International Workshop on Next Generation Nucleon Decay and Neutrino Detectors (NNN16)

chaired by Jun Cao (高能所), Miao He (高能所)

from Thursday, 3 November 2016 at **08:30** to Saturday, 5 November 2016 at **18:00** (Asia/Shanghai)
at **IHEP (A214)**

Summary for Parallel session 2:
Sensors/Electronics/DAQ

Zhimin Wang

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With **Thomas Lindner (**Triumf**), Matthew Worcester (**BNL**),** Matthew Wetstein(IA State),

NNN’16, Beijing, 2016-11-05

14:00 - 18:00 **Parallel 2: sensors/electronics/DAQ**

Conveners: Thomas Lindner (T), Matthew Wetstein (I), Matthew Worcester (B), Mr. Zhimin WANG (中国科学院高能物理研究所)

Location: B326

14:00 **The KM3NeT Digital Optical Module** *24'*
Speaker: Ronald Bruijn (Nikhef)
Material: Slides

14:24 **Technical developments towards IceCube-Gen2** *24'*
Speaker: Juan-Pablo Yanez (University of Alberta)
Material: Slides

14:48 **PMT instrumentation of JUNO** *24'*
Speaker: Dr. Zhonghua Qin (高能所)
Material: Slides

15:12 **LAPPD** *24'*
Speaker: Andrey Elagin (U)
Material: Slides

15:36 **Coffee break** *24'*

16:00 **A new ADC chip Vulcan for PMT readout** *24'*
Speaker: Mr. Christian Grewing (Forschungszentrum Juelich: Electronics and Analytics)
Material: Slides

16:24 **Frontend electronics for Hyper-K** *24'*
Speaker: Marcin Ziembicki (W)
Material: Slides

16:48 **SP TPC** *24'*
Speaker: Shanshan Gao (www.bnl.gov)
Material: Slides

17:12 **ICARUS** *24'*
Speaker: Ms. guang meng (infn)
Material: Slides

17:36 **nEXO** *24'*
Speaker: Mr. Wenhuan Wu (高能所)
Material: Slides

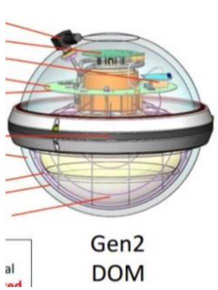
- Parallel session 2
  - Sensors
  - Electronics
  - DAQ
- Apologize for the partial summary and not highlight all your points.
- For more technical details, please refer to the parallel talks

Sensors: photon detection

- According to the larger and larger target volume, smart/intelligent/digital PMT or module showing more advantages: digitize signal/control with front end electronics directly considering cost, signal quality, reliability etc.
- Fast timing (<100ps), large area and vertex sensitive LAPPD is under developing and testing

KM3NeT

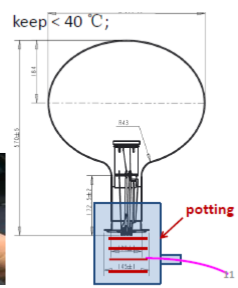
IceCube-Gen2

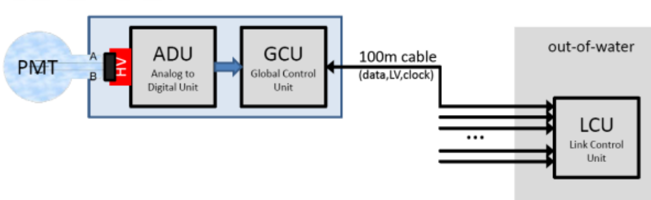


JUNO

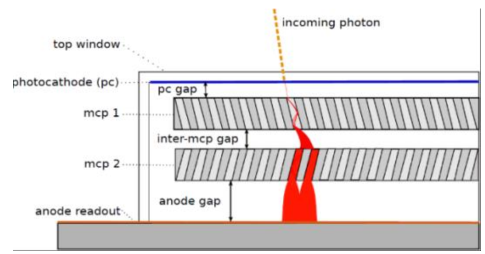
20inch

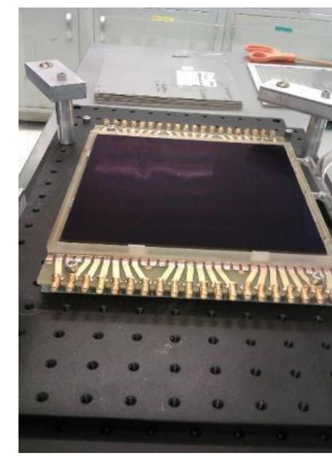
3inch



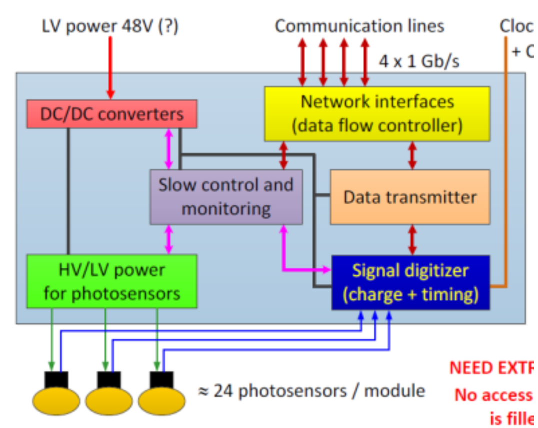


LAPPD





Hyper-K



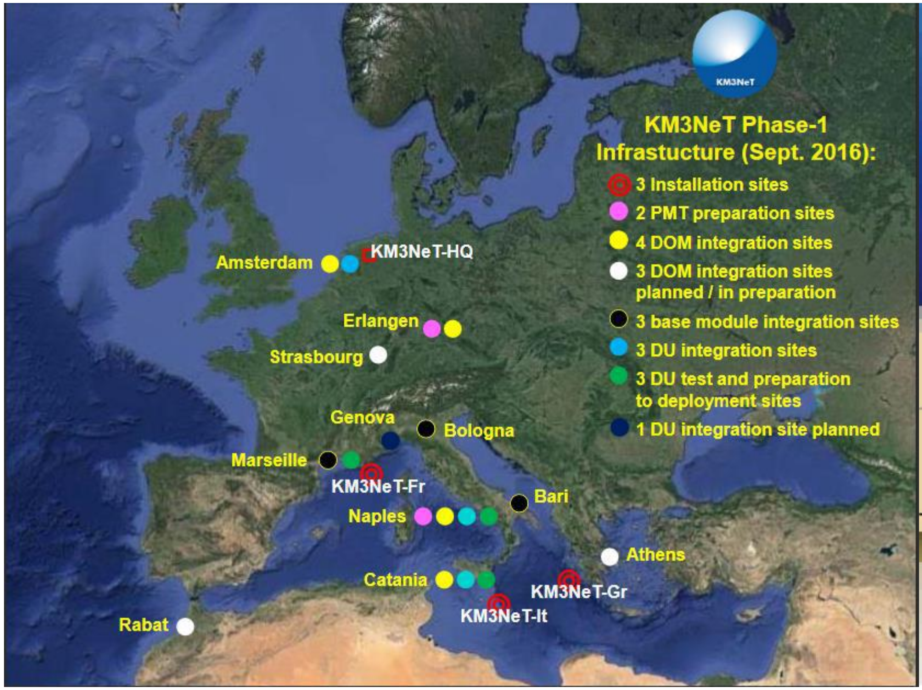
Ronald Bruijn (Nikhef)

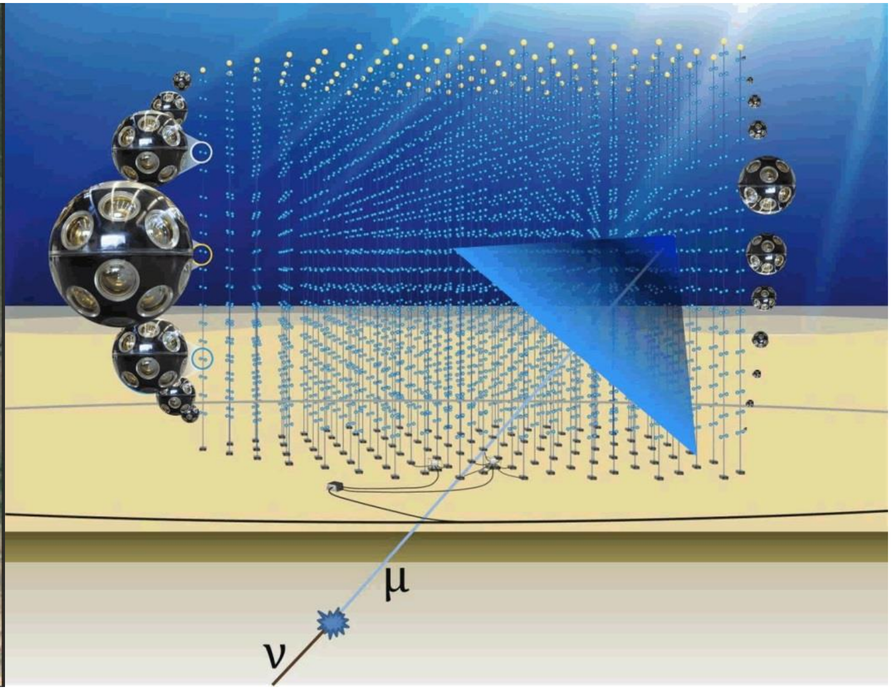
KM3NeT

- Cherenkov light
- Large area, good efficiency, photon counting
- Hold of >400bars: Sea-bed: ~3.5 km deep
- Full directional detection
- Monitoring and calibration
- Reliability, lower power consumption
- Cost effective

ARCA and ORCA
5.7 Mton to ~ Gton

Pressure water
Un-changeable with reliability





Digital Optical Module (DOM)

Multi-PMT Concept

Segmented photocathode : 31 3” PMTs in a 17” sphere
(equivalent to 3 10” PMTs)

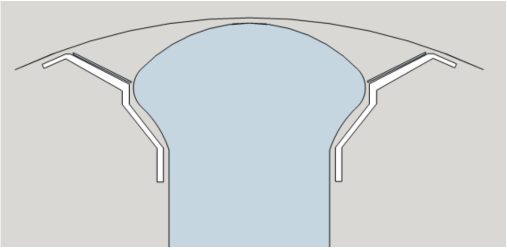
+ All front-end and digitization electronics, slow control sensors and supporting mechanics

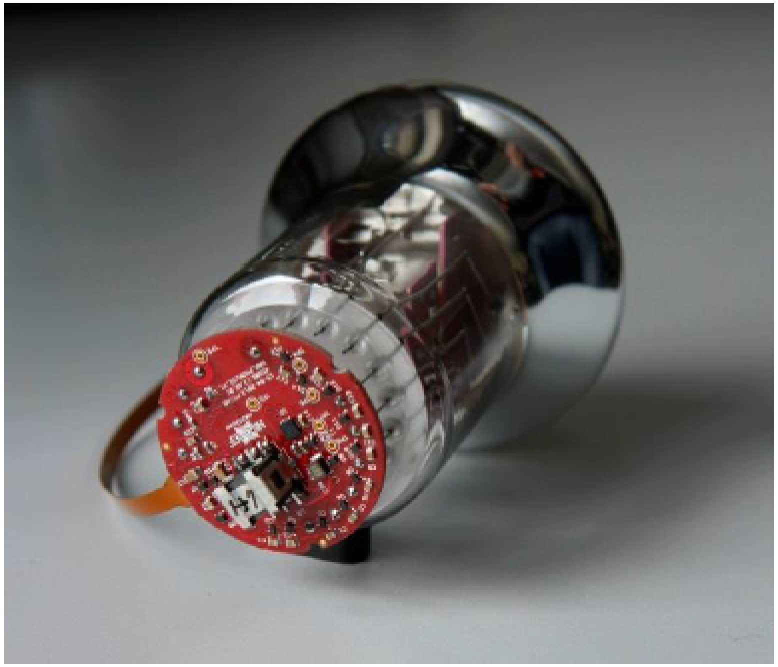
KM3NeT
Digital **O**ptical **M**odule
(DOM)

Advantages

- Large photocathode area
- Directional Sensitivity
- Photon Counting
  (1 vs 2 vs … photons, background suppression)
- Less overhead
- Cost effective
- Minimal glass penetrations

PMT bases and light concentration





PMT base – KM3NeT design

- HV generation on the base
  - Cockroft-Walton circuit
  - Input 3.3 V
  - Output to -1400 V
  - Controlled by custom ASIC : **Coco**
- Time-over-threshold readout (ToT)
  - Custom ASIC: **PROMiS**
  - Pre-amplifier
  - Digitization on the base
  - LVDS signal output
- LOW power (140 mW for 31 PMTs)
- HV and threshold adjustable over I2C
- Each base has a unique electronic identifier
- 3.3 V, I2C, LVDS over thin kapton cable
- Adjustable for different PMT manufacturers

Negative HV on photo-cathode

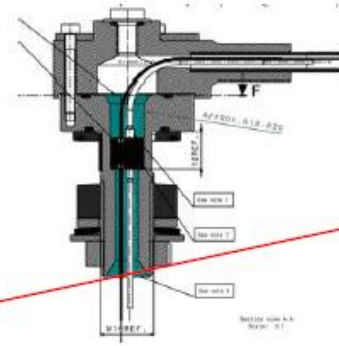
Gain: 3 $*10^6$

HV tuned to set ToT to a specific value at fixed threshold

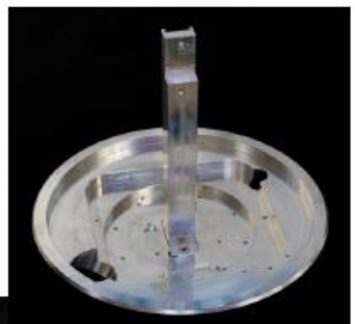
Mechanics

Selected Mechanics

'Penetrator' (KM3NeT design)
- Feedthrough for power and optical fibre
- Holds of 400 bar

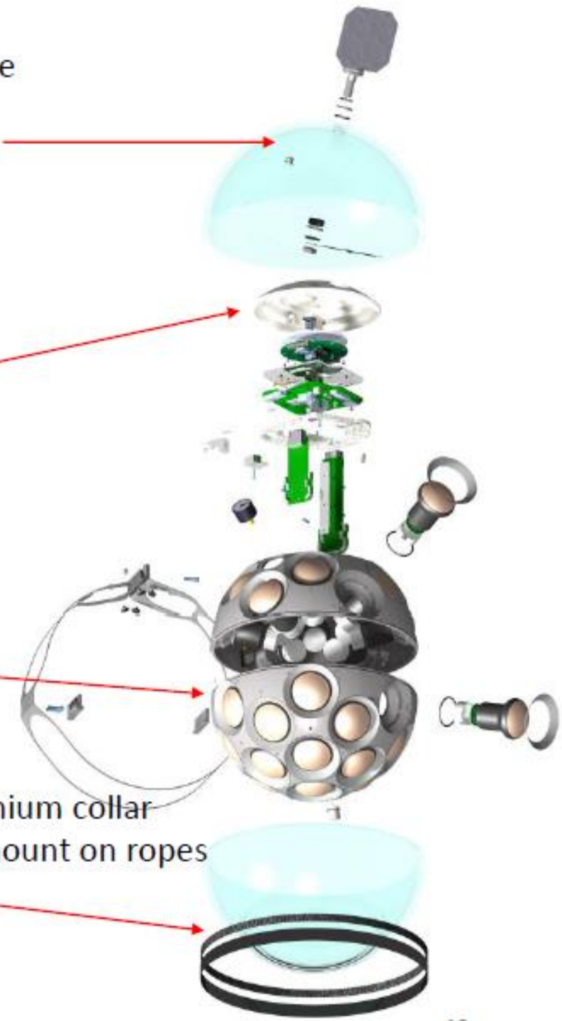


Cooling structure (mechanical support and passive cooling)



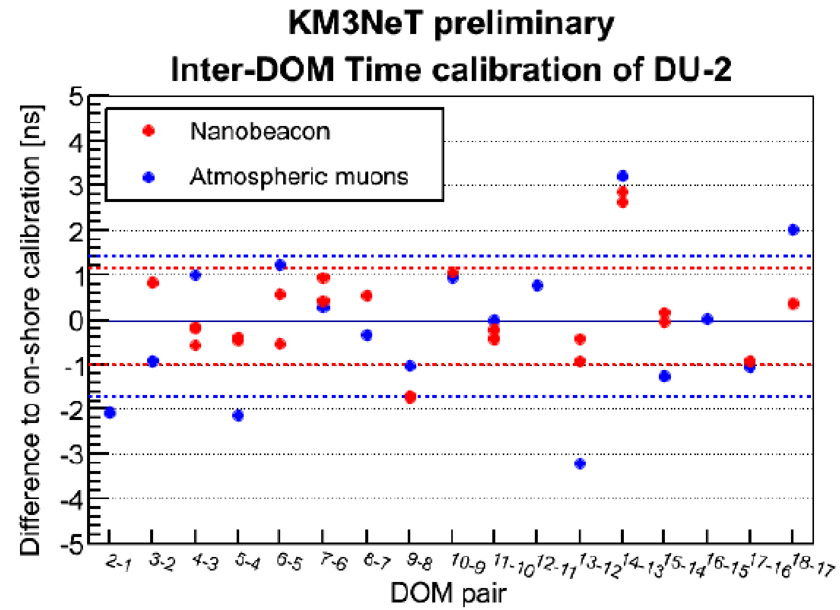
3D printed support structure (SLS)
- Defines PMT, piezo, led, ... positions
- Barrier for optical gel

Glass sphere (comes in 2 halves) withstands up to 670 bar

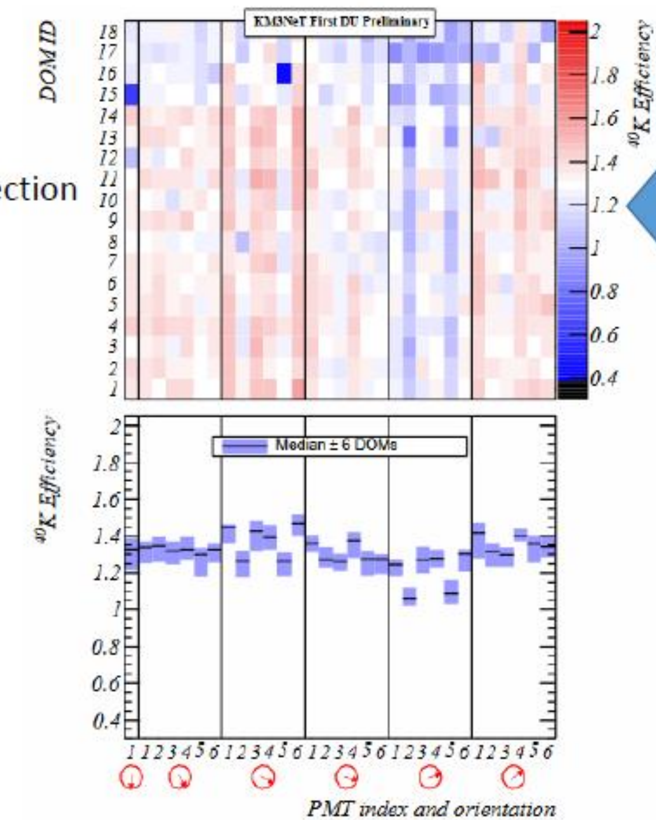


Titanium collar to mount on ropes

Timing and efficiency



Along detection unit



PMTs in DOM

Ver
influence of DOM mechanics

Photons are blocked

17

Pressure ice
Un-changeable with reliability

Juan-Pablo Yanez (University of Alberta)

IceCube-Gen2

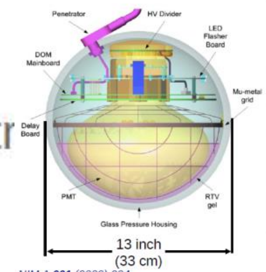
A wide band neutrino observatory

» Optical, radio & surface veto

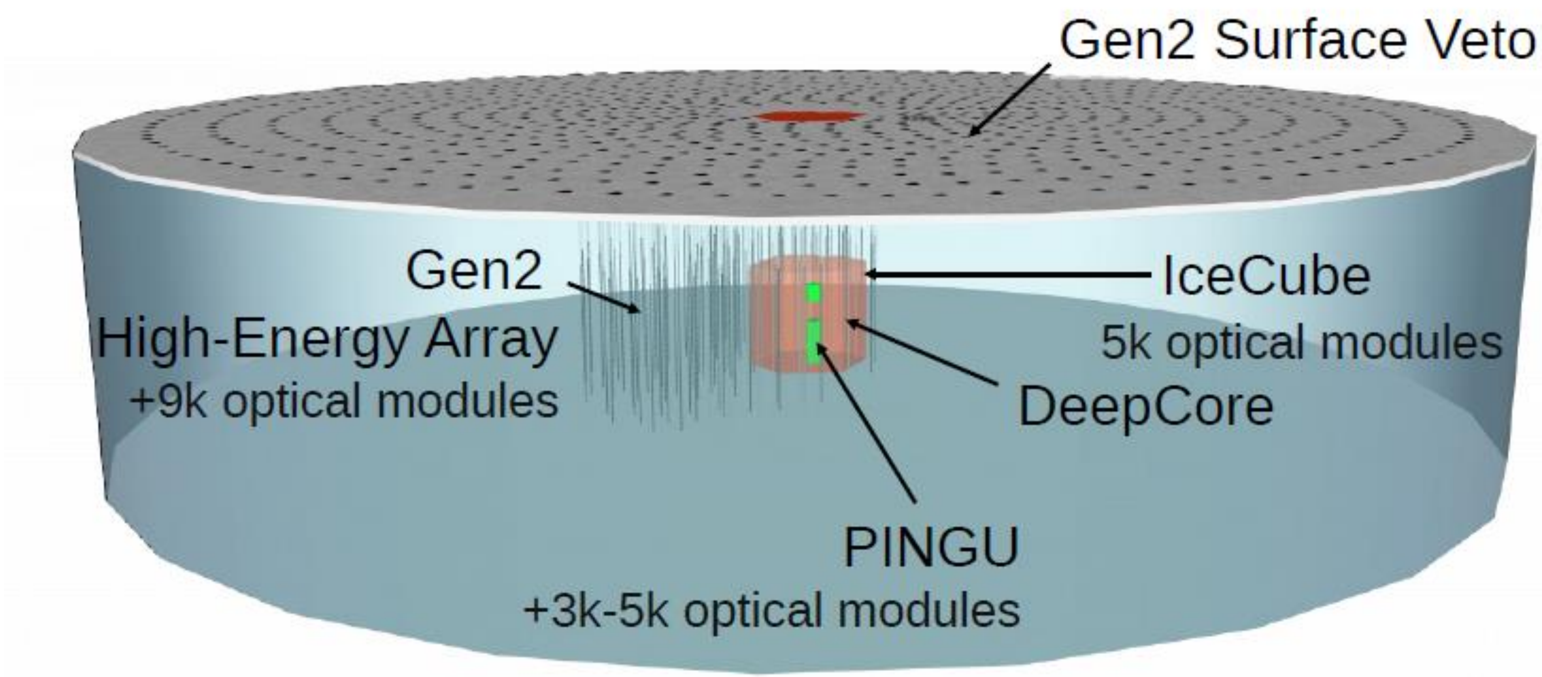
» MeV to EeV ν detection range → supernovae … astr

» Requires additional 13k to 15k optical modules

IceCube Digital Optical Module



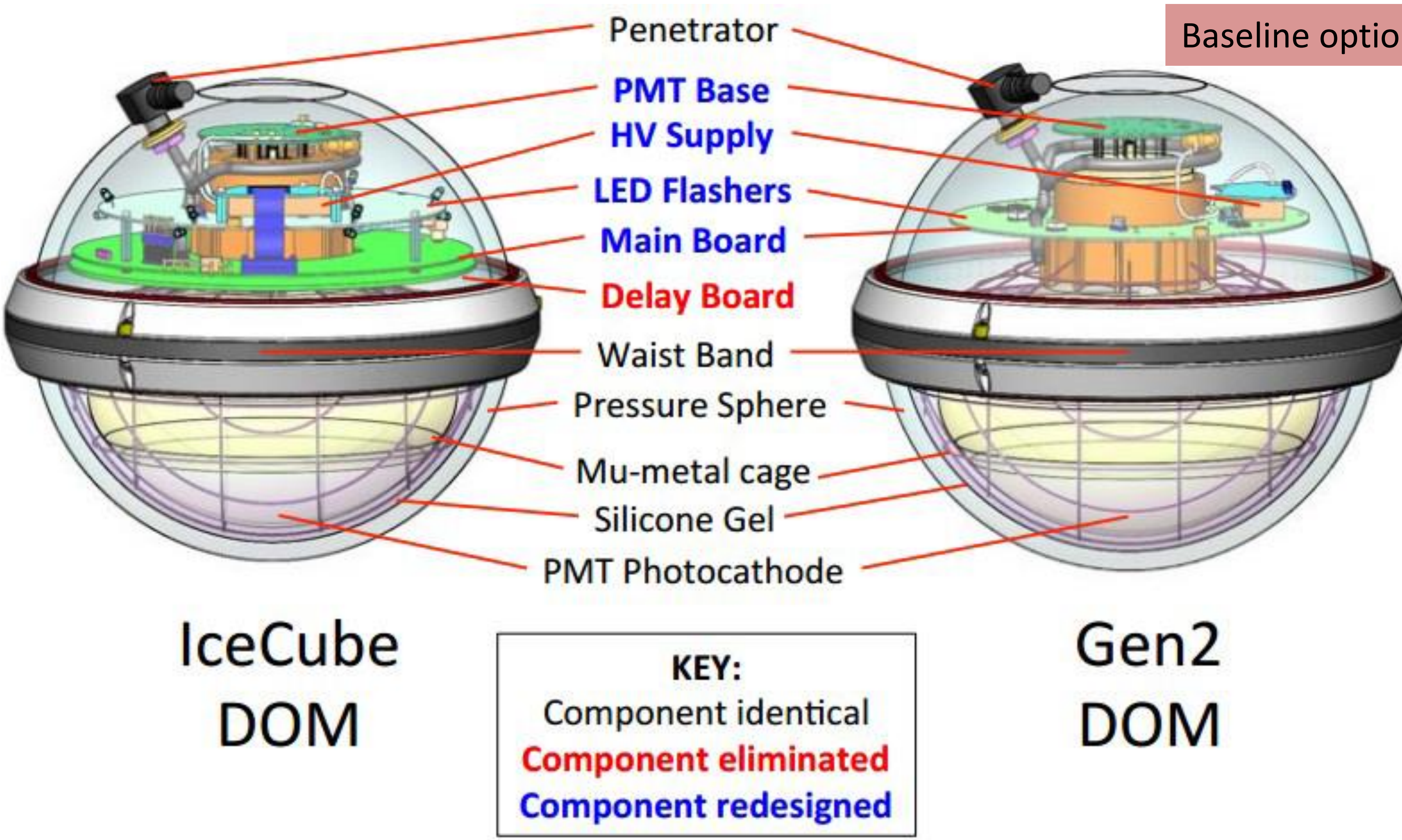
NIM A 601 (2009) 294



Pressure rating 700 bar

IceCube-Gen2 DOM

Baseline option



Gen2 DOM other candidates

mDOM

- Directional information
- More sensitive area per module
- Precise timing

PoS(ICRC2015)1147

D-Egg

- Directional information
- More sensitive area per module
- Smaller geometry

PoS(ICRC2015)1137

WOM

- More sensitive area per $
- Small diameter
- Lower noise rate
- Lower UV threshold

PoS(ICRC2015)1134

LOM

- Small diameter
- Directional info.
- More area per module

IceCube Digital Optical Module

Segmented modules, more but smaller PMTs
Uniform angular coverage
Dynamic digitization scheme
~1W/module

- IceCube DOM

Improve

  - Single, large (10") PMT per module
  - Full waveform digitization
  - Glass transmissivity of 0.5 at ~350 nm
  - Calibration LEDs on-board
  - Power consumption ~3W

  - Discriminator
  - Local coincidence logic for readout
  - Delay line: 75ns
  - Redundant digitizers

Get rid of

Keep

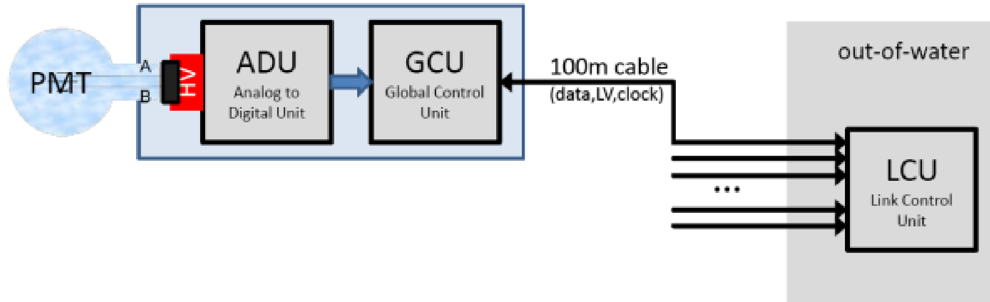
- Photon counting capabilities to high charge (1-thousands pe)
- Withstand > 550 bar freeze-in pressure
- Survive shock vibration
- Gel cushioning for optical coupling, electronics

Pressure water
Un-changeable with
reliability

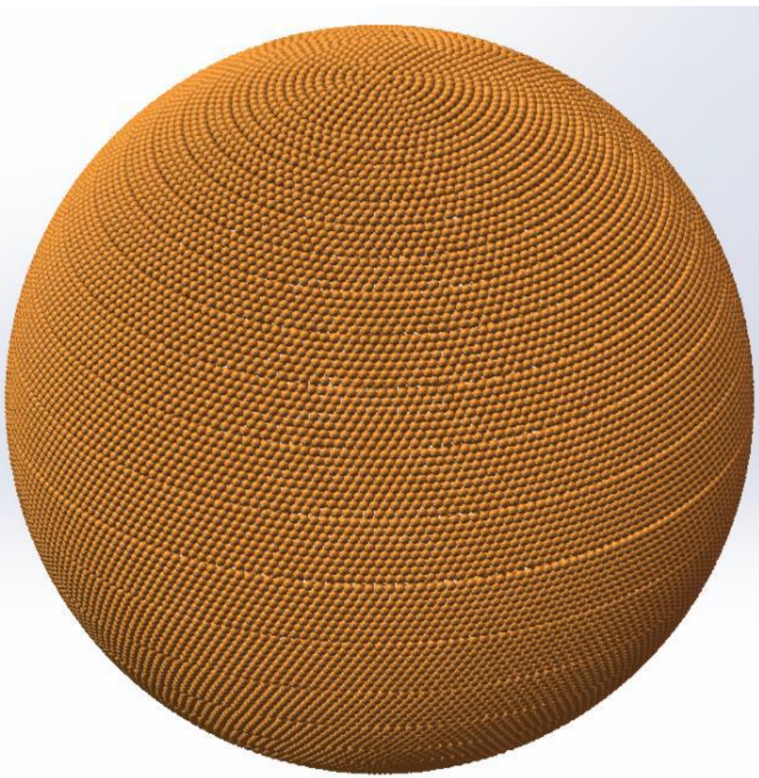
Zhonghua Qin (IHEP)

JUNO PMT system

- 20 kton Liquid scintillator
- ~75% photon cathode coverage
- High efficiency, energy response
- Double calorimetry
- waveform measurement
- Implosion protection

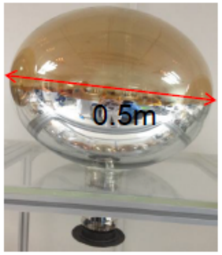


Requirement on PMT performance



- The main Parameters for each PMT:

Parameter list	typical value (lower limit)		
	MCP PMT	Dynode PMT	3 inch PMT
PDE (QE*CE) @420nm	27% (>24%)	27% (>24%)	25% (QE)
Non-uniformity of PDE	8% (< 10%)	5% (<15%): within ±70°; 20%(<30%): within ±80°;	/
Gain	10^7	10^7	10^6
HV	2500 V (<2800V) @Gain=10^7	2000V (<2500V) @Gain=10^7	1000V@10^6
P/V	3.5 (>2.8)	3 (>2.5)	≥2
TTS(FWHM)	12ns (<15ns)	2.7ns (<3.5ns)	≤3.5
Rise/Fall time	1.7ns / 12ns	5ns / 9ns	/
Dark rate	20kHz (<30kHz)	10kHz (<50kHz)	≤1.5KHz
Ratio of Pre-pulse/After pulse	0.5% (<1%) / 1% (<2%)	0.8% (1.5%) / 10% (<15%)	/
Non-linearity @ Gain=10^7, 0-1000pe	< 10%	< 10%	/
Radioactivity level (ppb)	^{238}U:50, ^{232}Th:50, ^{40}K:20	^{238}U:400, ^{232}Th:400, ^{40}K:40	/
Pressure tolerance	Up to 0.8MPa	Up to 0.8MPa	Up to 0.8MPa



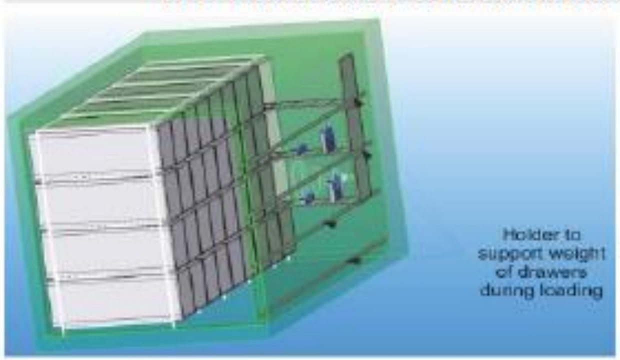
MCP-PMT

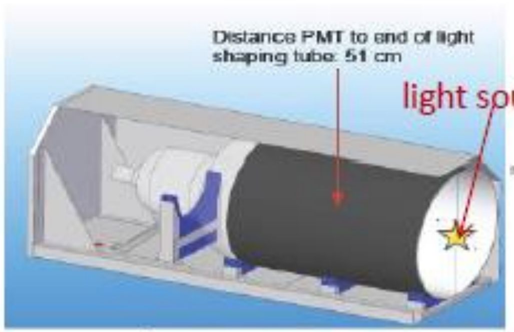
Dynode -PMT

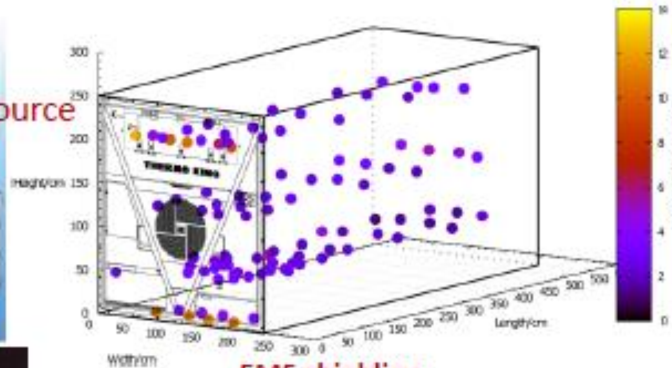
3inch-PMT

PMT mass testing /characterization (1)

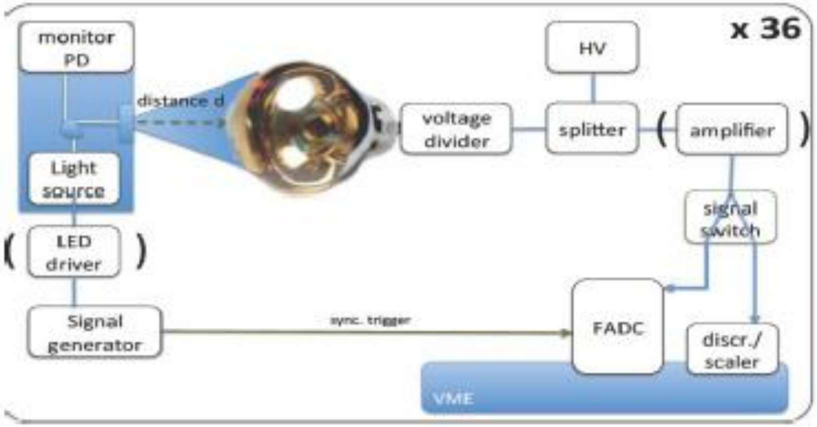
- Four test facilities will be equipped in standard commercial container
  - each container can test 36 PMTs in parallel;
  - LED located in each testing drawer box;
  - homogeneous light field produced by the light shaping tube;
  - earth magnetic field shielded to less than 10%;
  - commercial electronics used for the first two containers and JUNO electronics for the rest;
  - the first test facility will be available by end of 2016;

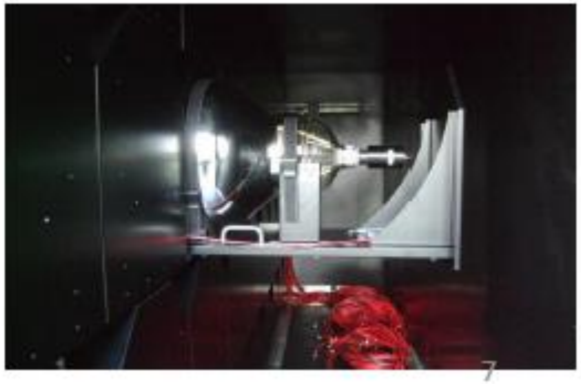




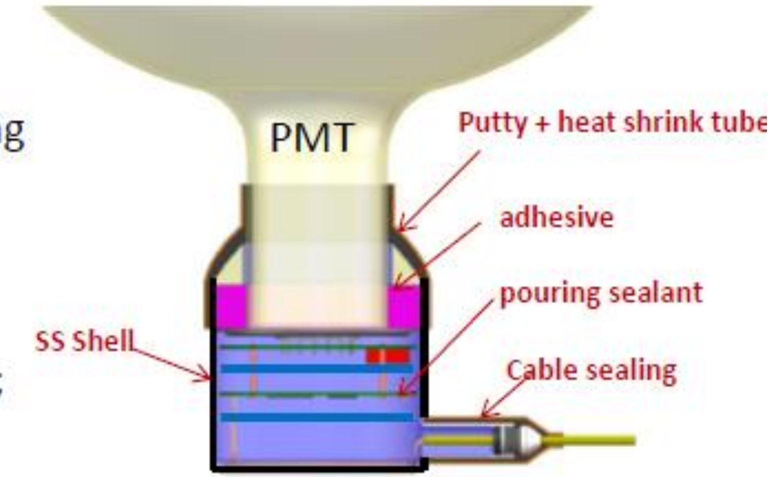


EMF shielding





Waterproof Potting (2)



- preliminary design of the potting scheme

  -with multiple waterproof layers: putty + glue + pouring sealant;

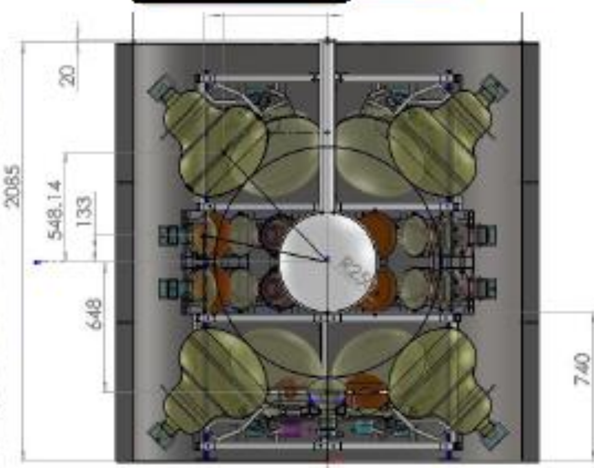
  - a stainless-steel shell will be the encloser for heat conducting;

  - HDPE as the cable jacket for easier surface treatment;

- Potting for JUNO prototype

  - only HV divider was there;

  - totally 40 PMTs with different types potted;



- work on going: many samples for heat conducting test, puttty test, thermal cycle test , and connector study.

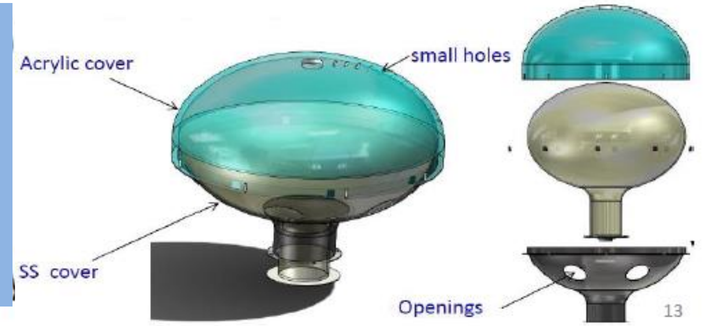
Heat conducting test

Test of putty

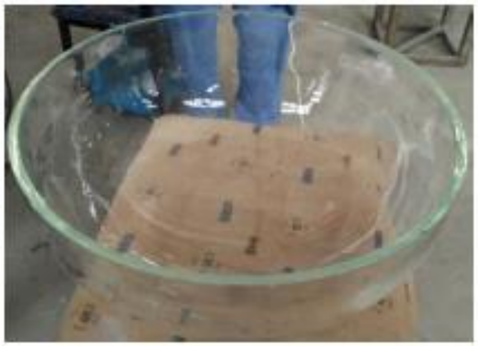
thermal cycle test

connector prototype

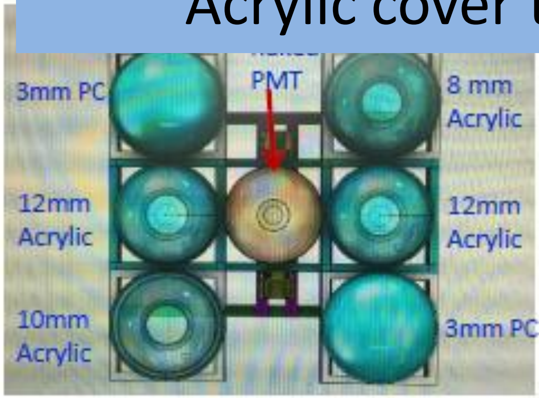
Implosion protection design and test

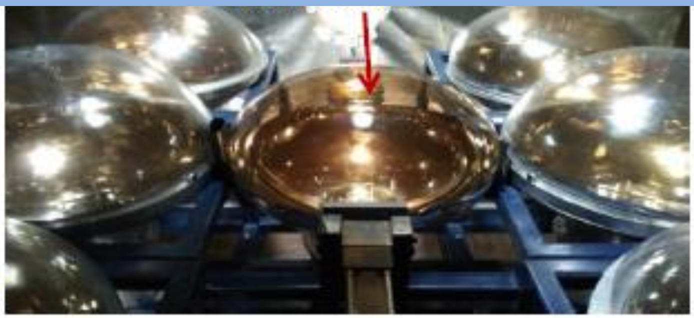


test

PC or PETG not working with thickness < 5 mm, and loss light significantly with thickness > 5 mm
Acrylic cover thickness >= 9 mm is a good choice for JUNO.

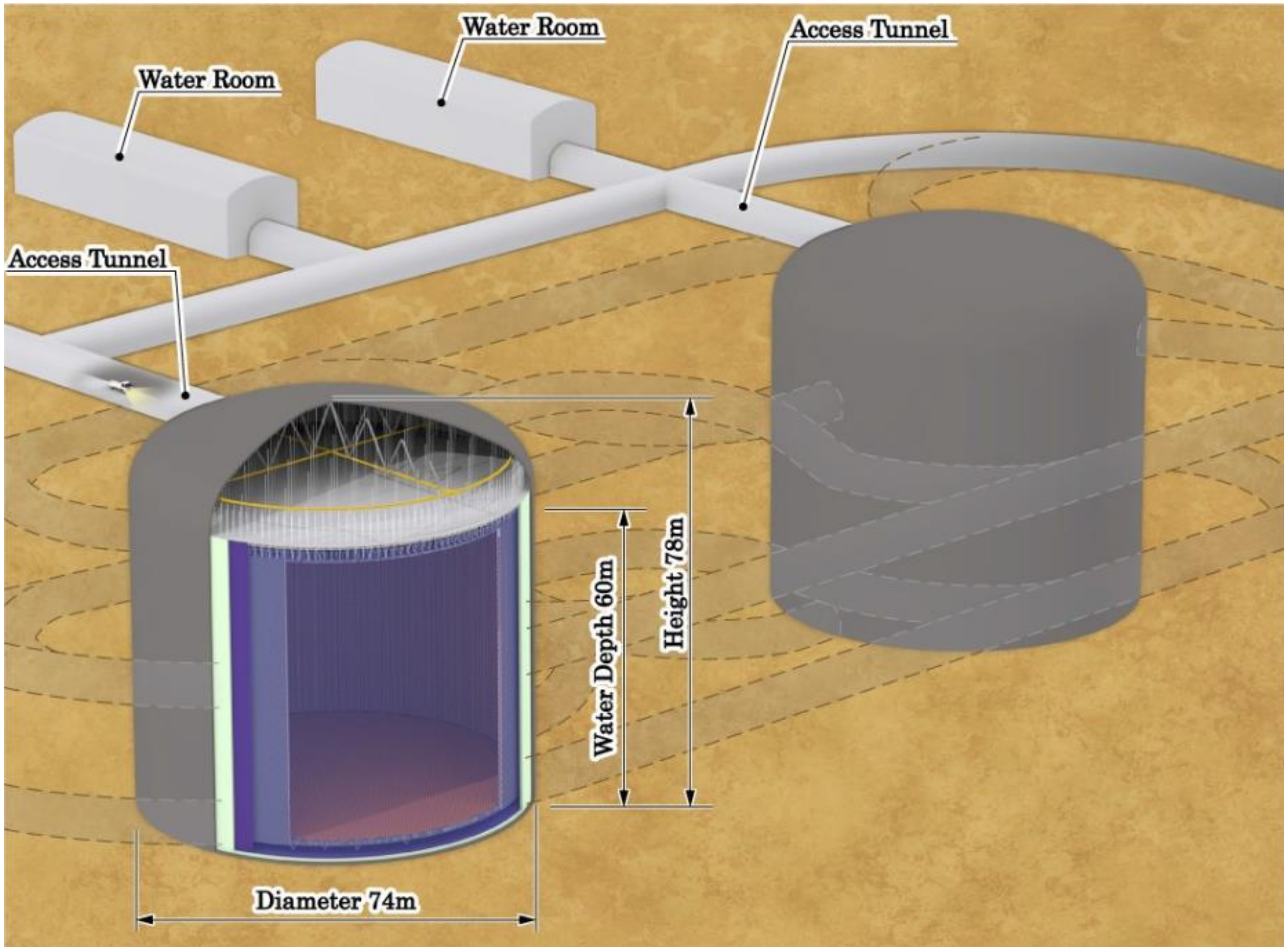





Pressure water
Un-changeable with reliability

Marcin Ziembicki (W)

Hyper-K



- Giant underground water Cherenkov Detector
  - Two tanks
  - 520 kt of ultrapure water
  - 93,400 photo-sensors (80,000 ID + 13,400 OD)
- Measure charge and timing of pulses coming from Cherenkov photons.

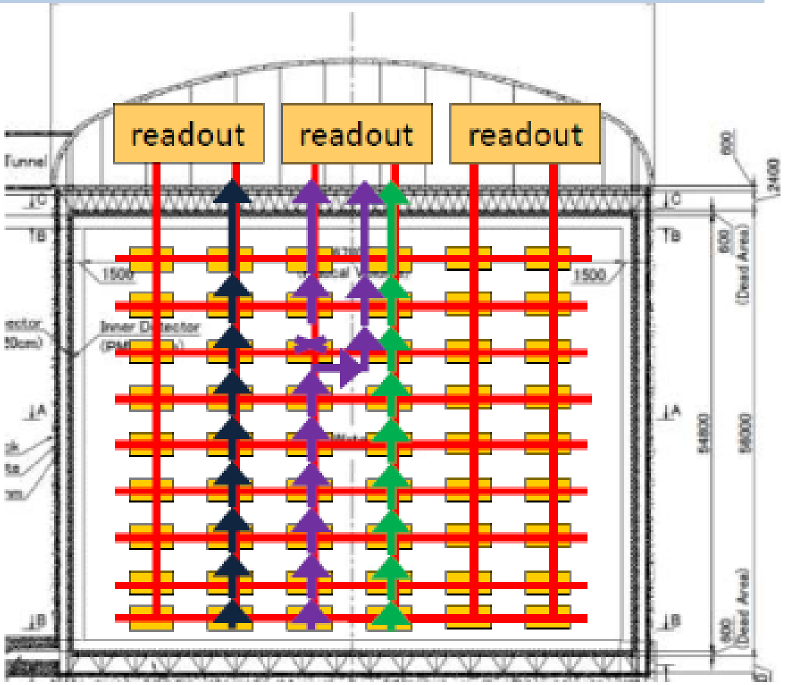
Front end electronics under water (current baseline design)

ADVANTAGES:

- Shorter cables
  - Better signal quality
- Smaller number of cables
  - Savings on weight and structure costs

DISADVANTAGES:

- Hydrostatic pressure at the bottom of the tank (~6 atm)
- Poor to none serviceability
  - Extreme reliability is a must!
- Limits for power consumpti
  - Heat dissipation affects wate circulation

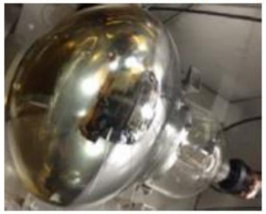


20" High QE Box&Line PMT

t_r = 6.8 ns
BW ≅ 52 MHz
TTS 1 p.e. (σ) = 1.7 ns

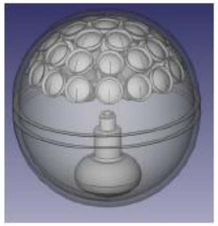
Baseline option

20" High QE HPD with ∅20mm AD



(*) t_r = 16 ns
BW ≅ 22 MHz
TTS 1 p.e. (σ) = 1.6 ns

multi-PMT (specs. for 3" PMTs)



t_r = ~2.5 ns
BW ≅ 140 MHz
TTS 1 p.e. (σ) < 1 ns (?)

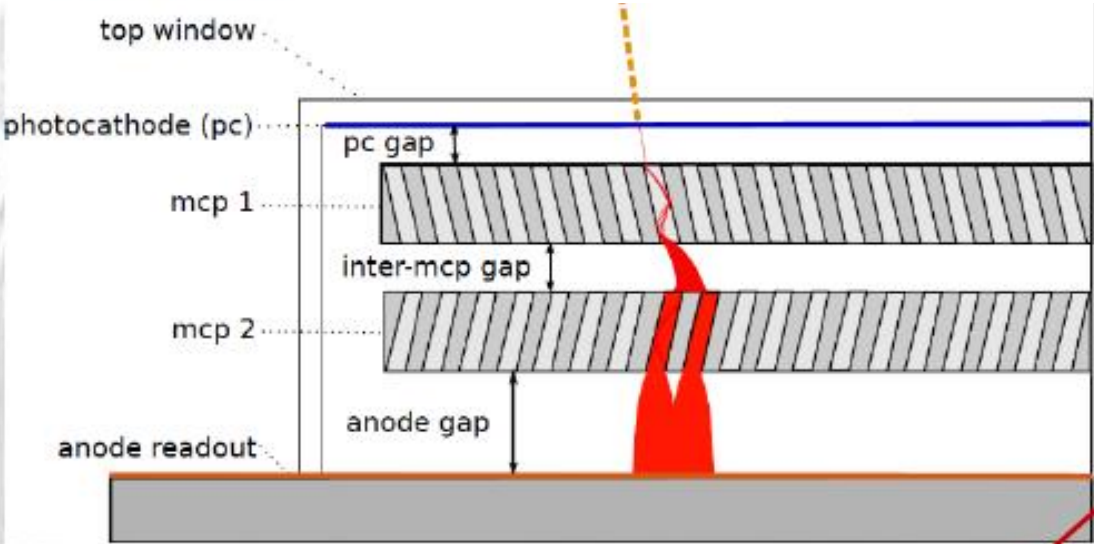
(*) Rise time and TTS are limited by a pre-amplifier. Intrinsic TTS is ~1ns.

Andrey Elagin (U)

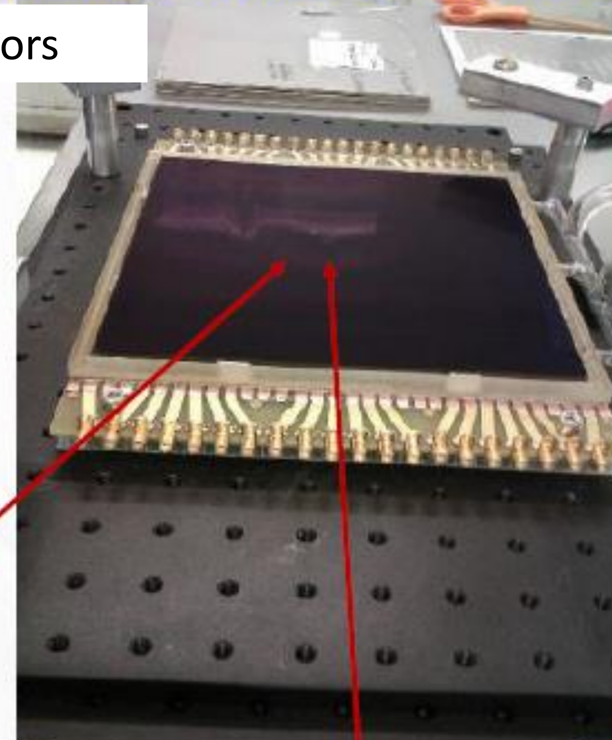
LAPPD

Large-Area Picosecond Photo-Detectors

20x20 cm^2

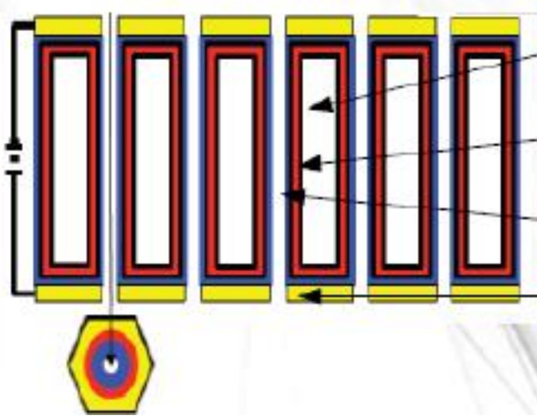


Micro-Channel Plates (MCPs)

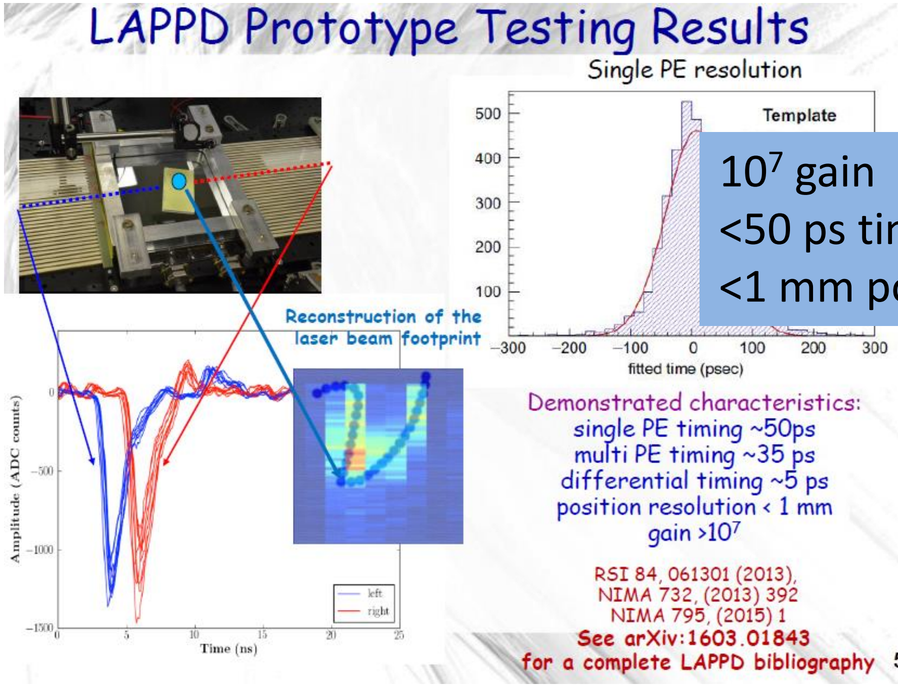


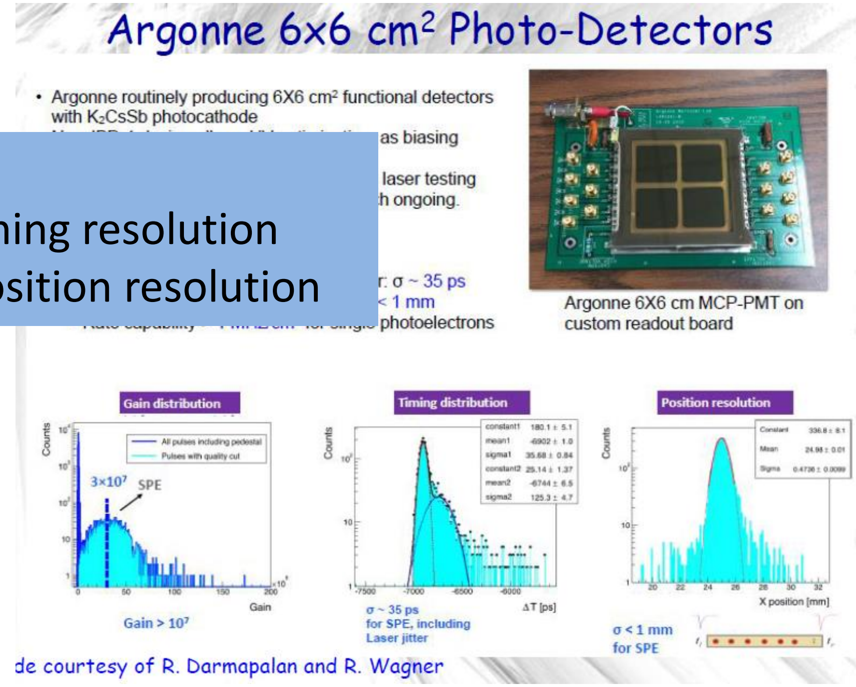
Atomic Layer Deposition (ALD)

- J.Elam and A.Mane at Argonne
(process is now licensed to Incom Inc.)
- Arradiance Inc. (independently)



- Material: borofloat glass
- Area: 8x8"
- Thickness: 1.2mm
- Pore size: 20 μm
- Open area: 60-80%

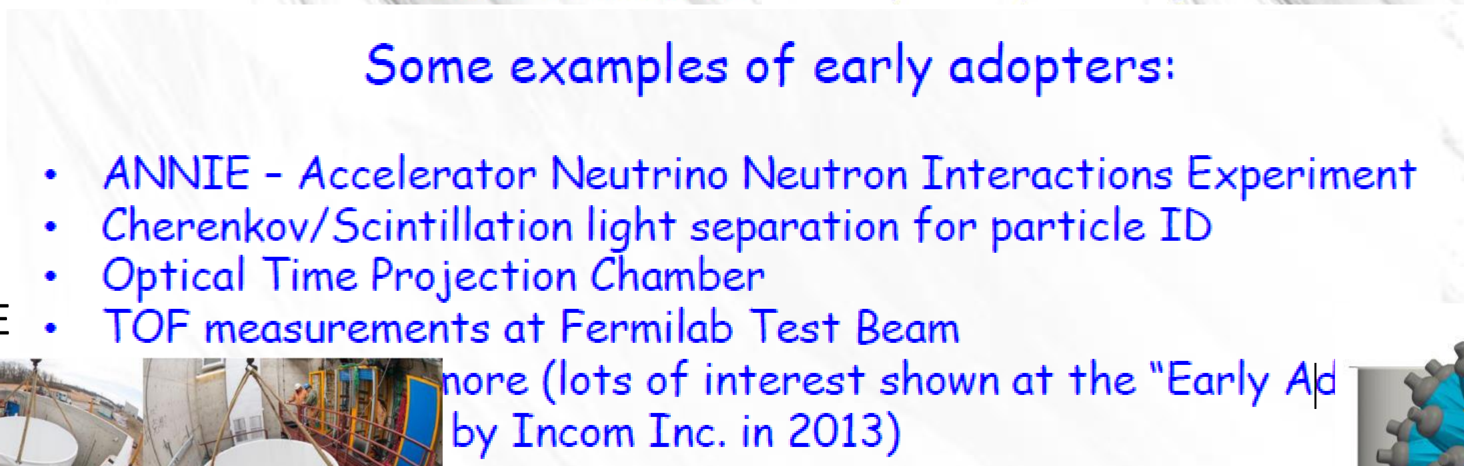




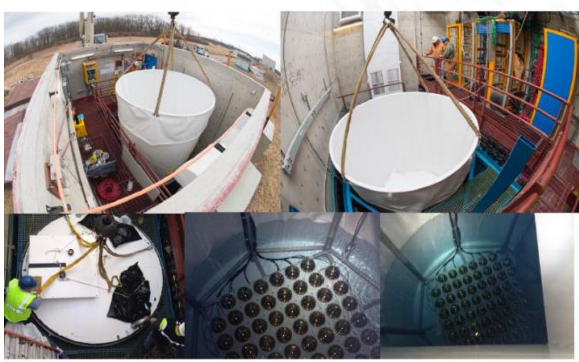
10^7 gain

<50 ps timing resolution

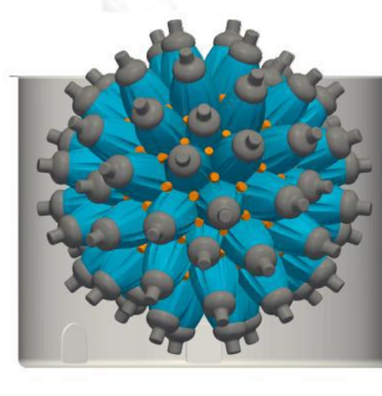
<1 mm position resolution



ANNIE



NuDot



Electronics

- Front end electronics for photon detection
  - Hit: photon counting
  - Timing: leading edge
  - Time over threshold (ToT): Width of pulse
  - Multi Discriminators
  - Amplitude
  - Charge
  - Waveform sampling

KM3NeT

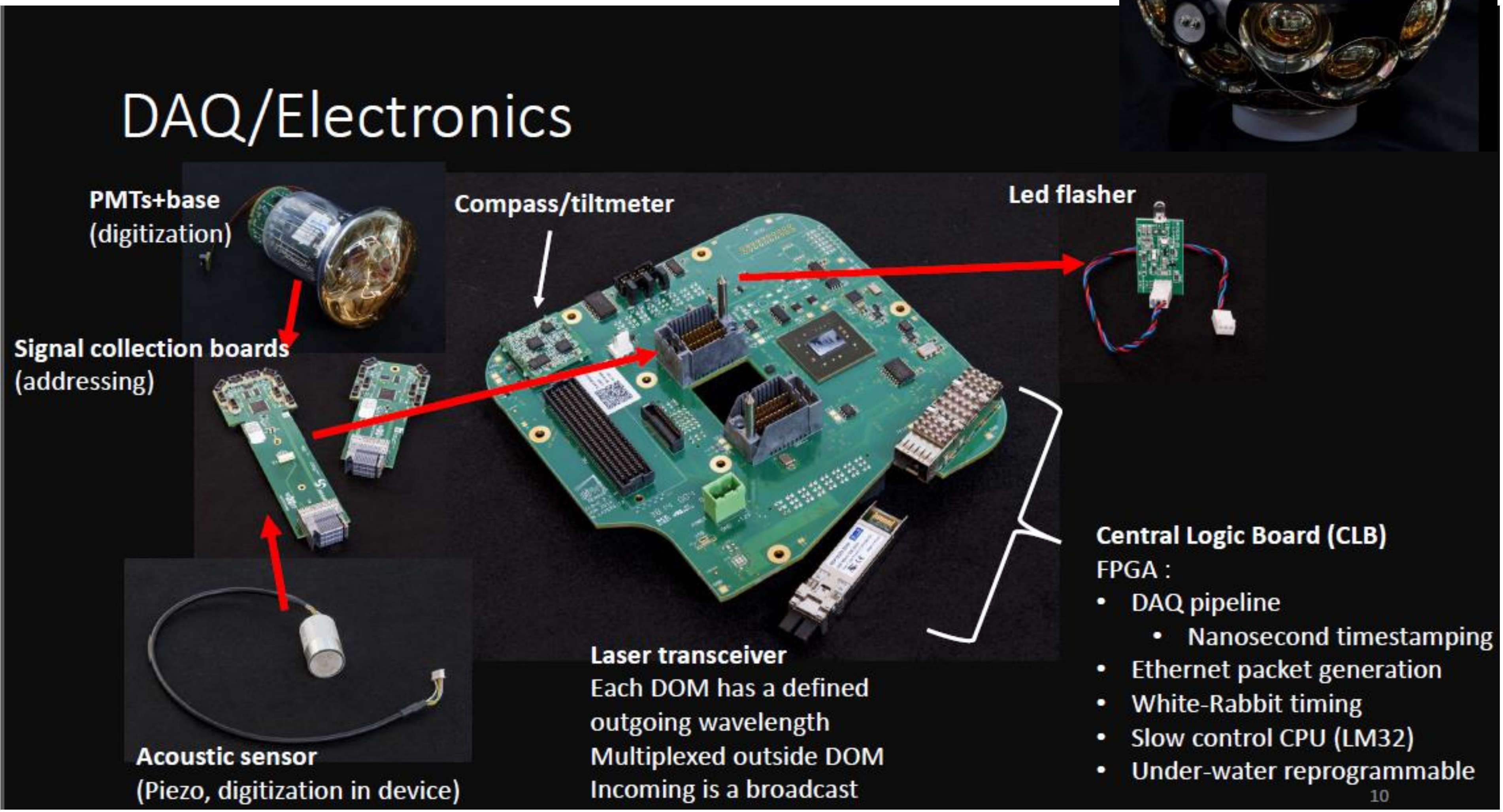
IceCube-Gen2

Hyper-K
Under investigation

JUNO

Considering physics requirements, partial or full information recording, reliability, power consumption, cost, …

KM3NeT


DAQ/Electronics
PMTs+base
(digitization)
Compass/tiltmeter
Led flasher
Signal collection boards
(addressing)
Central Logic Board (CLB)
FPGA :
• DAQ pipeline
• Nanosecond timestamping
• Ethernet packet generation
• White-Rabbit timing
• Slow control CPU (LM32)
• Under-water reprogrammable
Laser transceiver
Each DOM has a defined
outgoing wavelength
Multiplexed outside DOM
Incoming is a broadcast
Acoustic sensor
(Piezo, digitization in device)
10

~140mW@31 PMTs

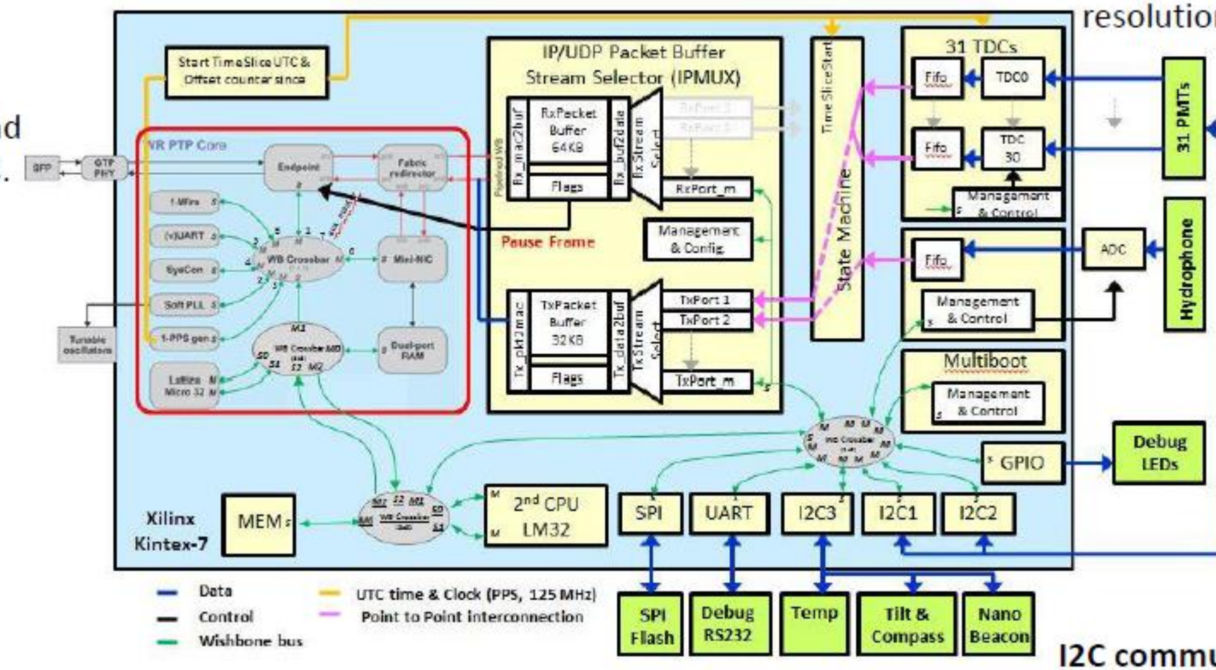
KM3NET

DAQ/Electronics: FPGA

IP/UDP (ethernet) packet creation
Multiple streams
(PMTs, acoustic, monitoring)

High-Speed TDCs
LVDS inputs from PMTs
Hit time and ToT. 800ps/$\sqrt{12}$ resolution

White Rabbit PTP core
for time synchronization and Ethernet over optical fibres.



Multiboot system
(fail-safe reprogramming)

LM32 CPU
Control from shore
(Slow control, DAQ pipeline, White Rabbit, other sensors)
Implements software state machine

UART
Serial terminal
Tunneled over ethernet

I2C communication
HV and thresholds
Compass/tiltmeter
Led Flasher
Temperature/Humidity

11

~1W/module

IceCube-Gen2

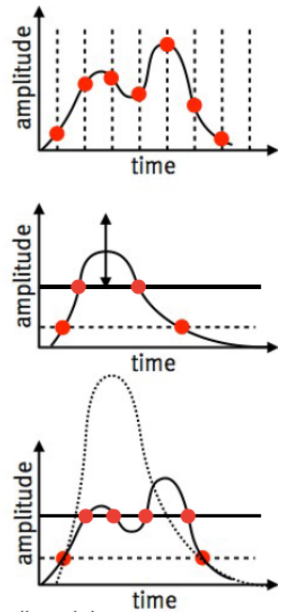
ADC

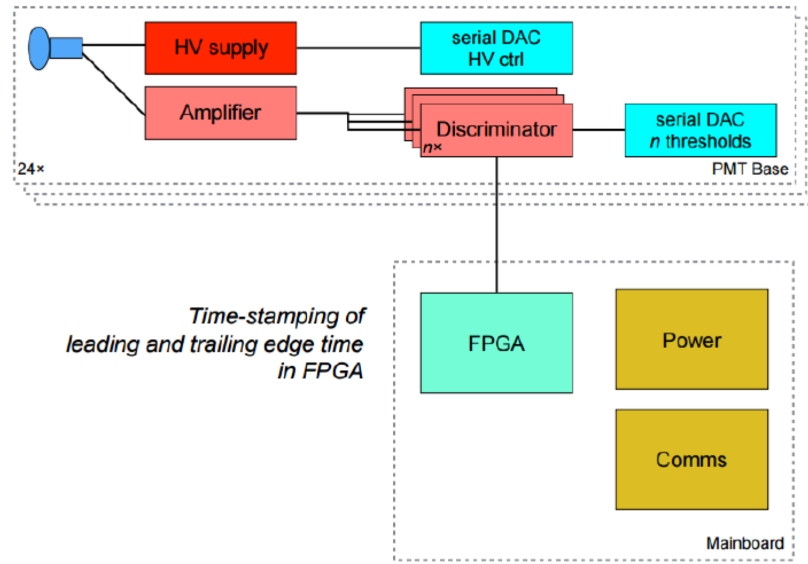
- Measure amplitude at fixed times
  - Conventional approach, used in IceCube
  - Power consumption too high for multiple PMTs

Leading edge time and time-over-threshold*

- Measure at a fixed amplitude
  - Low power, no current flow below threshold
  - Need multiple thresholds/discriminators

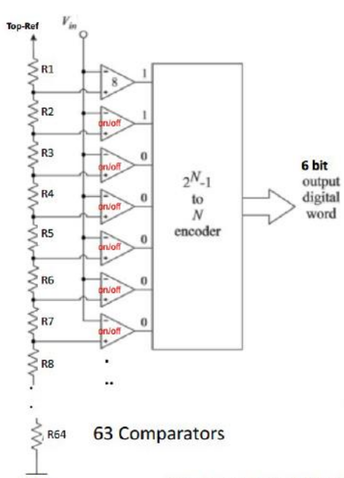
Baseline option





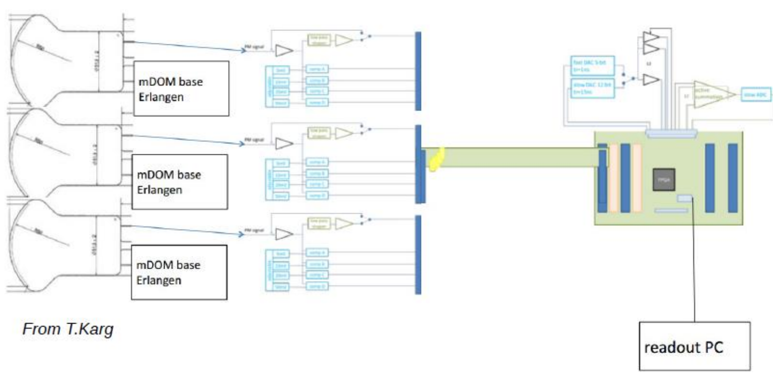
From T.Karg

Discriminators



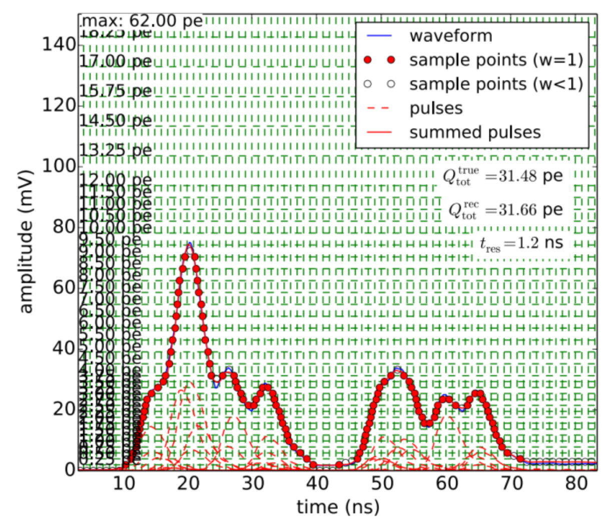
© Jürgen Röber (LTE)

Readout chain



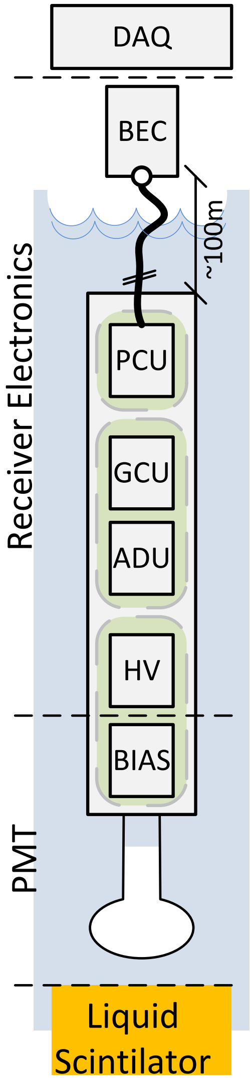
From T.Karg

Reconstructed waveform



Christian Grewing
(Forschungszentrum Juelich: Central Institute of Engineering, Electronics and Analytics)

ADC Chip Vulcan for JUNO PMT waveform sampling



- The receiver electronics are attached to the PMT underwater for:
  - Lower data bandwidth on the cable
  - Programmable signal threshold modes
  - Local data storage (RAM) for supernova events
  - Programmable digital signal pre-processing to further reduce data bandwidth
- Intelligent PMT developed together with several groups in Asia and Europe

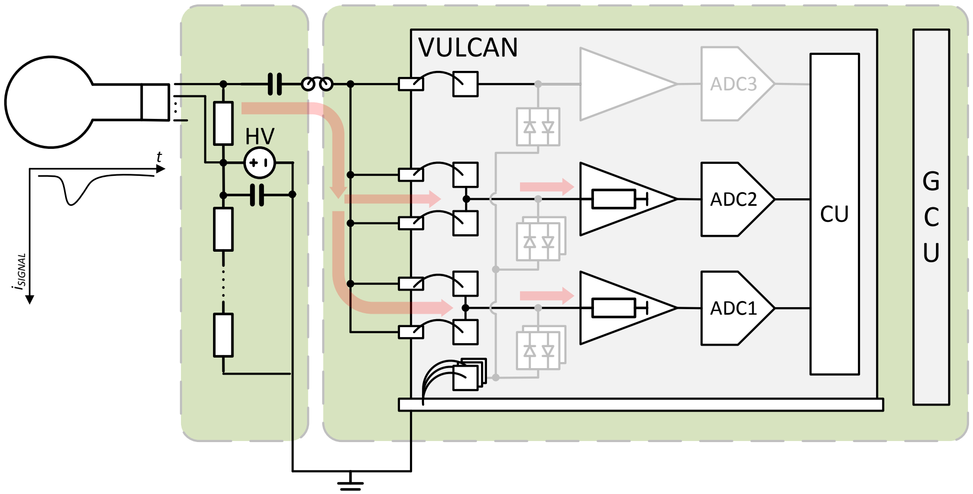
General Control Unit (GCU): Instituto Nazionale di Fisica Nucleare, Università di Padova

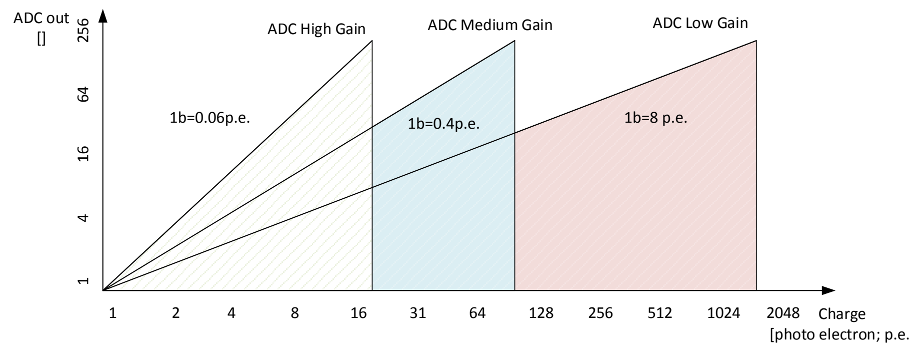
- Connection to the BEC and control of the HV and ADU
- LVDS signal interface to the ADU
- Dedicated fast memory (2GB) for local signal storage (supernova)
- Configurable digital processing of the signal and signal over threshold generation

Analog to Digital conversion Unit (ADU), Vulcan System on Chip: Forschungszentrum Jülich, ZEA-2

- Highly linear, low noise receiver
- 3 - 8bit, 1Gb/s Flash ADC with programmable characteristics
- Programmable data reduction and low jitter clock generation
- Configurable trigger schemes, overshoot compensation
- All integrated regulators w/o external capacitors for all internal supplies

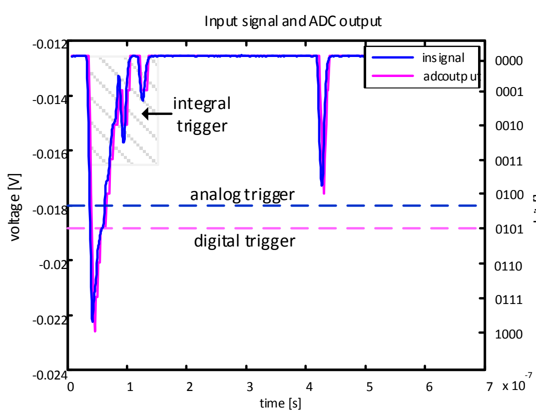
Signal Mode





1. Two signal chains with programmable gains and parallel TIA inputs, combined input resistance R ≈ 5Ω
2. With larger input currents >20mA the TIA inputs saturate, the ESD diodes open with a combined resistance R ≈ 5Ω, The voltage over the diodes is measured with the third signal chain

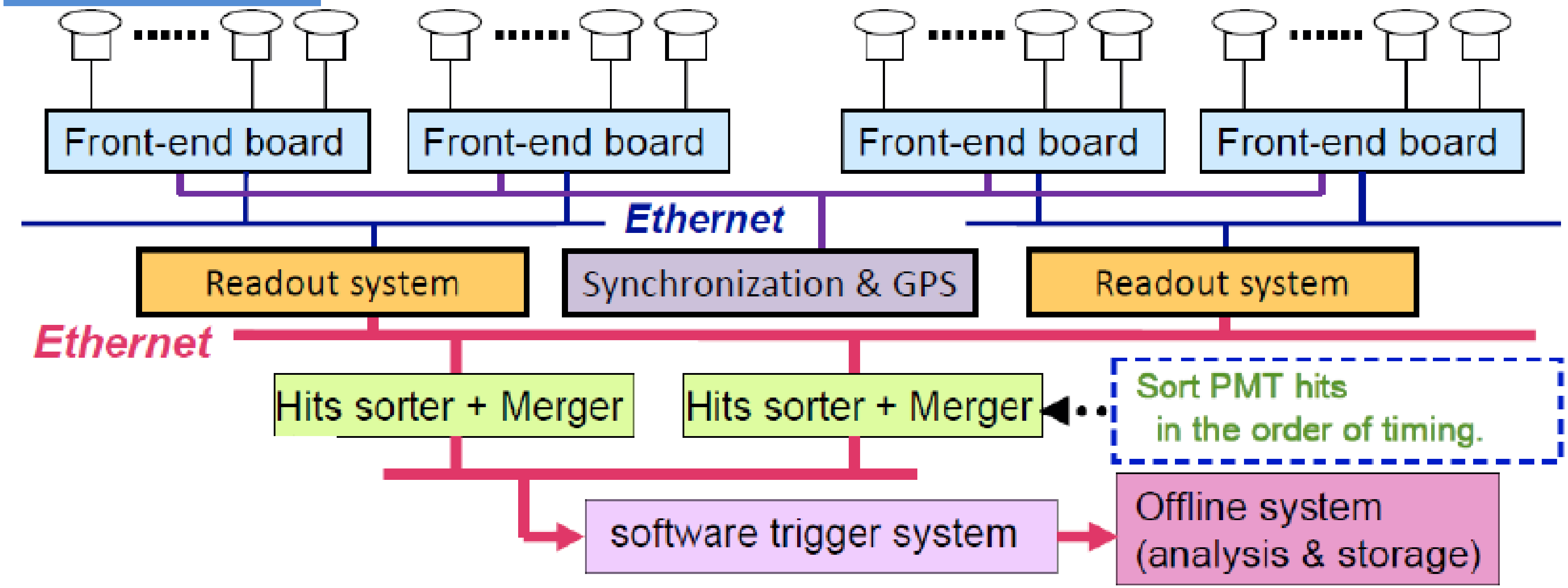
Signal over Threshold



3 LVDS trigger lines are available one for each of the 3 ADC
Configurable trigger modes:

- Analog voltage comparator for fastest trigger
- Digital threshold value
- Integrating the last 8/16/32 values and compare with digital threshold

Hyper-K Overview of the System



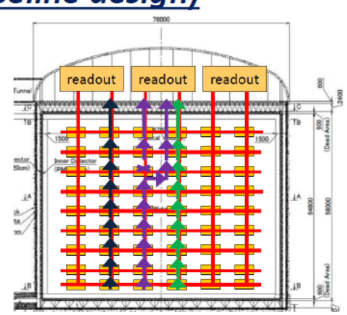
Option 2 – water (current baseline design)

ADVANTAGES:

- Shorter cables
  - Better signal quality
- Smaller number of cables
  - Savings on weight and structure costs

DISADVANTAGES:

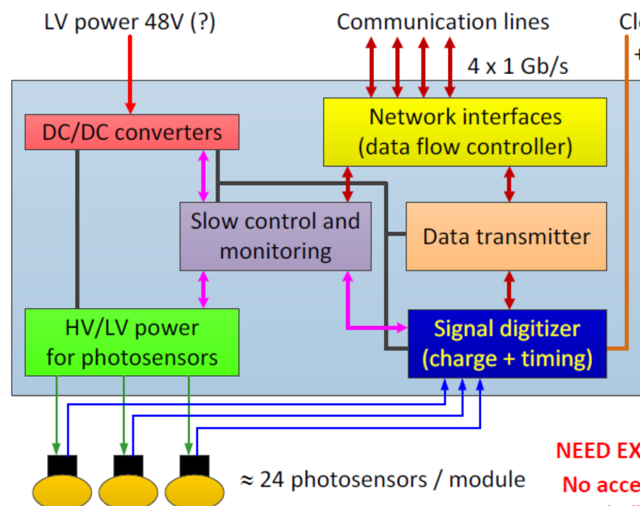
- Hydrostatic pressure at the bottom of the tank (~6 atm)
- Poor to none serviceability
  - Extreme reliability is a must!
- Limits for power consumption
  - Heat dissipation affects water circulation



Mesh-type connection

- Avoid single point of failure
- Lower module transmits data to upper module; if unable, then to its neighbors
- On-going R&D on protocol and expected data rates

Frontends – Module



All in water-tight chassis

Entire chassis probably filled with silicon or other material

Estimated weight of chassis + filler + board (size ≈9U VME) is ≈ **43 kg**

NEED EXTREME RELIABILITY!

No access once the detector is filled with water!

Hyper-K Digitization Options

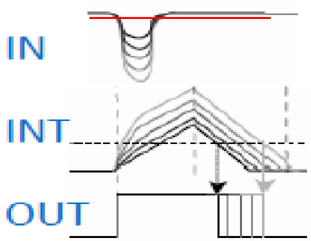
Super-K used

Option 1
QTC + TDC

Signal from PMT

Option 2
Waveform sampling

QTC



Discriminate to get a trigger. Start the output pulse

Integrate the pulse.

Start discharging. Stop the output pulse once discharged.

Use TDC to record beginning and end of the square pulse.

Shape the pulse.

Optional

Sample the pulse.

Digitally filter the pulse.

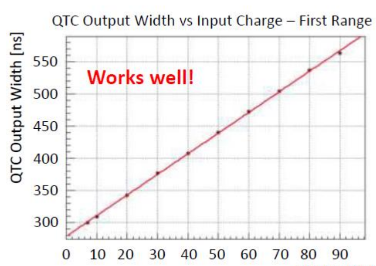
Optional

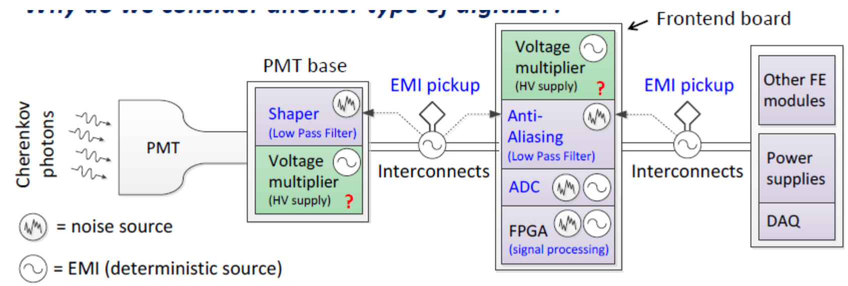
Use digital signal processing for triggering and estimation of time of arrival & pulse charge.

Time & Charge

~0.5 W/channel

TDC = Time to Digital Converter
QTC = Charge to Time Converter





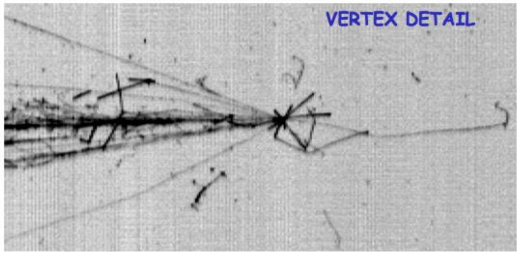
Cold Electronics for LAr and LXe

- Readout electronics developed for low temperatures (77K-300K) is an ***enabling*** technology for noble liquid detectors for neutrino experiments
  - Front end ASICs are integrated with the TPC electrodes in noble liquid to minimize the capacitance and **noise**
  - On chip **digitization** to convert to digital signals inside detector cryostat
  - **Multiplexing** to high speed serial link, to reduce cable plants, minimize outgassing, make possible the scalability to larger detector volumes

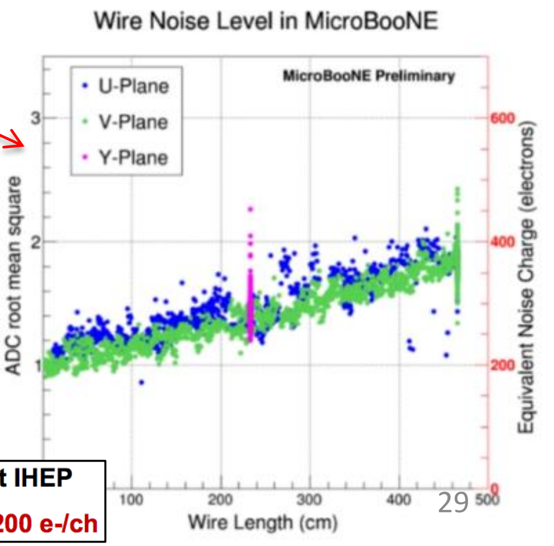
- First step: ICARUS
  - Cold LArTPC with warm FE and digitization
  - Achieved excellent S/N (G. Meng's slides)
  - Planned warm electronics upgrade for SBN

The first neutrino event! 0.6 mm spatial resolution in 8m image size.

Extremely high quality image thanks to the very high S/N of electronics (not forgetting purity, mechanical precision and stability…).



- Next generation: MicroBooNE, ArgoNeuT, LArIAT, others…
  - Cold FE with warm digitization
  - Overall achieved excellent S/N (slides from Asaadi, Bishai, Mooney)
  - Beginning to produce physics results



- Future development: large LArTPCs
  - ProtoDUNE-SP/SBND toward DUNE
  - Cold FE to achieve low S/N
  - Cold digitization for simplicity of large cryostat design
  - Dual-phase unique amplification and "warm" CE (Shuoxing's slides)

S. Gao's slides

- nEXO readout in LXe
  - Cold FE, option to use either warm or cold digitization
  - Which option achieves necessary S/N? (Wenhuan's slides)

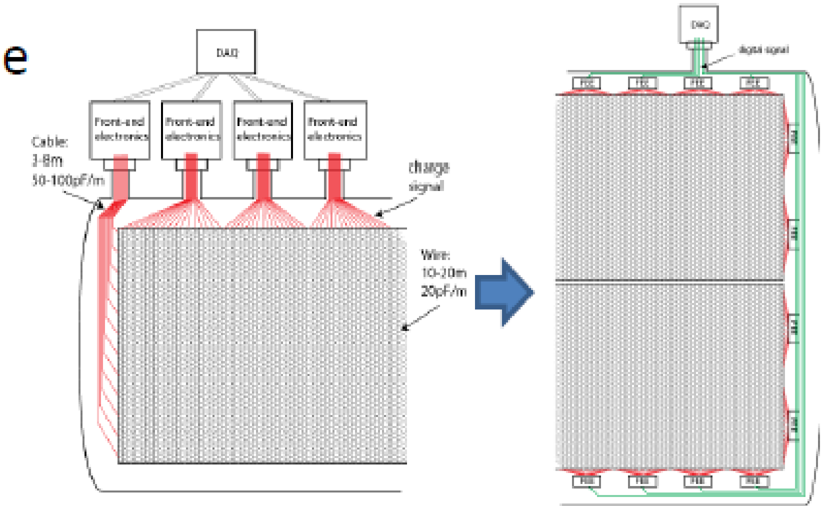
- **On-going R&D at IHEP**
- **Critical spec.: <200 e-/ch**

Shanshan Gao (bnl)

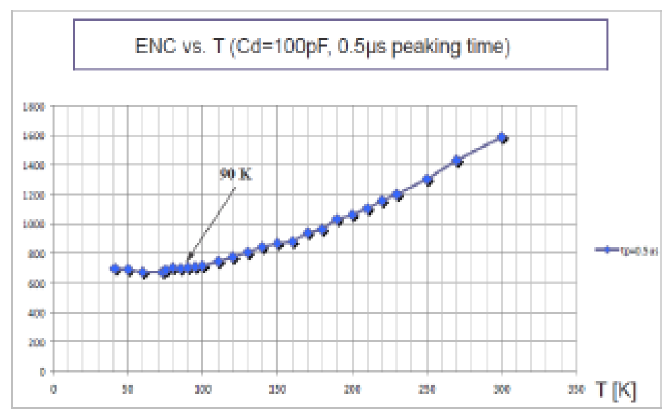
Cold electronics

Advantages of CE

- Having front-end electronics in the cryostat close to the wire electrodes
  - Yields the best SNR
- Highly multiplexed circuits with fewer digital output
  - Greatly reduce the number of cryostat penetrations
  - Give the designers of both the TPC and the cryostat the freedom to choose the optimum configurations
- CMOS in LAr has less than half the noise as that at room temperature, higher mobility and higher transconductance /current ratio



Warm readout to cold readout



Test result of ASIC in 0.25 μm

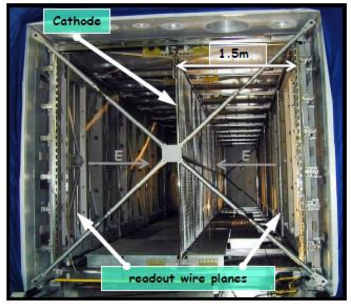
guang meng (infn)

ICARUS

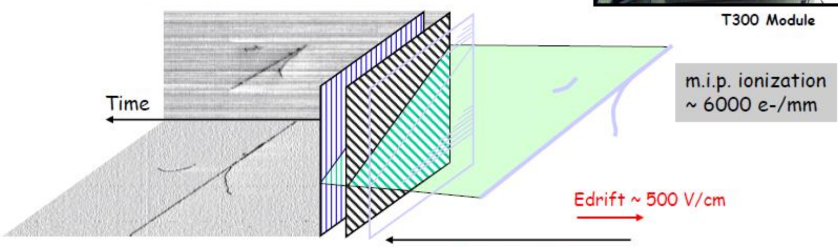
ICARUS T600 TPC

ICARUS T600 is the *unique* example of very large mass liquid argon (LAr) Time Projection Chamber (TPC). It provides 3D imaging of any ionizing event (like an electronic bubble chamber). A major feature is the continuous sensitivity, self triggering capability, and calorimetric measurement.

- 2 identical T300 modules adjacent (3.6m x 3.9m x 19.6m each)
- 2 chambers per module, 1.5 m drift length each
- 3 readout wire planes per chamber wires at 0, ±60° (ind1, ind2, coll view)
- 53248 wires, 3 mm pitch and plane spacing



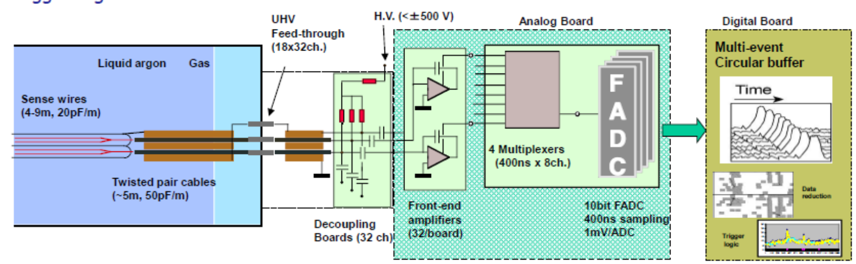
T300 Module



Drift direction
Electrons drift velocity = 1,5 mm/μs

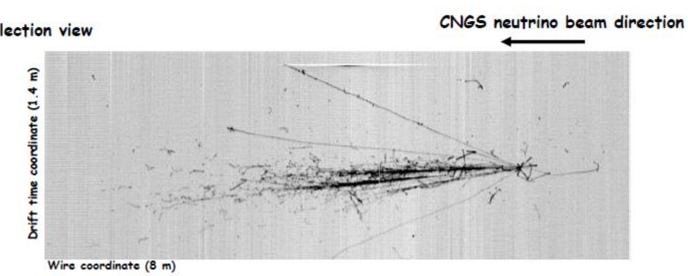
ICARUS front-end electronics

- The ICARUS T600 read-out electronics was designed to provide continuous digitization and waveform recording of the signals from each wire of the TPC.
- **Decoupling Board**: it receives 32 analogue signals from the chamber and passes them to the analogue board via decoupling capacitors; it also provides wire biasing voltage and distribution of the test signals.
- **Analog Board**: it hosts 32 front-end low noise charge sensitive pre-amplifiers, performs data multiplexing and data conversion ADC (10 bit). The sampling period for each channel is 400 ns.
- **Digital Board**: it provides multi event buffer memory for 32 channels, data compression, and trigger logic.



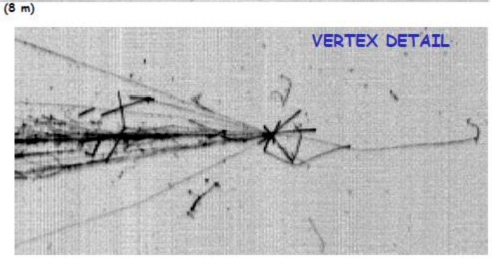
- Signal to noise ratio (S/N) better than 10 and a ~ 0.6 mm single point resolution were obtained during the LNGS run, resulting in precise spatial reconstruction of events, allowing for measuring muon momentum by multiple scattering (MS) with Δp/p ~16% in the 0.4-4 GeV/c range.

CNGS neutrino interaction in ICARUS T600 (May 2010)



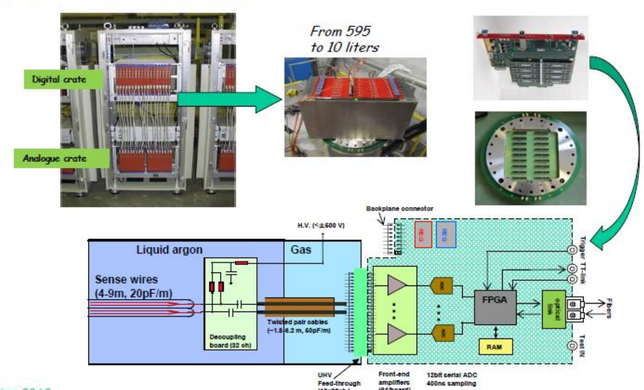
The first neutrino event!
0.6 mm spatial resolution in 8m image size.

Extremely high quality image thanks to the very high S/N of electronics (not forgetting purity, mechanical precision and stability…).



New simplified/compact design

- A new, compact design, has been conceived to host both analogue and digital electronics on a single board directly connected to the proprietary flanges.
- One mini-crate, mounted on the flange, can host 9 boards for 576 channels, 64 channels each.
- The backplane of the crate distributes the power supply and local control signals.
- A single boards hosts 64 front-end low noise charge sensitive pre-amplifiers, 64 serial 12 bit ADC (2.5 MHz), FPGA, memory, optical link interface…

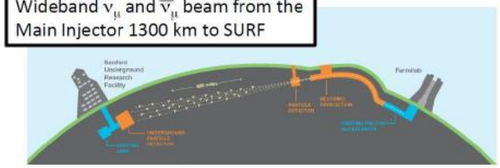


Shanshan Gao (bnl)

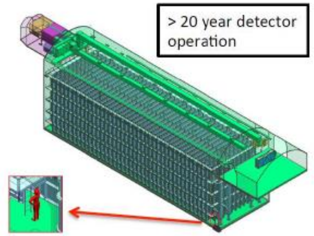
Overview of ProtoDUNE-SP

- Deep Underground Neutrino Detector (DUNE)
  - DUNE will take neutrino beam data from Fermilab in the Long Baseline Neutrino Facility (LBNF) starting in 2026

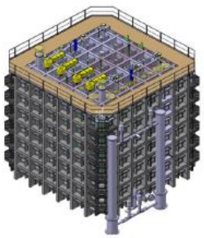
Wideband ν_μ and $\overline{\nu}_\mu$ beam from the Main Injector 1300 km to SURF



> 20 year detector operation



DUNE single phase far detector module
10 kton fiducial volume LArTPC at 4850L

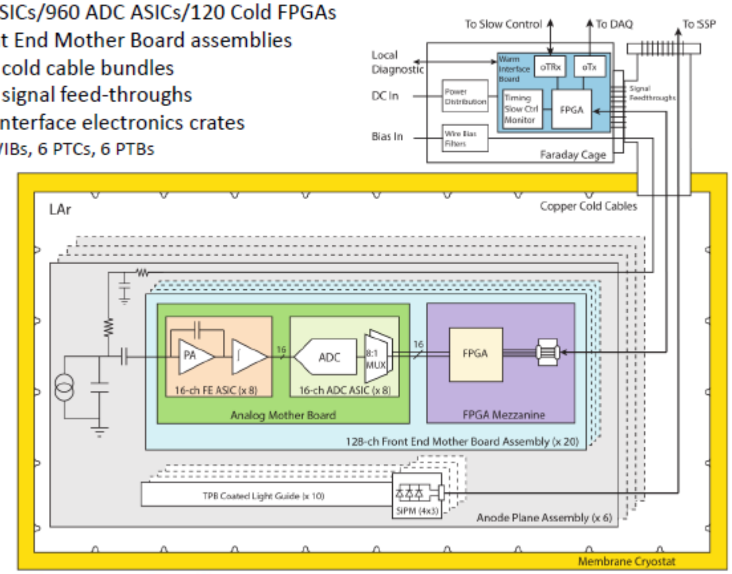


ProtoDUNE-SP

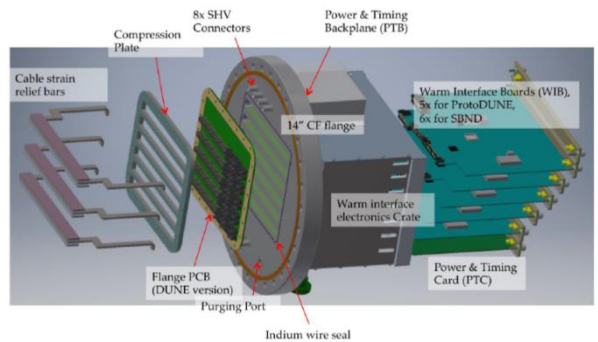
- ProtoDUNE-SP
  - 700 ton LAr TPC
  - Full scale components of DUNE far detector module
  - Will sit in H4 beam line @CERN
- Goals
  - Measure detector response to known particles
  - Confirm modeling and simulation
  - Validate mechanical and electrical design and interfaces

ProtoDUNE-SP TPC Readout Electronics

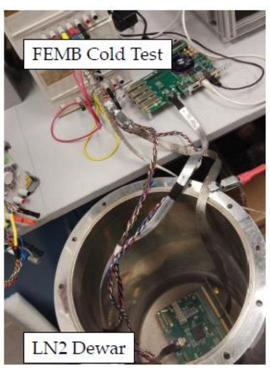
- Front End Electronics System
  - 960 FE ASICs/960 ADC ASICs/120 Cold FPGAs
  - 120 Front End Mother Board assemblies
  - 6 sets of cold cable bundles
  - 6 sets of signal feed-throughs
  - 6 warm interface electronics crates
    - 30 WIBs, 6 PTCs, 6 PTBs

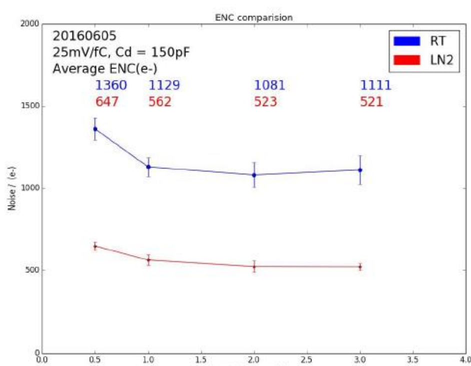


Signal Feed-through and Warm Interface Boards



FEMB Noise Measurement

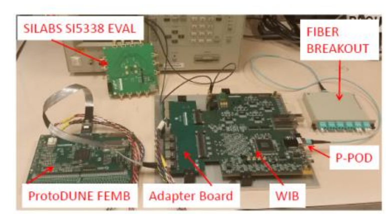


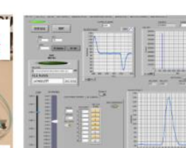


1129e- at RT and 562e- at LN2 @ 1us peaking time

SBND WIB + ProtoDUNE FEMB

platform can be set up without signal feed-through





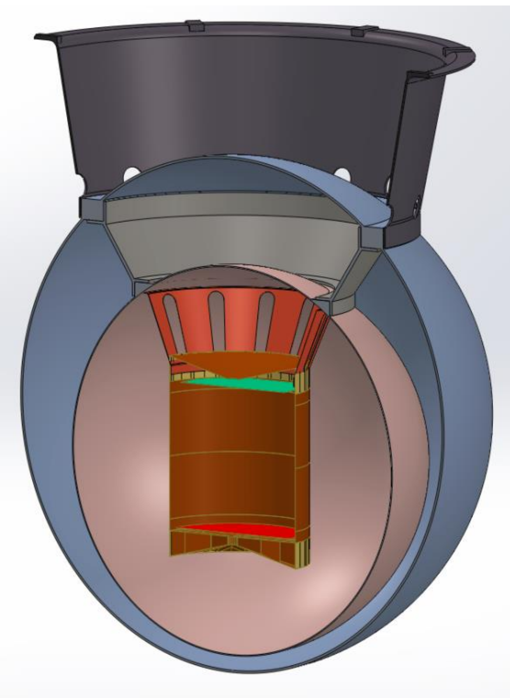
Real-time channel data

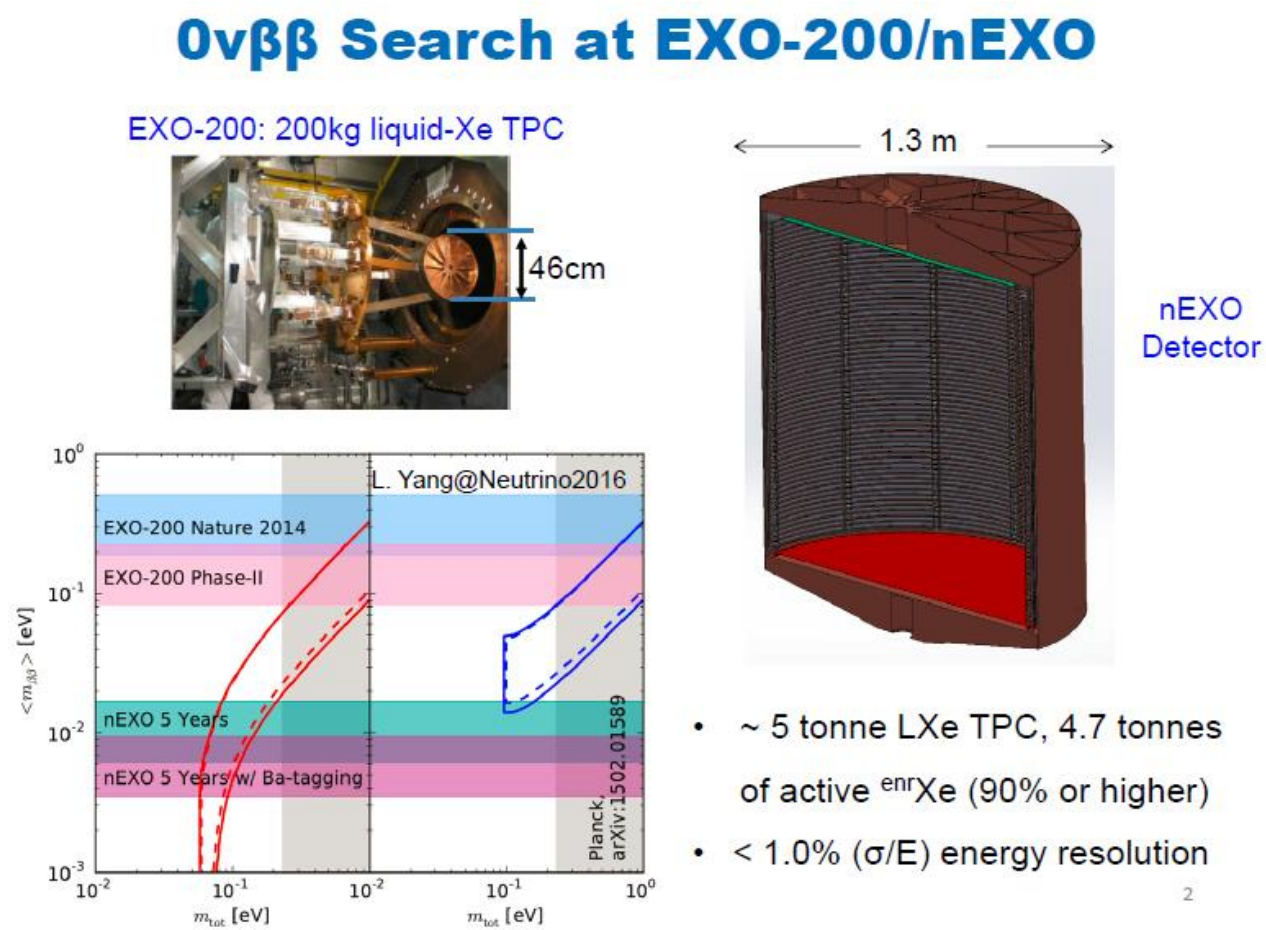
- Utilize engineering development tools used at BNL
  - Can be used simultaneously with DAQ system
  - Will simplify debugging of entire system

Wenhuan Wu (IHEP)

Lower noise with CE
Lower radioactivity

nEXO





Energy resolution from 1.2% (EXO) to 1% (nEXO) at Q value

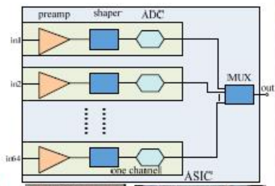
Adapting LAr ASIC readout similar to BNL

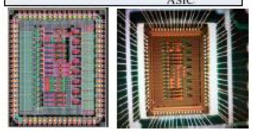
Cold ASICs for Charge readout(IHEP)

- On-going R&D at IHEP
- Critical spec.: <200 e-/ch
- Two schemes:
  - Digital multiplexing→
    - Individual ASICs designs done (pre-Amp, ADC)
    - Integration need be done
    - Tested with tile
  - Analog multiplexing→
    - Based on analog sampling technique
    - v2 has been tested

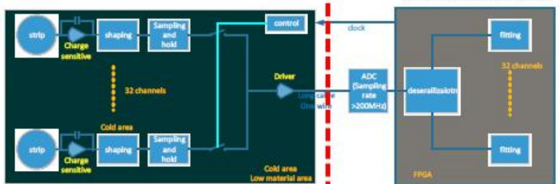
  (integrated with charge tile)

Cold | Warm





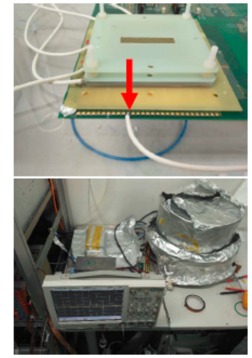
- Two chips have already designed and tested
- Need more tests (ADC's cold, noise, etc.)
- Need to be merged



Cold | Warm

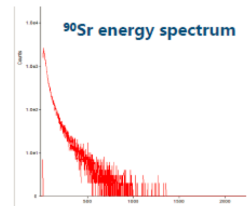
7

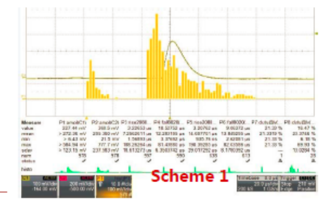
Measurement results(IHEP)

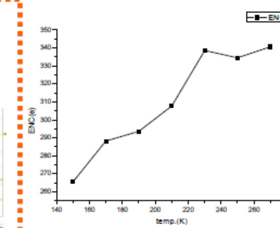


Specification	Value	Note
VDD	AVDD=1.8/DVDD=3.3	Analog power/Digital power
Peaking time	2μs /4μs	Tune switch to change
Sampling frequency	<132M	2M sampling rate/channel
ENC	~265e-	@160K
INL	<0.4%	@160K
Input signal rate	>1kHz	High rate performance
Linear range	-64fC~-0.32fC	Negative polarity
Power dissipation	<3mA@1.8V/channel	NOT include output buffer

- Radioactive Source: ^{90}Sr
- The energy spectrum fit well with ^{90}Sr's spectrum







ENC decreases as T goes down

Scheme 2

9

Critical spec.: <200e-/ch; tested ~265e-/ch

Digital multiplexing vs. Analog multiplexing

Digital multiplexing

- Advantage
  - All digital processing
  - Simple system
- Challenges
  - More power
  - Analog & digital crosstalk
  - Too much data processing on chip
  - High-speed serial data transmission, may be a challenge

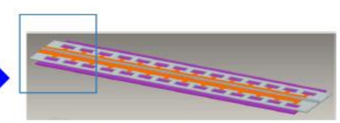
Analog multiplexing

- Advantage
  - No ADCs
    - make chip's architecture as simple as possible, also the DAQ
    - Low crosstalk between analog and digital
  - Share one buffer on chip and one ADC external, power reduced greatly
  - Off chip ADC could be high sampling frequency to improve SNR
  - Minimize number of cables between cold and warm (2clk+2power+1output)
- Challenges
  - Shielding(P+G) become important
  - Noise performance a little worse

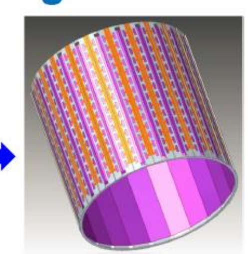
8

From single channels to large tiles

SiPM module



SiPM Ladder



Barrel (e.g, 24 ladders)

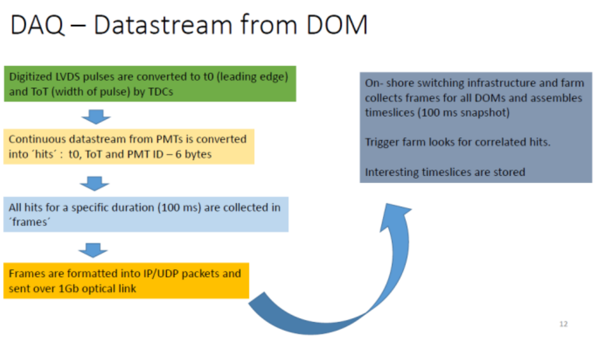
- In the next few months, they should be able to demonstrate a single channel readout.
- Perform an intermediate demonstration with 10 x 10 cm^2 tile?
- For analog SiPMs, approximately 20~30 channels, about the size for an ASIC based readout, also the size of proposed Si interposer.

15

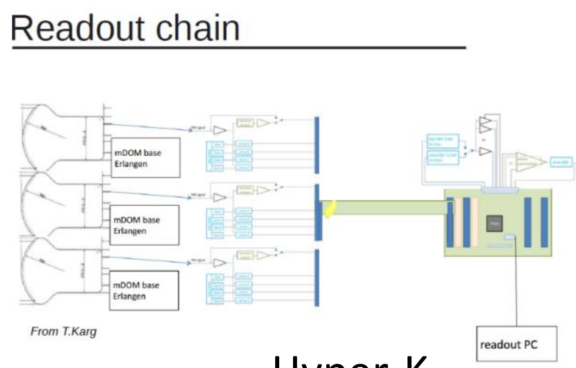
DAQ

- From the view of intelligent/digital PMT or modules, fiber or net cables are used for digital data transferring in tens to thousands meters distance directly to PC for further analysis, even no global triggering.
- The issues are the event builder, bandwidth, data volume.

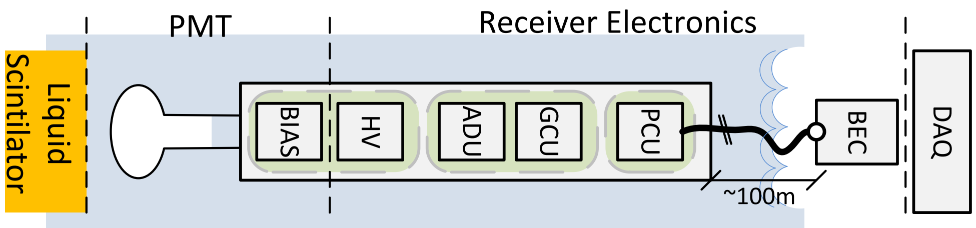
KM3NeT



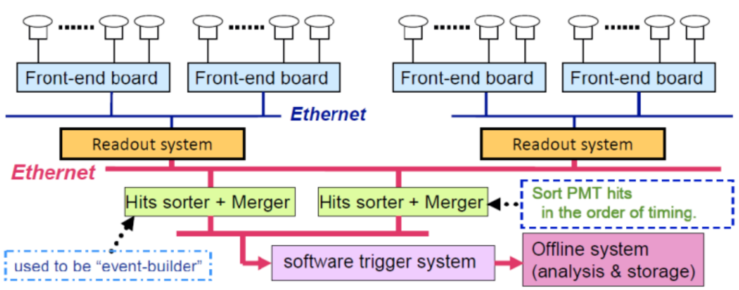
IceCube-Gen2



JUNO

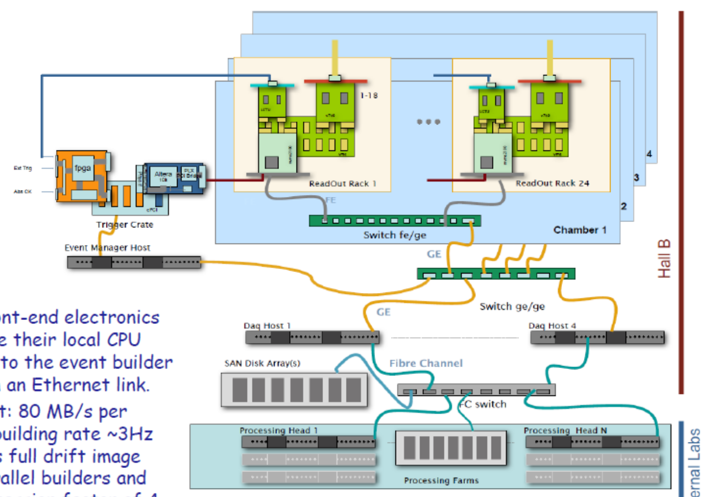


Hyper-K



ICARUS

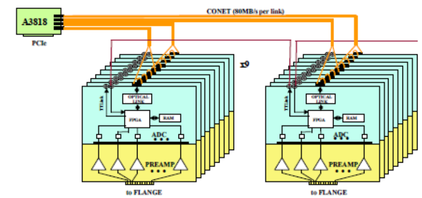
ICARUS T600 DAQ event builder

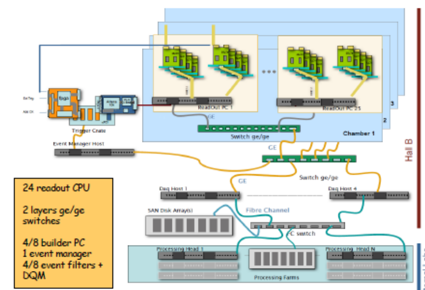


- The 96 front-end electronics crates have their local CPU connected to the event builder PC through an Ethernet link.
- Throughput: 80 MB/s per chamber, building rate ~3Hz for a 1.6ms full drift image using 4 parallel builders and data compression factor of 4.

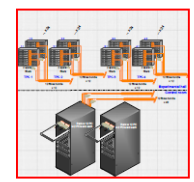
Upgrading DAQ

- The system provisionally uses the CONET transfer protocol.
- Each mini-crate (flange) will require two CONET loops.
- Each A3818 can handle 4 loops (2 flanges).
- On each PC can host 2 A3818, a total of 24 readout PC will be needed for the whole detector





- The readout DAQ could keep the existing DAQ architecture, simply replacing the VME CPU in each readout unit with a PC equipped with a CONET interface. Expected building rate ~15Hz without data compression.



- The whole DAQ can be hosted in a 54U rack
- 4 X 24 fiber bundles (+ spares) from control room to mini crate (~50/100m)

From 3Hz to 15Hz

Lossless data compression

Online lossless data compression

- In data collected with T600 LAr-TPC, the difference between one sample and the previous one is within ± 7 ADC counts in more than about 98% of the cases.
- This allows for storing the differences instead of the full 10 bit data, using fewer bits.

Compression scheme

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
4-bit Difference of channel N				4-bit Difference of channel N+1				4-bit Difference of channel N+2				4-bit Difference of channel N+3			

Difference

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	0	0	0	10-bit full difference											

- Assuming to handle data in 2-Byte format, the choice is to pack four 4 bit difference (± 7 ADC counts) obtaining a ~4 compression factor.
- When the difference is larger than |7|, the full difference is stored in 2-Byte with a 4 bit flag (1000).
- The compression efficiency is affected by the large energy deposition from e.m showers or high dE/dx tracks.
- During LNGS run the real measured compression factor was 3.92.

Differential value storing with 4bits instead of total 10bits, with ~4 compression factor

Words for summary

- Huge detector target volume asking for more intelligent detecting sensors
  - Directional
  - High efficiency
  - Cost effective
  - High Reliability
- More photon sensors come true or under developing
  - 20” MCP PMT
  - LAPPD
- Front end electronics and DAQ also updating our mind and design
  - Cold electronics for better SNR and sensitive measurement

Thanks for your attention!

Thanks all the speakers and attendance
of Parallel session 2.