Summary of parallel session 1
- Detector and Calibration -

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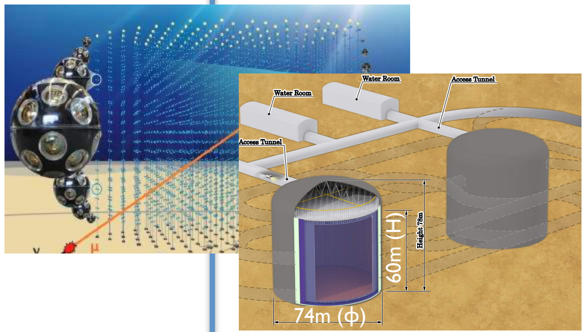
2016/11/5
NNN16 @Beijing

Structure of parallel session 1

- Liquid scintillator target
  - Ultralow background LS and related technologies (Grzegorz Zuzel)
  - LS-based 0vDBD detector (Haruo Ikeda)
  - JUNO central detector and calibration strategy (Mengjiao Xiao)
  - Water-based LS detector technology (Minfang Yeh)
- Water target
  - Hyper-Kamiokande detector design and calibration (Hide-Kazu TANAKA)
  - Calibration of the KM3NeT Detector (Salvatore Viola)
- Liquid argon target
  - Single-phase LArTPC (Jonathan Asaadi)
  - Double-phase LArTPC (Shuoxing Wu)
  - Calibration of LArTPC (Michael Mooney)

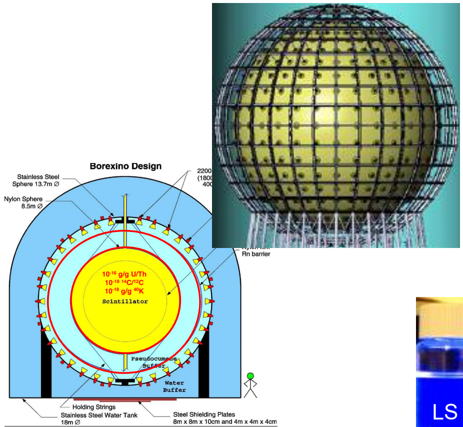
Characteristic of three types of detectors in this session

Size/maturity

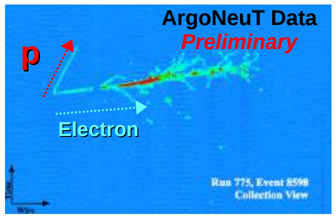


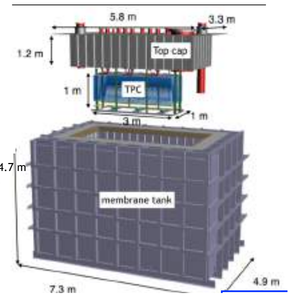
H_2O

LAr

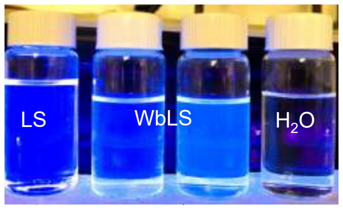


H_2O+LS





LS



Calorimetric → + Imaging capability

Another axis: low background at low energy

Points of discussion in detector performance

- LS: low BG
  - Borexino: Rare gas radioactivity (Ar, Kr, and Rn)
  - KamLAND/SNO+: primordial RI and its daughters
- H2O+LS: Attenuation length, Cherenkov/Scinti separation, and filteration
- H2O: Deployment of photosensors and photo sensor performance
- LAr: Charge/scintillation readout method

Points of discussion in calibration

- LS
  - Calibration source deployment system w/o contaminating LS, confirmation of uniformity, and (non) liniearity
- H2O+LS
  - Light yield as fn. of concentration
  - Quenching
  - Attenuation and scattering
- H2O
  - Positioning & timing adjustment among PMTs (KM3Net)
  - More convenient/sophisticated calibration sources (HK)
- LAr
  - Response functions for readout system
  - Drift path/diffusion/life time of electrons

LS

Jianglai Liu prepared slides for JUNO/WbLS

Outline

G. Zuzel

NNN'16

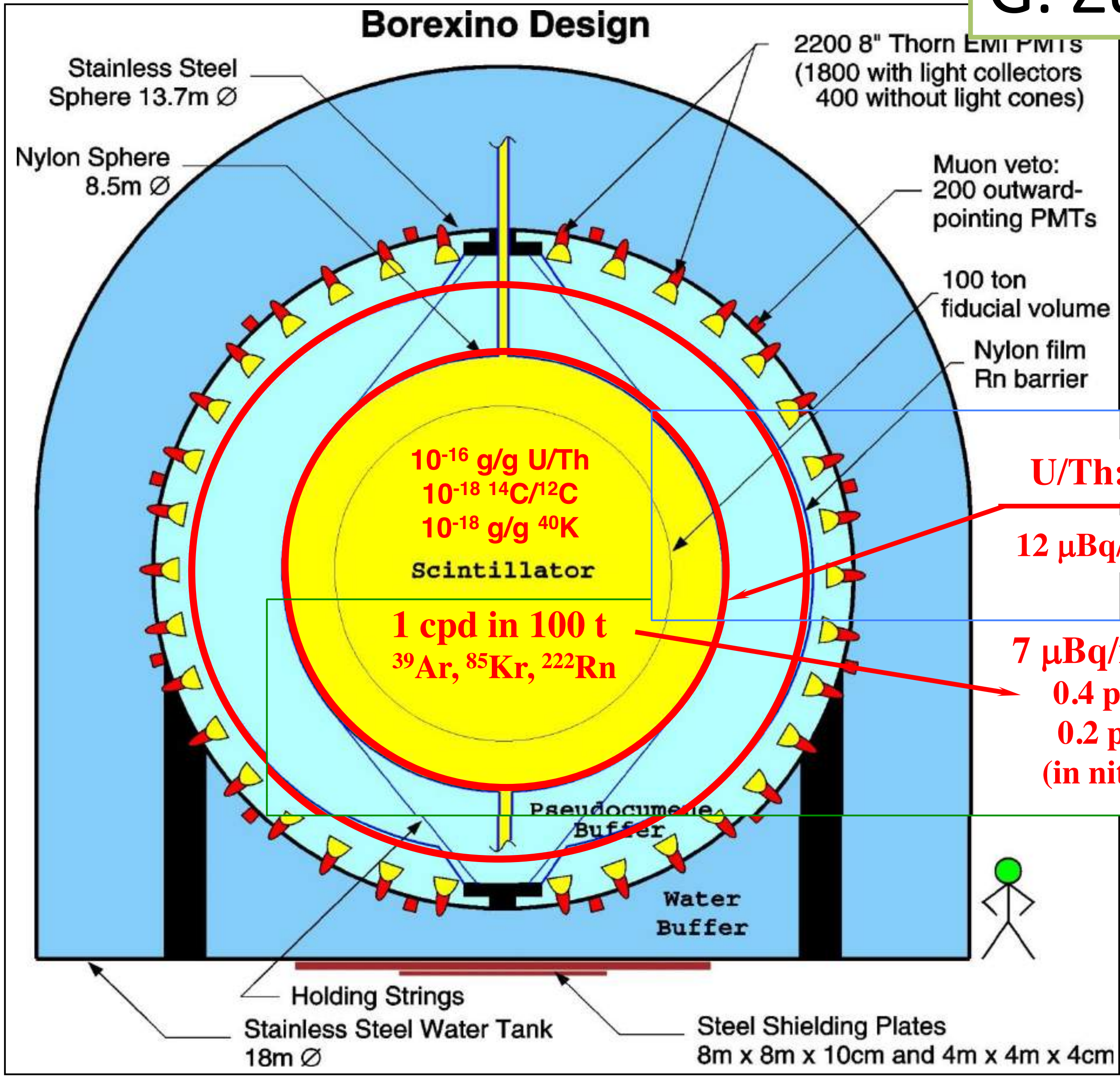
- Ultra-pure LS: BOREXINO
- Internal and external background: mitigation techniques
- LS purification
- Conclusions

These processes are equivalent to construct their detector!

BORExINO design

G. Zuzel

NNN'16



U/Th: ~1 ppt

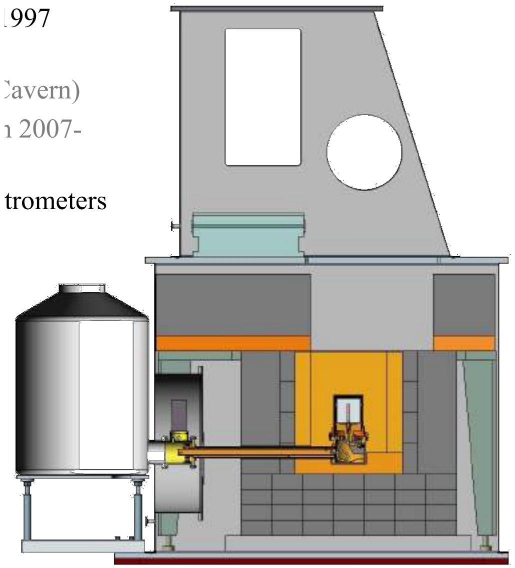
12 μBq/kg ^{226}Ra

7 μBq/m^3 ^{222}Rn
0.4 ppm Ar
0.2 ppt Kr
(in nitrogen)

.997

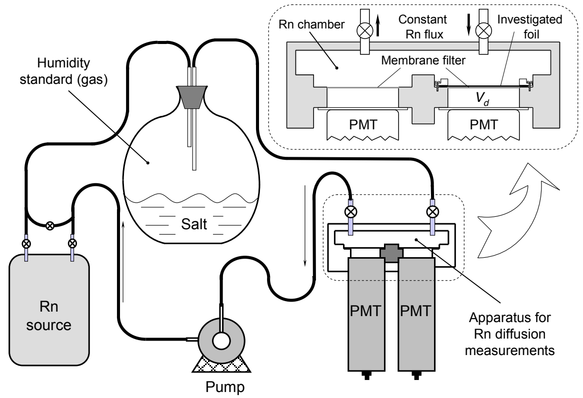
Cavern)
n 2007-

trometers

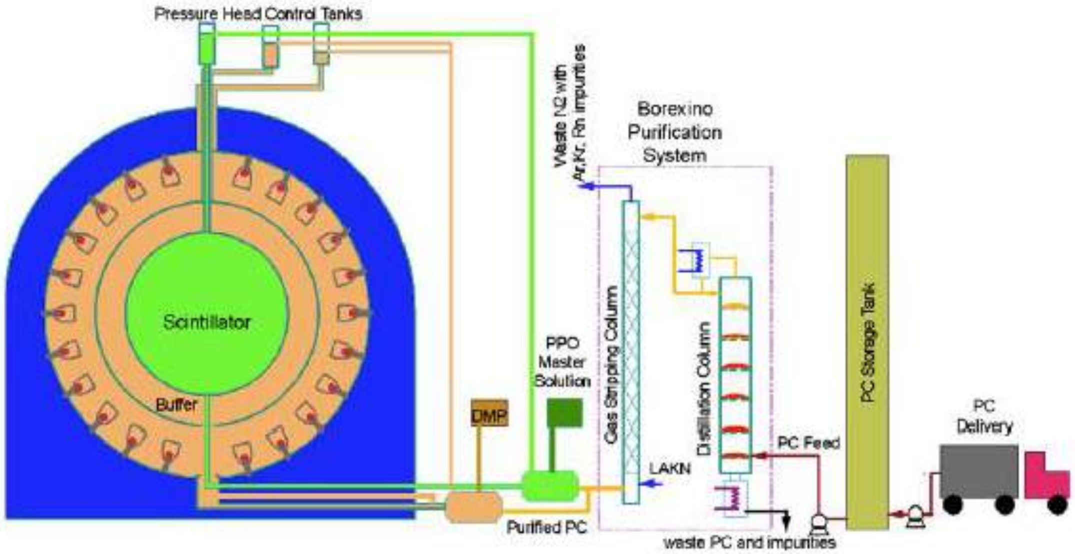


^{222}Rn emanation

^{222}Rn diffusion



Sensitivity: D ~ 10^{-13} cm^2/s
d_e ~ 2 µm



G. Zuzel

Construction of nylon vessels

LS based 0νββ detector

H. Ikeda

Merit

- Ultra **low background environment** by LS purification for neutrino detectors.
  (U,Th ~10^{-18} g/g by water extraction, distillation, adsorption…)
- Active shield itself.
- Large size detector can store **much 0νββ source**.
  (ton size)
- On-off observation is possible for ^{136}Xe.

Demerit

- Can **not see 2 electron tracks**.
  (10cm/√E[MeV] order vertex resolution)
- 2νββ signals BG case.
  (worth energy resolution, short live time of 2νββ)
- Not easy for dissolving metal 0νββ sources into LS.
- LS rerated backgrounds.
  (long lived spallation productions)
- Large photons by cosmic ray muon. (PMT ringing, after pulse)

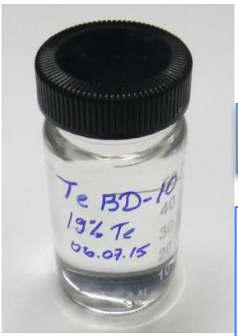
SNO+ Status and Schedule

H. Ikeda

- Now filling with water (~77% complete)
- November 2016: first delivery of LAB for commissioning scintillator purification plant
- Scintillator filling in 2017
- Late 2017: purification of tellurium, adding tellurium to the liquid scintillator
- Early 2018: start double beta decay search

$T_{1/2} > 1.96 \times 10^{26}$ yr (90% CL) 5yr

$m_{\beta\beta} < 36\text{-}90$ meV

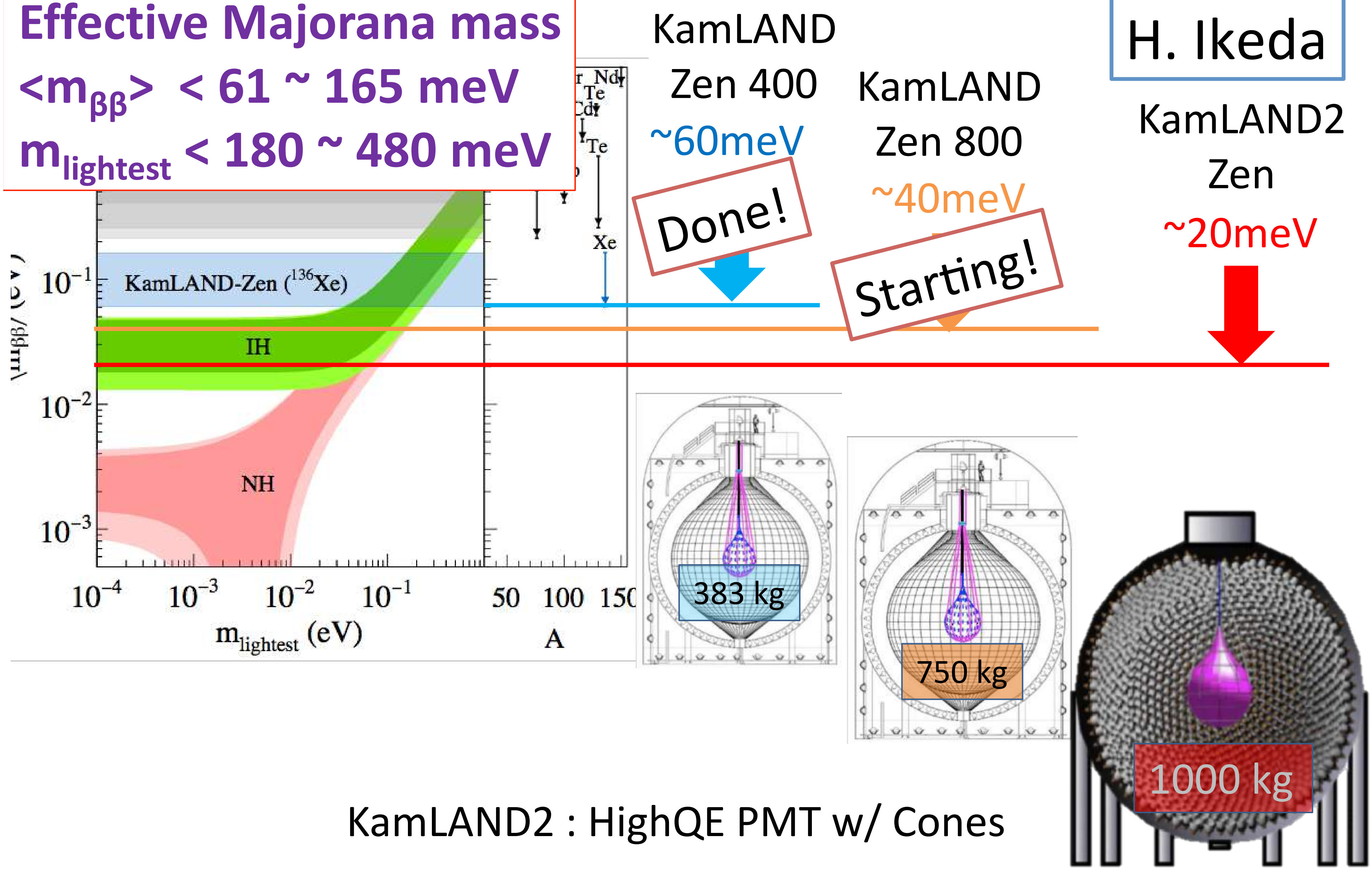


must purify all components of scintillator cocktail to achieve ultra-low backgrounds for NLDBD

KamLAND-Zen Sensitivity

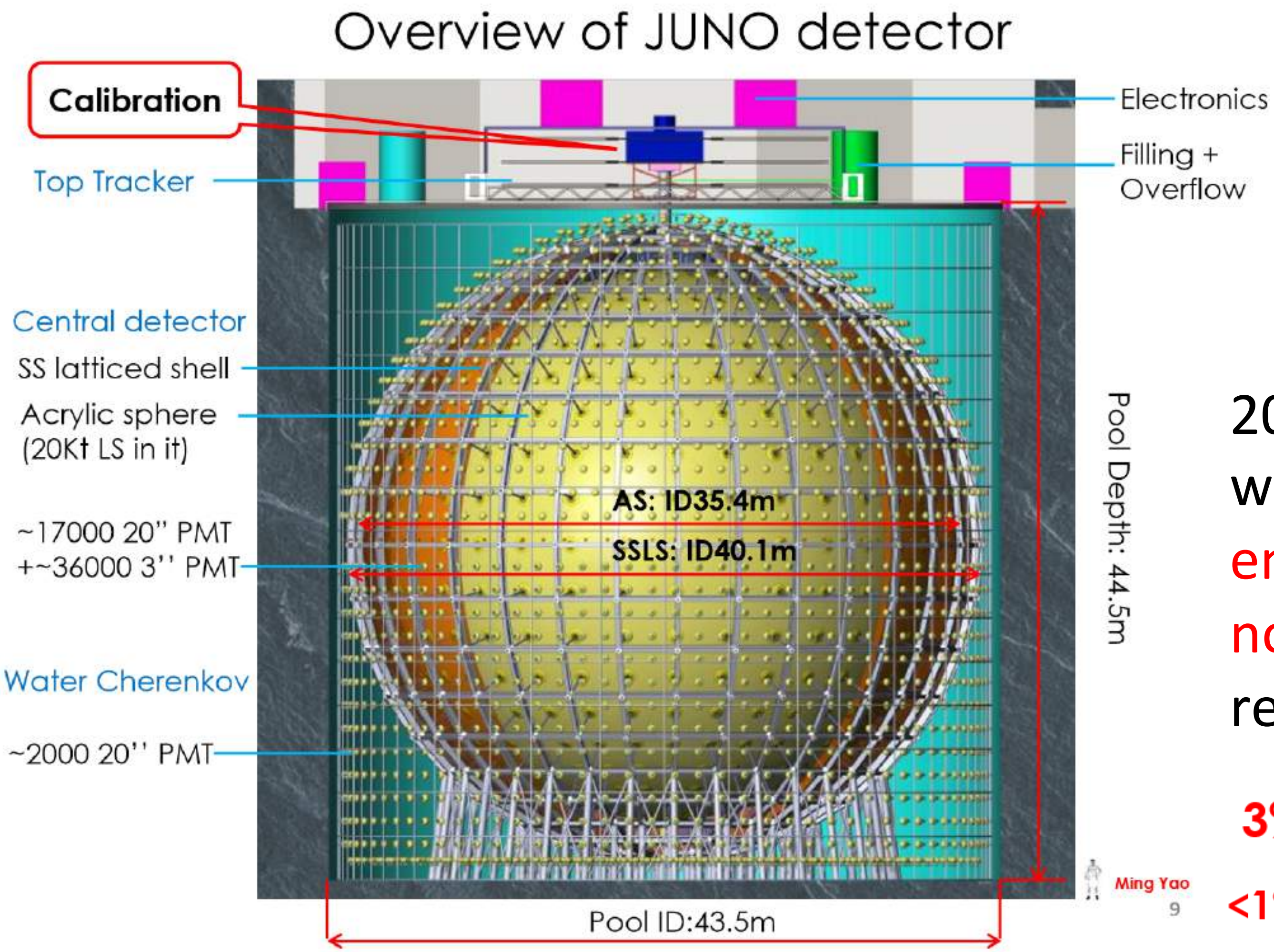
Effective Majorana mass
$\langle m_{\beta\beta} \rangle$ < 61 ~ 165 meV
$m_{lightest}$ < 180 ~ 480 meV

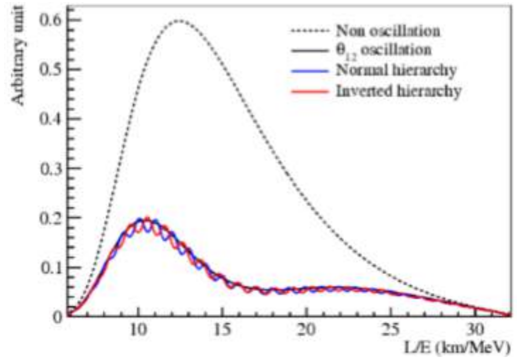
H. Ikeda



KamLAND2 : HighQE PMT w/ Cones

JUNO experiment (M. Xiao)





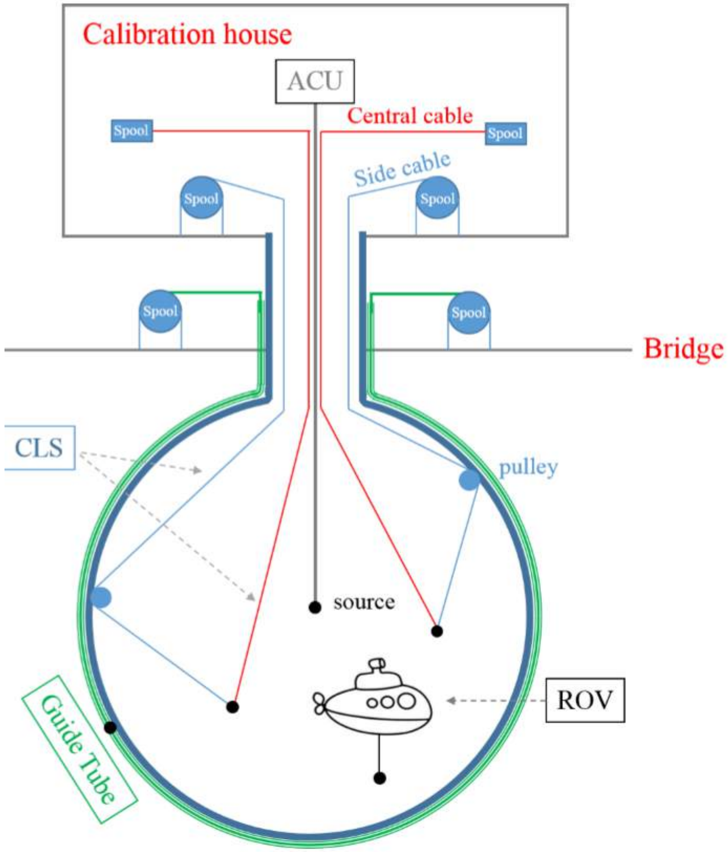
20 kton LS detector with challenging energy resolution and nonlinearity requirements

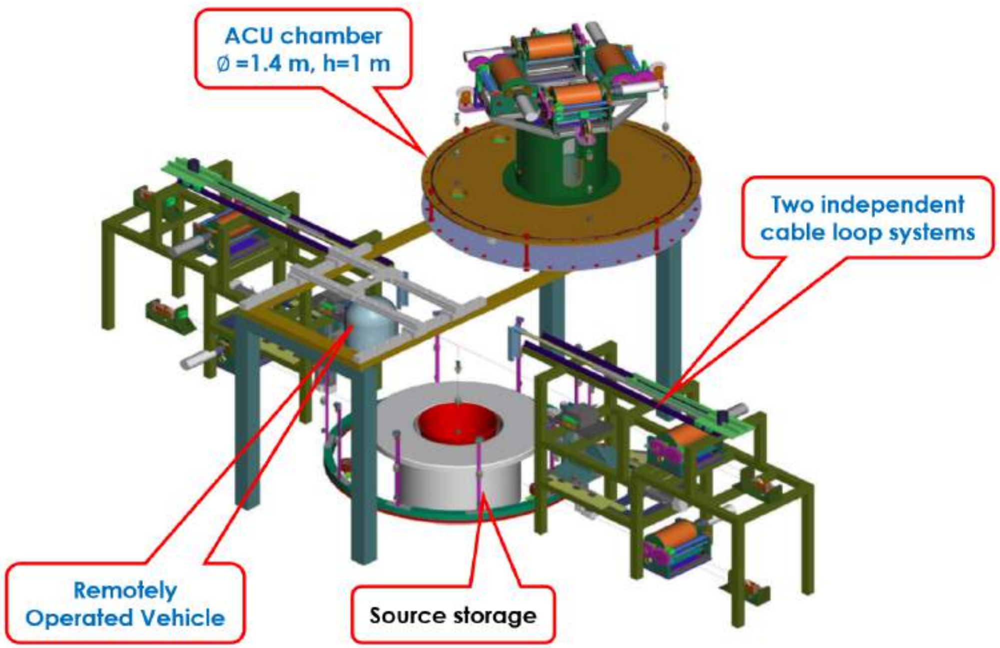
3%/√E energy resolution

<1% energy scale uncertainty

Calibration strategy

Many sources and number of independent deployment system

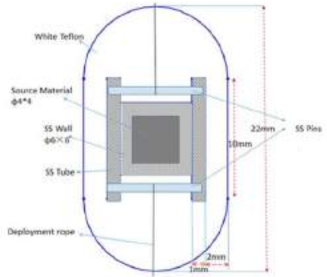


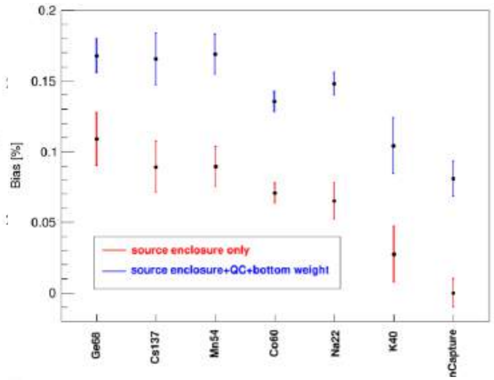


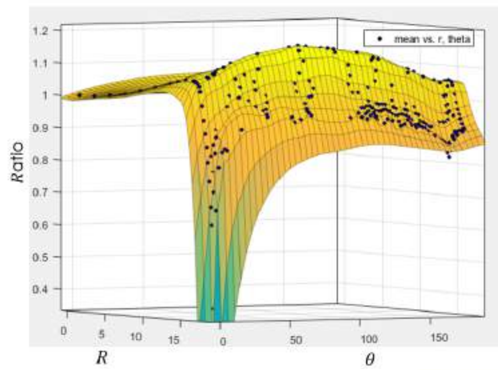
Demonstration in simulation

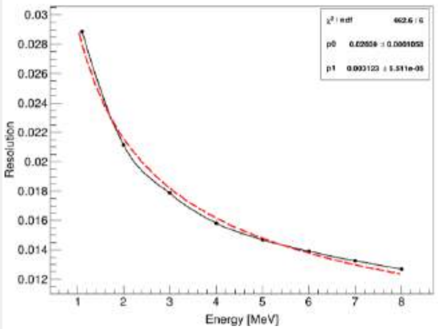
- With the MC simulation, the current calibration strategy should allow us to achieve 3%/√E energy resolution and <1% energy scale uncertainty.

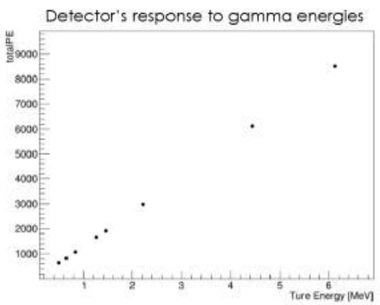
- Energy bias: specially designed sources to minimize shadowing effects to <0.2%
- Uniformity map using a single gamma source in a plane + phi symmetry sufficient for positrons
- Nonlinearity: traditional gamma approach and novel e-/e+ approach

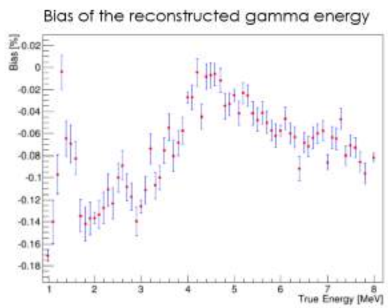


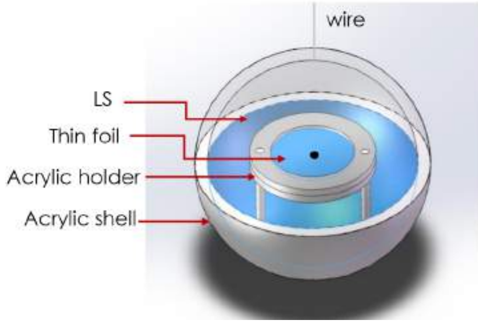


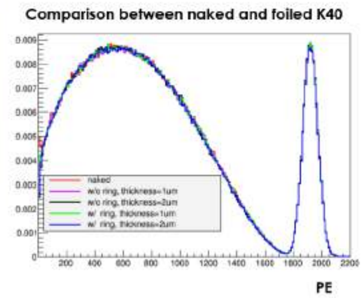






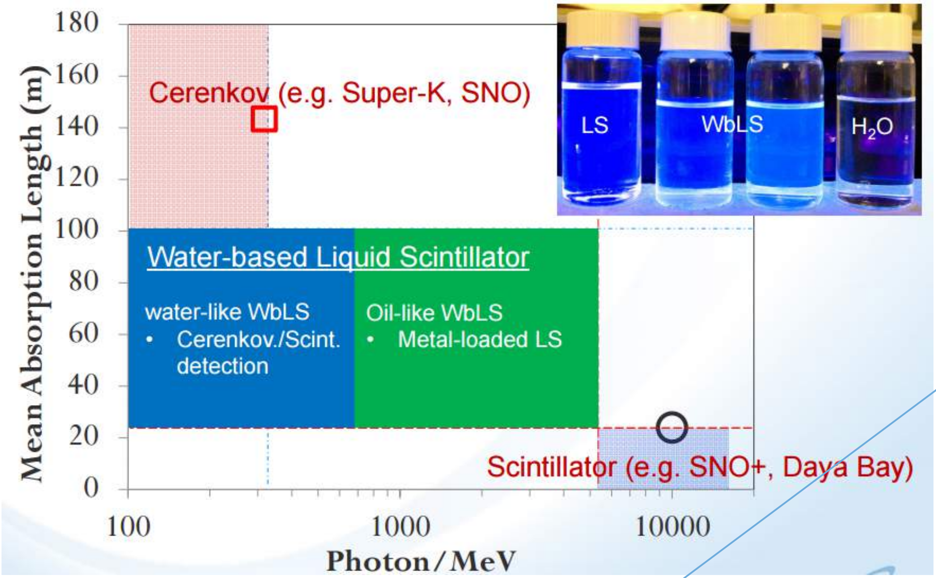


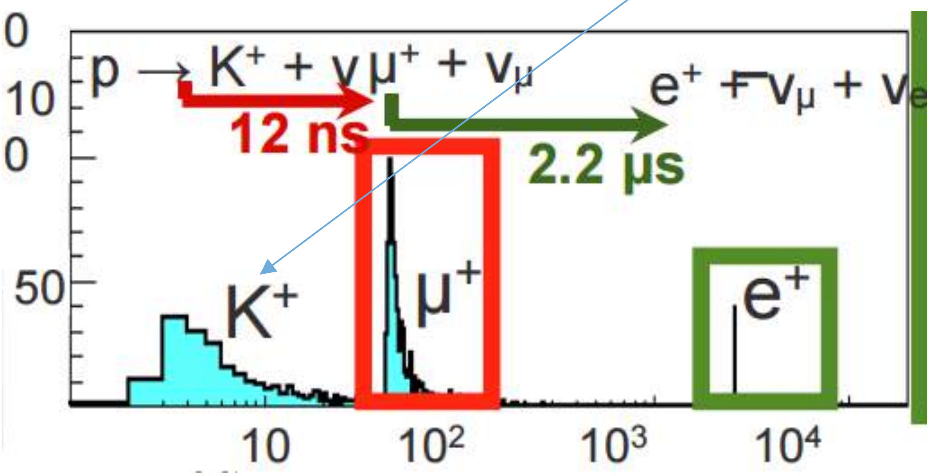




H_2O+LS

Water-based liquid scintillator (WbLS) (M. Yeh)

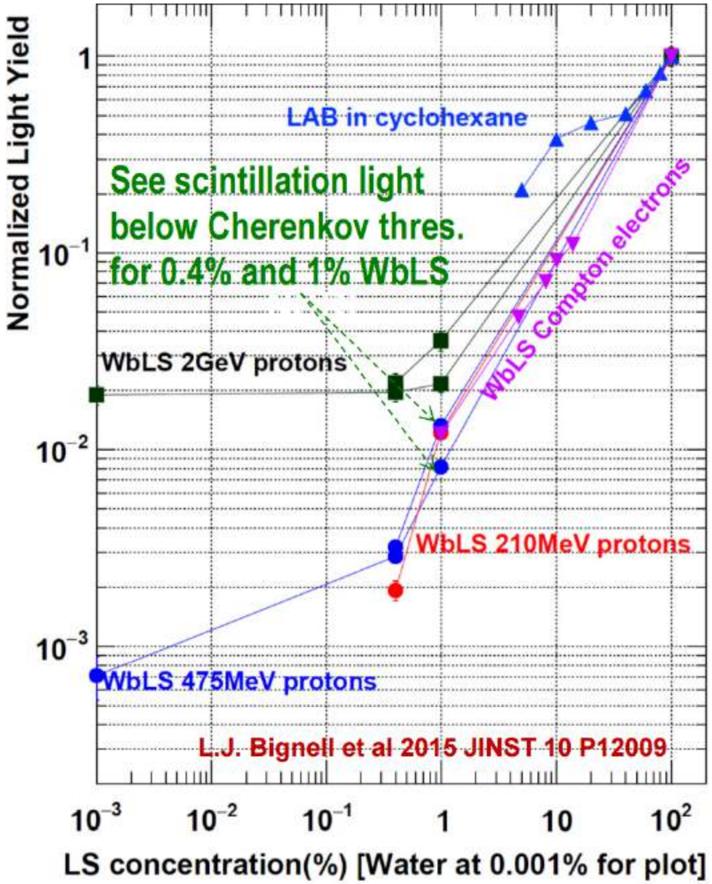




- **A novel scintillation liquid ranging from pure organic to pure water**
  - Cherenkov (directional) and scintillation (isotropic)
    - Energy measurement below Cherenkov threshold ($p \rightarrow K^+\bar{\nu}$)
  - Particle identification
    - Timing separation of fast Cherenkov from slow scintillation
  - Adjustable scintillation light yield (0%~15% LS)
  - Long attenuation length
  - Cost effective (~\$30/ton) compared to LS (\$3k/ton
  - Environmental for confined space or close to accelerator facility)
- **A new metal loading technology to hydrophobic elements: Te, Li, K, Pb,…,etc.**

Technology developments

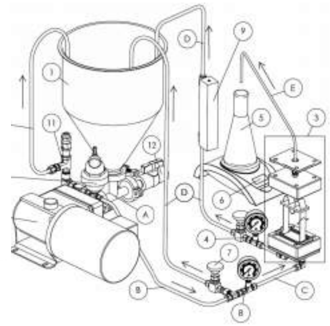
Light yield scale with the LS concentration ☺

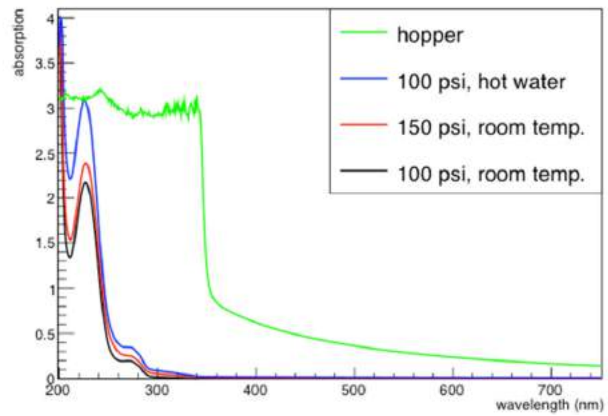


Online purification while maintaining organic compound in water?

One could try and separate the organic and water stream, purify the water stream, then remix.

Recent success in separating out the active WbLS components at a level >99% with flow rates high enough to be used in THEIA

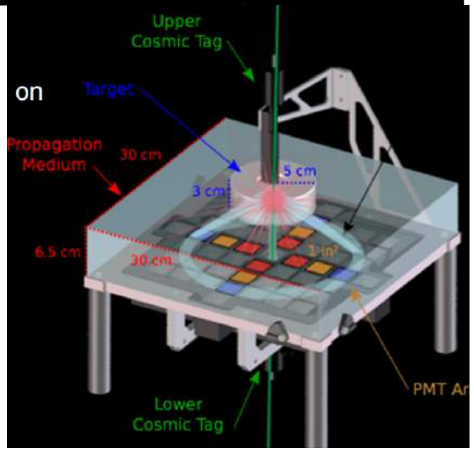


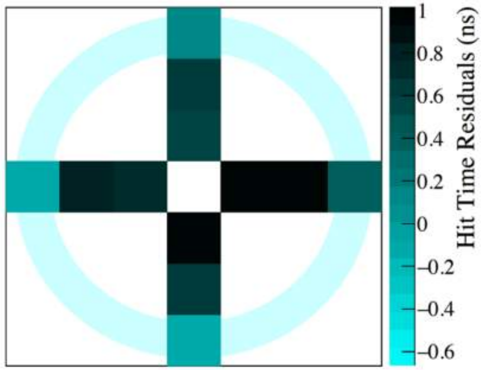


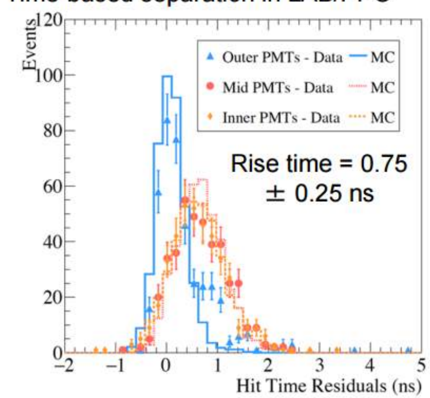
Separating Cerenkov from scintillation

CHESS:
CHErenkov-Scintillation Separation

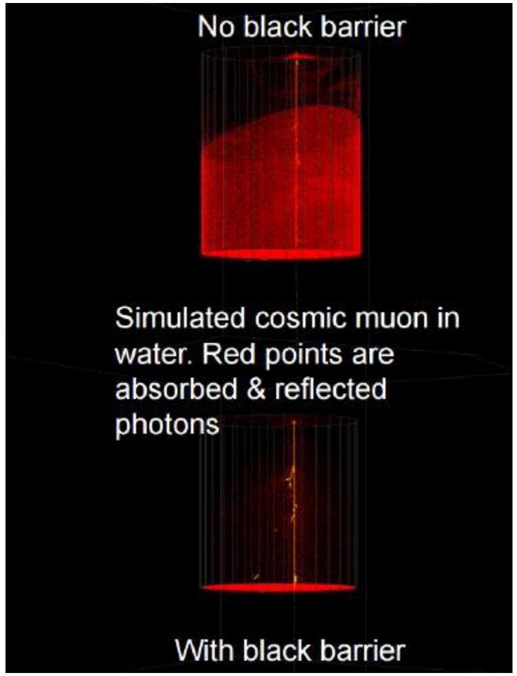
Orebi Gann research group
Supported by LBNL LDRD (FY '15-16







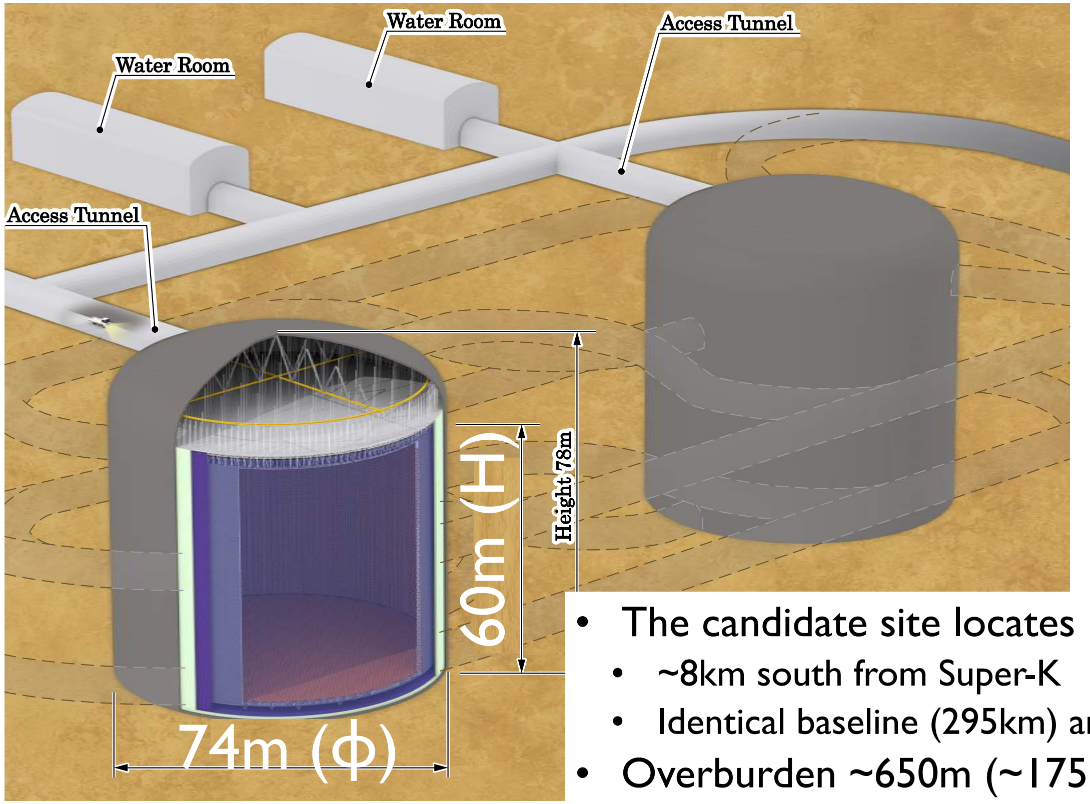
1000 liter WbLS Demonstrator



- Cherenkov separation as a function of %WbLS
- Installations of Teflon-barrier, water system, degas, LN_2 system, PMTs/electronics, DAQ
- Filled with water; followed by WbLS in 01/2017

H2O

Hyper-K detector

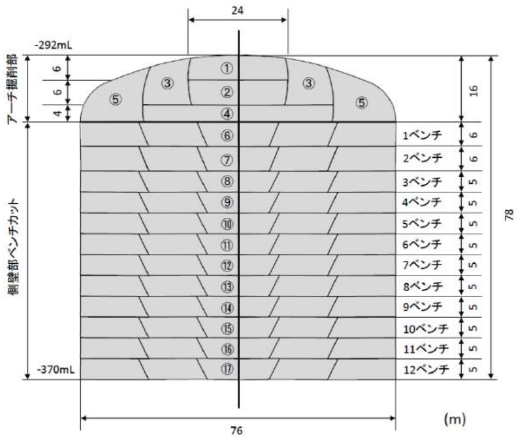


Hidekazu
Tanaka

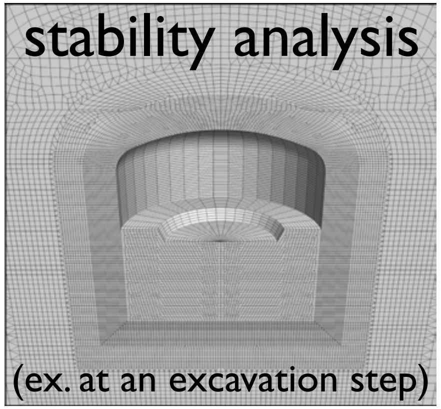
- The candidate site locates under Mt. Nijugo-yama
  - ~8km south from Super-K
  - Identical baseline (295km) and off-axis angle (2.5deg) to T2K
- Overburden ~650m (~1755 m.w.e.)

- Two cylindrical-shape detectors in stages
  - 74m diameter, 60m water-depth
- Fiducial volume: 0.37Mton
  - ~20 times larger FV than Super-K
- 40% photo-coverage (inner-detector: 80k PMTs)

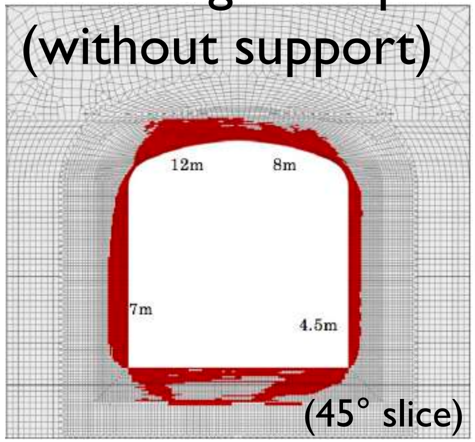
Excavation steps



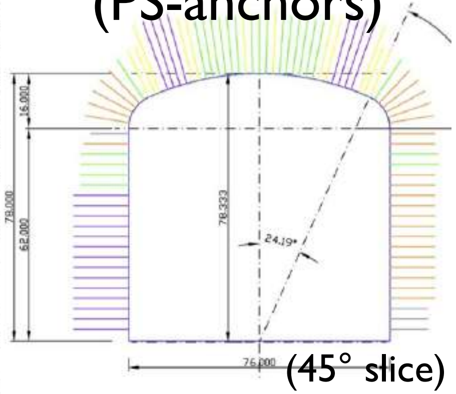
3D model for stability analysis



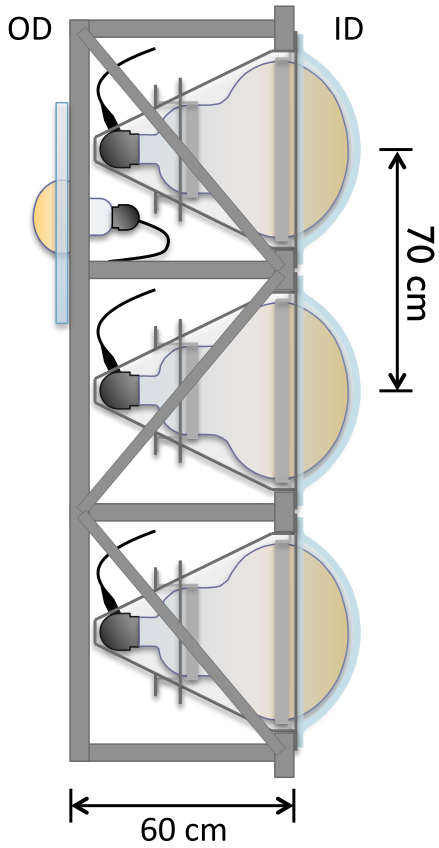
Plastic region depth (without support)

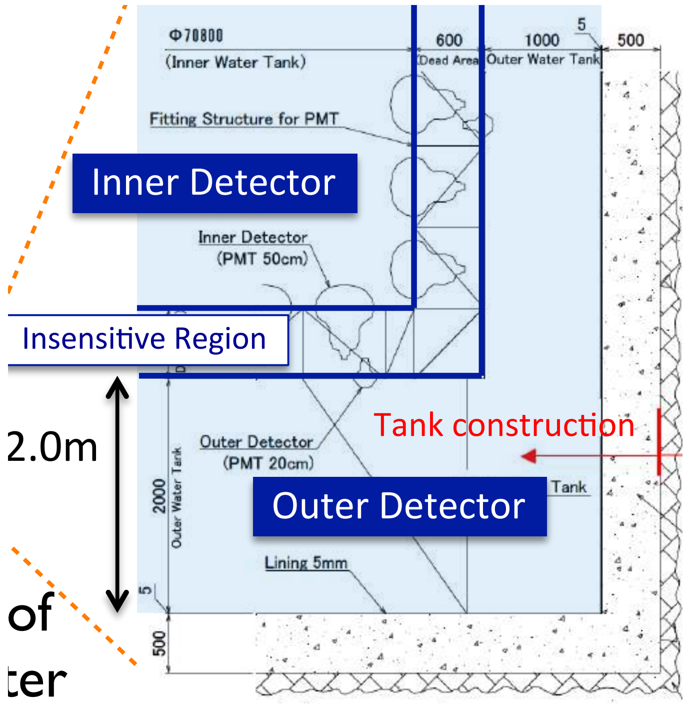


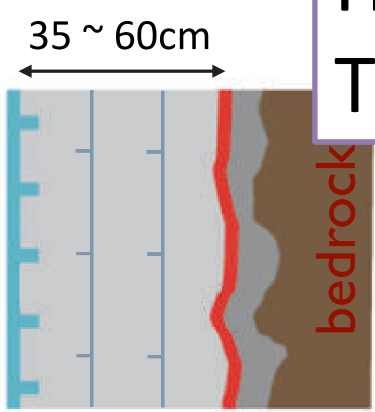
Cavern support (PS-anchors)



Hidekazu Tanaka

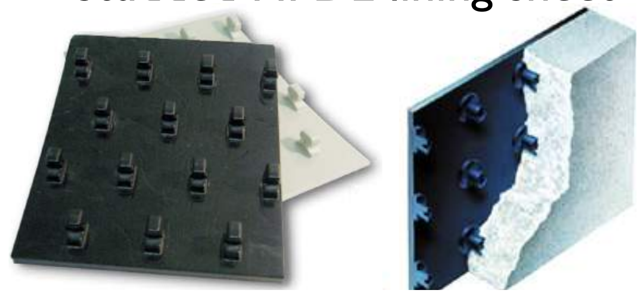






HDPE liner automatically fastened on the concrete

Studded HPDE lining sheet



HK detector calibrations

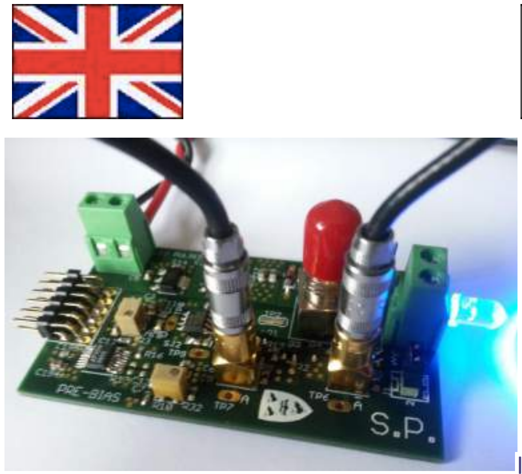
- Hyper-Kamiokande detector calibrations designed based on Super-K calibrations
  - Feasible techniques/methods for large water C detector
  - SK calibration paper: NIM A 737 (2014) 253-272
- Several R&D projects are in progress to develop more sophisticated calibration systems and sources for Hyper-K

Hidekazu Tanaka

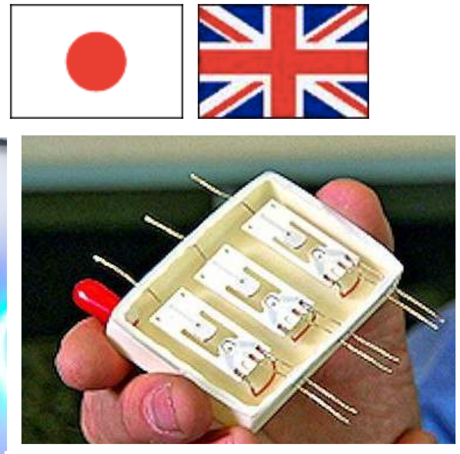
Photosensor Test Facility

Automated calibration system

Integrated light injection system



Compact neutron generator

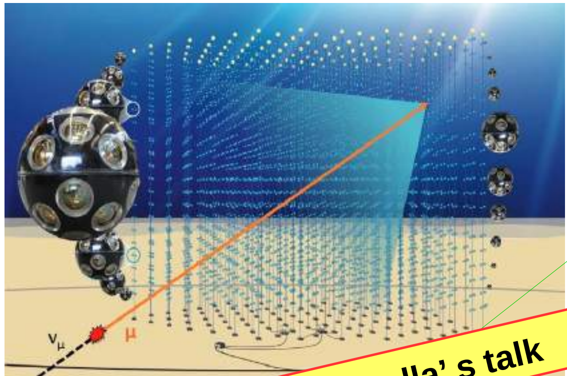


IEEE TRANSACTIONS ON PLASMA SCIENCE VOL. 40, NO. 9, SEPTEMBER 2012

The KM3NeT detector

S. Viola

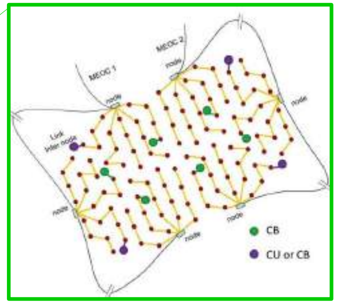
KM3NeT will be a distributed research infrastructure. A network of cabled observatories located in deep waters of the Mediterranean Sea. Centrally managed: common hardware, software, data handling and control.



See Marco Circella's talk

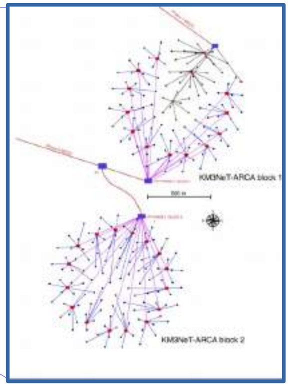
Letter of Intent for KM3NeT 2.0
2016 J. Phys. G: Nucl. Part. Phys. 43 084001

KM3NeT – ORCA (Phase 2)
Oscillation Research with Cosmics in the Abyss



- 1 building block
- 115 Detection Units (DU)
- 18 Digital Optical Modules (DOMs) equipped with 31 3''- PMTs
- 9 m inter DOM distance
- 6 Mton volume

KM3NeT -ARCA (Phase2)
Astroparticle Research with Cosmics in the Abyss



- 2 building blocks (few km among the blocks)
- 115 Detection Units (DU)
- 18 Digital Optical Modules (DOMs) equipped with 31 3''- PMTs
- 36 m inter DOM distance
- 1 km^3 volume

KM3NeT ARCA (Phase 2) performance

Project requests
DOMs position accuracy < 20 cm
DOMs orientation accuracy < 3°
Calibrated PMT amplitude response
Relative hit times accuracy ~ 1 ns

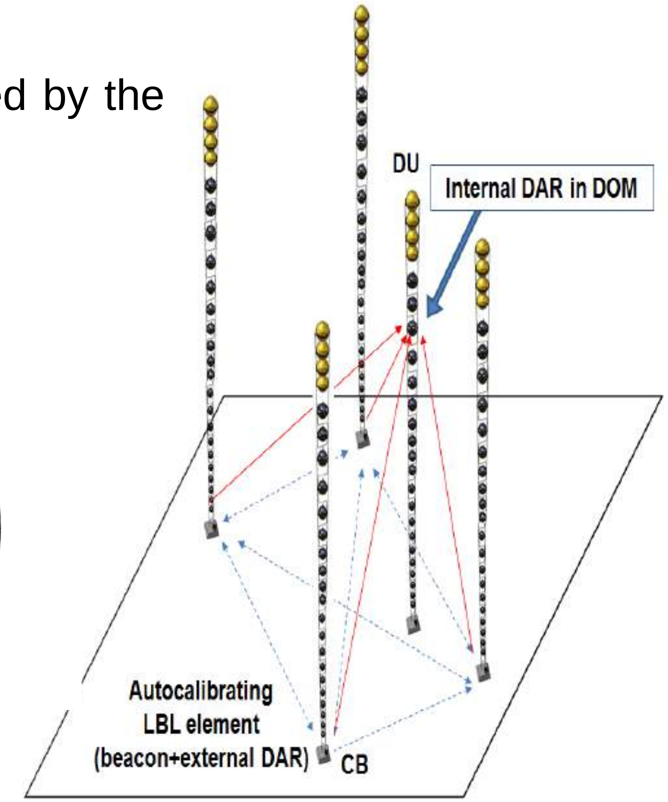
S. Viola

Relative timing adjustment

The time calibration of each PMT of the telescope is obtained by the combination of:

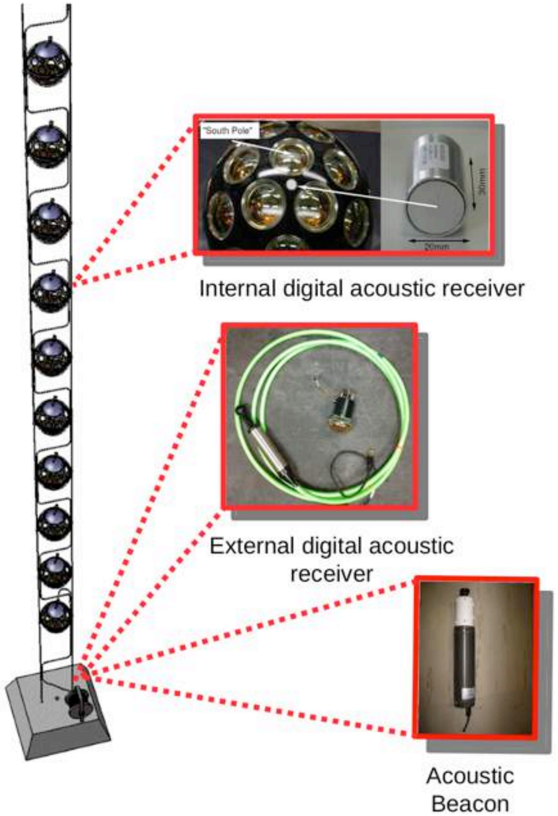
- Calibration of the shore station and seabed infrastructures (asymmetry measurements)
- Intra-DOM calibration 40K
- Inter-DOM calibration LED, muons
- Inter-DU calibration laser, LED, muons

Digital Optical Module (DOM)



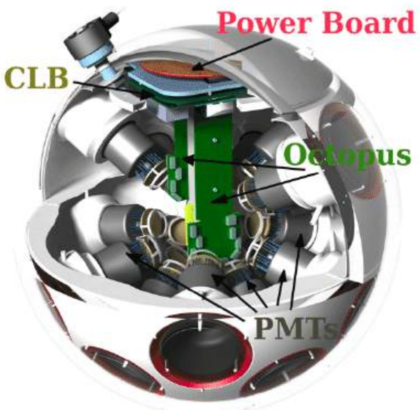
S. Viola

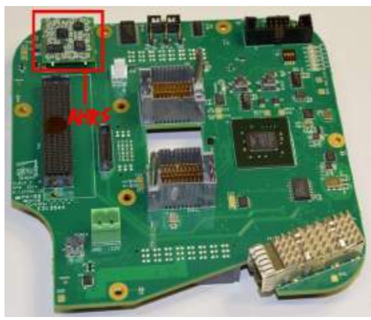
Positioning system



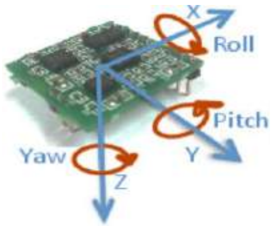
- **Beacon signals must be detected at distances of 1 km**
-
- **Suitable frequency range 20 kHz-50 kHz**
- ✓ **lowest level of PSD (~40 dB re 1 uPa²/Hz)**
- ✓ **attenuation (0-10 dB/km)**

Monitoring of the absolute orientation and acceleration of each DOM through an Attitude & Heading Reference System





Control Logic Board (CLB)



AHRS

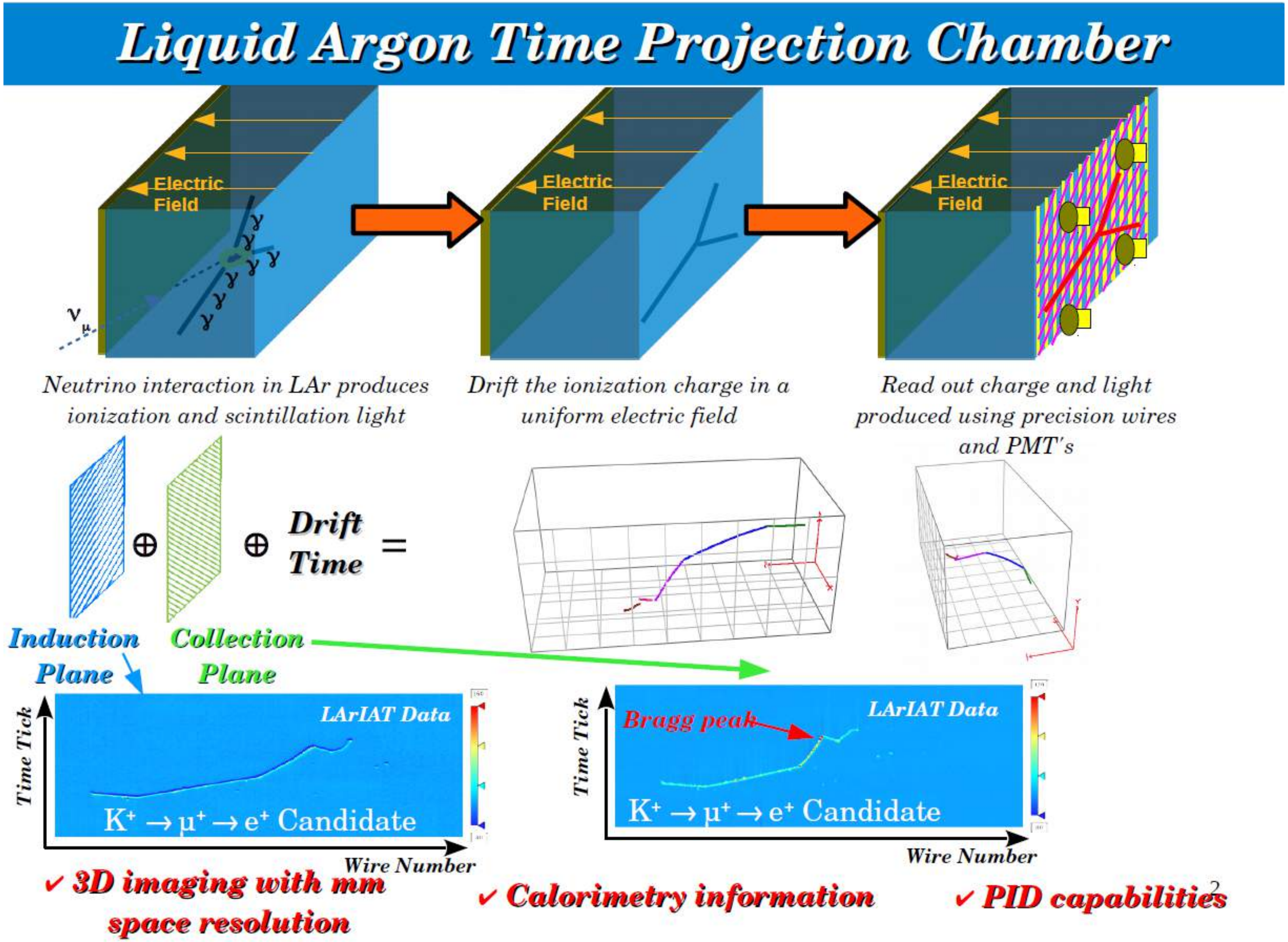
Attitude & Heading Reference System

- **Triaxial accelerometer** LIS3LV02DL
- **Triaxal magnetometer**
- HMC5843
-

LAr

Xin Qian prepared slides for single/double LAr

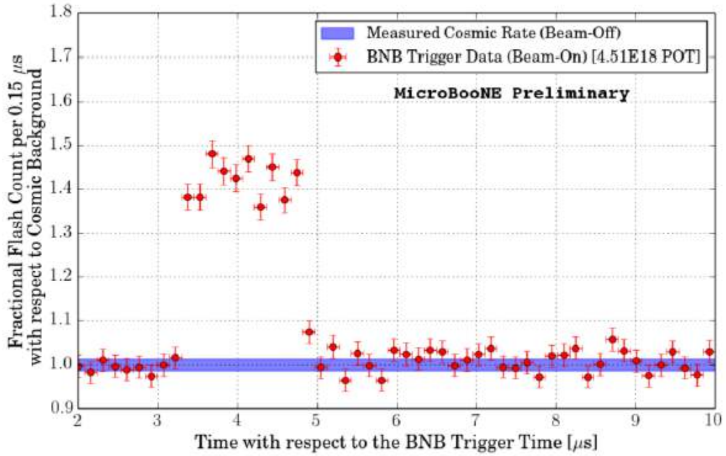
Single-Phase LArTPC (J. Asaadi)

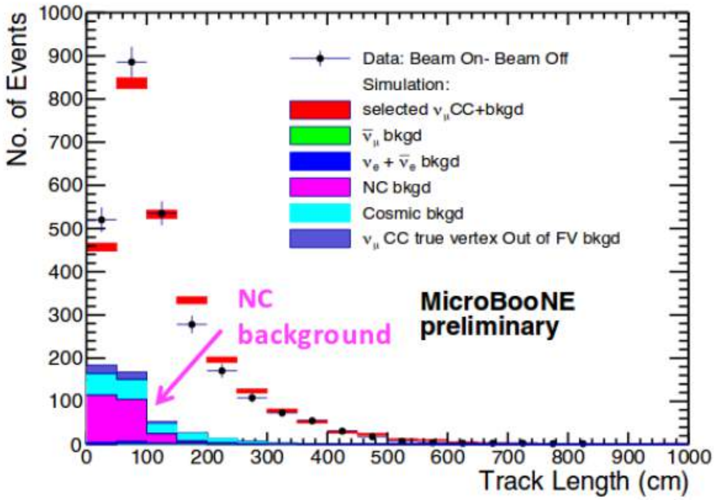


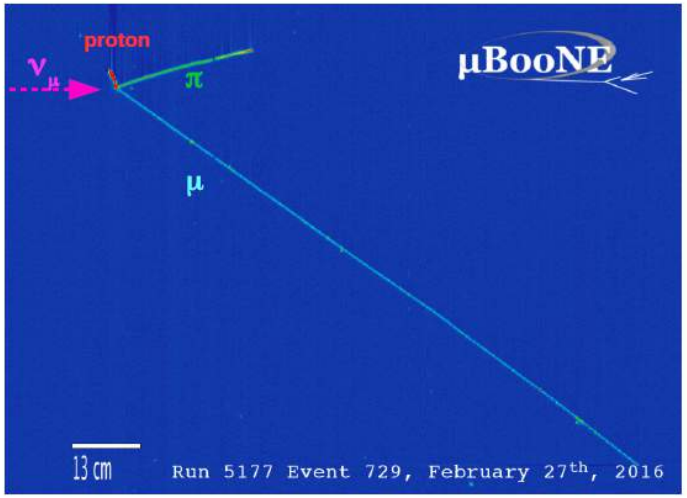
State-of-art Performance (J. Assadi)

Example of putting it all together: MicroBooNE

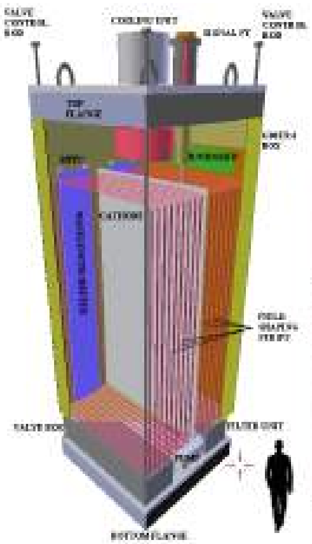
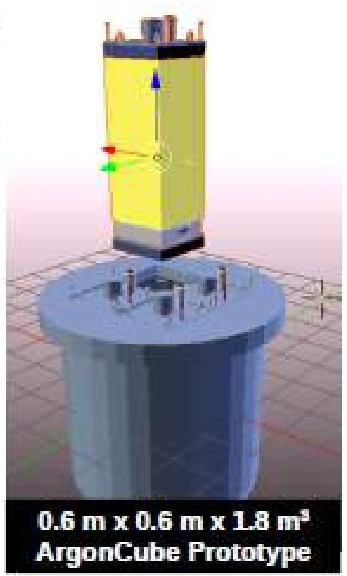
- **MicroBooNE has been successfully recording neutrino interactions since late 2015**
  - First neutrino results were announced just this year!

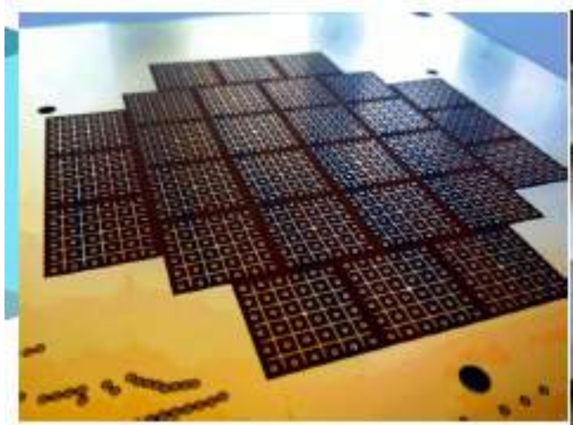


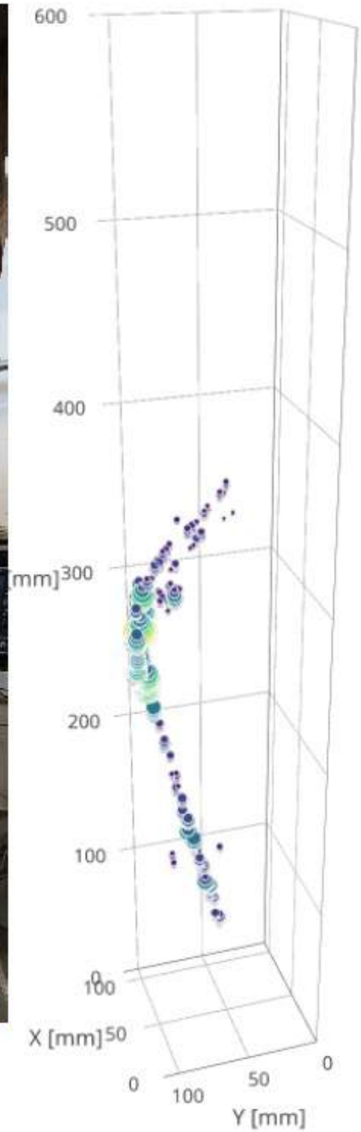




ArgonCUBE: R&D for the future (J. Asaadi)



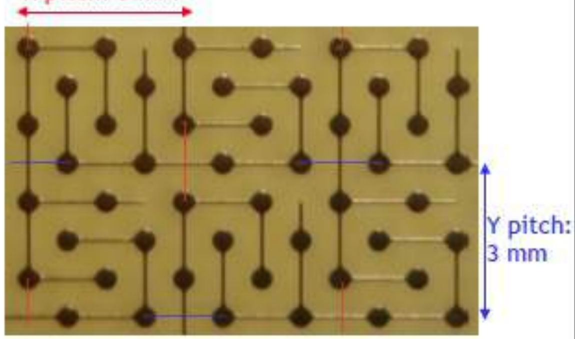


- 2D pixel-readout technology potential for the DUNE near-detector

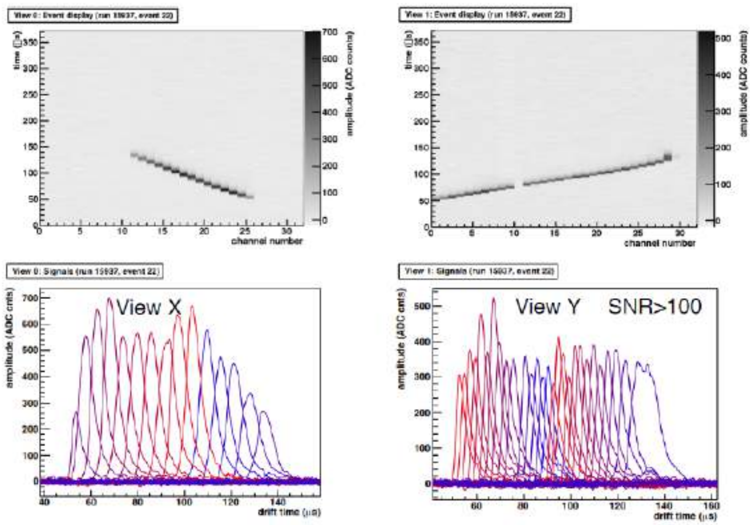
Double Phase LArTPC (Shuoxing)

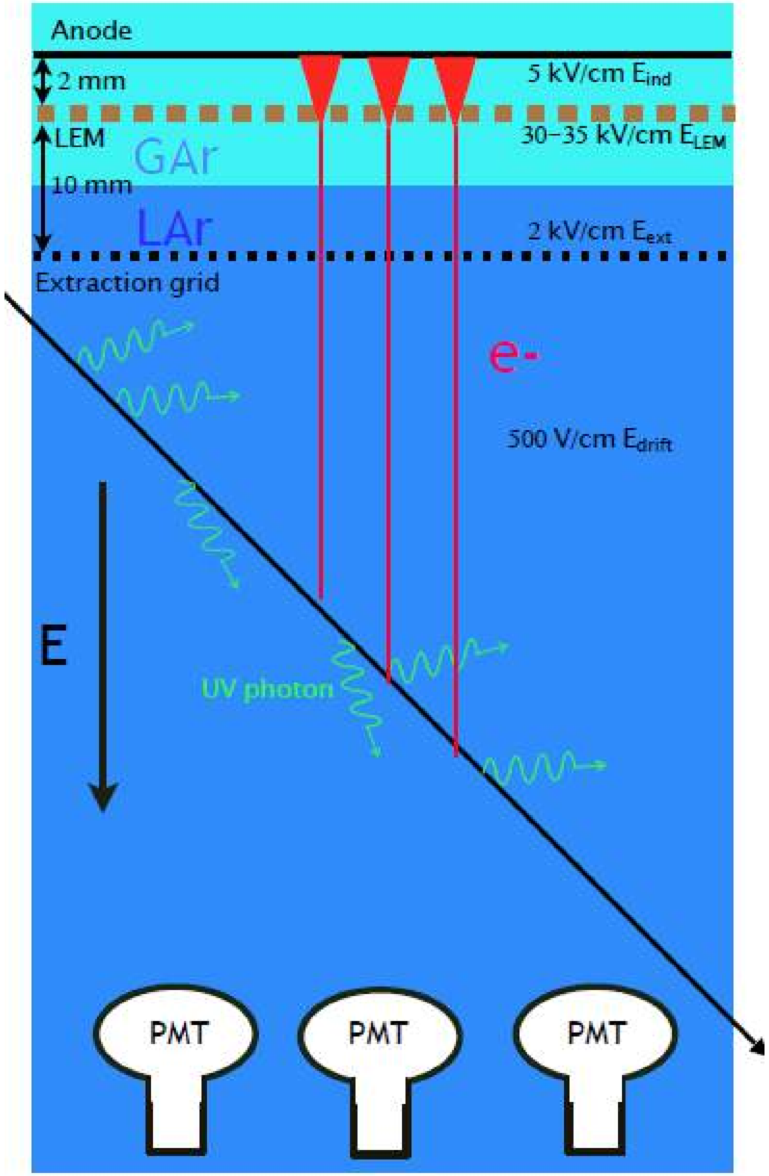
PCB type anode

Lower capacitance=lower noise



- 2 views on the same layer
- Inter-strip capacitance ~ 150 pF/m (input capacitance 450 pF for 3 m as DUNE)
- Industry production method (standard PCB technique)





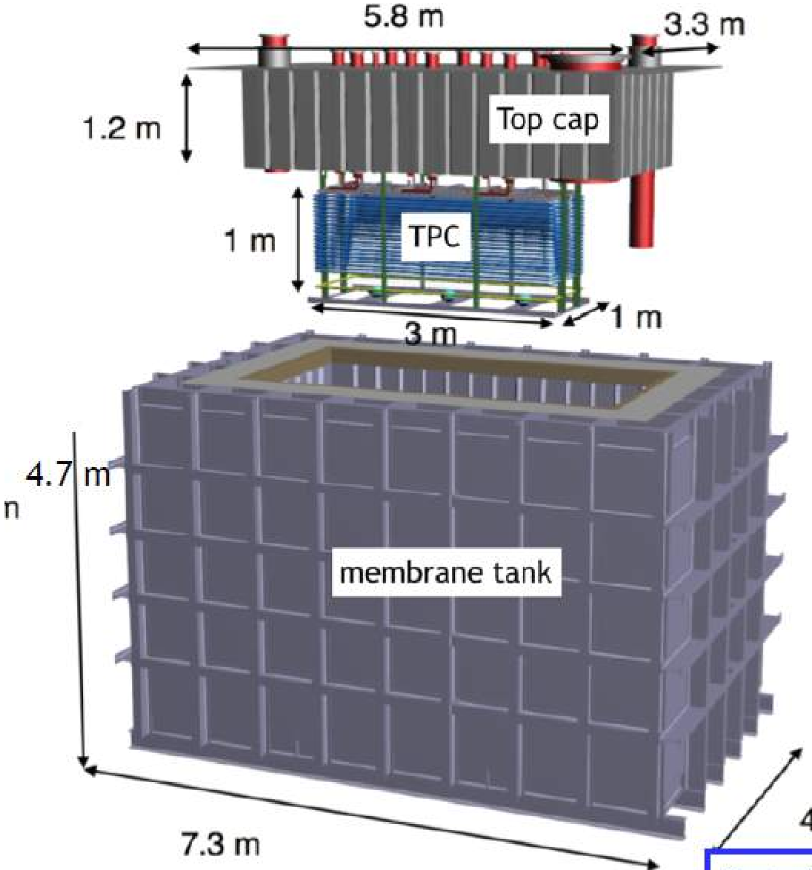
The WA105 experiment at CERN

– double phase LAr LEM TPC demonstrators

DLAr-proto

3x1x1 m³ active (24 ton LAr total)

- cosmic trigger only
- scaling up to 24 ton mass
- intermediate step towards 3x3 m² CRP

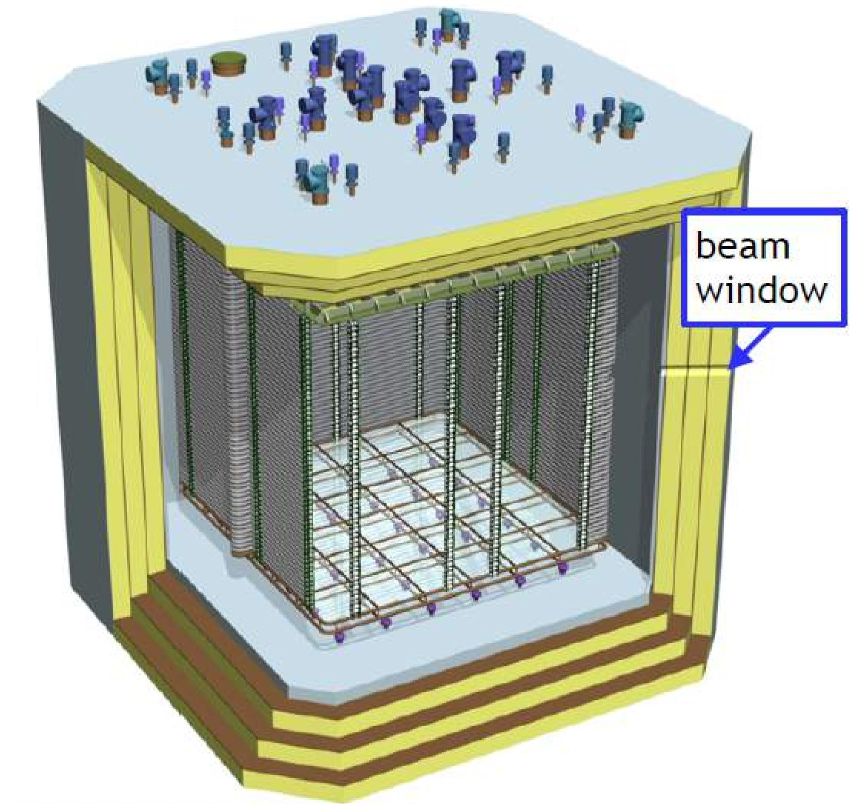


Operation November 2016

DLAr (ProtoDUNE-DP)

6x6x6 m³ active (700 ton LAr total)

- beam test data (CERN SPS)
- many interesting physics topics
- basic readout 3x3 m² CRP



Timescale: 2016-2019

Detailed progress will be reported on Saturday talk

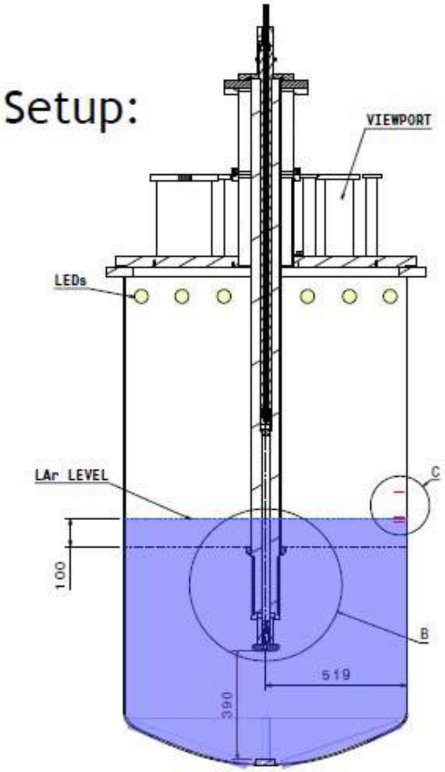
ETH

300 kV HVFT test

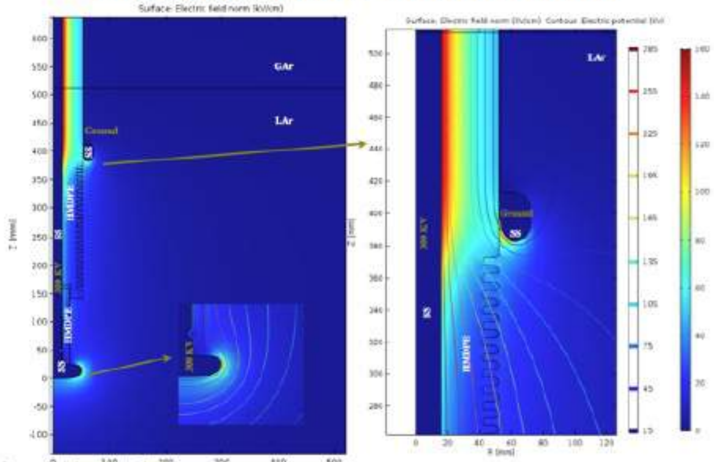
WA105

HV requirement for DP detectors:
WA105-6x6x6: -(300-600) kV
WA105-3x1x1: -(50-100) kV
DUNE-DP: -600 kV

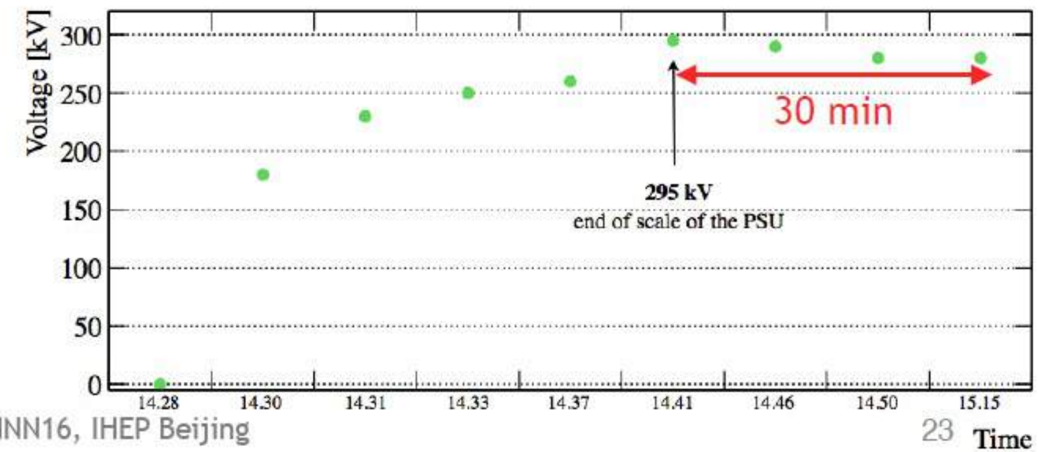
Setup:



Electric field simulation:



HV ramping-up history:

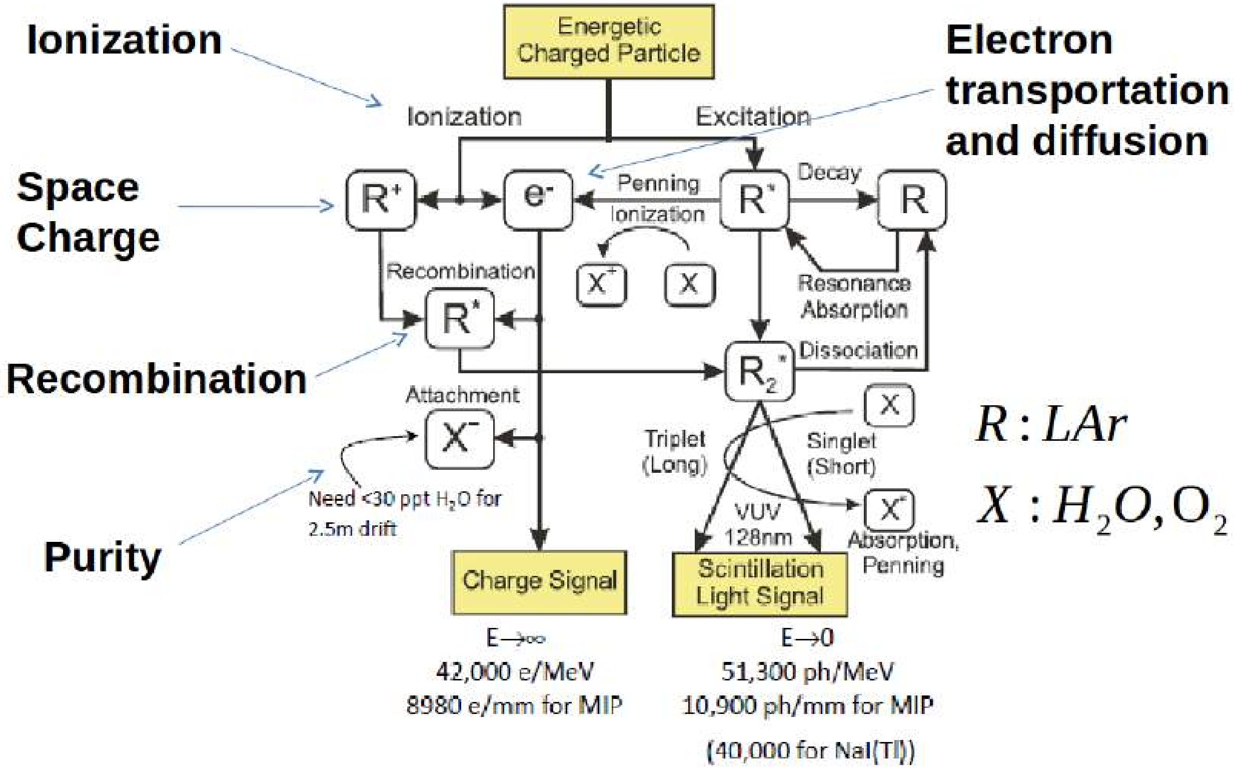


Calibration Scheme

BROOKHAVEN NATIONAL LABORATORY

- Must understand detector effects to develop LArTPC technology
  - Essential for SBN and DUNE
  - Noise removal, space charge effects (SCE), wire response, energy scale, diffusion, e- lifetime, etc.

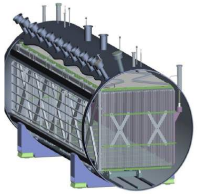
M. Mooney



$R : LAr$

$X : H_2O, O_2$

Important to understand detector effects and develop calibration scheme for unbiased, precise determination of ionization charge.

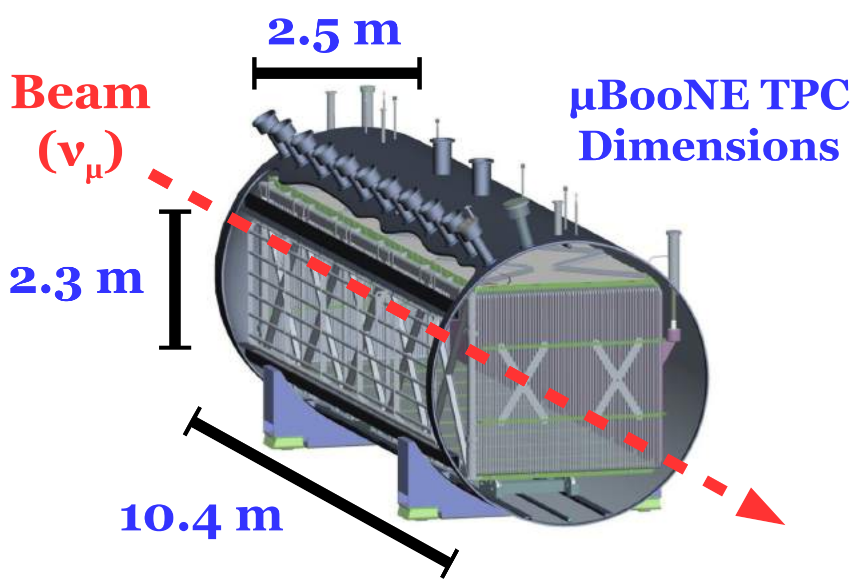


Case Study: MicroBooNE

M. Mooney

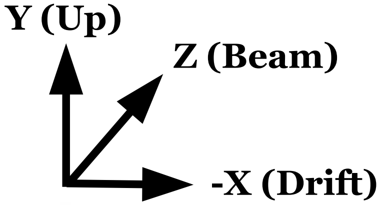
- "Micro Booster Neutrino Experiment"
  - Accelerator ν experiment @ FNAL
  - LArTPC with 89 ton active mass
  - Non-evacuated liquid argon fill
  - Cold (in LAr) front-end electronics
  - Near-surface operation
  - UV laser calibration system

- Physics goals:
  - Investigate MiniBooNE low-energy excess
  - Measure first low-energy ν-Ar cross sections
  - R&D for future detectors
  - Key step for Short Baseline Neutrino (SBN) program

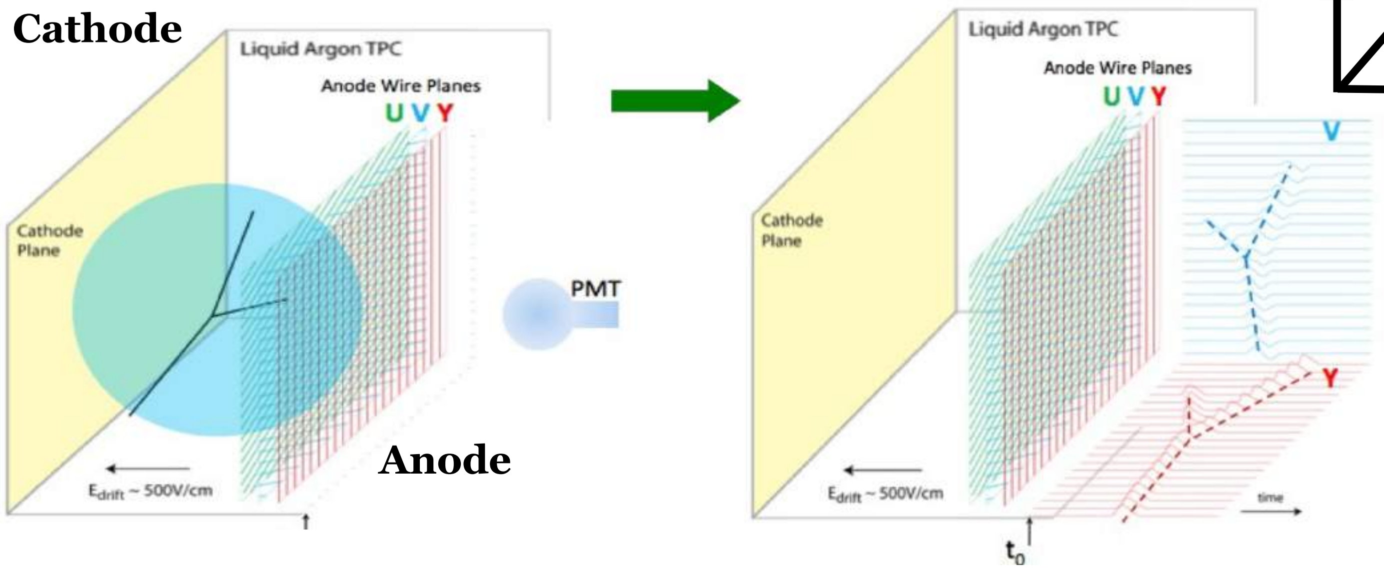


♦ 3D event reconstruction by combining signals from all three planes (minimum two needed), each with 3 mm wire pitch

- **Millimeter-scale spatial resolution**



NIM 120 (1974), no. 2, 221-236



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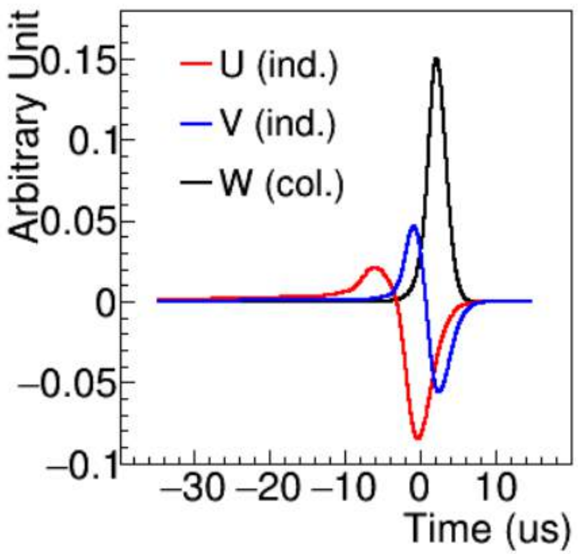
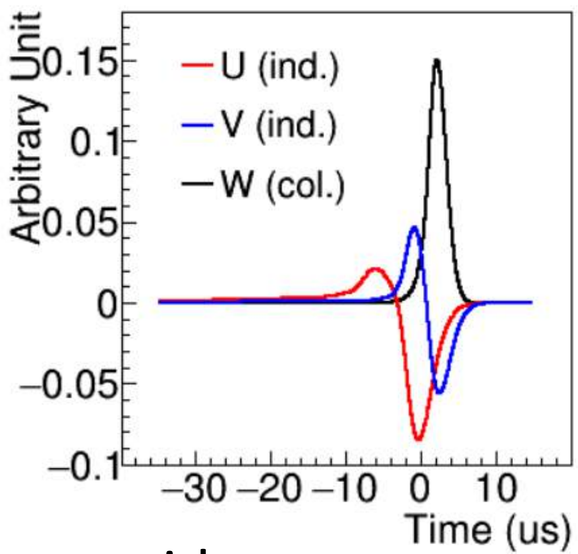


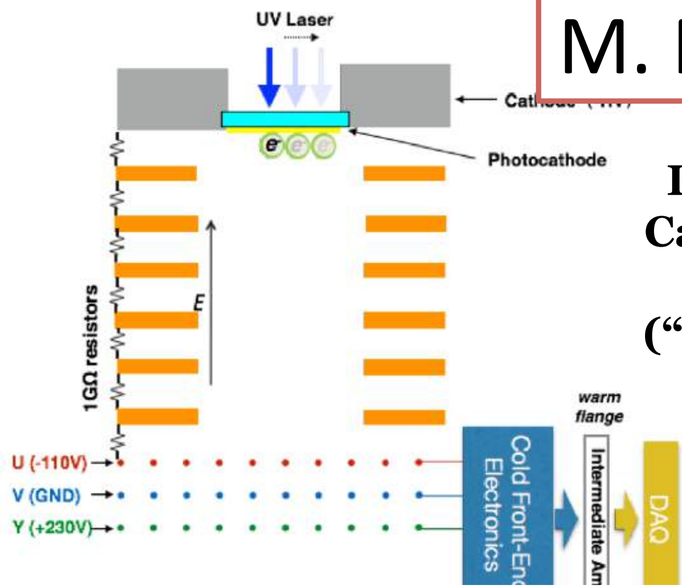
Must remove correct field response of wires in deconvolution to enable unbiased charge estimation

M. Mooney

Field Response Measurement

M. Mooney



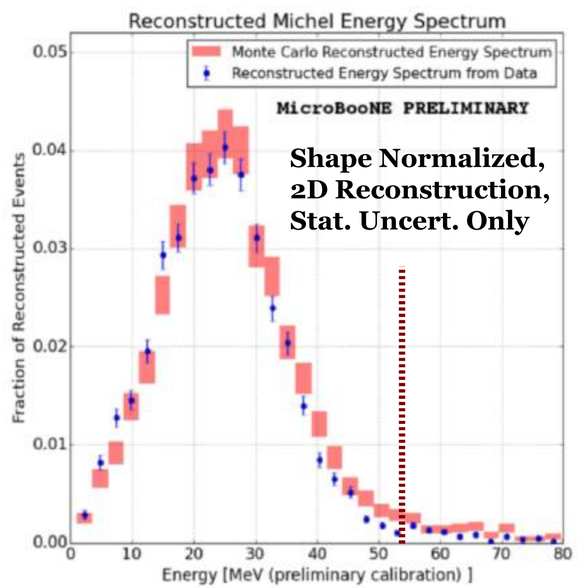


LAr Field Calibration System ("LArFCS")

Need to consider:

- Signal to nearby wires
- Space charge effect caused by slow drift of Ar+ by CR muons
- Electron lifetime
- Diffusion
- Charge clustering

➔ high-level candles: Michel electron



Summary

- To realize NNN, many people are working on various target materials (here, all liquid) and good progress they have:
  - pure LS/LS rich WbLS: low BG
  - water rich WbLS: light yield, attenuation, scintillation/Cherenkov, and filteration
  - H2O: more sophisticated, low cost detectors/calib
  - LAr: readout and detector response