Intermediate detectors per T2HK e gli upgrade del ND280

Gianfranca De Rosa INFN-Napoli
What Next, Padova 1 Dicembre 2014

ND280 Upgrade for T2K-T2HK

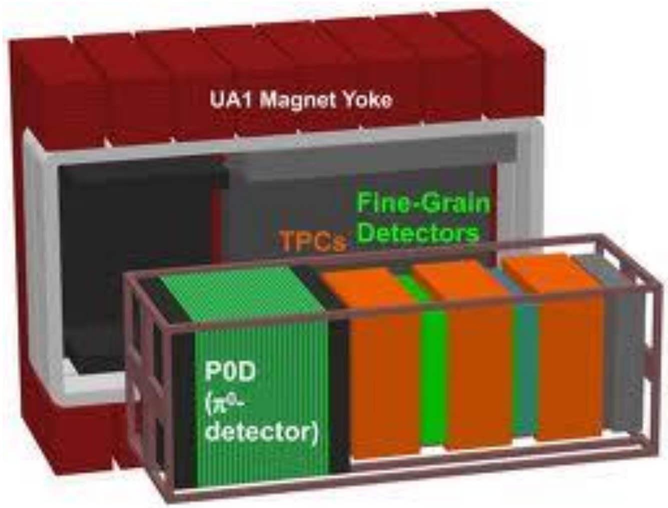
Several studies being performed for a possible upgrade

- Water target with vertex information
  - water based scintillator target
  - high pressure TPC, fiber tracker

- Enhancement on side/backward going tracks
  - Trip-t electronics upgrade or better calibration

- Neutrino-nucleon cross section for model input
  - D_2O and CH targets

ND280 Upgrade for T2K (T2HK)



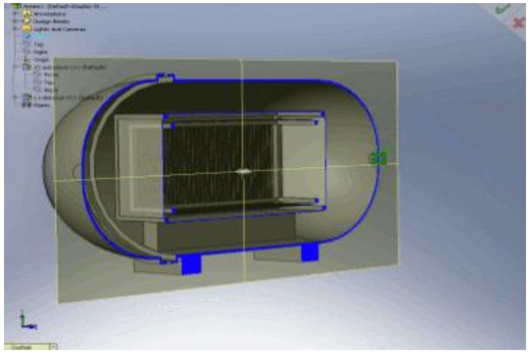
ν_e	Systematic sources(%)	ν_μ
3.1	Flux & Combined Cross-Sections	2.7
4.7	Independent Cross Sections	5.0
2.4	Pi Hadronic Interactions (FSI)	3.0
2.7	SK Detector Efficiencies	4.0
6.8	**TOTAL**	**7.6**

1) ND280 improvements:

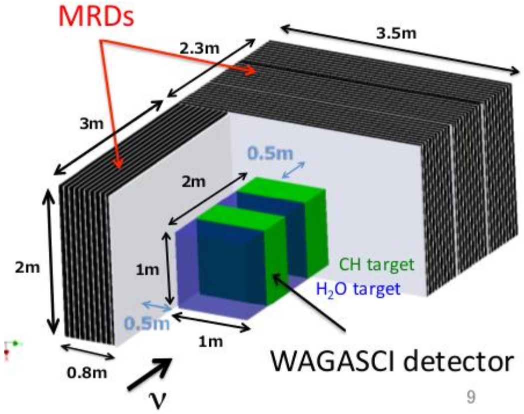
- Replace with D_2O to the FGD2 and PØD water layers. Quasi-free neutron target.
- Replace scintillator with WbLS to measure deposited charge from water/D_2O layers.

2) Add new detectors in the 280m pit:

High Pressure TPC (HPTPC):

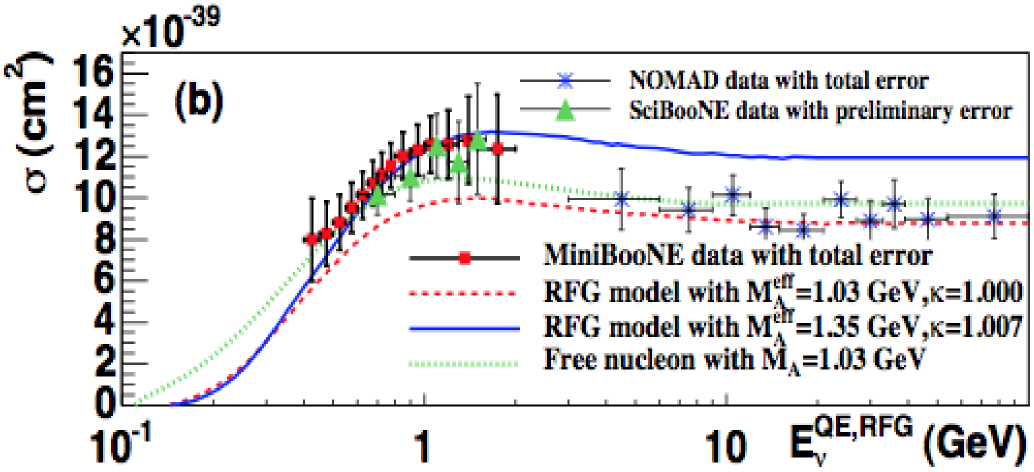


Water-grid scintillator detector:

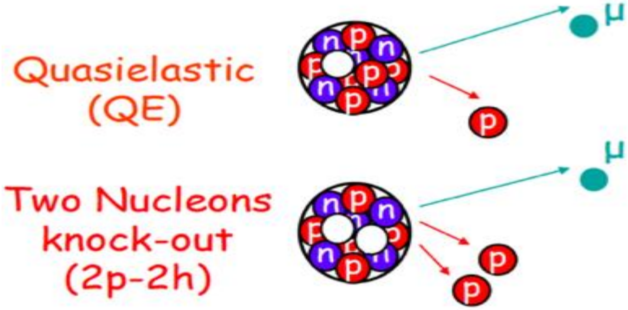


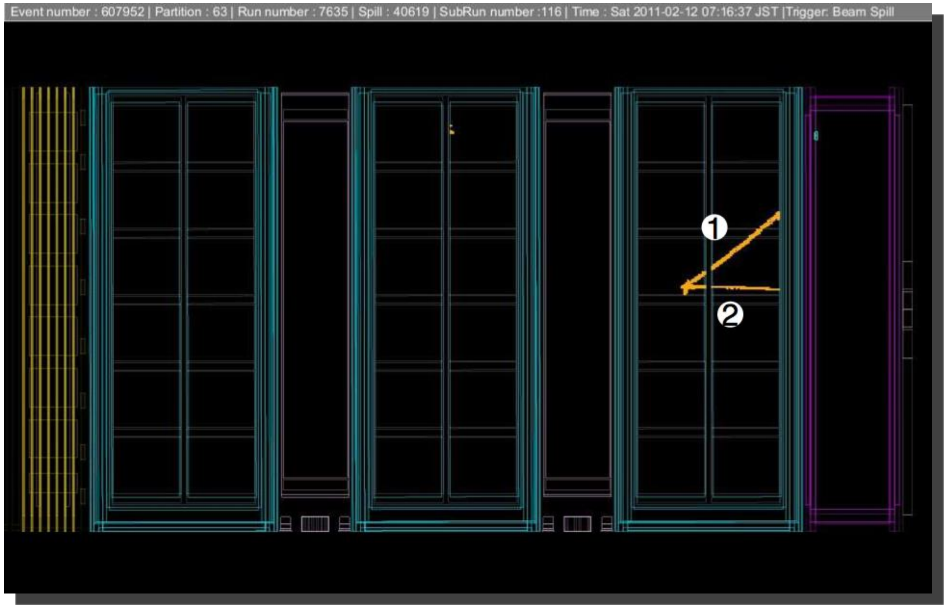
High-Pressure Gas TPC

- Significant discrepancies on proton multiplicity and momentum distributions
- Need low momentum threshold to reduce xsec systematics
- Important differences lie below threshold for liquid detectors



arXiv:1002.2680 [hep-ex]




Event number : 607952 | Partition : 63 | Run number : 7635 | Spill : 40619 | SubRun number :116 | Time : Sat 2011-02-12 07:16:37 JST |Trigger: Beam Spill

HPTPC:

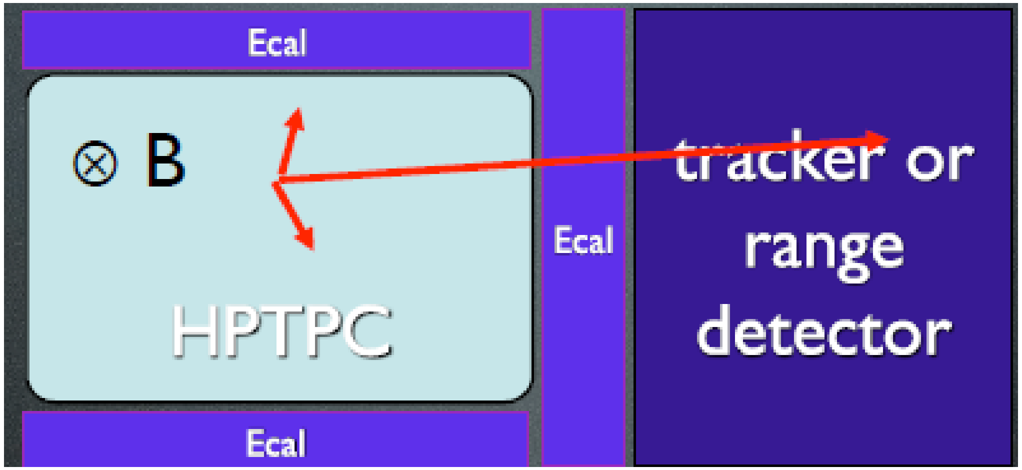
- to study low momentum final state particles and in particular resolve vertex
- to reduce xsec systematics

*** Possibile interesse INFN**

High-Pressure Gas TPC

The ND280 tracker and P0D can be replaced with a high pressure time projection chamber

- Sensitive to <100 MeV/c protons
- High momentum particles are measured with a tracker or range detector
- Surrounded by a calorimeter for neutral particle containment
- Several different nuclear targets can be used/alternated:
  He, Ne, Ar, CF_4 to study A-dependence of cross sections and FSI

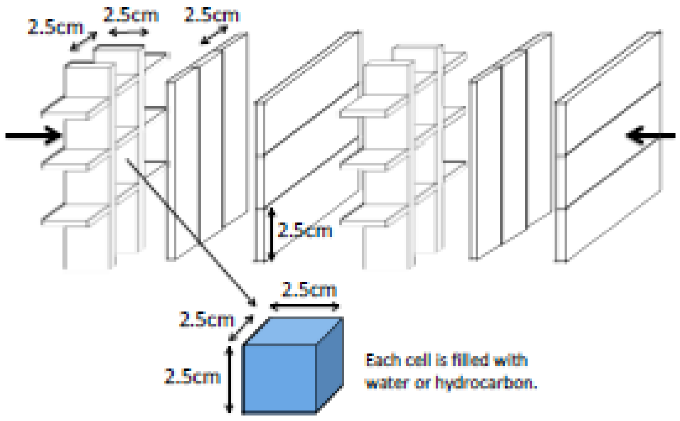


New detectors in the 280m pit

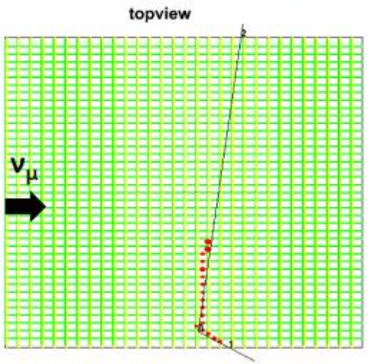
Water-grid scintillator detector

Goals:

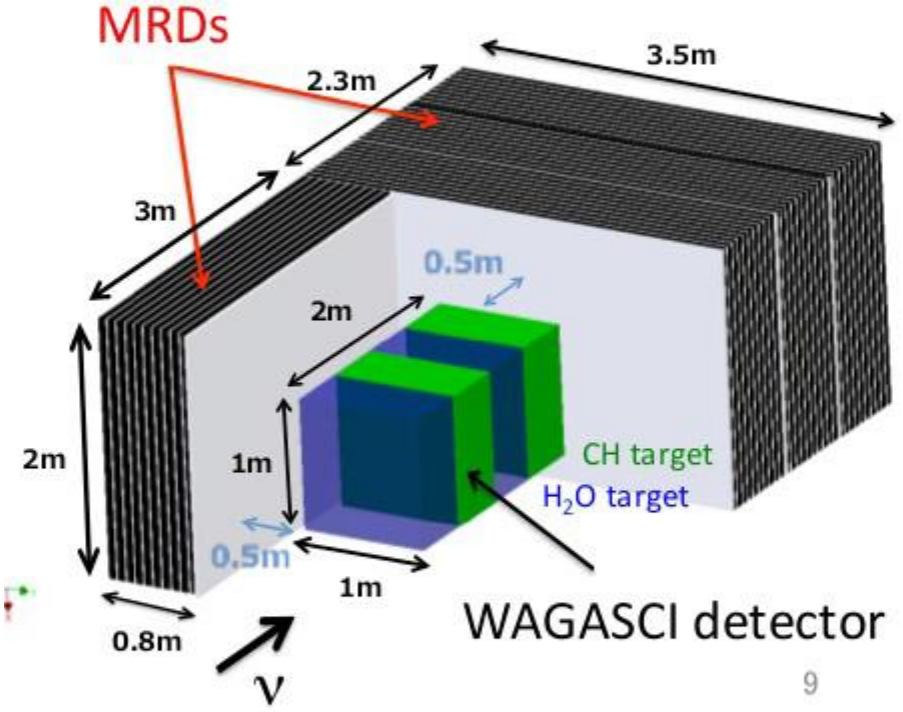
- H_2O to CH cross section ratios with 3% accuracy
- Cross sections on H_2O and CH with 10% accuracy



H_2O/CH detector
(3D grid-like structure)

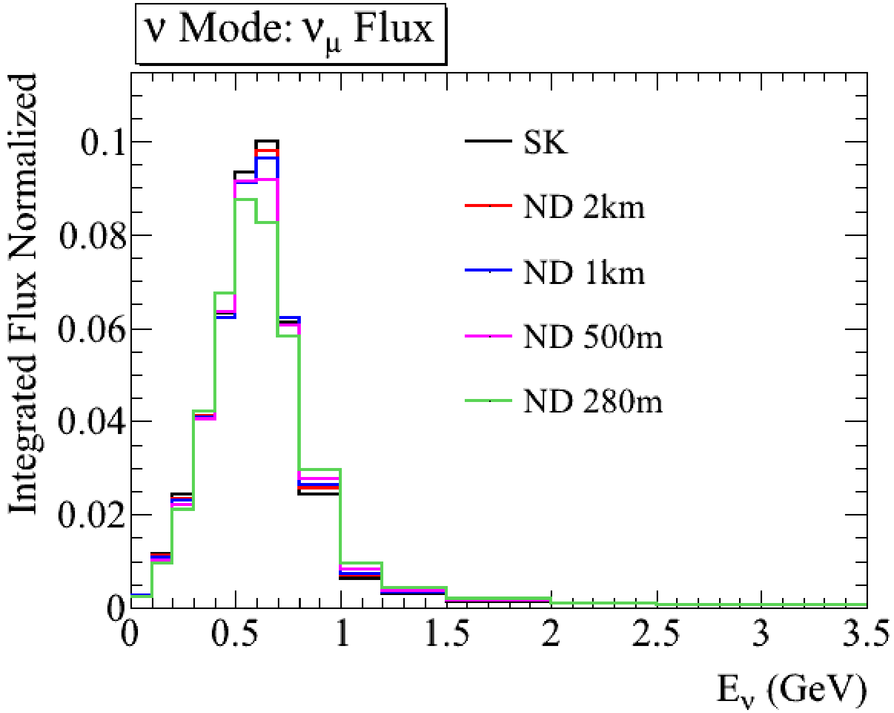


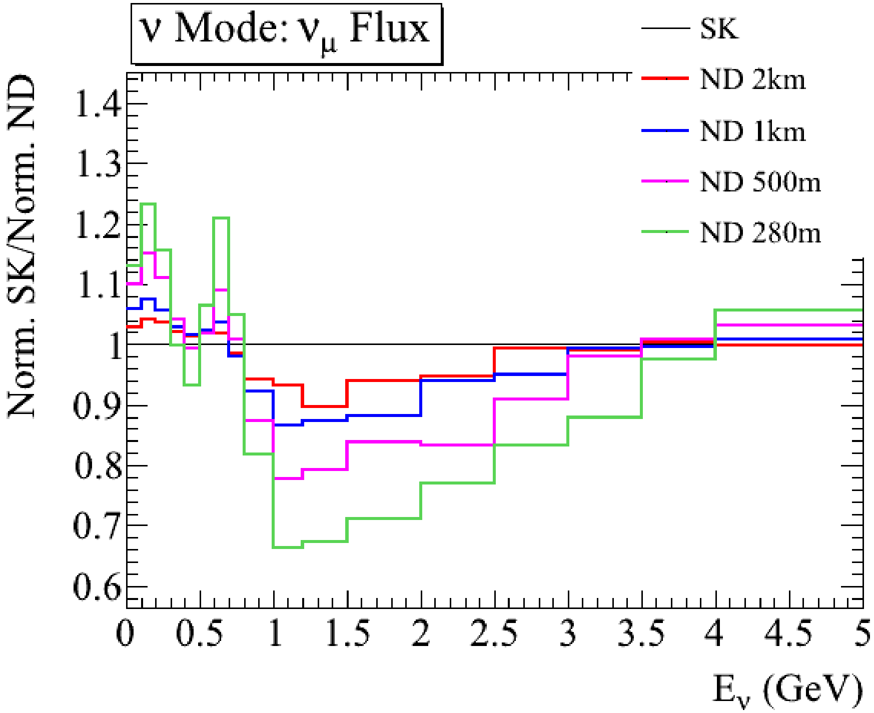
Box for
Japanese sweets (Wagashi)



WAGASCI detector

Additional Near Detectors





At 280m: neutrino source not point-like, spectral differences with respect to SK

Neutrino spectra at SK and 2km are almost the same: ~same beam → energy spectrum

To improve our current precision we need to improve our errors on the flux predictions

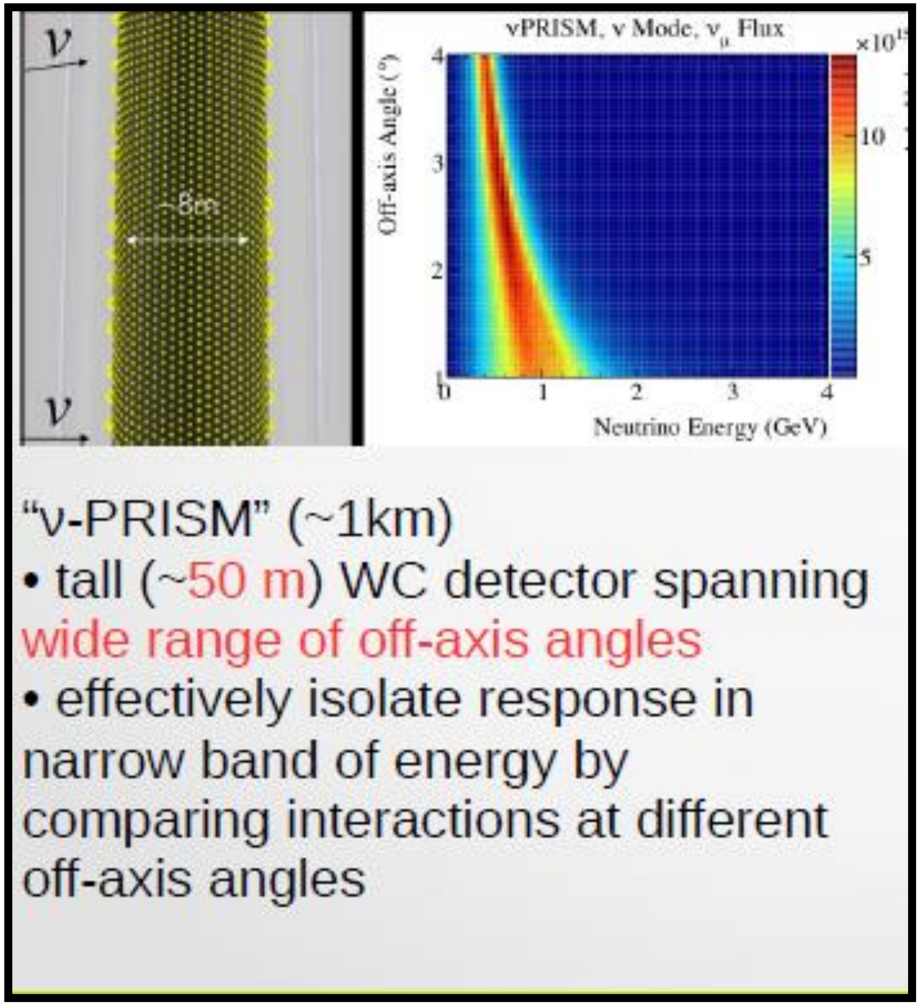
Additional Near Detectors

Build new detectors at 1-2km:
New cavern needed to host the detector.

More distant from target than 280 m, to minimize the near to flux extrapolation

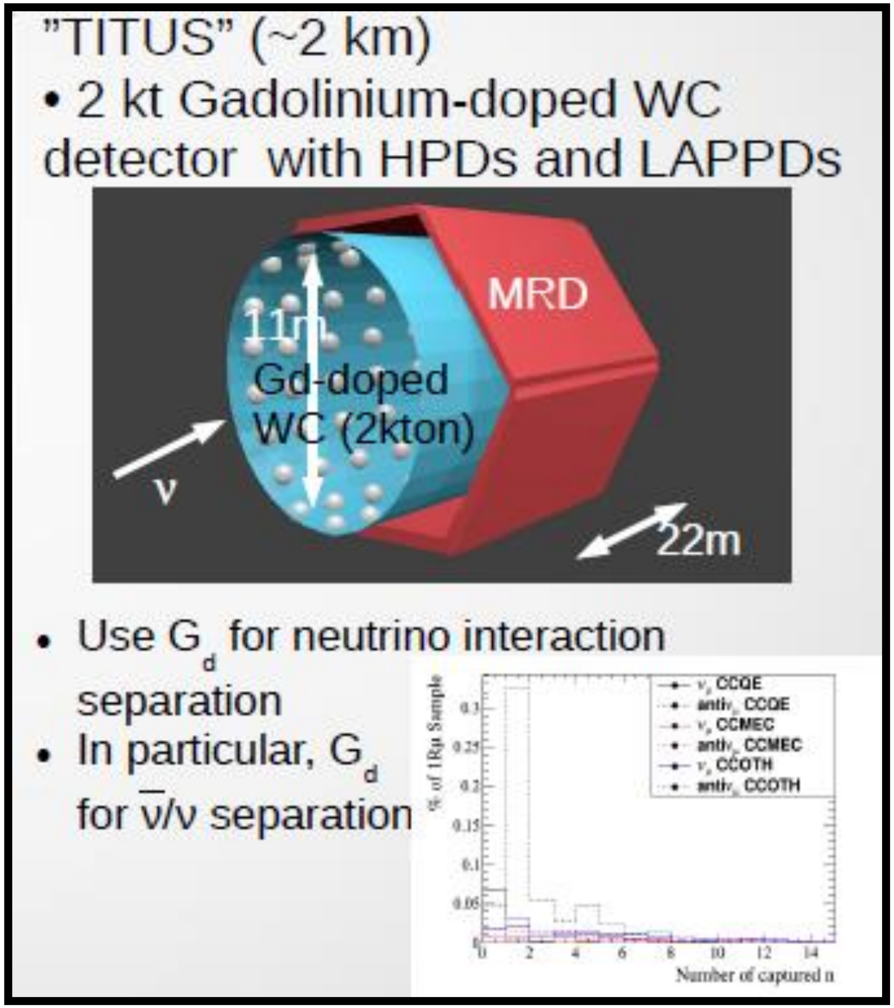
- Adopted technology is WC
- Same detector as far detector → minimize error propagation

Additional Near Detectors



"ν-PRISM" (~1km)

- tall (~50 m) WC detector spanning wide range of off-axis angles
- effectively isolate response in narrow band of energy by comparing interactions at different off-axis angles



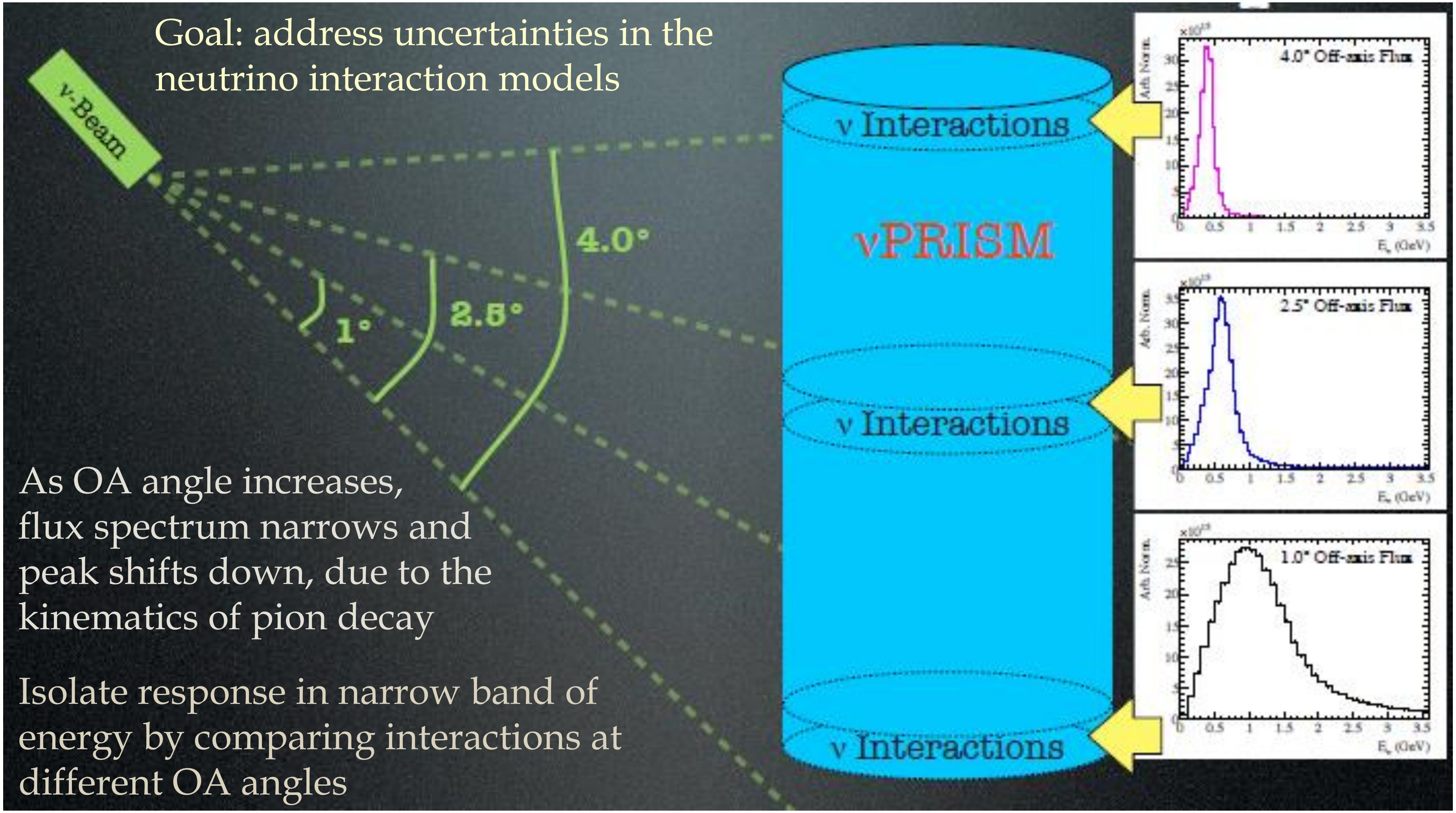
"TITUS" (~2 km)

- 2 kt Gadolinium-doped WC detector with HPDs and LAPPDs

- Use G_d for neutrino interaction separation
- In particular, G_d for $\overline{\nu}$/ν separation

νPRISM

ν **P**recision **R**eaction **I**ndependent **S**pectrum **M**easurement

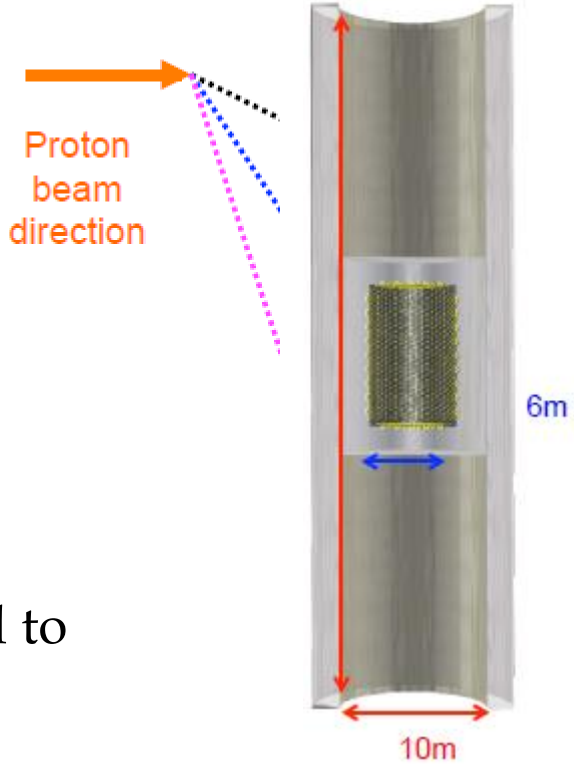


Goal: address uncertainties in the neutrino interaction models

As OA angle increases, flux spectrum narrows and peak shifts down, due to the kinematics of pion decay

Isolate response in narrow band of energy by comparing interactions at different OA angles

νPRISM



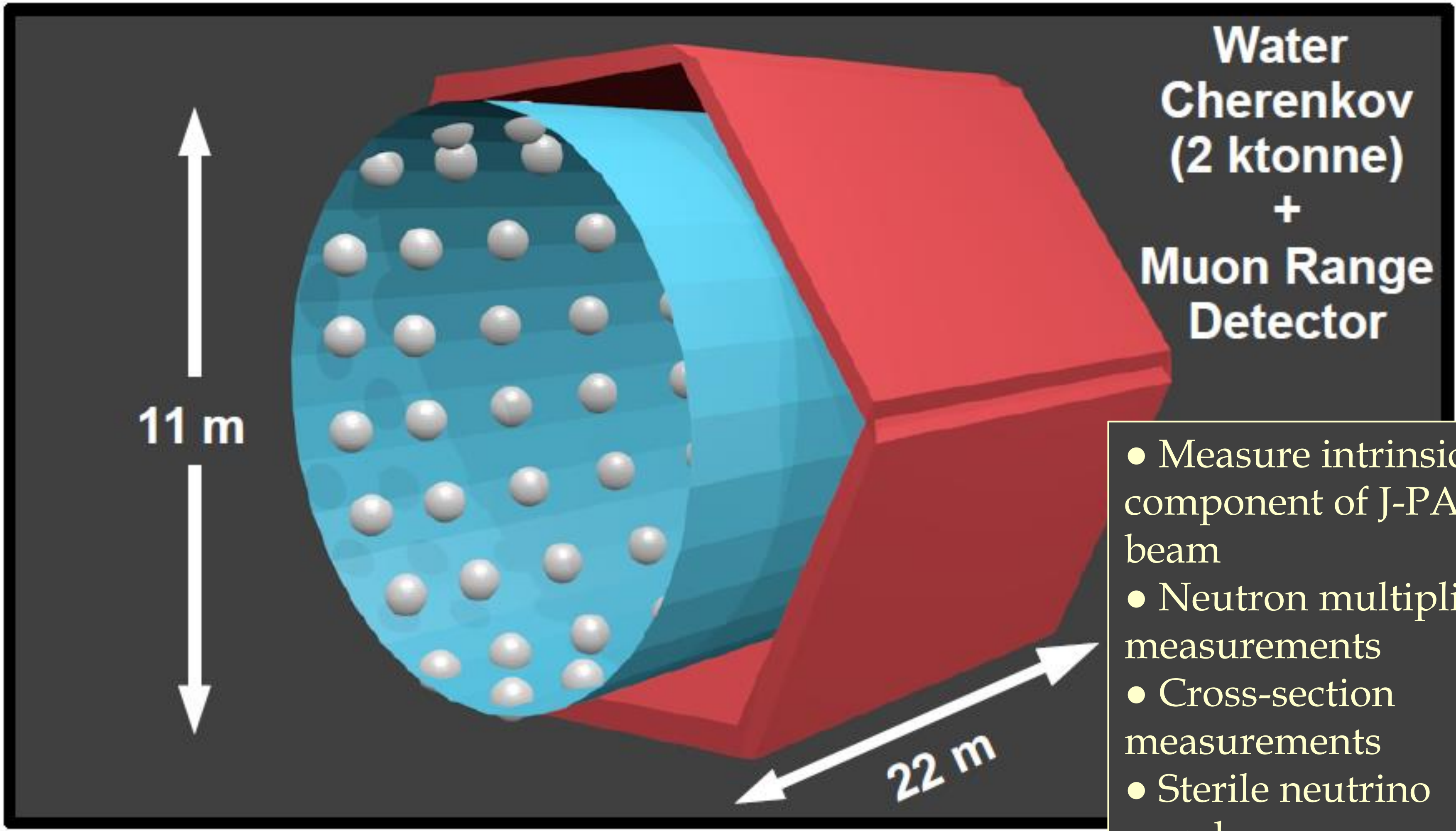
At 1km, to cover 0° – 6° would require a vertical depth of ~70m
§ Water Cherenkov detector with ~40% PMT coverage
§ Further cost reduction by instrumenting a movable portion of the detector
§ Detector assumes containment of up to p_μ=1 GeV/c muons
§ 6m inner diameter, 10m including outer detector

The νPRISM concept provides a data driven method to address uncertainties on the cross section model by using a combination of fluxes in a single detector

§ Can create a monoenergetic neutrino beam or an oscillated flux
§ Preliminary studies indicate significant reduction to bias in a realistic T2K-style analysis and beam
§ Novel cross section program and sterile search capability

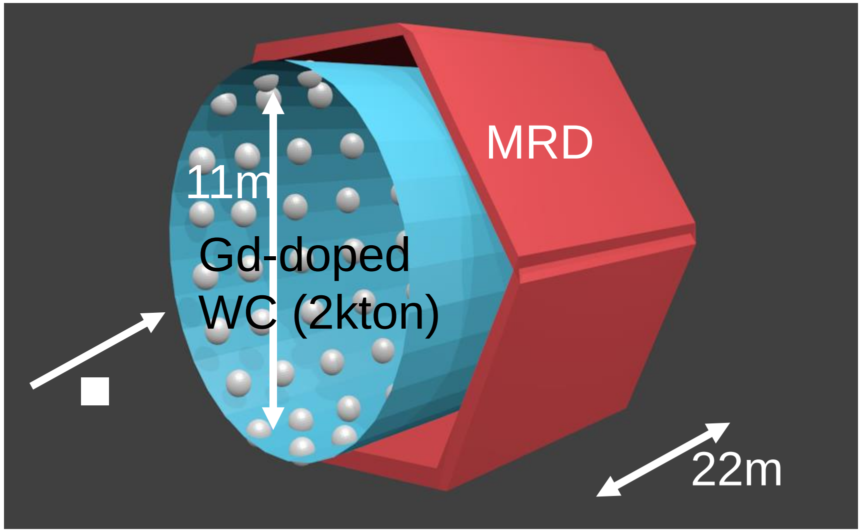
TITUS

The **T**okai **I**ntermediate **T**ank w/ **U**noscillated **S**pectrum



- Measure intrinsic ν_e component of J-PARC beam
- Neutron multiplicity measurements
- Cross-section measurements
- Sterile neutrino searches

TITUS Overview



Baseline design includes:

- 2 kton water Cherenkov tank
- **0.1% Gadolinium-doping**
- Partly enclosed by Muon Range Detector
  - Fe & plastic scintillator
  - End: 100 or 150 cm Fe
  - Side: 50 cm Fe (up to 75% coverage)

TITUS aims to use the Gadolinium as a tool to improve beam physics selection

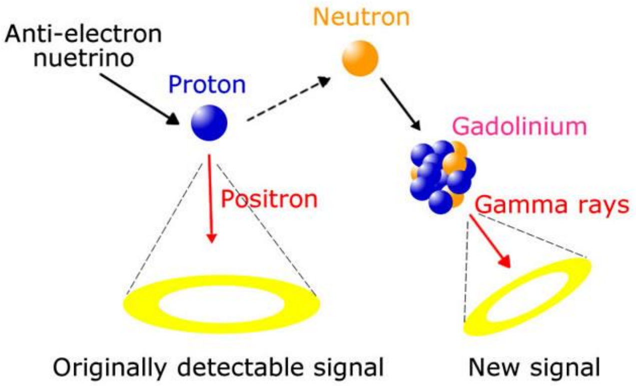
Add-ons / upgrades currently being investigated include:

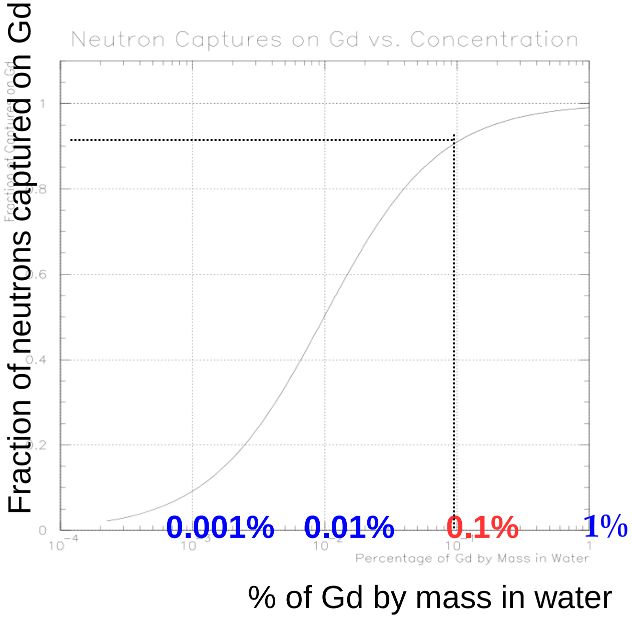
- Magnetised MRD (1.5 Tesla field) for charge-sign reconstruction
- Gd-doped water-based liquid scintillator

Gadolinium Doping

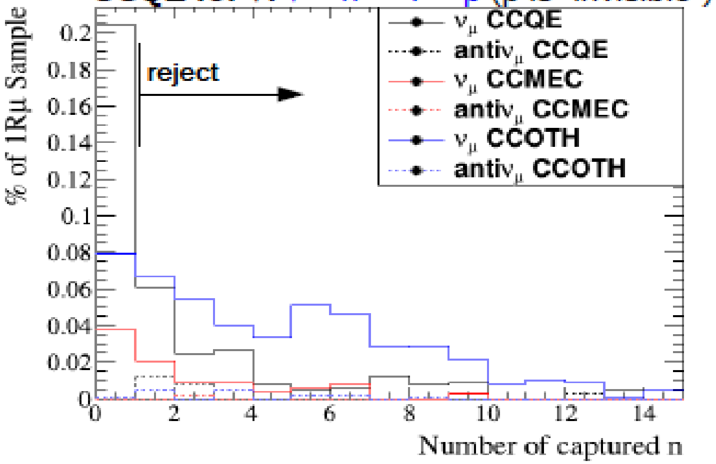
- **CCQE for ν:** $\nu + n \rightarrow l^- + p$ (p is "invisible")

  CCQE for $\bar{\nu}$: $\bar{\nu} + p \rightarrow l^+ + n$
- In ordinary water: n thermalizes, then captured on a free proton (H)
  - Capture time is ~200 msec
  - 2.2 MeV gamma emitted
  - Detection efficiency @ SK is ~20 %
- When n captured on Gd:
  - Capture time ~20 msec
  - ~8 MeV gamma cascade
  - 4 - 5 MeV visible energy
  - 100% detection efficiency
- 0.1% Gd concentration results in ~90% of neutron capturing in Gd
- Currently, EGADS experiment is investigating doping with gadolinium sulfate [$Gd_2(SO_4)_3$]



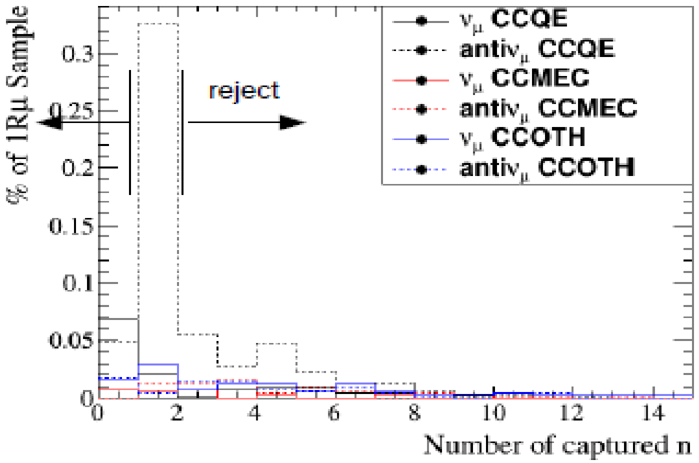


Gadolinium Doping



Beam in neutrino mode

CCQE for ν: $\nu + n \rightarrow l^- + p$ (p is "invisible")



Beam in anti-neutrino mode

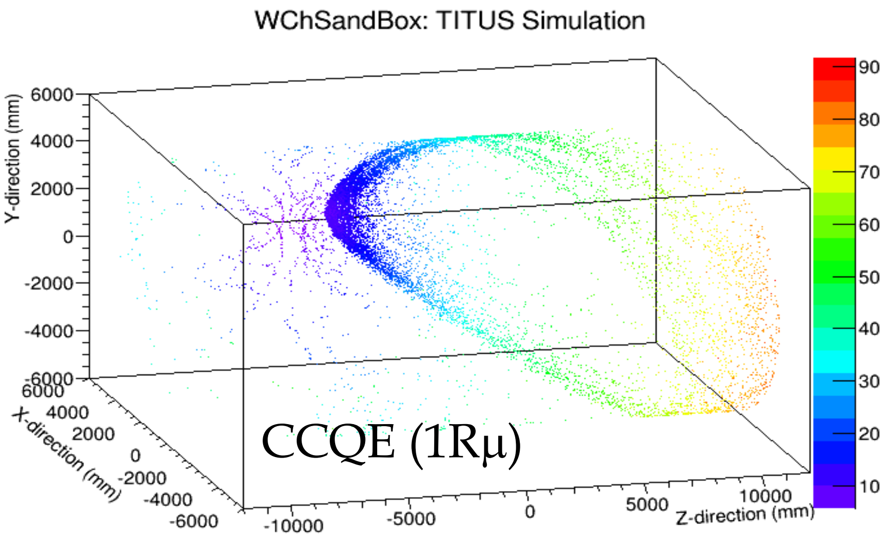
CCQE for $\bar{\nu}$: $\bar{\nu} + p \rightarrow l^+ + n$

- Use measured neutron multiplicity spectrum to:
  - Select "almost background-free" signal events
  - Highly improved neutrino and antineutrino separation in beam

- Enhanced sample purities:
  - ν_μ CCQE: 37% → **63%** with n = 0 requirement
  - $\bar{\nu}_\mu$ CCQE: 55% → **82%** with n = 1 requirement

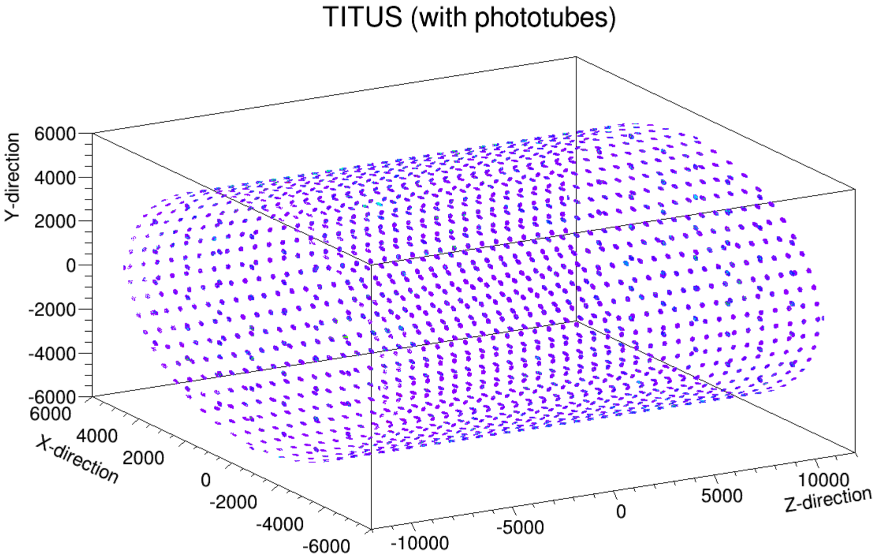
Future Gd-doped WC Detectors:
GADZOOK! Project, EGADS detector in Kamioka, ANNIE, WATCHMAN (WATer Cherenkov Monitoring of AntiNeutrinos), Advanced Scintillator Detector Concept (ASDC, *arXiv*:*1409.5864*)

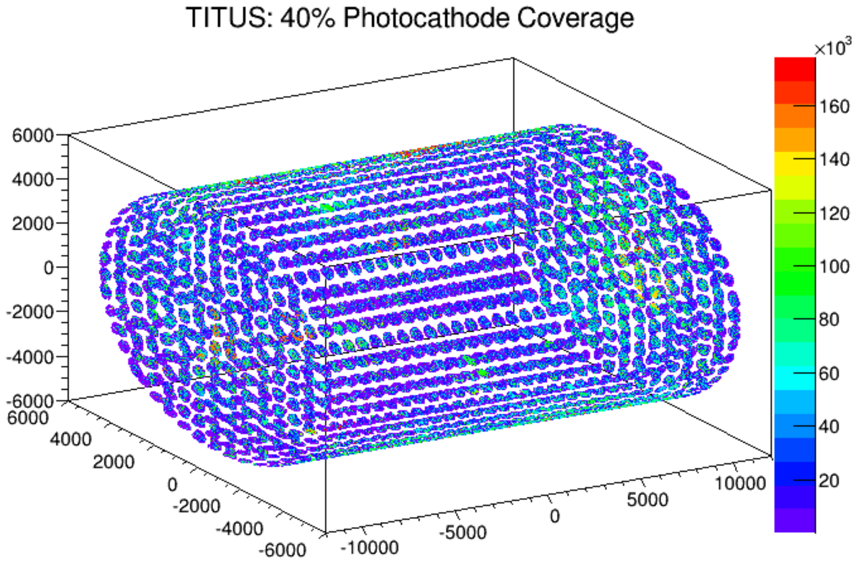
TITUS -WC Simulation


WChSandBox: TITUS Simulation

Photosensor optimisation currently underway:

- Four arrangements: 20″ PMT, 12″ PMT, 8″PMT, 8″ PMT + LAPPD
- Two coverages: 20% (HK), 40% (SK)


TITUS (with phototubes)


TITUS: 40% Photocathode Coverage

1 kton WC Prototype Detector

Japan, 2013/06: Awarded grant-in-aid for ~$1.2M.
Goals of the Prototype Detector (Shiozawa):

- Test of photo-sensors
- Feasibility study of HK water sealing
- Other possible items to be tested
  - DAQ electronics (under water?)
  - Outer detector photo-sensors
  - Automated calibration system
  - ...

TITUS: Possibile interesse INFN

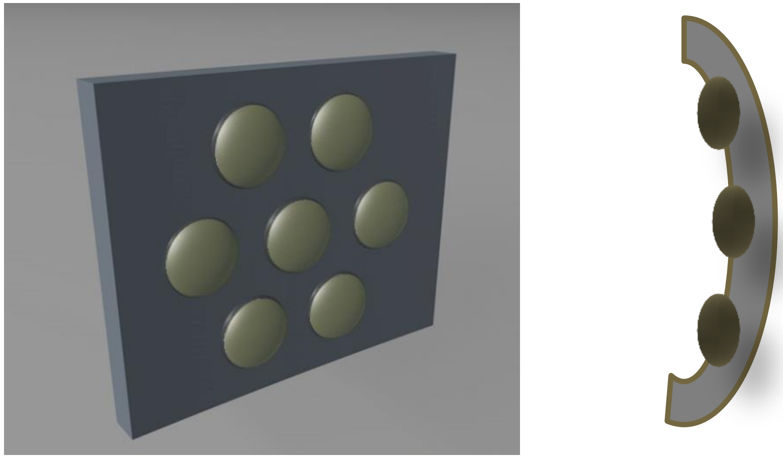
Photon detector System

From Km3Net experience
Multi-PMT system with small PMTs (DOM)

Use small PMTs

- Almost uniform coverage
- Photon counting
- Several manifacturer of small PMTs

Km3Net DOM



Proposed TITUS DOM

- studies on granularity for background rejection
- Studies on fiducial volume based on dedicated GEANT4 based simulation of Water Cerenkov detector

Photon detector System

Titus DOM:

- Define adequate design for application in Titus
  - At this stage, we suppose an exagonal structure with seven 3’’ PMTs
  - To be studied on the basis of GEANT4-based simulazion
- Demonstrate technical feasibility (very important to this, experience of Naples group in Km3Net DOM assembling and testing)
- Test in WC test detector in construction at Tokai site

This task is integrated into the activity of project JENNIFER (Proposal No: 644294 - JENNIFER - MSCA-RISE, Strategic objective: H2020 MSCA-RISE-2014), just approved by EU and currently in the phase of Grant Agreement signing procedure.

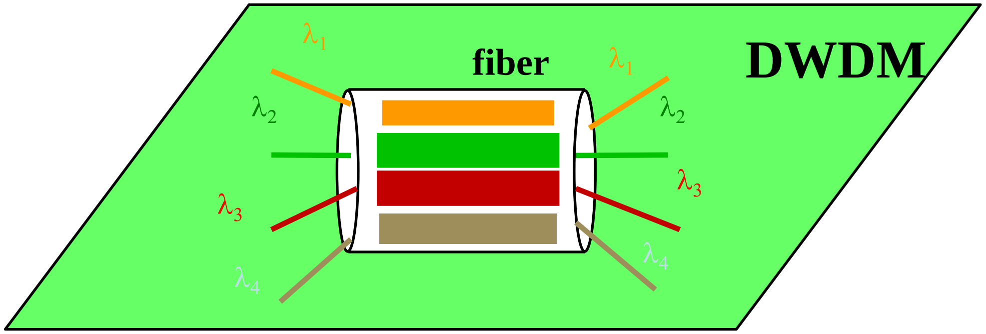
DOM electronics

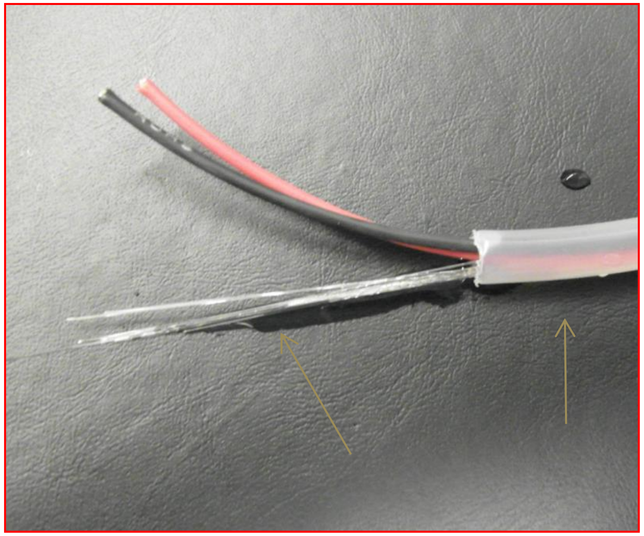
From Km3Net experience

DOM Contains Read out and Control/Command Electronics for PMT and instrumentation

- The DAQ system is based on an FPGA with an embedded processor inside the DOM
- Electronics, calibration devices installed inside the DOM

Data transport system is based on DWDM technology



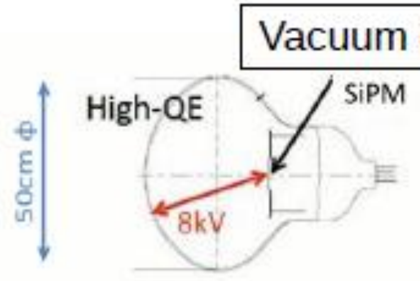


All electronics inside the DOM

Photo-sensors Studies
(for Hyper-K and new ND)

- Studying new generation of photosensors for much improved performance.

Vacuum Silicon PhotonMultiplier (Naples)

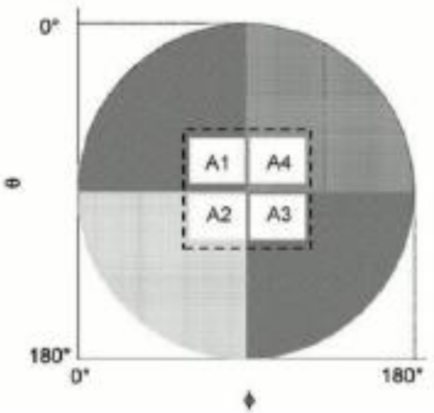


Very Large Photocathode for the VSiPMT

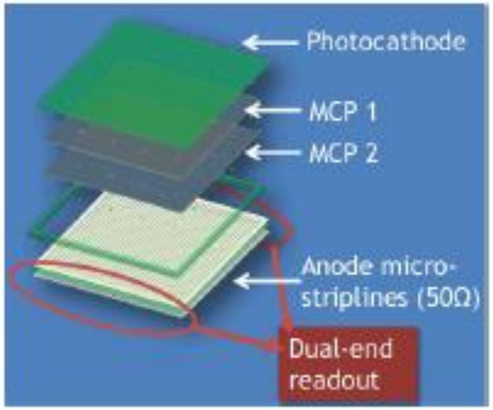
Advantages with respect to the HPD solution: higher gain

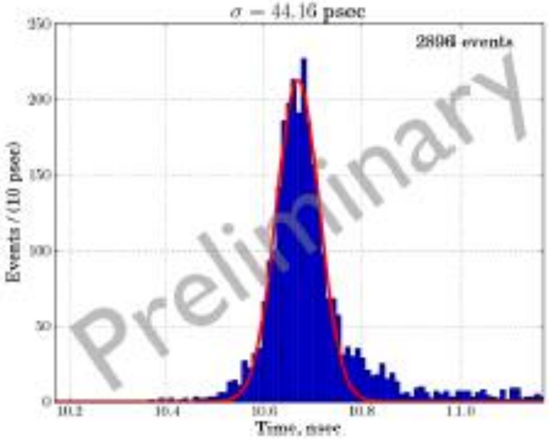
Segmented Photocathode VSiPMT

Each segmented part focusing on a SiPM



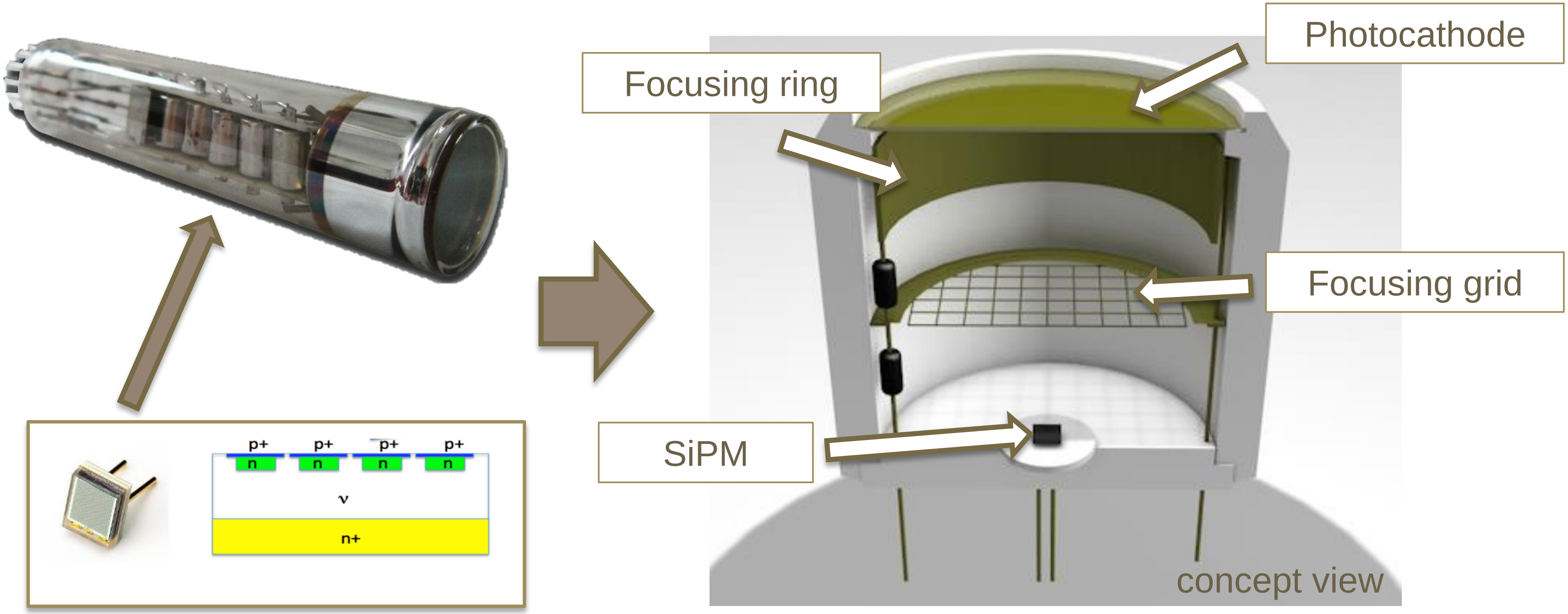
Large Area Picosecond Photo-Detector (UK)





Vacuum Silicon PhotoMultiplier Tube (VSiPMT)

An innovative design for a modern hybrid photodetector based on the combination of a Silicon PhotoMultiplier (SiPM) with a Vacuum PMT standard envelope



Photocathode

Focusing ring

Focusing grid

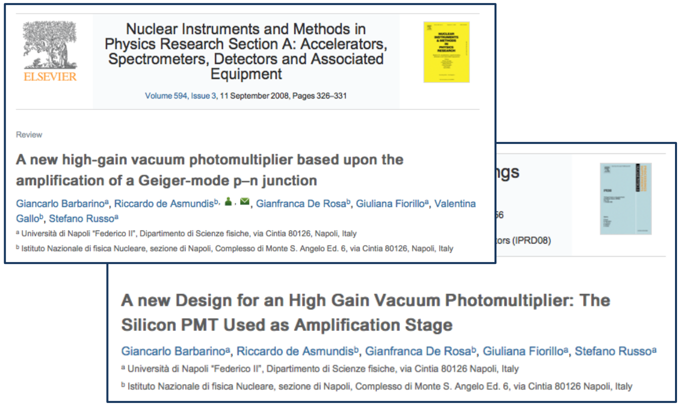
SiPM

concept view

The classical dynode chain of a PMT is replaced with a SiPM, acting as an electron multiplying detector, in place of dynode chain

GC . Barbarino et al

Vacuum Silicon PhotoMultiplier Tube (VSiPMT)



Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 594, Issue 3, 11 September 2008, Pages 326–331

Review

A new high-gain vacuum photomultiplier based upon the amplification of a Geiger-mode p–n junction

Giancarlo Barbarino[a], Riccardo de Asmundis[b], ✉, Gianfranca De Rosa[b], Giuliana Fiorillo[a], Valentina Gallo[b], Stefano Russo[a]

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A new Design for an High Gain Vacuum Photomultiplier: The Silicon PMT Used as Amplification Stage

Giancarlo Barbarino[a], Riccardo de Asmundis[b], Gianfranca De Rosa[b], Giuliana Fiorillo[a], Stefano Russo[a]

[a] Università di Napoli "Federico II", Dipartimento di Scienze fisiche, via Cintia 80126 Napoli, Italy

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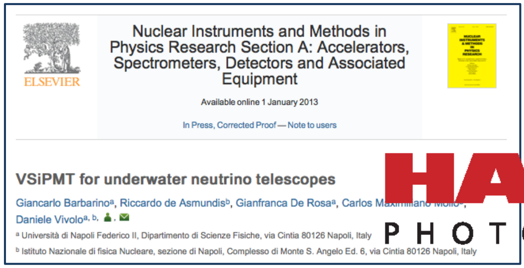

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Available online 1 January 2013

In Press, Corrected Proof — Note to users

VSiPMT for underwater neutrino telescopes

Giancarlo Barbarino[a], Riccardo de Asmundis[b], Gianfranca De Rosa[a], Carlos Maximiliano Mollo[b], Daniele Vivolo[a, b], ✉

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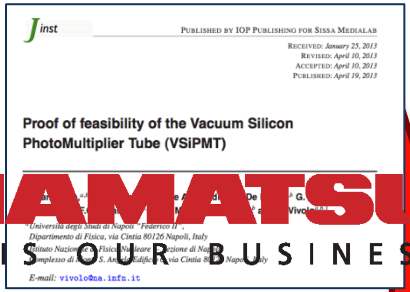

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Proof of feasibility of the Vacuum Silicon PhotoMultiplier Tube (VSiPMT)

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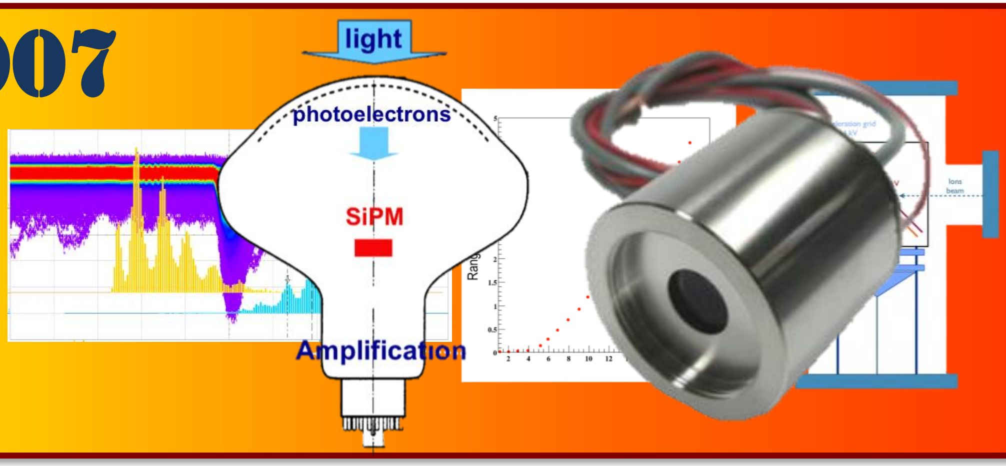
HAMAMATSU
PHOTON IS OUR BUSINESS

2007



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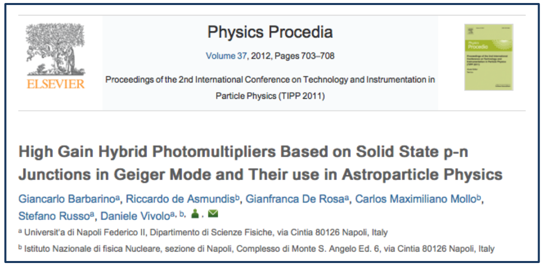

Physics Procedia

Volume 37, 2012, Pages 703–708

Proceedings of the 2nd International Conference on Technology and Instrumentation in Particle Physics (TIPP 2011)

High Gain Hybrid Photomultipliers Based on Solid State p-n Junctions in Geiger Mode and Their use in Astroparticle Physics

Giancarlo Barbarino[a], Riccardo de Asmundis[b], Gianfranca De Rosa[a], Carlos Maximiliano Mollo[b], Stefano Russo[a], Daniele Vivolo[a, b], ✉

[a] Universit'a di Napoli Federico II, Dipartimento di Scienze Fisiche, via Cintia 80126 Napoli, Italy

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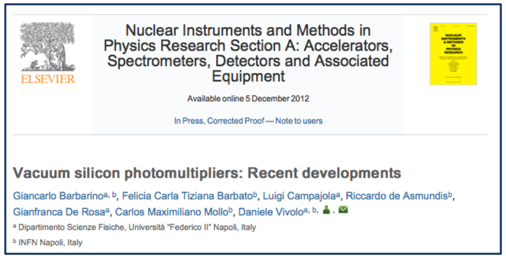

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Available online 5 December 2012

In Press, Corrected Proof — Note to users

Vacuum silicon photomultipliers: Recent developments

Giancarlo Barbarino[a, b], Felicia Carla Tiziana Barbato[b], Luigi Campajola[a], Riccardo de Asmundis[b], Gianfranca De Rosa[a], Carlos Maximiliano Mollo[b], Daniele Vivolo[a, b], ✉

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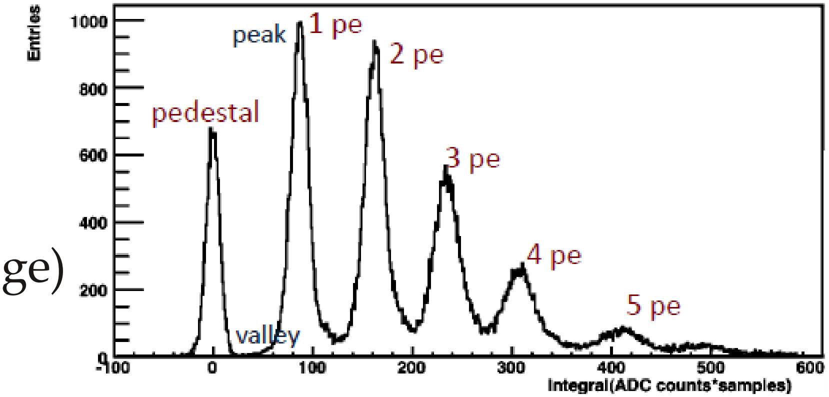
VSiPMT in TITUS

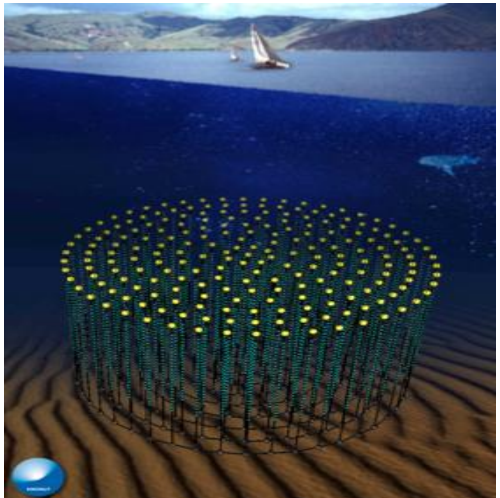
- Excellent photon counting capabilities
- Photon Detection Efficiency: ≈23% @ 407nm
- High gain: $10^5 \div 10^6$, HV-stable
- Good timing performances: TTS < 0.5ns
- Low power consumption: 5mW (amplifier stage)
- SPE resolution 17.8%
- Peak-to-valley ratio ≈65



Studies on using innovative hybrid PMTs, VSiPMTs, developed by Naples INFN group

VSiPMT will be Test in WC test detector in construction at Tokai site

This task is integrated into the activity of project JENNIFER



Application to under-water neutrino telescopes

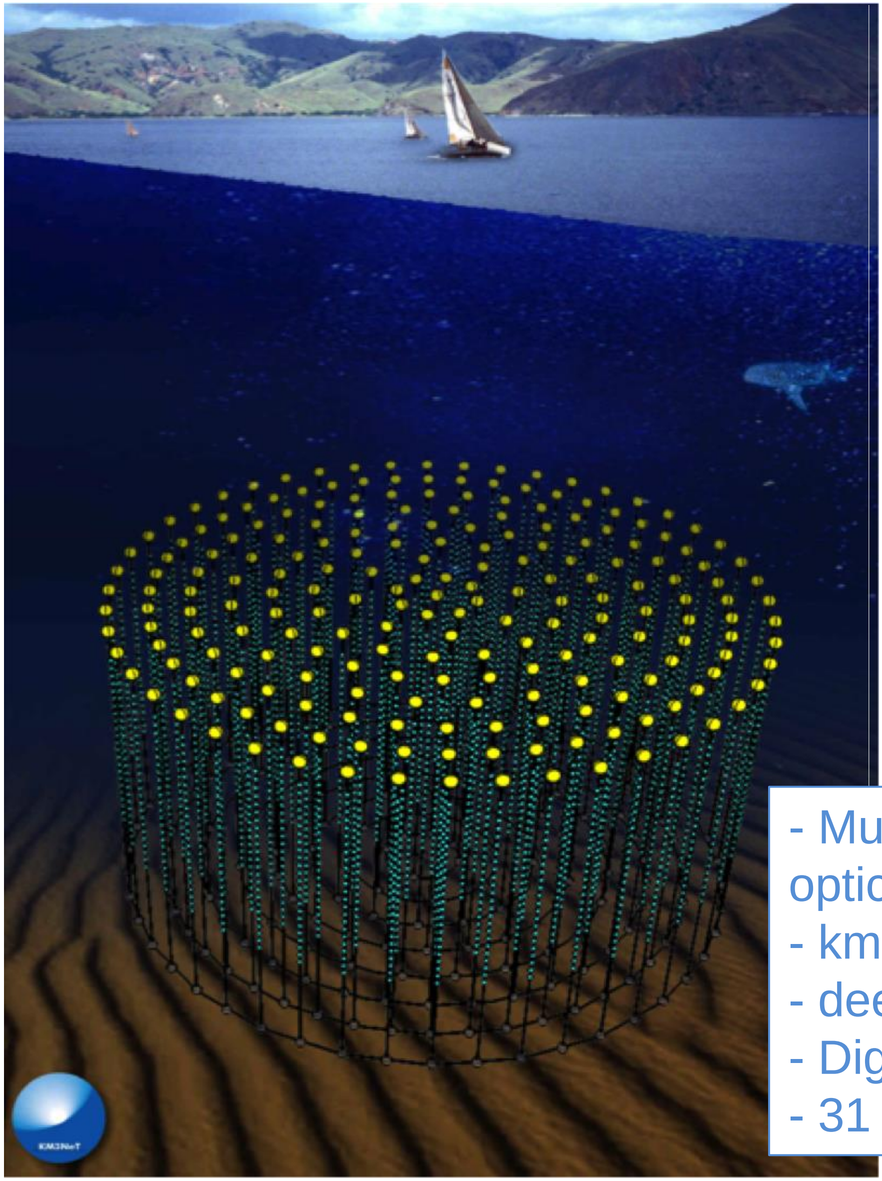
KM3NeT DOM

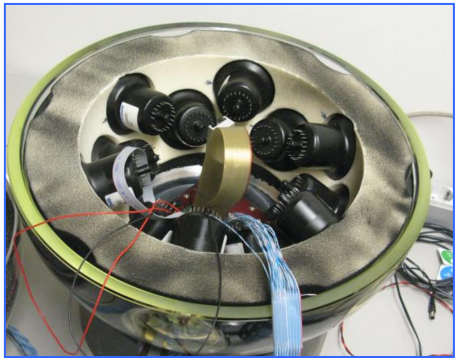
Conclusions

- Programma sperimentale estremamente intenso per i prossimi anni
- Forti sinergie tra gruppi Europei in T2K
- R&D di interesse per altri futuri esperimenti
- …….

Grazie!!

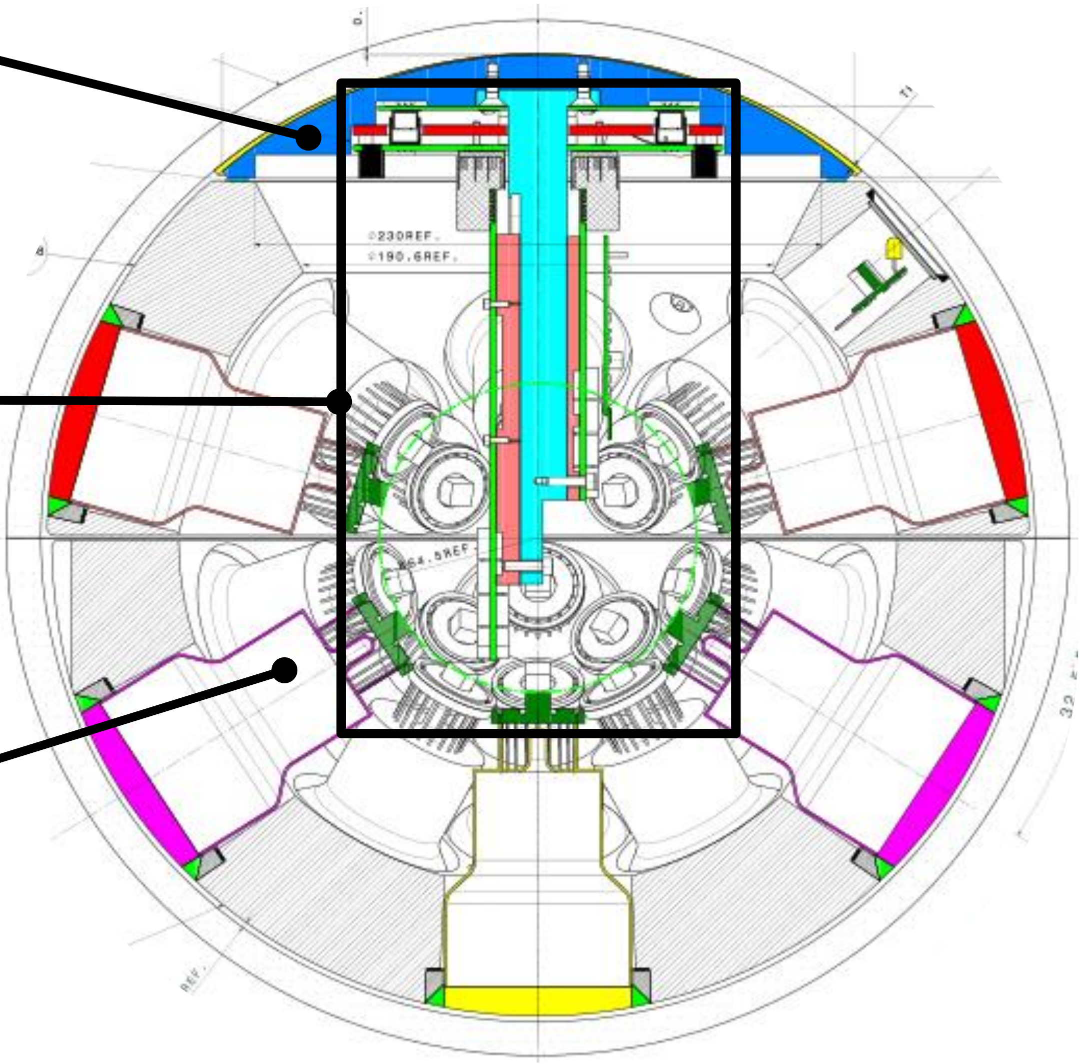
The KM3NeT experiment





- Multi-site 3-D array of optical detectors
- km^3 volume
- deep sea infrastructure
- Digital Optical Modules
- 31 PMTs each

Km3Net DOM internal description

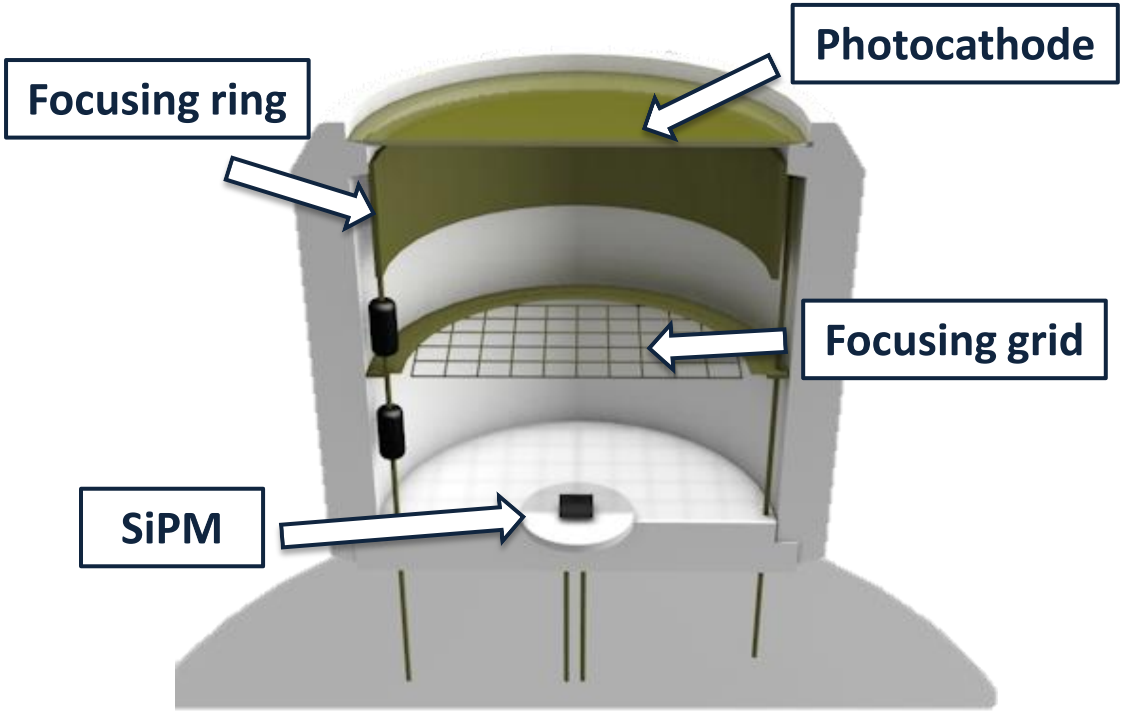


Heat conductor
Mechanical support

Read Out
Electronics

Photomultipliers

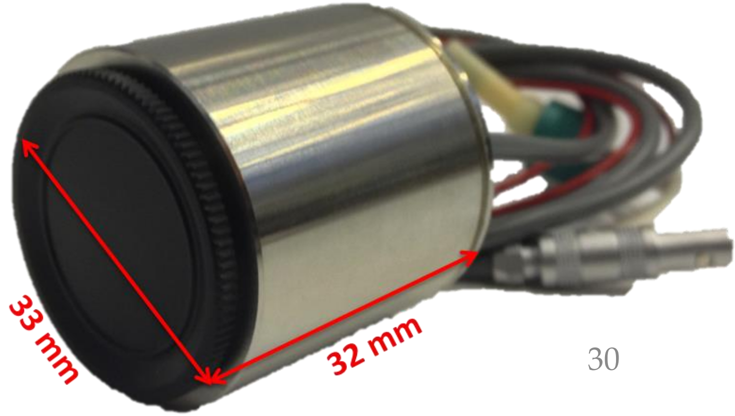
Vacuum Silicon PhotoMultiplier Tube VSiPMT



Prototype	ZJ5025	ZJ4991
SiPM Area (mm²)	1×1	1×1
Cell size (μm)	50	100
Total number of cells	400	100
Fill Factor	61%	78%

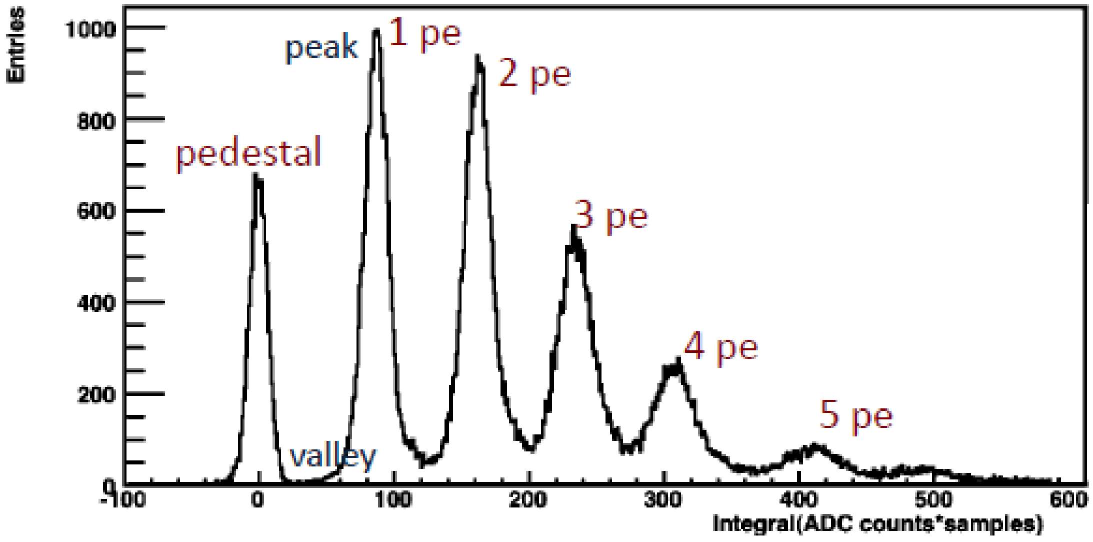
Two prototypes by Hamamatsu Photonics

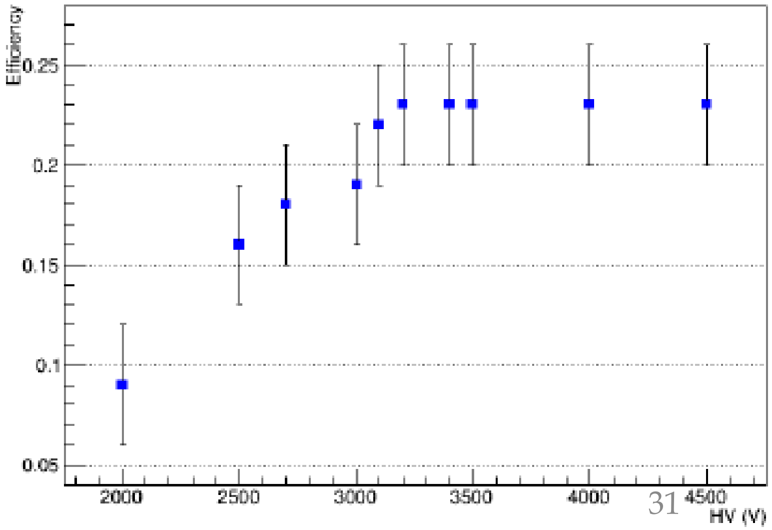
- 7x7 mm^2 Borosilicate glass entrance window
- 3 mm Ø GaAsP photocathode
- p$^+$nvn$^+$ configuration
- special non-windowed MPPC series

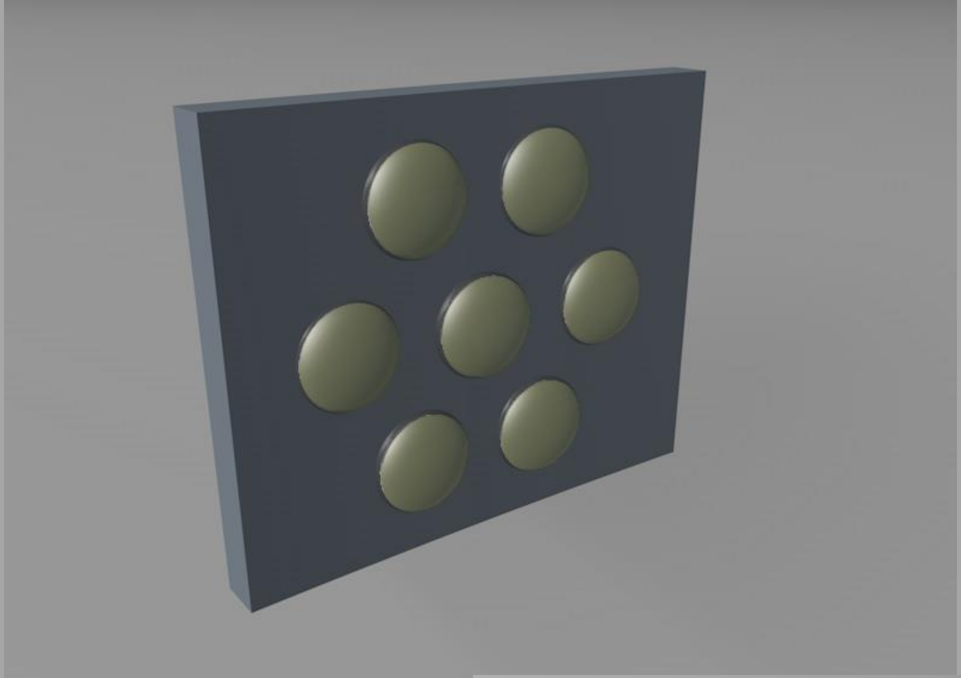


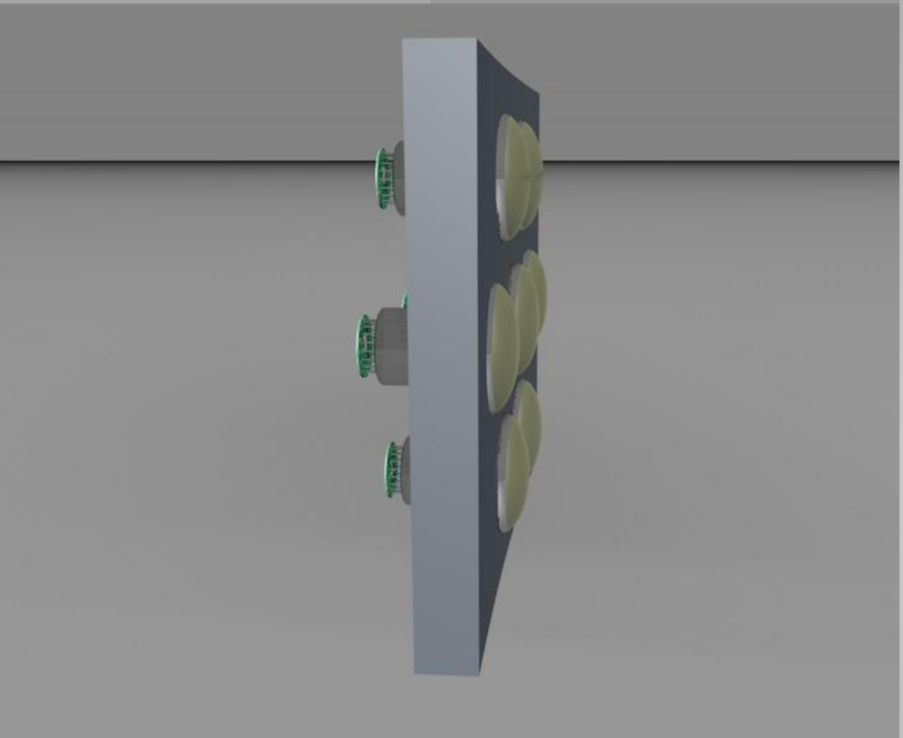
VSiPMT features

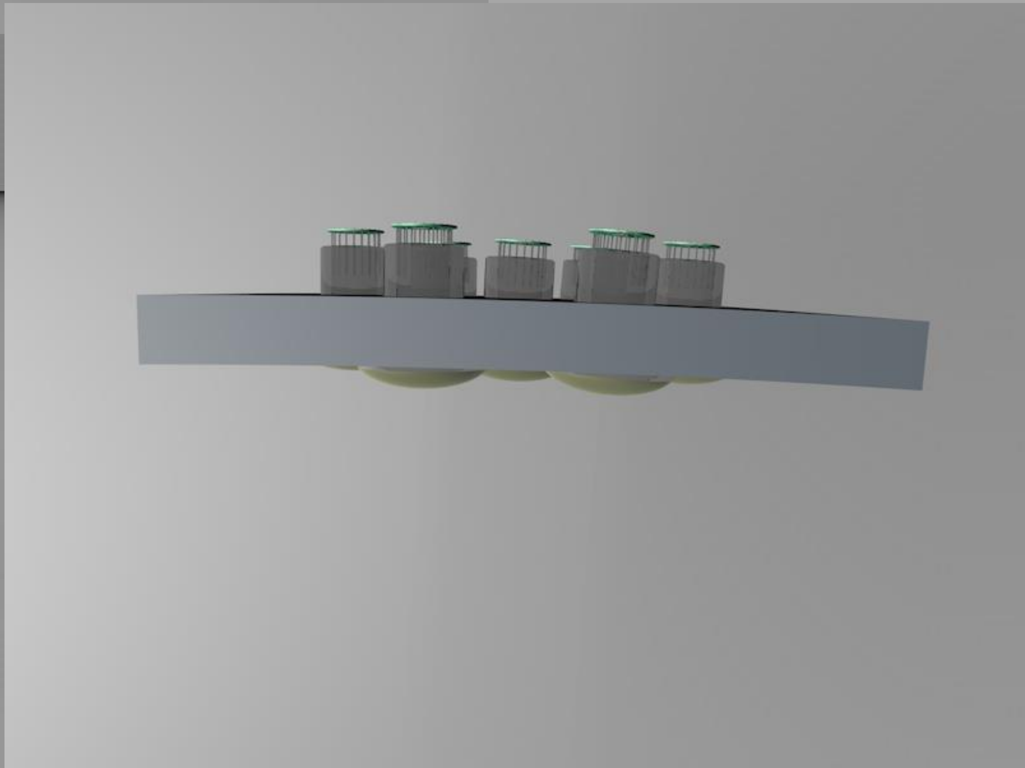
- Excellent photon counting capabilities
- Photon Detection Efficiency: ≈23% @ 407nm
- High gain: $10^5 \div 10^6$, HV-stable
- Good timing performances: TTS < 0.5ns
- Low power consumption: 5mW (amplifier stage)
- SPE resolution 17.8%
- Peak-to-valley ratio ≈65











Km3Net
Digital Optical Module

The Digital Optical Module (DOM)

- Multi-PMT DOM
- 31 small PMTs
- Almost uniform coverage
- Photon counting
- Minimize pressure transitions
- All electronics inside

Multi-PMT Optical Module

- 31 3″ PMTs inside a 17″ glass sphere

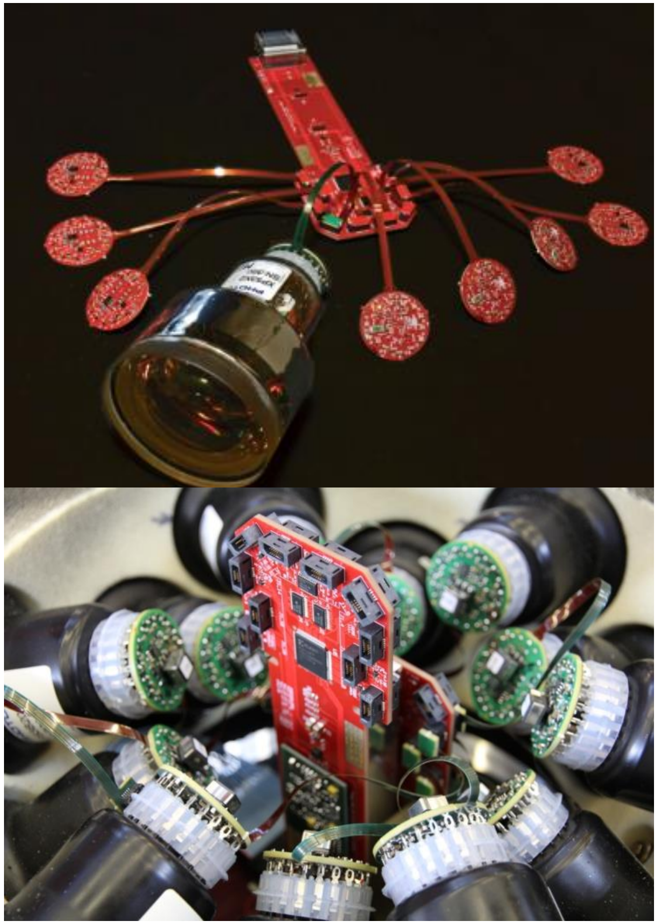
Cooling shield and stem

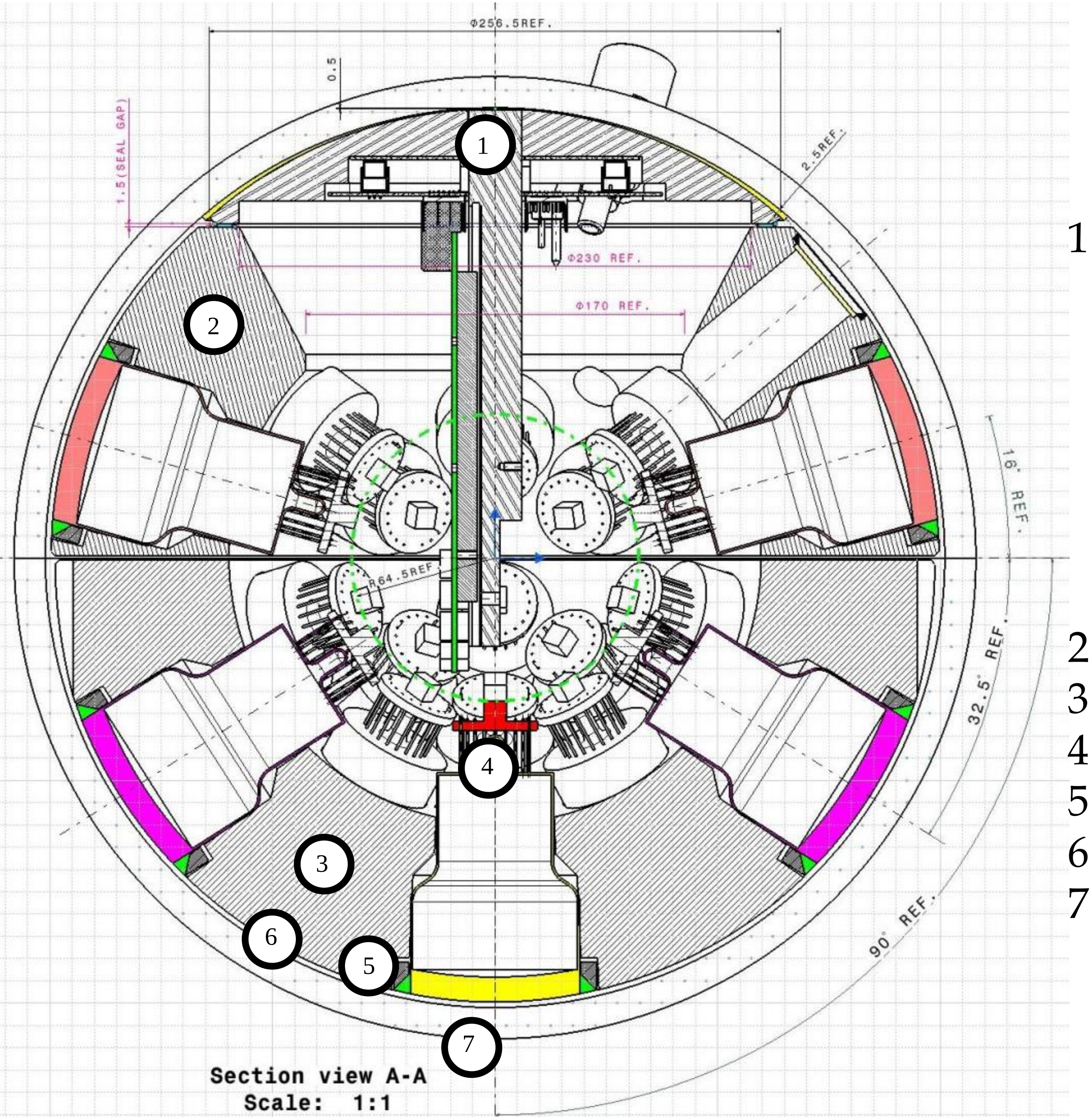
- Single vs multi photon hit separation
- Larger photocade area per OM

Multi-PMT Optical Module

The Digital Optical Module (DOM)

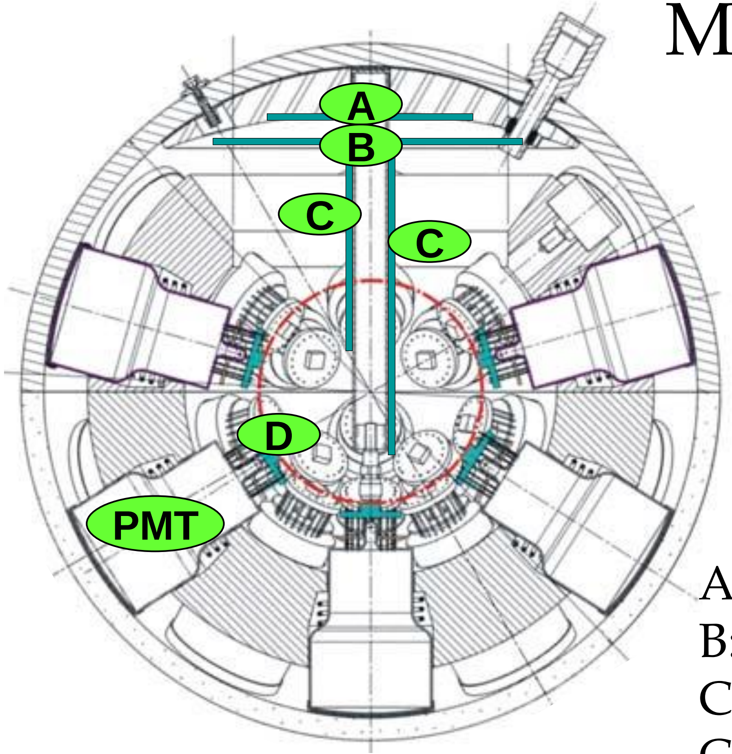
- New design HV with <35 mW power consumption
- 12 PMTs in top
- 19 PMTs in bottom
- Front matched to sphere
- Supported by foam cores via concentrator ring
- Optically coupled with optical gel



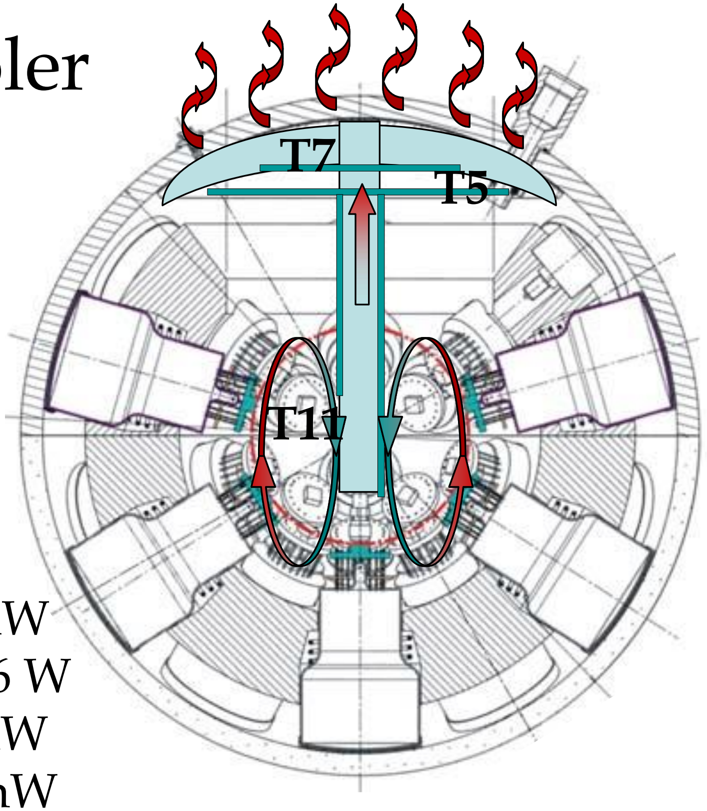


1. Alluminium heatsink
    - power board
    - sphere logic board
    - octopus long board to PMT bases
2. Top foam core
3. Bottom foam core
4. PMT with base
5. Reflection ring
6. Gel interface
7. Glass sphere

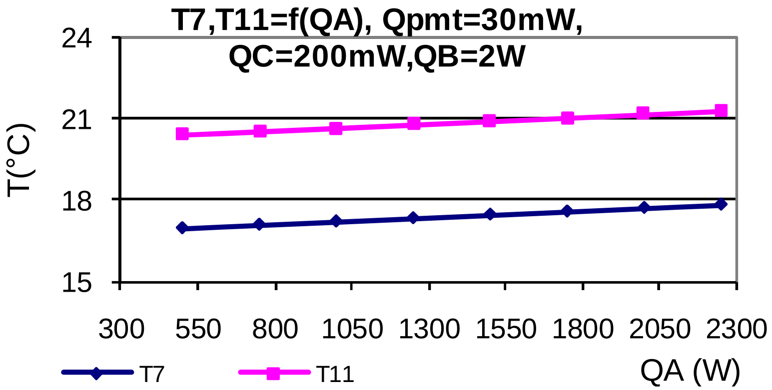
Mechanical cooler

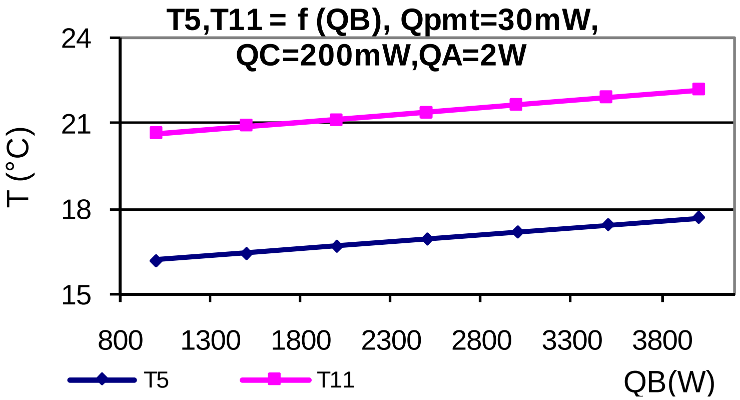


Heat removed by convection D and conduction AB C

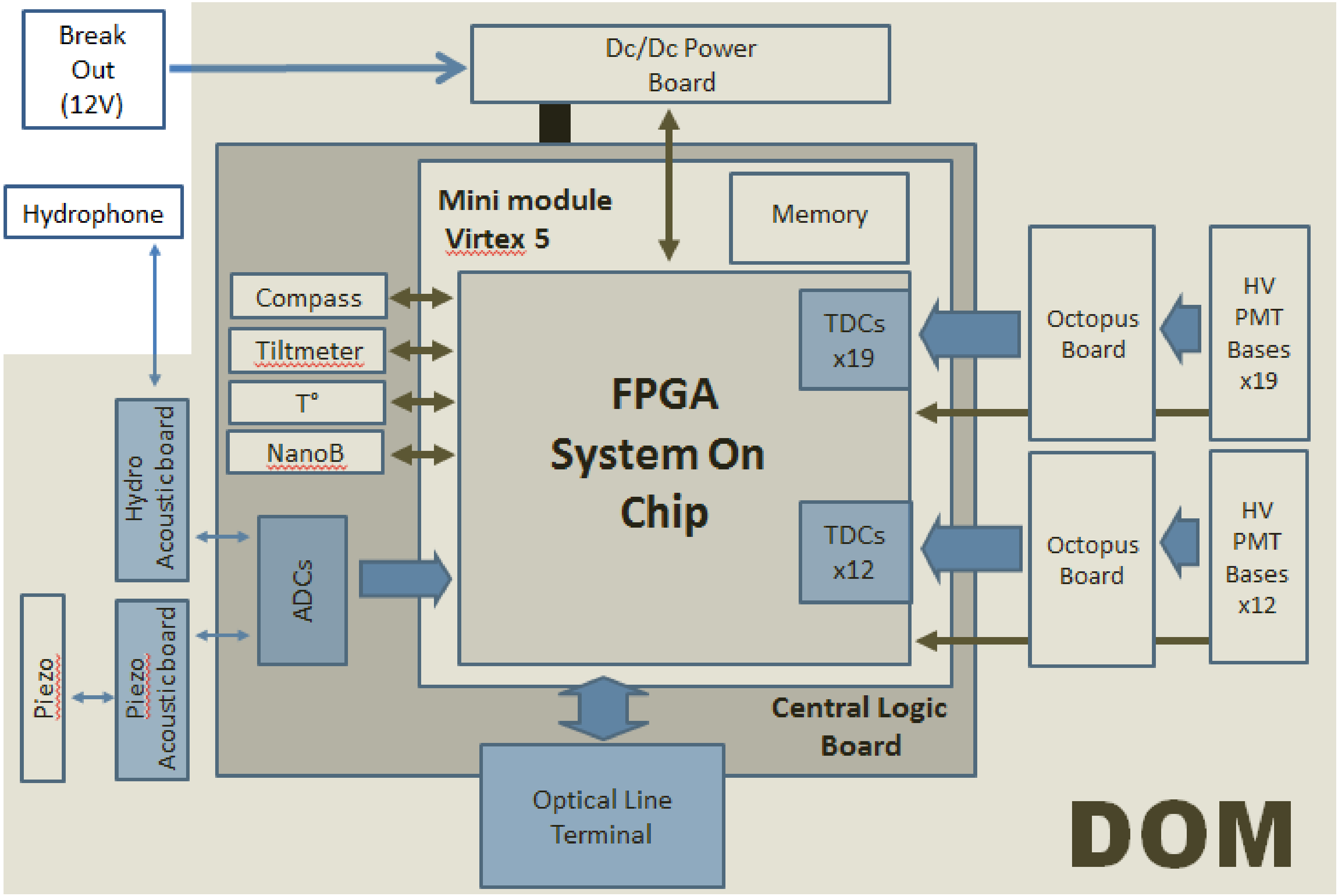


A: power board 900 mW
B: OM logic board 5.06 W
C: Octopus short 70 mW
C: Octopus long 270 mW
D: PMT base 35 mW (x 31)
Tot: ≈ 7 W





DOM electronic description

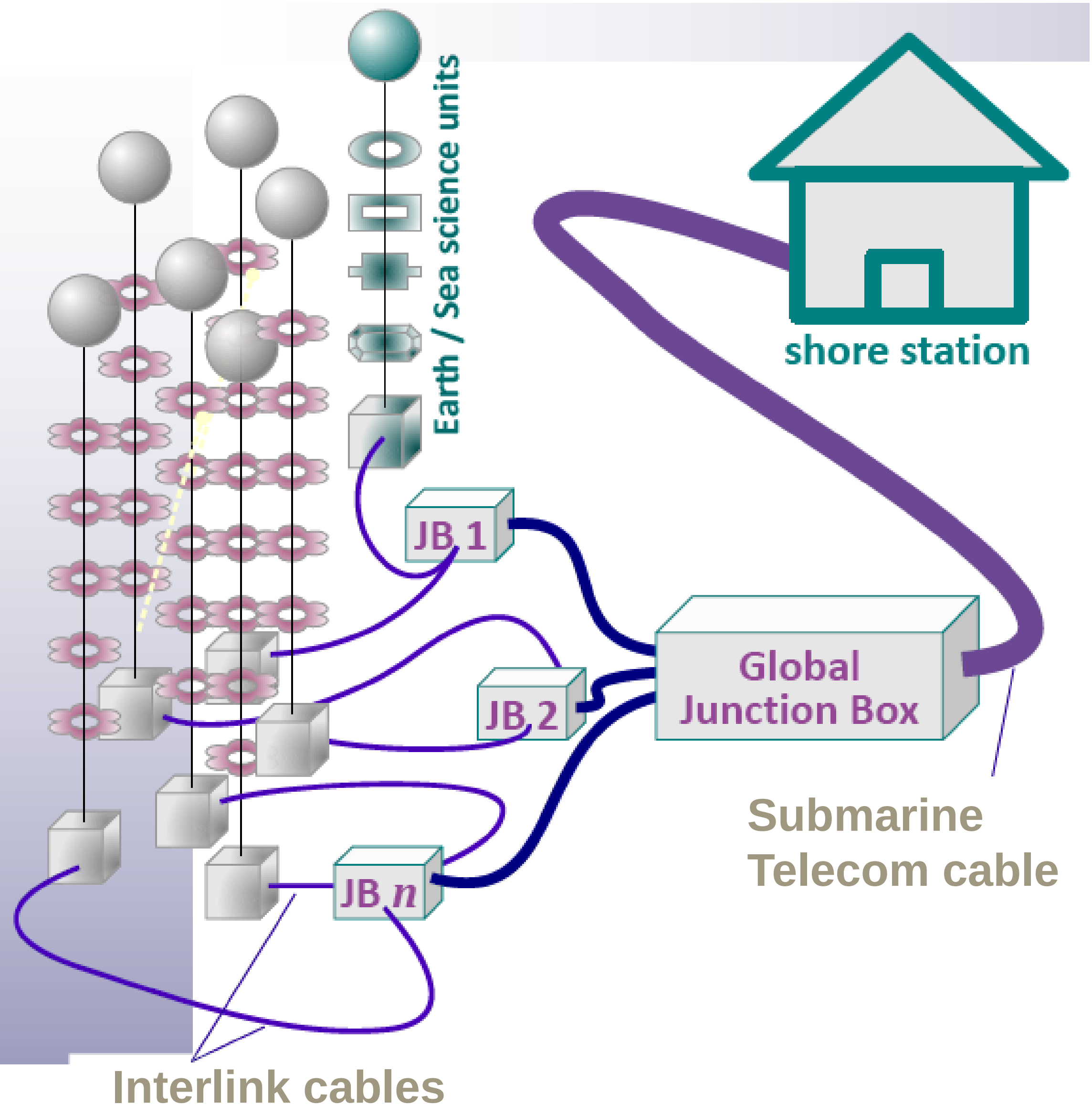


⟷ Control & Command (I2C Link)

➡ Data Readout

Optical Network

Electronics & Data Readout Concepts



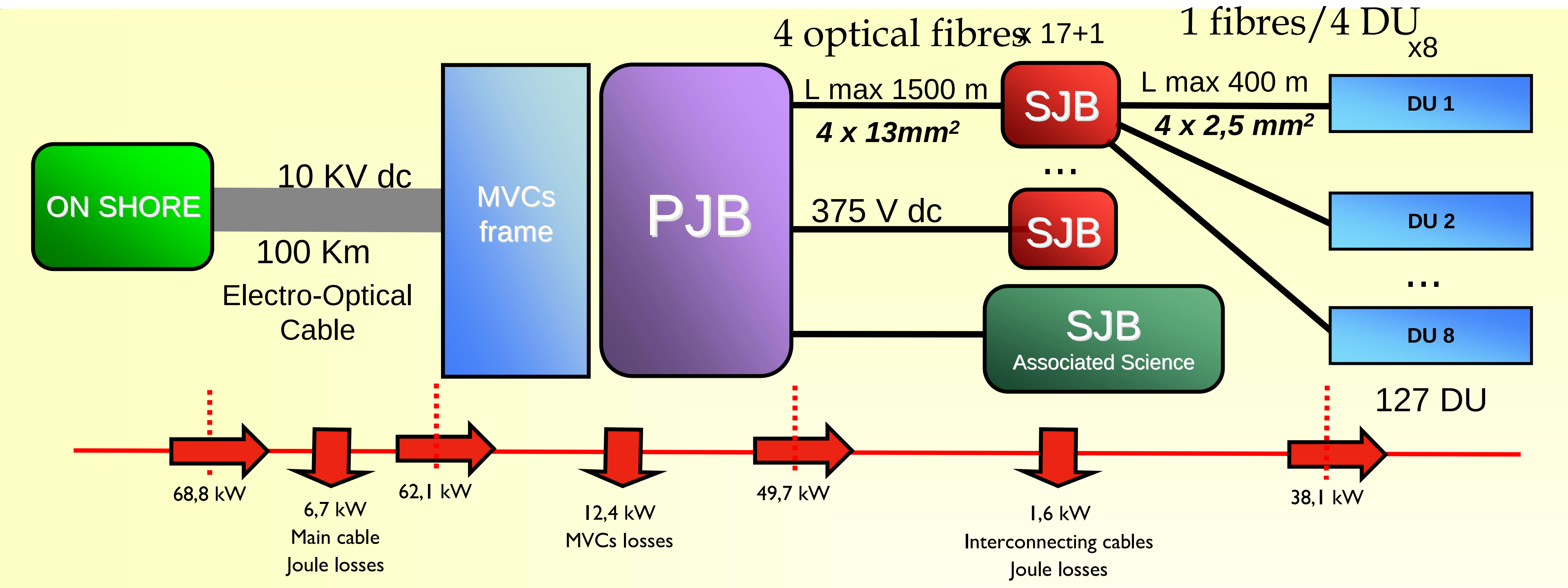
- **Front-end options studies**
- New improved front-end chip in the deep-sea
  - New FPGA/CPU

- Minimize active electronics in deep-sea
  - Reflective optical modulator
  - **on-shore** timestamp

- Both options use **fibers, Wavelength Division Multiplexing and Point-to-point networks**

- **"ALL DATA TO SHORE"**

On-shore – off-shore power transmission

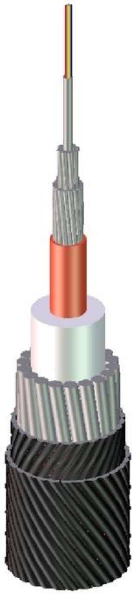


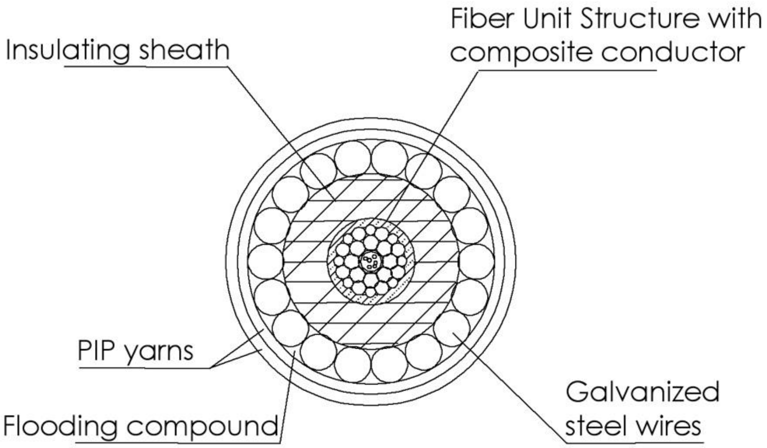
DU = 300 W

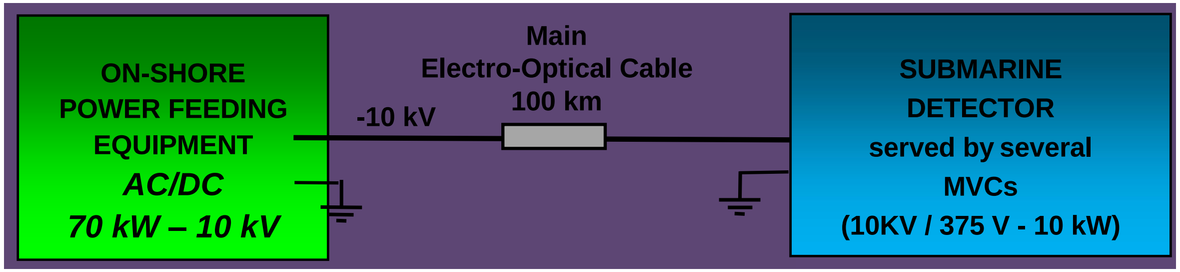
Total power loss: 30%
10% on the main cable
20% in the Medium Voltage Converter (MVC)

The NEMO/KM3 electro-optical cable

DC solution with sea return







ON-SHORE POWER FEEDING EQUIPMENT
AC/DC
70 kW – 10 kV

-10 kV

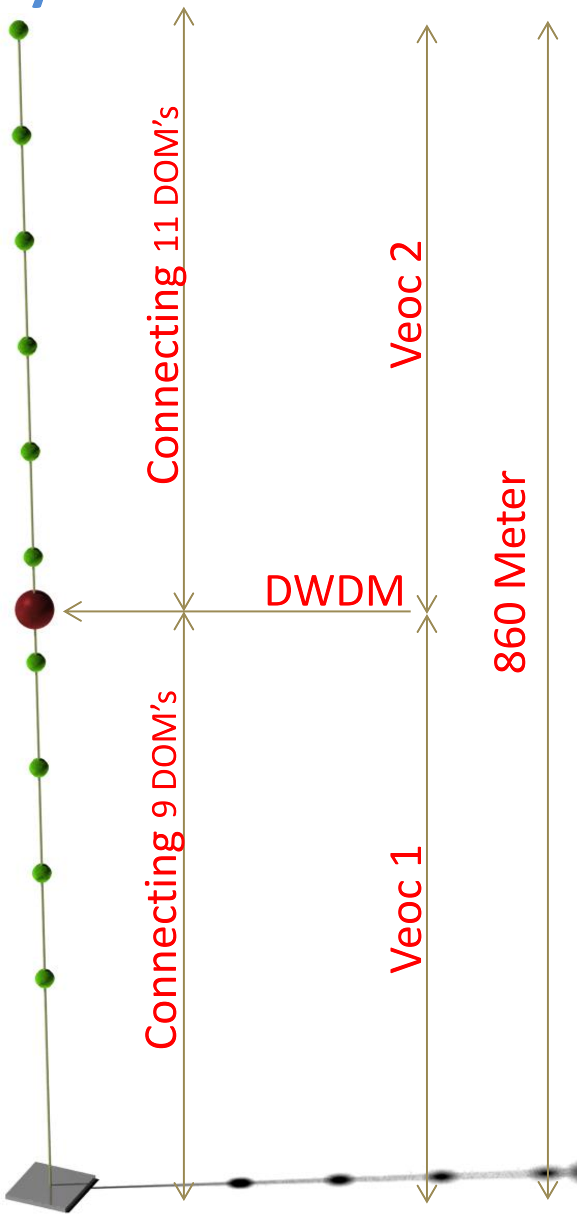
Main
Electro-Optical Cable
100 km

SUBMARINE DETECTOR
served by several MVCs
(10KV / 375 V - 10 kW)

Working Voltage 10 kV
Power up to 100 kW
Optical fibres 20

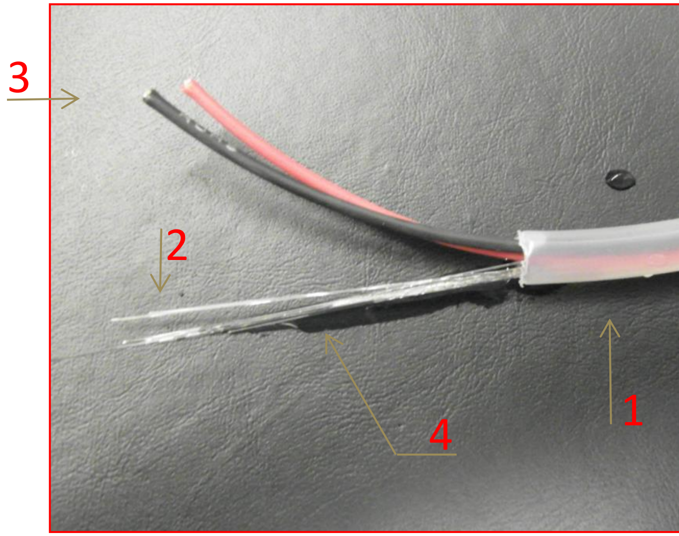
Converter
Vin 10 kV DC
Vout 400 DC
+
Splitter ottico

Layout



Cross section of the pressure balanced cable

1) Outer shell ¼ LDPE Tube
2) 11 optical fibers
3) 2 Electrical wire
4) Oil Filling

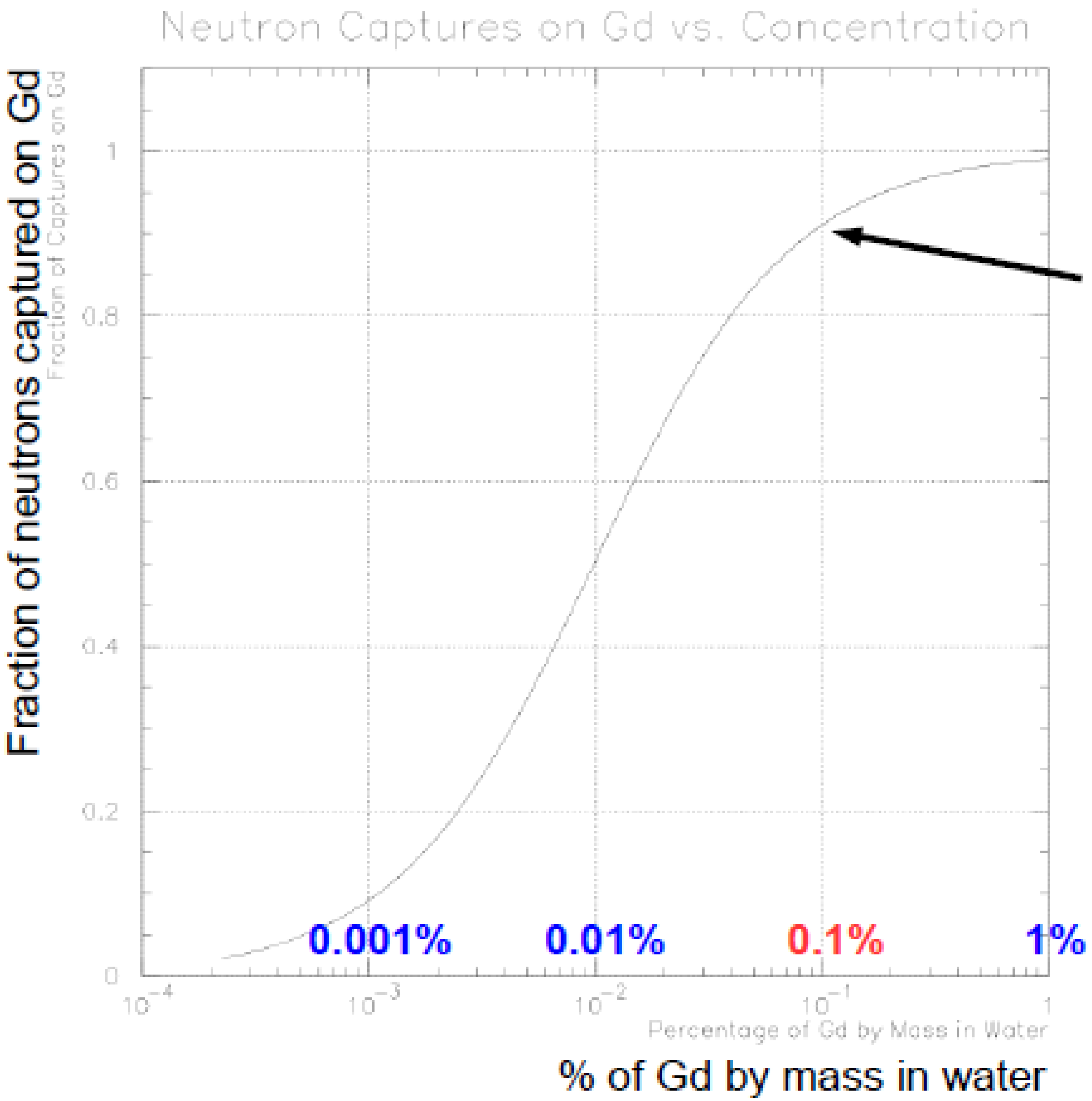


The 20 wavelength for each detection unit are de-multiplexed in a central place thus requiring 11 bidirectional fibres in vertical cable, 9 bidirectional down.

Channel spacing: 50 Ghz, 0,4 nm.

Detectors

Neutron Capture w/ Gd

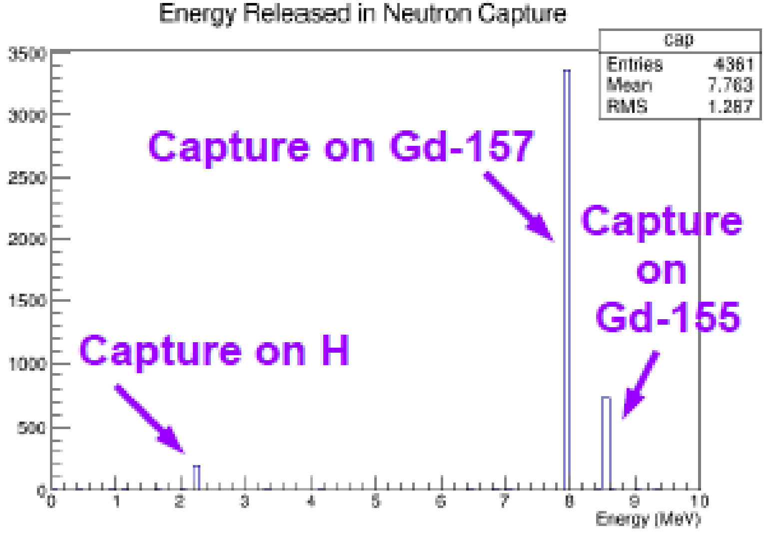


Cross-section for neutron capture is:

- ~49,000 barns for Gd
- 0.3 barns for H

0.1% Gd concentration results in ~90% of neutrons capturing on Gd

Currently, EGADS experiment is investigating feasibility of doping with gadolinium sulfate [$Gd_2(SO_4)_3$]

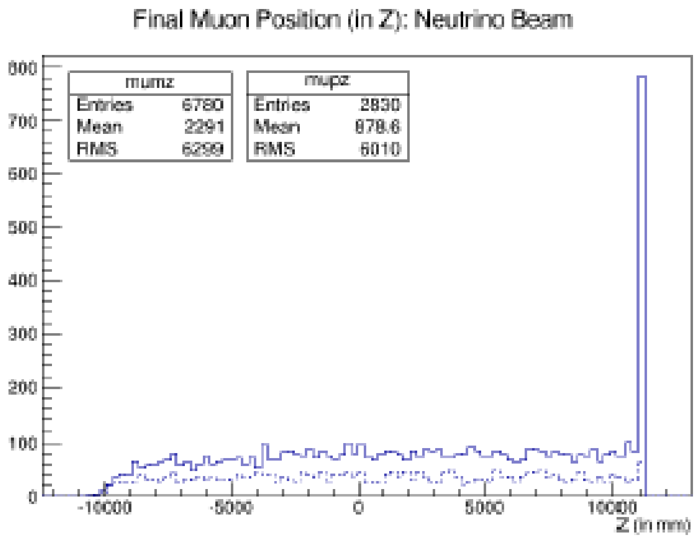


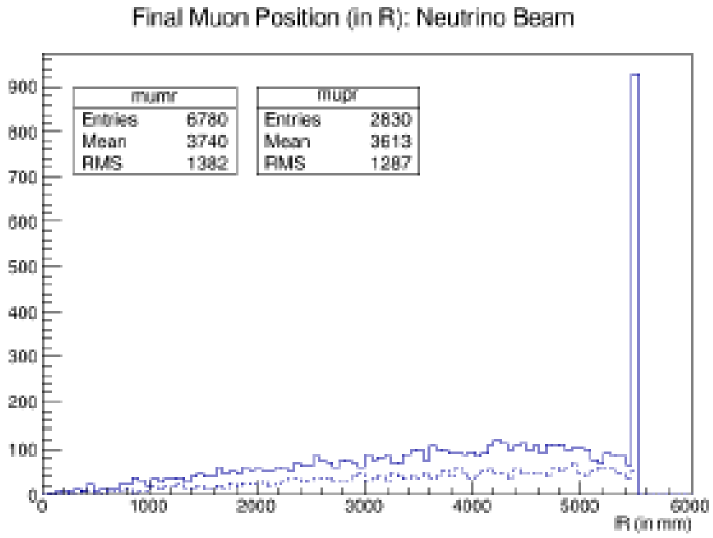
Physics Benefits of Gd

- "Wrong sign" neutrino discrimination
  - From T2K sensitivity studies, we know that running a mix of neutrino mode & antineutrino mode enhances δ_{CP} sensitivity
  - Antineutrino mode has greater contamination from neutrinos
  - With Gd-doping, can separate ν from $\bar{\nu}$ in TITUS to understand contamination, characterize beam, and reduce systematics for Hyper-K

- Neutron capture can be used to separate CCQE from CC MEC and CC Other, to enhance purity of CCQE in CC0π sample:
  - ν_μ CCQE: 0 neutrons
  - ν_μ CC MEC: 0.2 neutrons (average): $\nu_\mu + (n\text{-}n) \rightarrow \mu^- + p + n$
  - $\bar{\nu}_\mu$ CCQE: 1 neutron
  - $\bar{\nu}_\mu$ CC MEC: 1.8 neutrons (average): $\bar{\nu}_\mu + (p\text{-}n) \rightarrow \mu^+ + n + n$ (~80%)
    $\bar{\nu}_\mu + (p\text{-}p) \rightarrow \mu^+ + p + n$ (~10%)

WC + MRD





- Muons that escape the water tank enter the MRD
- Range within MRD provides μ momentum
- Example shown is 10,000 event sample in ν-mode
    - Nearly no backwards exiting events
    - Most wrong-sign muons contained
- **Magnetized MRD offers complementary information to neutron tagging with gadolinium**
- At high-Eν, μ escapes MRD
    - Charge-sign easy to determine
    - Can be used to calibrate and validate ν / $\bar{\nu}$ discrimination via Gd
- At lower energies (*i.e.*, oscillation region), charge reconstruction less efficient
- Curvature in MRD is **complementary** information to neutron multiplicity
    - **Combination of WC + MRD can give very accurate particle / antiparticle separation!**

New Near Detector Technologies: LAPPD*s Approach

UK exploring

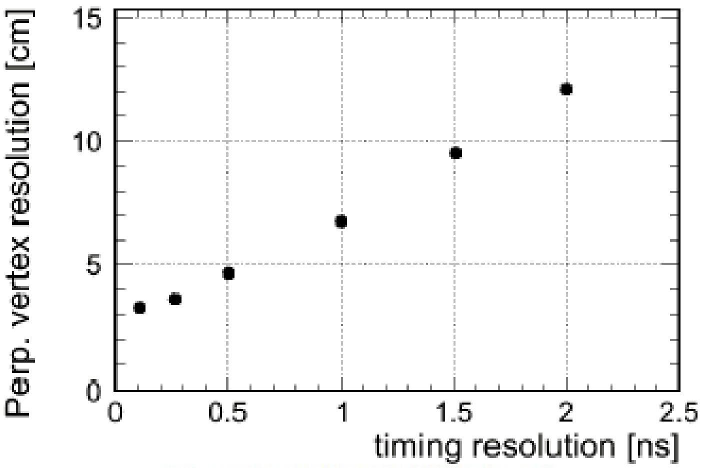
Currently limited by PMT transit time spread to 2-5ns (per photons)

LAPPD collaboration has shown the benefit of sub-ns resolution

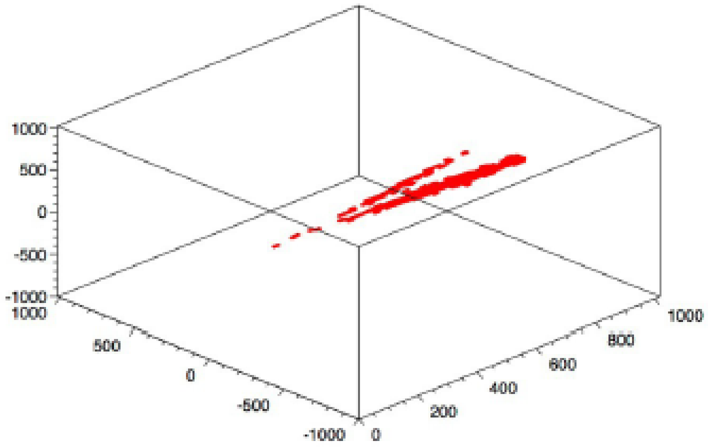
–Improved vertex resolution

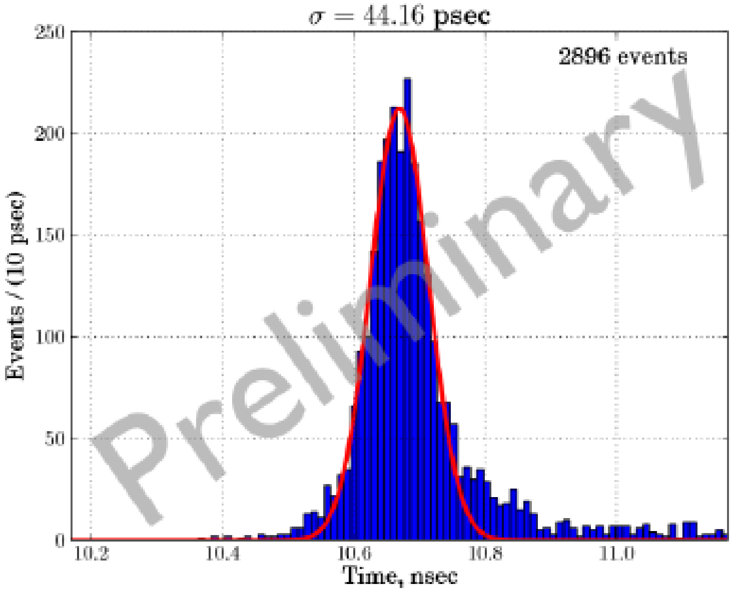
–Improved pattern recognition

T. Xin, I Anghel, M. Wetstein, M. Sanchez



Reconstructed 1.5 GeV Pi0 (geant)





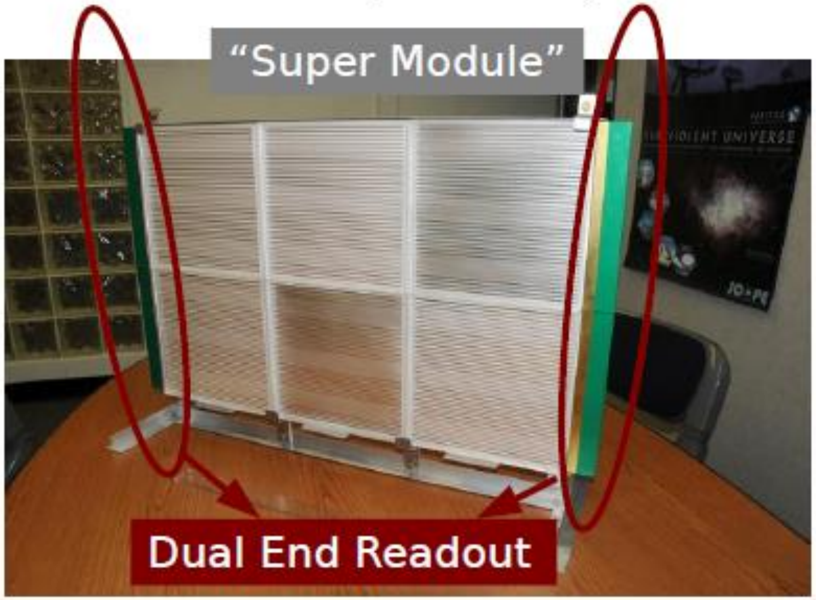
*Large Area Picosecond Photo-Detector

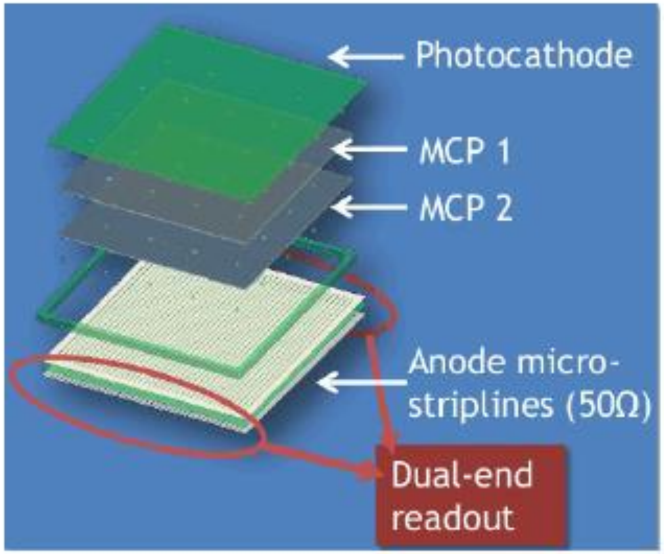
LAPPDs Approach

Development of large-area, relatively inexpensive Micro-Channel Plate (MCP) photo-detectors

- 8" x 8" phototubes = 'tile' (large active area)
- Gain >= 106with two MCP plates
- Transmission line readout –no pins!
- Fast pulses + low TTS ~30ps

Currently transitioning from development through commercialization. First test in a WC tank: Annie (Atmospheric Neutrino Neutron Interaction Experiment)





The project: VSiPM

GC . Barbarino
et al

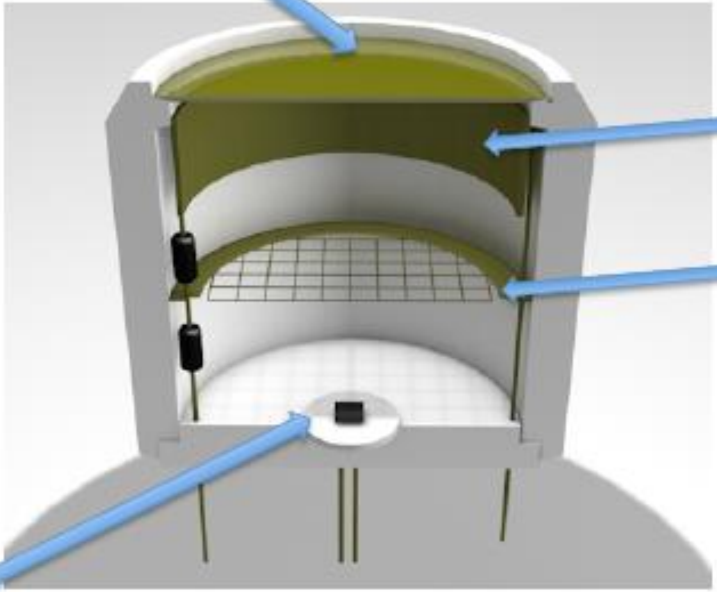
Vacuum Silicon PhotoMultiplier Tube (VSiPMT)

SIPM is:

- **Compact**
- **Cheap**
- **Single photon capability**
- **Linear**
- **Low voltage operation**

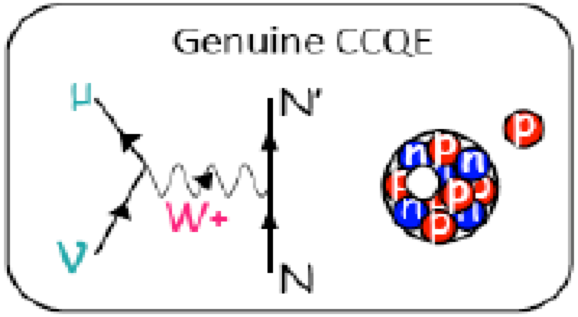
BUT

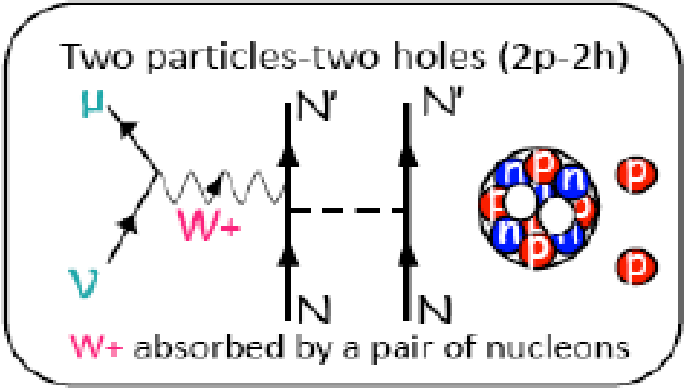
Small sensitive surface



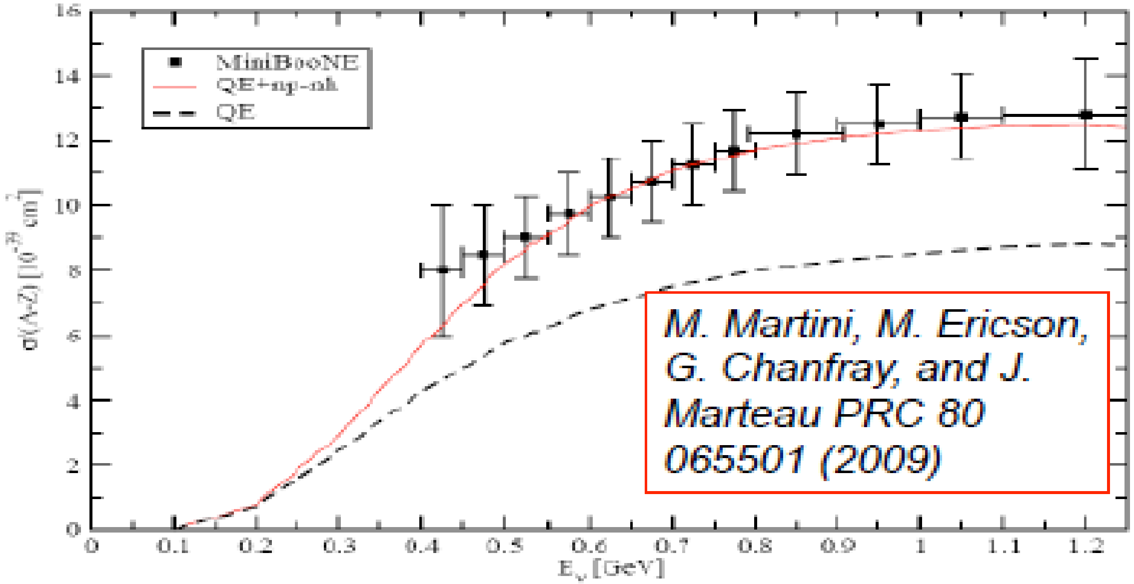
A combination of a classical vacuum glass PMT standard envelope hosting a photocatode and a Silicon PhotoMultiplier (SiPM) acting as an electron multiplying detector (in the place of the dinodes chain).

Are we really measuring "CCQE"?


Genuine CCQE


Two particles-two holes (2p-2h)

W+ absorbed by a pair of nucleons



M. Martini, M. Ericson, G. Chanfray, and J. Marteau PRC 80 065501 (2009)

"Multinucleon" processes may explain the enhanced CCQE cross section observed by MiniBooNE, SciBooNE experiments

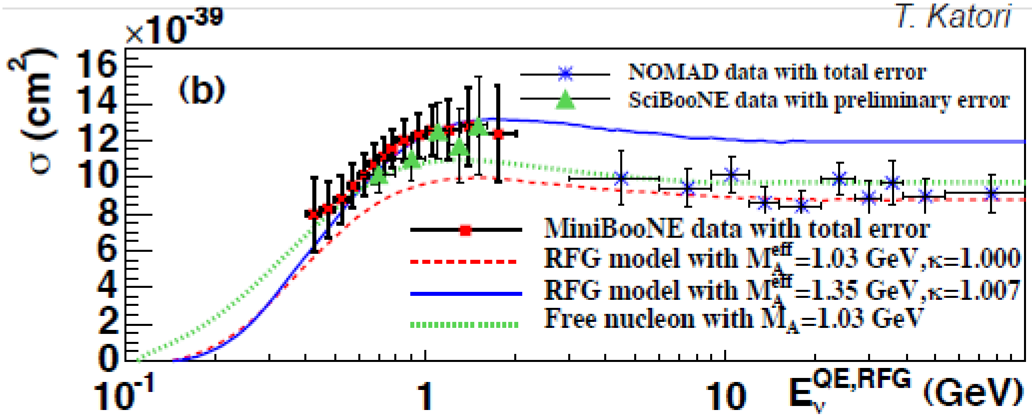
- Neutrino can also interact on a correlated pair of nucleons
- CCQE interaction simulated as interaction on a single nucleon (1p1h)

Cross-section systematics

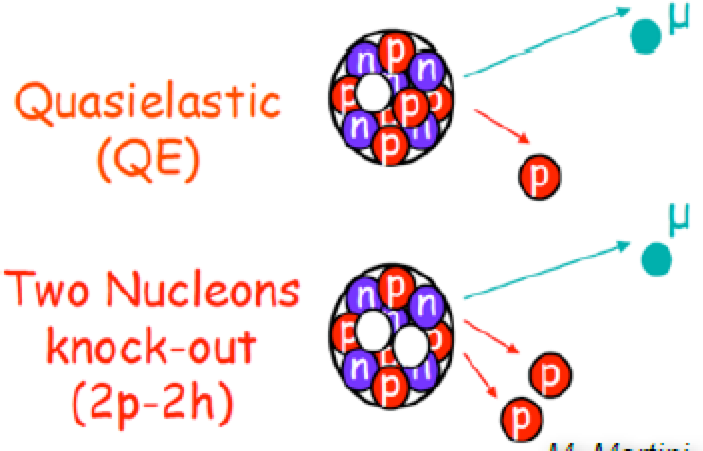
- Recent ν_μ CCQE data show low/high E_ν discrepancies
  - MiniBooNE/SciBooNE & NOMAD
- Explanation: multinucleon scattering—not simulated by neutrino interaction generator MCs

  ➡ Not included in MINOS, MiniBooNE, early T2K publications
- Misidentified events are not reconstructed correctly—results in biased E_ν

T. Katori



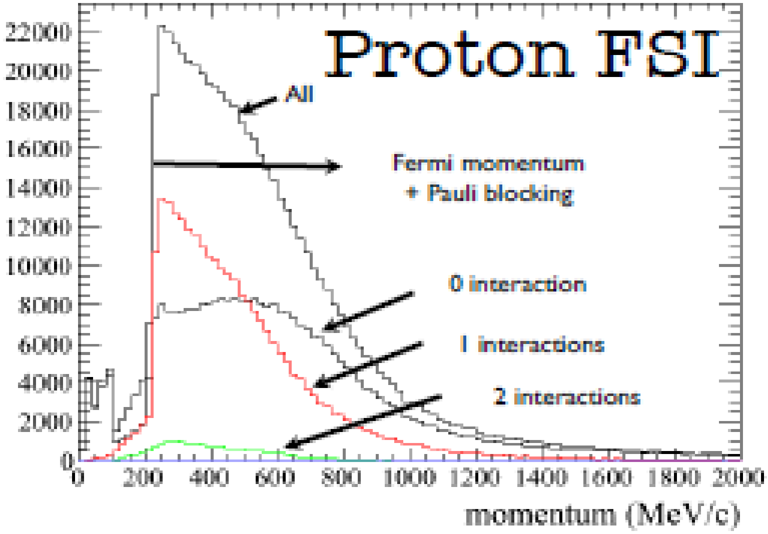
arXiv:1002.2680 [hep-ex]

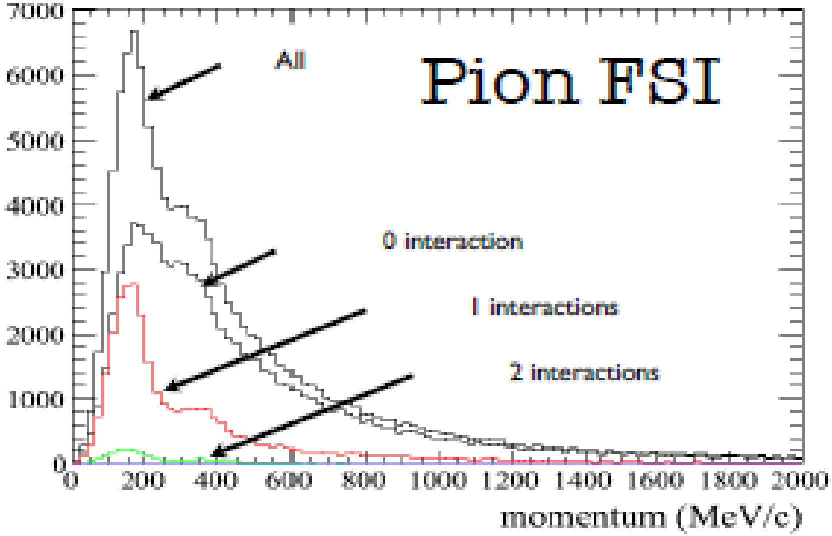


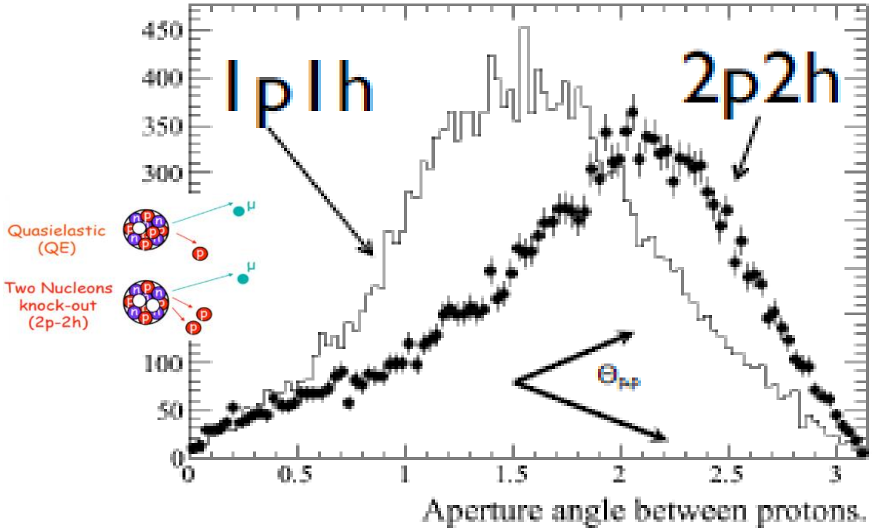
M. Martini

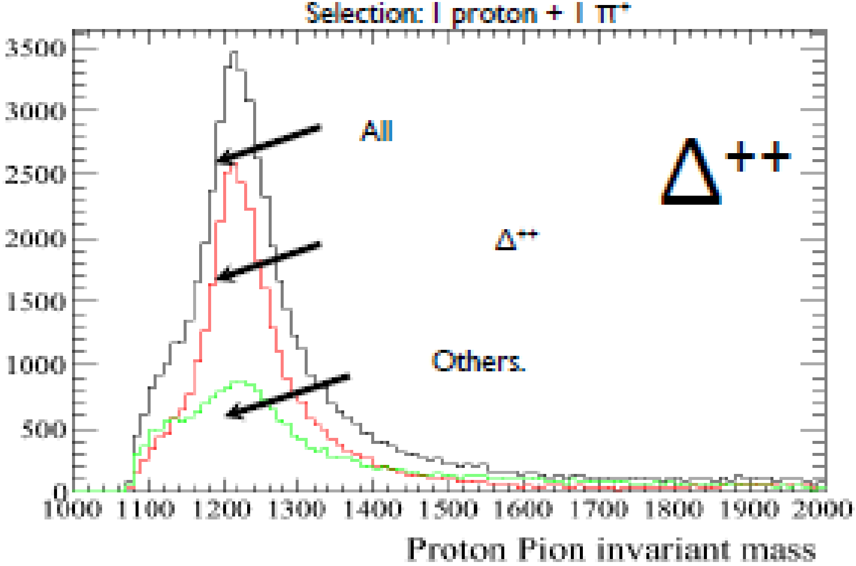
arXiv:0910.2622[hep-ex]

HPTPC Physics Goals









Much to learn from studying low momentum final state particles