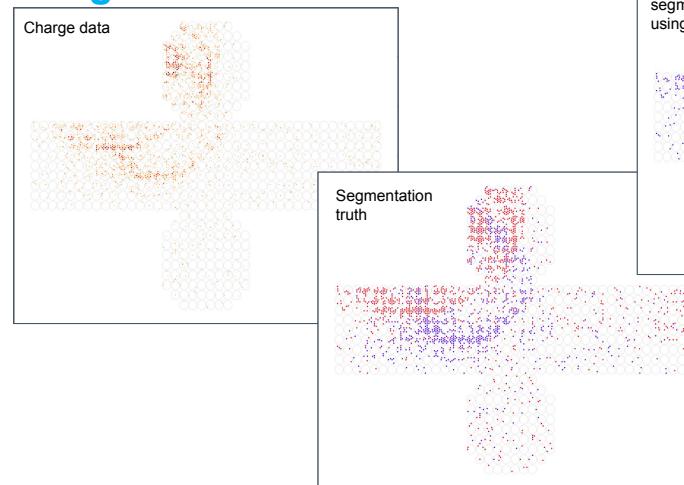
Reconstruction in WC detectors

Classification: Particle type identification (PID)

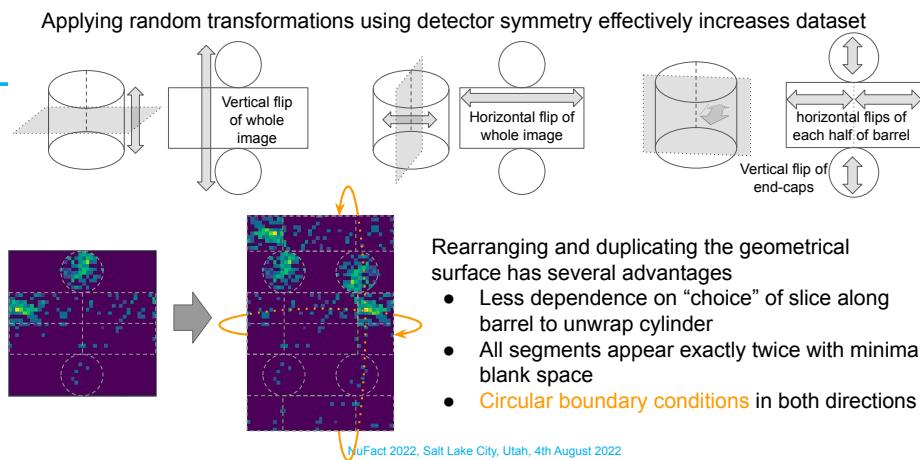
- Different particles produce different types of rings



Segmentation results



Works well with separated or partially overlapping rings



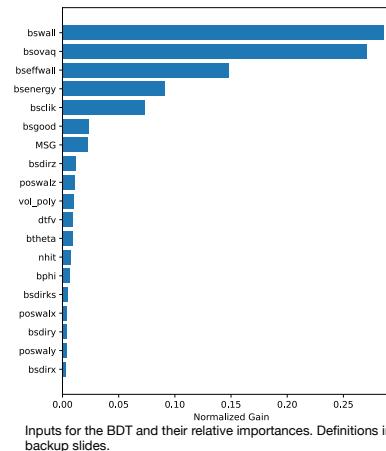
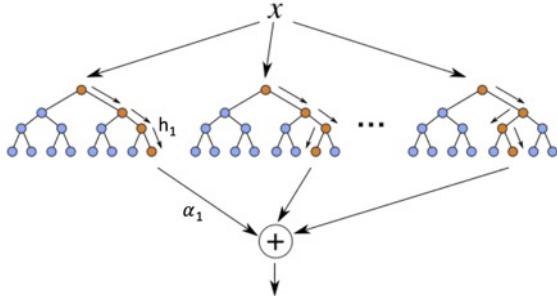
fiTQun on CPU: 1 event takes more than 1 minute
ML reconstruction on GPU: 100,000 events per minute

8

ML Methods for Super-K Solar v Classification

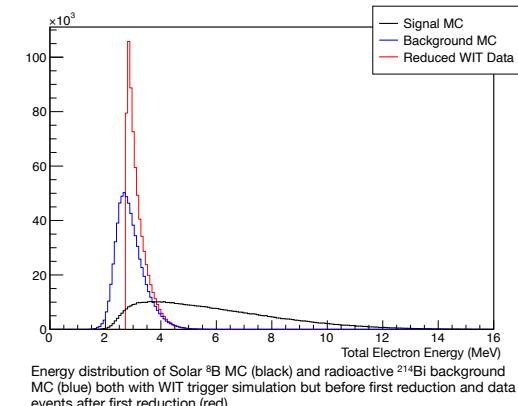
Alejandro Yankelevich

Boosted Decision Tree (BDT)

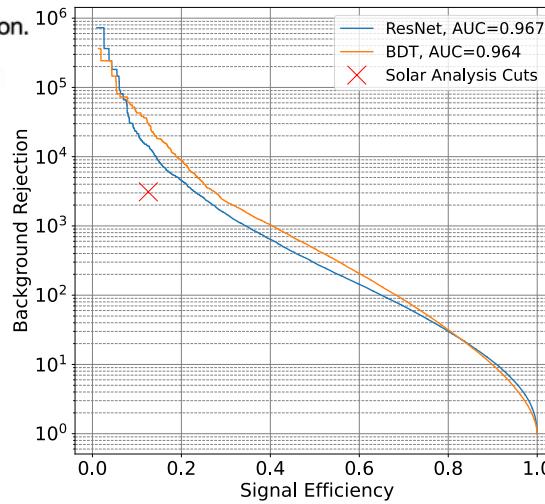


Motivation

- Super-K solar analysis excludes events below 3.49 MeV kinetic (4 MeV total) recoil electron energy.
 - Radioactive background dominates in this region.
- Want to identify solar neutrinos at lower energies



BDT rejects 6x background as solar analysis cuts for same efficiency.



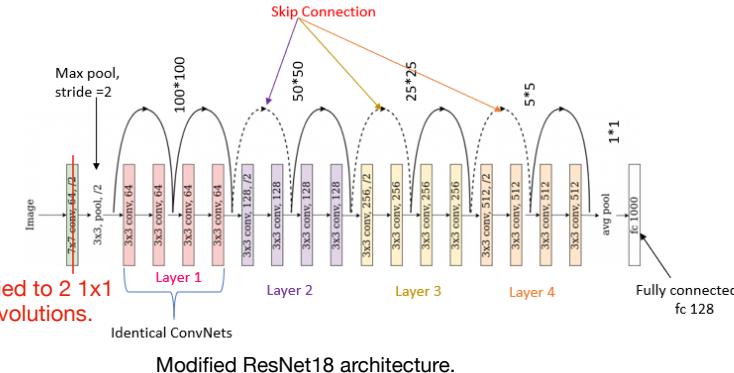
Energy distribution of Solar ${}^8\text{B}$ MC (black) and radioactive ${}^{214}\text{Bi}$ background MC (blue) both with WIT simulation but before first reduction and data events after first reduction (red).

1/FPR vs Signal Efficiency. All events $2.49 \text{ MeV} < E_{\text{kin}} < 3.49 \text{ MeV}$.

ResNet CNN



WatChMaL

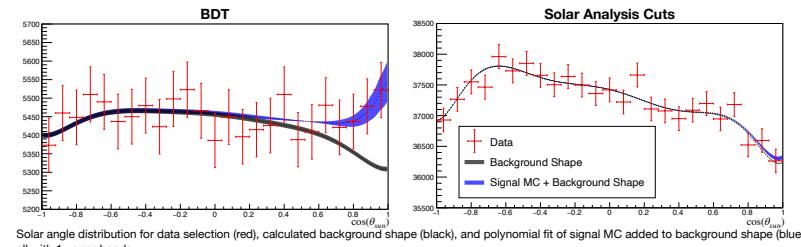


Modified ResNet18 architecture.

Solar Angle Distributions

- After BDT selection, use same methods as SK solar analysis.
 - BDT trained on MC with randomized solar direction.
- Generate background shape by scrambling solar direction and event direction for all events.

Generate signal shape with polynomial fit to unmodified signal MC.



Solar angle distribution for data selection (red), calculated background shape (black), and polynomial fit of signal MC added to background shape (blue) all with 1σ error bands.

Poster titles

- Posters
 - **Gain calibration using dark hits in off-time region of regular data at JSNS2 experiment** (RyeongGyoon Park)
 - **Mass test setup for DUNE SiPMs characterization** (Marco Guarise)
 - **First light detection with an optical Time Projection Chamber** (Robert Amarinei)
 - **A High Rate Readout System for a High-Efficiency Cosmic Ray Veto for the Mu2e Experiment** (Simon Corrodi)
 - **Construction of a new scintillation tracker in T2K experiment** (Masaki Kawaue)
 - **Detectors of the Telescope Array Experiment** (Jihyun Kim)

Conclusions

- Covered active R&D topics
 - Precise imaging, photon collection
 - Electronics readout, w/ precise timing decision, trigger
 - Precise calibration
 - Reconstruction with machine learning, less systematics
- Technical R&D is essential
to improve sensitivities on neutrino/muon researches.
- Thank all of you reporting/discussing
the latest technologies in the various field.