

WG2: Detector Technology Development

Sehwook Lee
on behalf of WG2 Speakers

Kyungpook National University

AFAD 2018, Daejeon, January 30 2018

WG2: Detector Technology Development

- ***1□ talks***
- ***Various detector R&D efforts***
 - ***GEM***
 - ***TPC***
 - ***Calorimeter***
 - ***Liquid scintillator for neutrino experiments***
 - ***□***

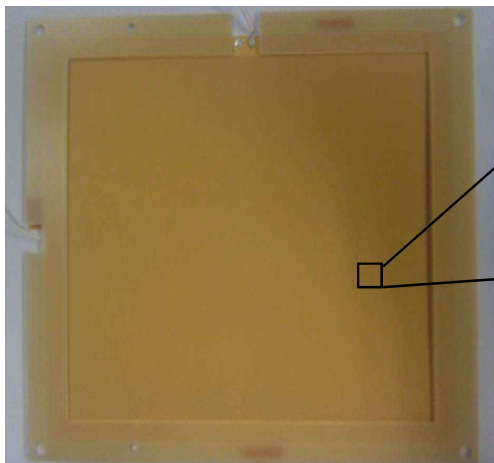
GEM Production Machines



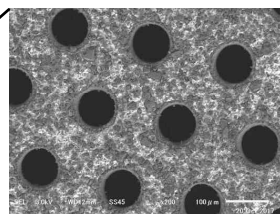
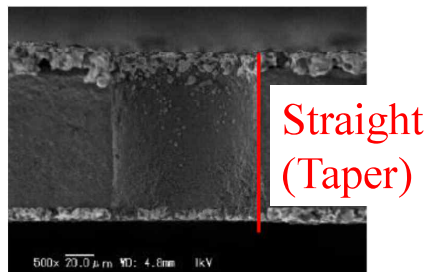
Jason Lee showed that Korea CMS and Mecaro Ltd. built the mass production system⁸ to produce GEM foil with a good quality control. GEM will be installed in the CMS detector at CERN.

Ceramic GEM

LTCC-GEM

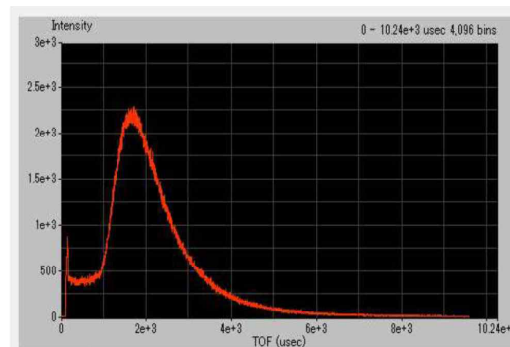


LTCC-GEM

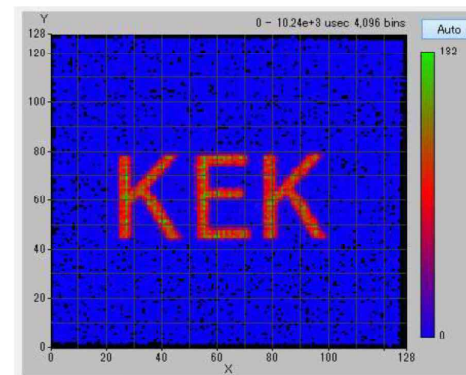


- Size : 100 mm×100 mm
- Hole diameter : 100 μ m (70 μ m)
- Hole pitch : 200 μ m (140 μ m)
- Thickness : 100 μ m (50 μ m)
- Material of Electrode : Au (Cu)

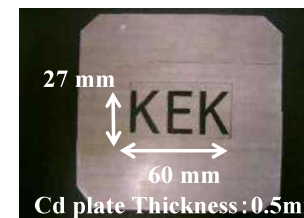
Results



Time of Flight distribution for 0-10 msec.
Flight length : ~4m
Thermal neutron peak : ~1.7msec



Two-dimensional image (10cmx10cm
with ToF cut (Cd cut off))



Shoji Uno (KEK)

Shoji Uno introduced Ceramic GEM which is an alternative way to resolve the serious damage (carbonization) by a large discharge. It is still under developing.

GEM for pEDM measurement



Polarimeter and asymmetry

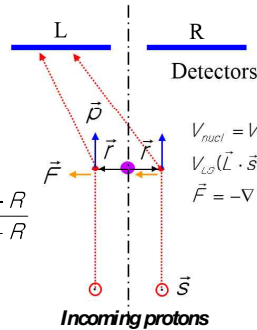
- ❖ Use asymmetrical proton scattering on Carbon target
 - Hadronic elastic scattering (spin-orbit interaction)
 - Asymmetrical proton hit distribution on the detector plane
 - L/R (U/D) asymmetry for vertical (horizontal) component of proton polarization

➤ For spin 1/2 particle

$$\sigma(\theta) = \sigma_{unpol}(\theta) [1 + P_y A_y]$$

$$L/R \text{ asymmetry } \varepsilon_{LR} = P_y A_y = \frac{L - R}{L + R}$$

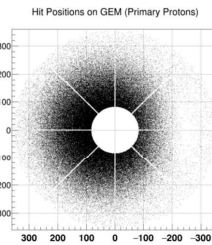
$$P_y = \frac{1}{A_y} \frac{L - R}{L + R}$$



$$V_{nuc} = V_0 + V_{LS}(\vec{L} \cdot \vec{S})$$

$$V_{LS}(\vec{L} \cdot \vec{S}) = -\vec{\mu} \cdot \vec{B}$$

$$\vec{F} = -\nabla V_{nuc}$$



Simulation by Hoyong Jeong

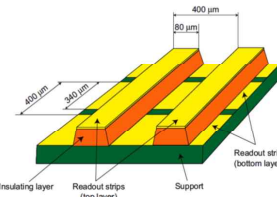
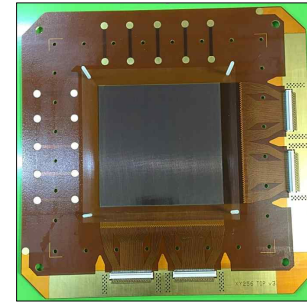
- P_y is calculated from the asymmetry with known A_y
- P_y changes in time due to the precession in E field.

Seongtae Park/Center for Axion and Precision Physics

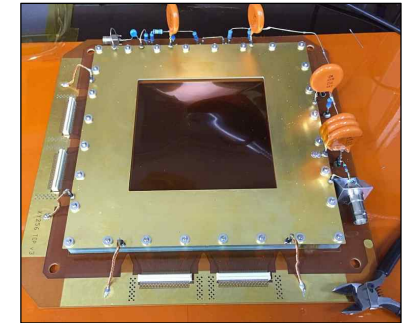
IBS/CAPP



CAPP GEM detectors



12 channel X-Y strip board
($R \approx 11 \mu\text{m}$), CERN PCB workshop



10x10 cm² GEM detector assembly



to beam test at COSY, Germany

Seongtae Park/Center for Axion and Precision Physics

IBS/CAPP

Seongtae Park (CAPP/IBS)

Seongtae Park is working on the proton EDM measurement. The main task is to detect asymmetrical protons scattering on Carbon target. In this experiment, GEM plays a main role to detect protons.

TPC for LAMPS experiment at RAON

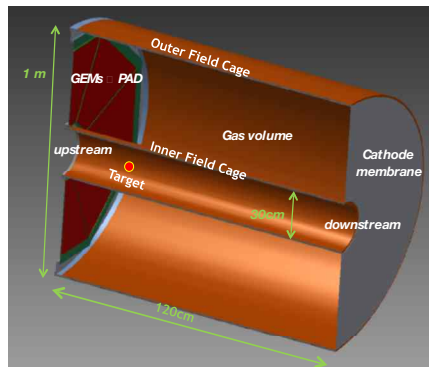
New design for LAMPS TPC

Why TPC re-designing

- Need to improve momentum resolution ($\Delta p/p$) of TPC initially designed ($v_D \approx 1 \text{ cm}/\mu\text{s}$, $L_d \approx 10 \text{ cm}$)
- Limited electronics channels of GET system for readout on both sides of TPC
- Expect more radiation damage on the electronics at downstream than upstream

Test results of TPC prototype

- Gain of triple GEMs at $V_{\text{GEM}} = 375 \text{ V}$: $\sim 8 \times 10^3$ in P-20 gas
- Drift velocity (v_D): over $6 \text{ cm}/\mu\text{s}$ in $E_{\text{FC}} = 155\text{--}205 \text{ V/cm}$ in P-20 gas
- Transverse diffusion (C_D): $\sim 400\text{--}500 \mu\text{m}/\sqrt{\text{cm}}$ in P-20 gas
- Position resolution (σ_p): $\sim 228 \mu\text{m}$ with $3 \times 10 \text{ mm}^2$ PAD



New design for LAMPS TPC

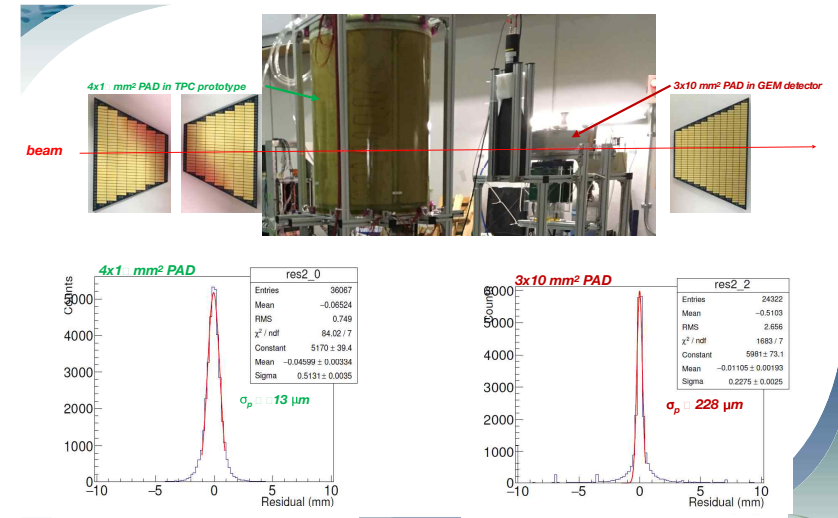
- Field cage of 120 cm long with v_D over $1 \text{ cm}/\mu\text{s}$
- Length: 120 cm
- Inner and outer diameters: 30 and 100 cm
- GEMs PAD in each 8 sectors
- PAD readout only in upstream for better position resolution
- GET system (Max. 30, 20 channels)

Disadvantages of wire method for TPC

- Difficult to handle thin wires & limited spacing in between wires
- Dead time for data taking due to gating grid
- limited operation with continuous wave (CW) beam

Advantages of GEM for TPC

- Physical strength better than wire
- Prevent positive ions in ion back flow (IBF)
- High gain and good radiation hardness
- Enable to be operated at high event rate and under CW beam



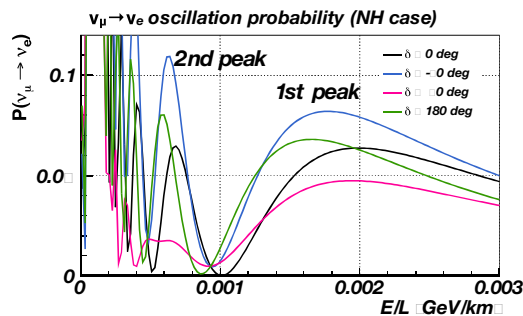
Min Sang Ryu (RISP/IBS)

Main tracking system for LAMPS experiment at RAON is Time Projection Chamber. For the readout, this TPC uses GEM instead of the typical wire readout due to advantages of GEM for TPC. Minsang introduced the prototype TPC and the beam test results.

Liquid argon TPC for neutrino experiment

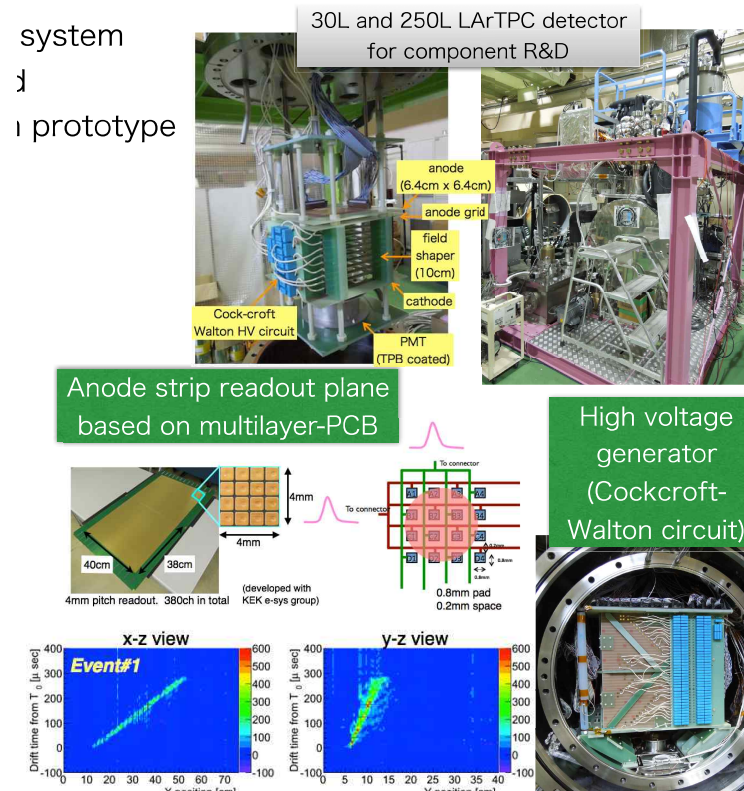
Why liquid argon TPC for ν experiment ? detector R&D at Japan

- Liquid argon TPC (LArTPC) has a capability of good particle identification and good energy resolution up to several GeV
- One of ways to measure ν CPV is to measure “oscillation pattern” with wide energy region
- A large size LArTPC (>10kton) is a candidate of neutrino detector for long baseline ν oscillation experiment, nucleon decay search, SN neutrino observation, atmospheric neutrino measurements etc.



ν interactions at a few GeV : multiple track events are dominant

Ken Sakashita (KEK/J-PARC)



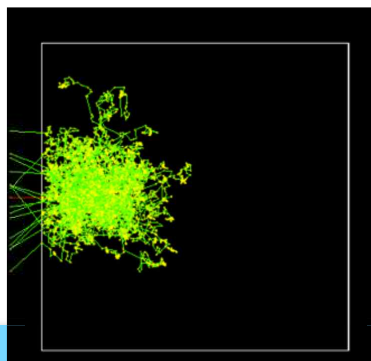
The liquid argon TPC has a good particle identification and energy resolution. This is a reasonable choice for neutrino experiment. Ken Sakashita presented the R&D efforts from a small LAr TPC to 1 kton prototype and the performance of LAr TPC.

Dual-Readout Calorimeter

total measurements

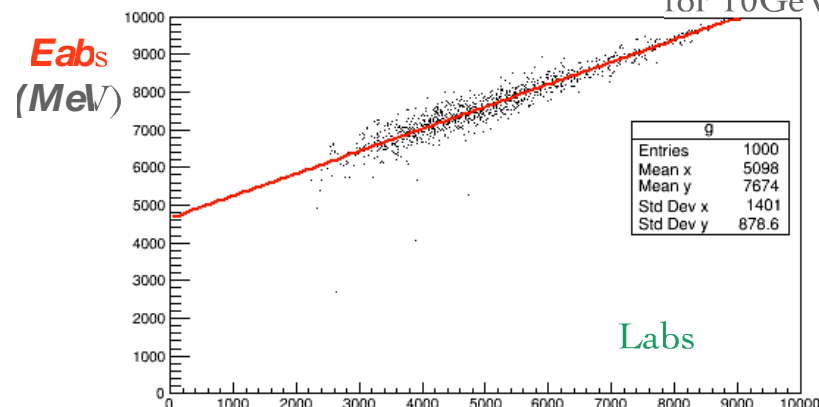
- GEANT4 simulation 2mx2mx2m time cut <100ns
 - Hadron model = FTFP-BERT
- homogeneous CAL. for exam, absorber : PbWO₄
- two measures from the calorimeter
- Labs : Track length \propto Cherenkov PbWO₄
- Eabs : dEdx \propto scintillation

□
→
green lines
are neutrons



Eabs vs Labs

- strong correlation between Eabs vs Labs for 10GeV pi



- with constant term in Eabs

T.Takeshita : JPS201-14pS34-3

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Tohru Takeshita (Shinshu Univ.)

Tohru Takeshita is working the dual-readout calorimeter using PbWO₄ crystal. He observed the correlation between scintillation and Cerenkov signal and try to achieve a good hadronic energy resolution using the dual-readout method.

NEOS Detector for Reactor Neutrinos

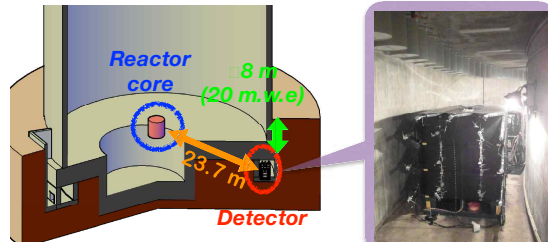
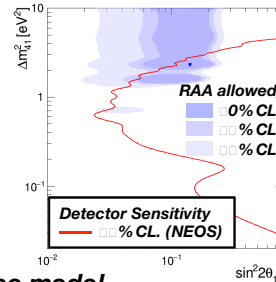
Experimental Site

Reactor Unit in Hanbit Nuclear Power Plant, Younggwang, Korea

- 2.8 GW_{th} commercial reactor
- Core size: 3.1-m diameter and 3.8-m height
- Low enriched uranium fuel (4.1% ²³⁵U)

Detector in tendon gallery

- 23.1-m baseline and 20-m.w.e overburden
- Most sensitive range is 100 eV sterile neutrinos
- Single detector
 - Understanding detector response and reference model



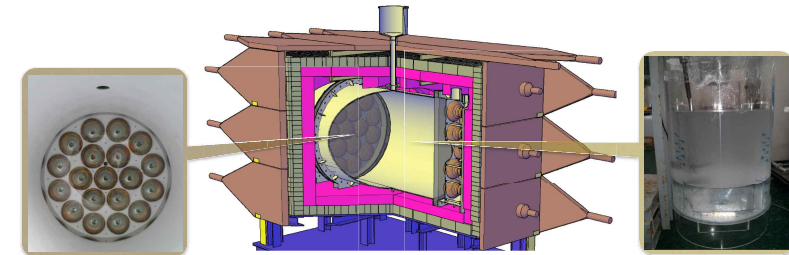
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NEOS Experiment

Young Ju Ko (CUP/IBS)

NEOS Detector



Photomultiplier tubes (PMTs)

- Two buffer tanks filled with mineral oil at both side of the target tank
- Acrylic windows b/w target and buffers
- 12 R and 12 (8 inch) PMTs are installed in each buffer tank.

Active target

- Homogeneous liquid scintillator (LS)
- 1008-L volume: (R, H) (1.1, 121) cm
- IBD in 0.1% Gd-LS
 - coincidence time 8 μs
- Mixed LS: LAB- and DIN-based LS (1:1)

LAB: Linear Alkyl Benzene
DIN: Di-isopropylnaphthalene

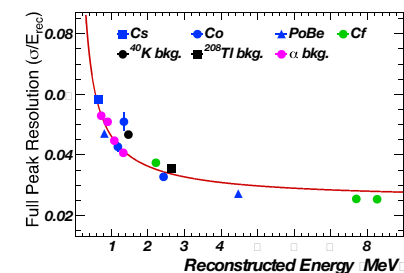
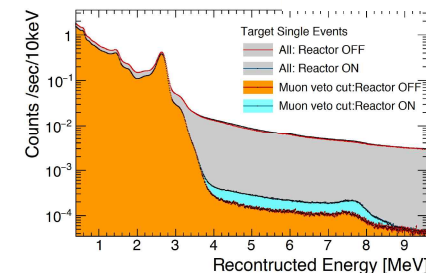
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NEOS Experiment

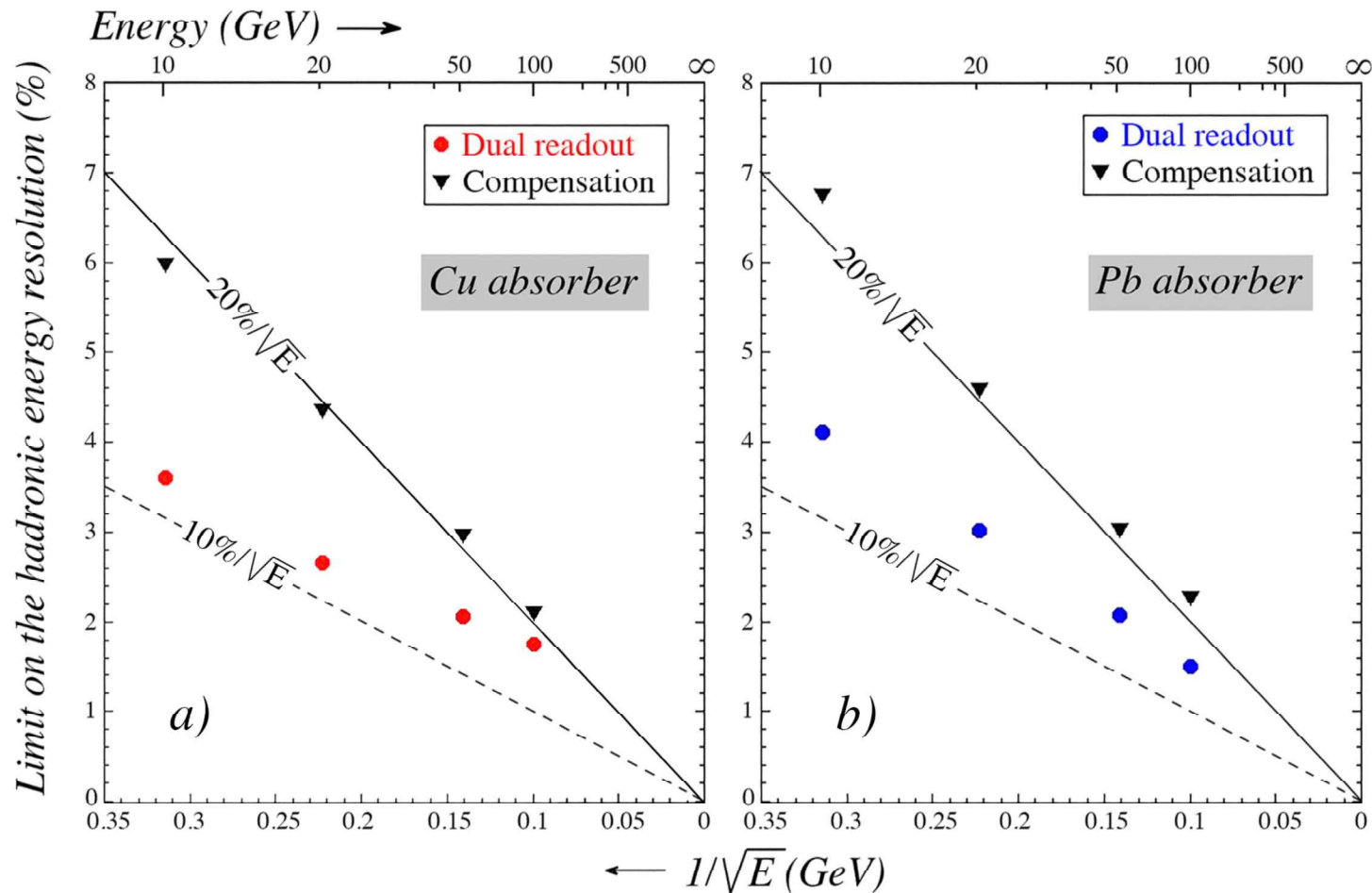
Energy resolution for full peak

- 4.8% at 1 MeV



NEOS Detector is the detector for the short baseline neutrino experiment consisting PMT and liquid scintillator. It is installed in the Hanbit nuclear power plant and detects neutrinos. Young Ju Ko showed the energy resolution of this detector was 4.8% at 1 MeV and physics result on search for light sterile neutrino search.

Limit on the ultimate hadronic energy resolution



Sehwook Lee (Kyungpook Natl. Univ.)

Dual-readout method and compensating calorimeters improve the poor hadronic energy resolution. Their ultimate hadronic energy resolutions were predicted by GEANT 4 simulation. According to the results, $20\%/\sqrt{E}$ can be achieved.

JUNO Neutrino detection capabilities

Supernova ν
 $\sim 10^4$ in 10s for 10kpc

Solar ν
 (10s-1000s)/ day

Reactor ν , $\sim 10^4$ / day
 Bkg: 3.8/ day

Atmospheric ν
 several/ day

Cosmic muons
 $\sim 2 \times 10^4$ /day

Geo-neutrinos
 1.1/ day

20k ton LS

100 m

3 GW, ~ 3 km

0.003 Hz/ m²
 21 GeV
 10% muon bundles

JUNO Detectors

Calibration

Top Tracker

Earth Magnetic Field shielding coils

Central detector
Steel Structure +
Acrylic sphere +
20kt Liquid Scin

Water Cherenkov
~2400 20" PMT

LS/ Water Filling room

Pool's height 44m
Water depth 43.5m

~18000 20" PMT+
~25000 3" PMT

AS: ID35.4m
SSLS: ID40.1m

Water pool diameter: 43.5m

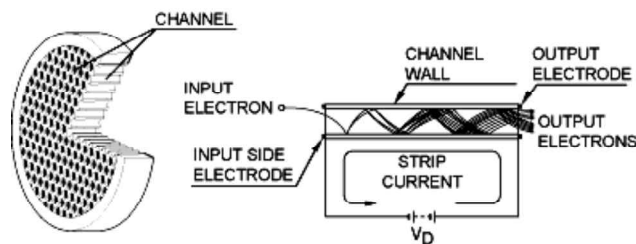
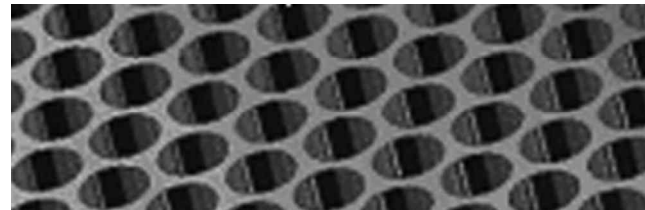
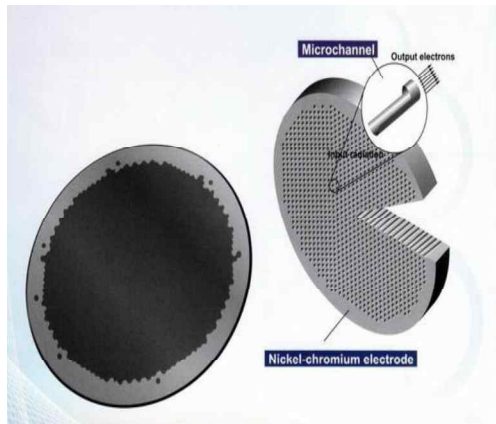
AS: Acrylic sphere; SSLS: stainless steel latticed shell

HZC PHOTONICS
TUBE TYPE: AP7200
SERIAL NO.: 7028
DATE: 2017-05-11
MADE IN CHINA

HZC PHOTONICS
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11

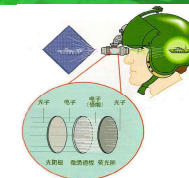
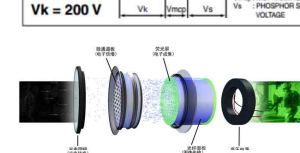
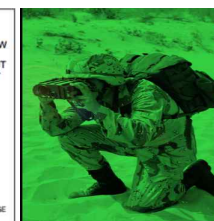
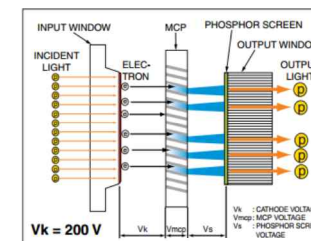
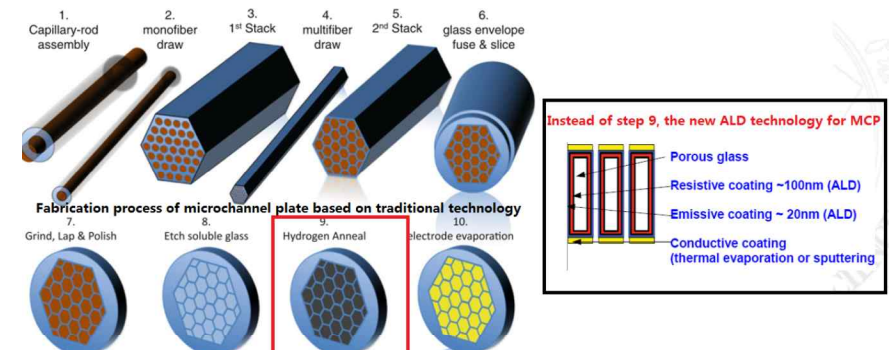
Microchannel Plate and its performance



Shulin Liu

3. Making progress

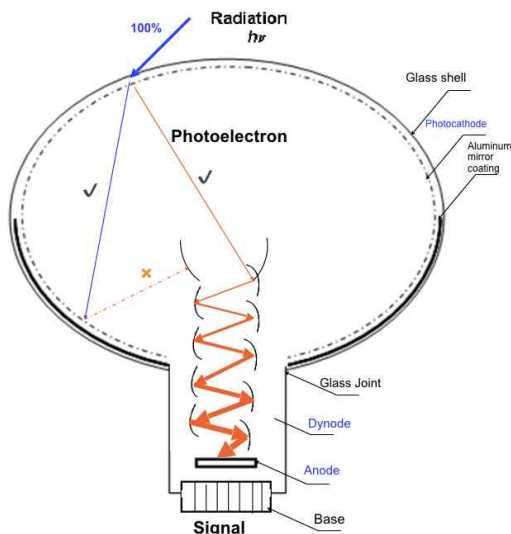
(traditional technology and the new technology made of MCP)



Each hole in the microchannel plate acts as one PMT dynode. It can be applied to the image intensifier, MCP-PMT and so on. Shulin Liu introduced the efforts of him and his collaborators to improve the performance of MCP PMT.

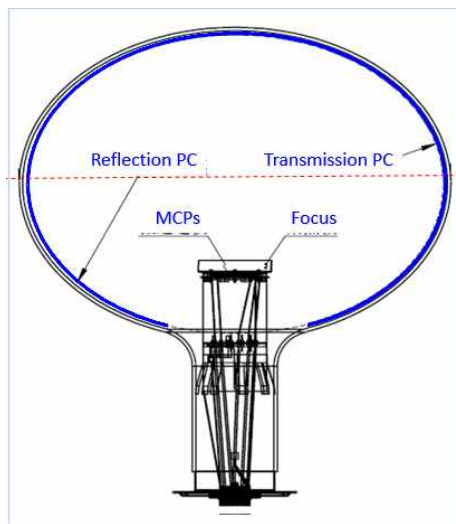
R&D for the 20 inch MCP-PMT

Photon Detection Efficiency (PE) □ QE_{Trans} □ CE



Dynode: (PE) □ QE_{Trans} □ CE

- 20% □ 0% □ 14% (200)
- 30% □ 0% □ 2% (201)



Dynode: (PE) □ QE_{Trans} □ CE

- 2% □ 100% □ 2% (201)

3.1 The 20 inch MCP-PMT production line (201)

- 2 units were working already in 201
- units were ready on the summer 201
- 14 units were ready on the winter 201

One Unit could produce 3PMTs in Two days

- □ □ 22 Units for the mass production
- □ □ 33 PMTs / 1 day (1PMT need 2 days)



The celebration for the 20 inch MCP-PMT production line (2016)



Aim:

1PMT need 2 days

total 33 pic/ day

30 pic PMTs (OK) /day

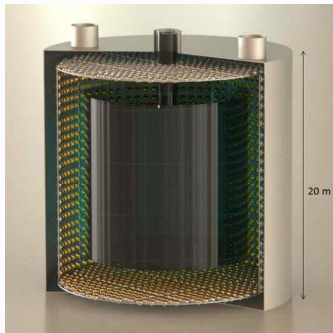
Sen Qian (IHEP)

JUNO experiment needs 20,000 of 20 inch PMT. For this experiment, MCP-PMT group replaced the dynode of PMT with the MCP. Mass production system is established which can produce 33 PMTs/day. Also, Sen Qian showed the test result of MCP-PMT such as Quantum Efficiency, TTS (Transfer Time spread) and so on.

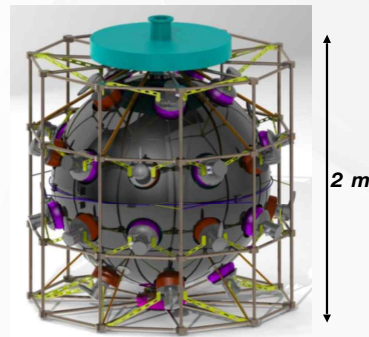
Liquid Scintillation Cerenkov Detector for Neutrino Experiment

Jinping Neutrino Experiment

- Total fiducial target mass of 2000 tons for solar neutrino physics
- Equivalently, 3000 tons for geo-neutrino and supernova neutrino physics

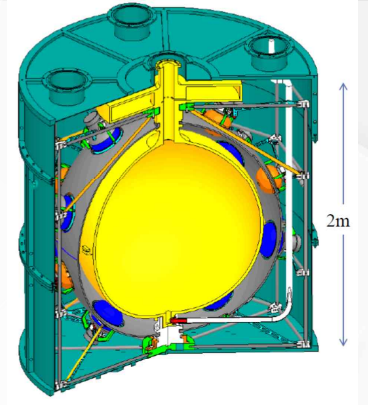


The conceptual design for a cylindrical neutrino detector at Jinping. Spherical inner vessel is also an option.

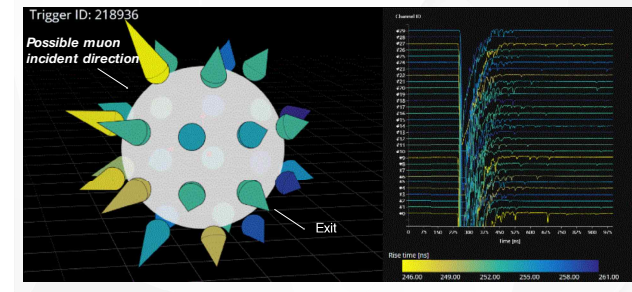


One ton prototype detector design. This detector is running now.

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Online real time event display (animation)
A cosmic ray muon candidate event

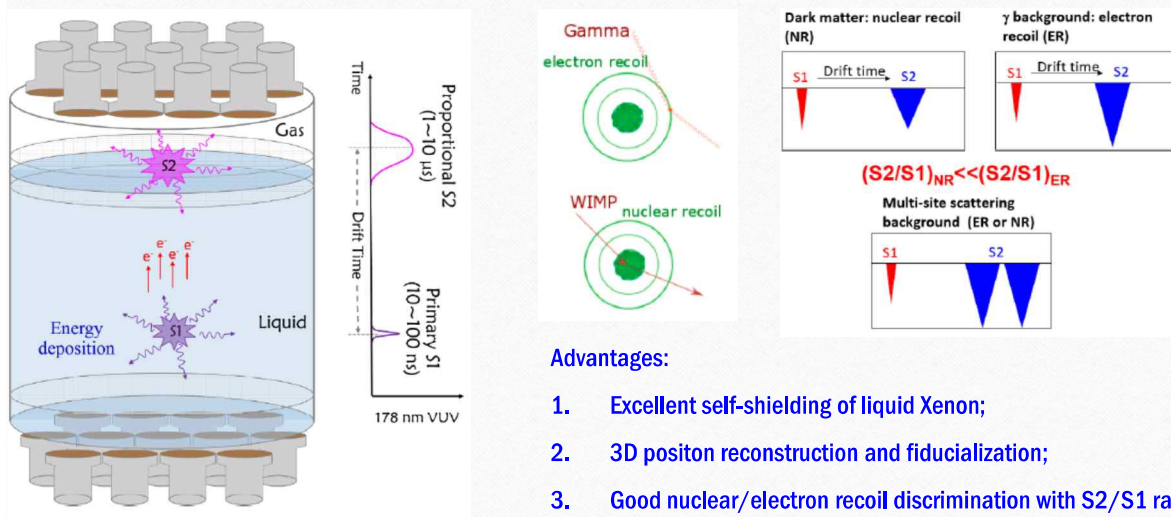


Guo Ziyi (Tsinghua Univ.)

Jinping Neutrino experiment is for the studies of solar, supernova, and geo-neutrinos. Due to the needs of high light yield and energy resolutions, they chose the liquid scintillation Cerenkov detector. Guo Ziyi showed the results of the 1-ton prototype detector before building the real experiment.

PandaX-4T Dark Matter Detector

Dual-phase Xenon TPC



Advantages:

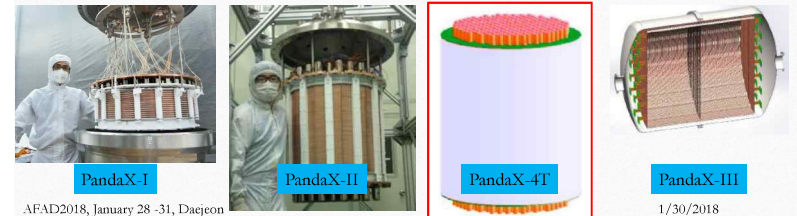
1. Excellent self-shielding of liquid Xenon;
2. 3D position reconstruction and fiducialization;
3. Good nuclear/electron recoil discrimination with S2/S1 ratio.

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1/30/2018

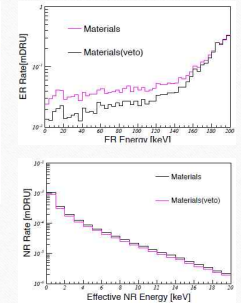
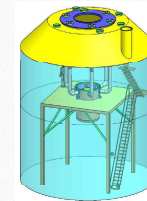
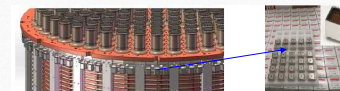
PandaX program

- Finished: PandaX-I, 2009-2014, 120kg, Dark Matter search
- Running: PandaX-II, 2014-2017, 580kg, Dark Matter search
- R&D: PandaX-4T (Dark Matter search), PandaX-III ($0\nu\beta\beta$, Shaobo's talk)



Background Control

- 5m pure water shielding
- Low radioactive materials
 - Obtaining the lowest ^{60}Co in SS
- Veto PMTs outside TPC
 - Assume 60 keV_{ee} veto threshold
 - Suppress 60% ER bkg, 15% NR bkg



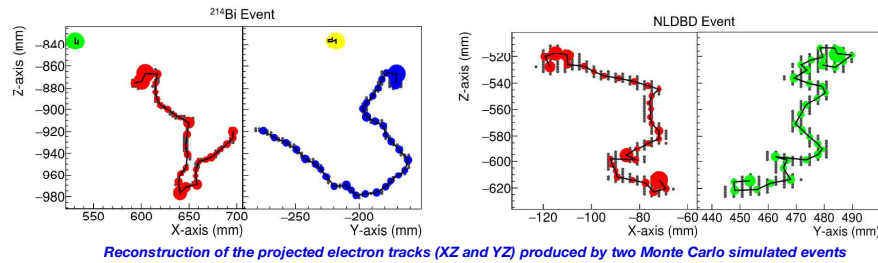
Jingkai Xia (Shanghai Jiao Tong University)

PandaX-4T is the one project of PandaX program which searches dark matter. This experiment uses Xenon TPC which can distinguish the signal of the nuclear recoil by dark matter and the background produced by the electron recoil energy when a gamma hit a atomic electron. Jingkai Xia explained their background control studies and the expected sensitivity. Now, PandaX-4T is under construction.

PandaX-III Xenon TPC for Neutrinoless Double Beta Decay



Background budget and projected sensitivity

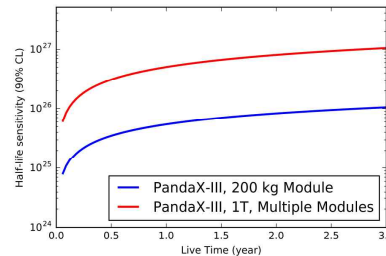


Background rate: 1×10^{-4} c/keV/kg/y in the ROI:

- Two independent Geant-4 MC: RESTG4 and BambooMC
- Topological analysis

Sensitivity expected:

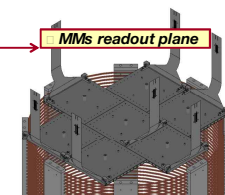
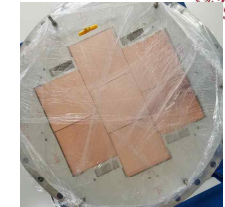
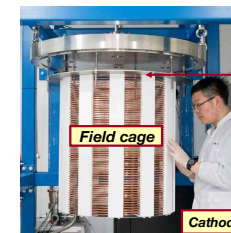
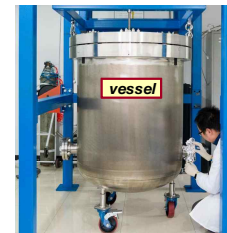
- First module: 10^{26} y half-life limit
- Ton-scale: 10^{27} y half-life limit



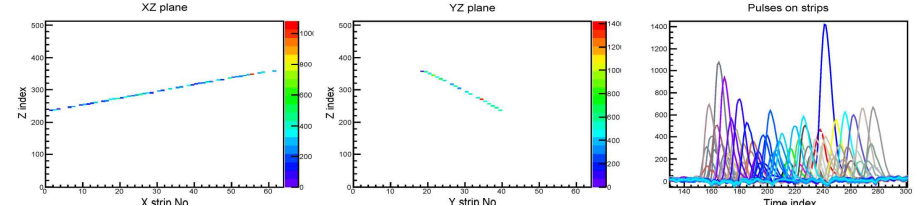
Prototype TPC



- Vessel: 600L (20kg Xe at 10bar in active region)
- 7 Micromegas modules
- Drift distance: 78 cm
- To optimize the design of Micromegas readout plane
- To study the energy calibration of TPC
- To develop algorithm of 3D track reconstruction



Muon track at 2 bar Xe: TMA



Shaobo Wang (Shanghai Jiao Tong University)

Xenon TPC for PandaX-III project is the detector for the neutrinoless double beta decay experiment. By measuring the trajectories of produced particle, the ultimately low background can be achieved. Shaobo Wang introduced his experience on the commissioning of the prototype TPC.