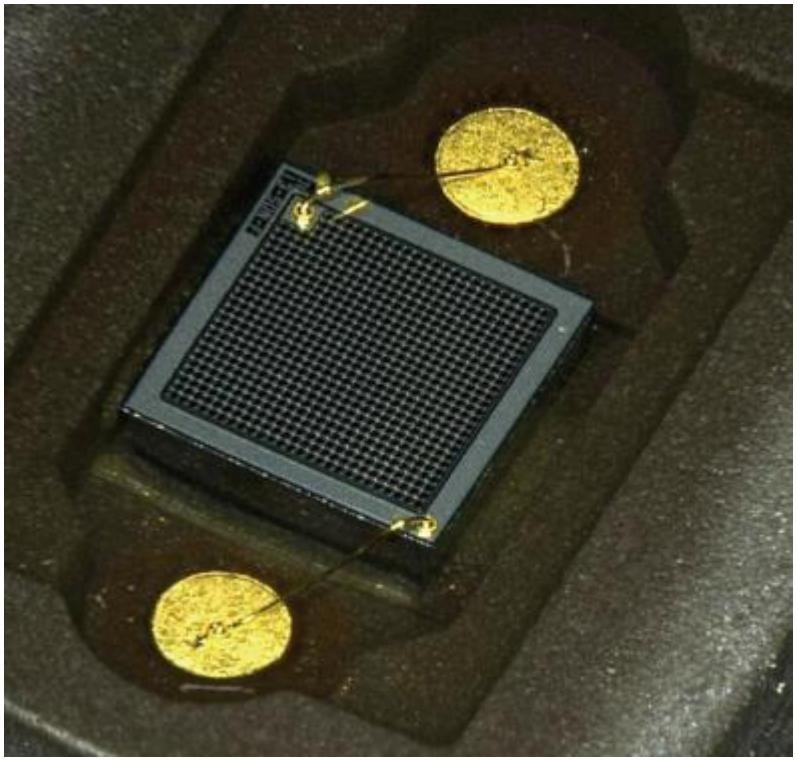
MPPC at T2K



南野彰宏（京都）

第3回次世代光センサーに関するワークショップ

@ 名古屋大学

Dec. 18, 2010

The T2K collaboration

~500 members, 61 Institutes, 12 countries

Canada
TRIUMF
U. Alberta
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany
U. Aachen

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova
INFN, U. Bari

Japan
ICRR Kamioka
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Osaka City U.
U. Tokyo

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroclaw

Russia
INR

S. Korea
N. U. Chonnam
U. Dongshin
U. Sejong
N. U. Seoul
U. Sungkyunkwan

Spain
IFIC, Valencia
U. A. Barcelona

Switzerland
U. Bern
U. Geneva
ETH Zurich

United Kingdom
Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC/RAL
STFC/Daresbury

USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

The T2K experiment

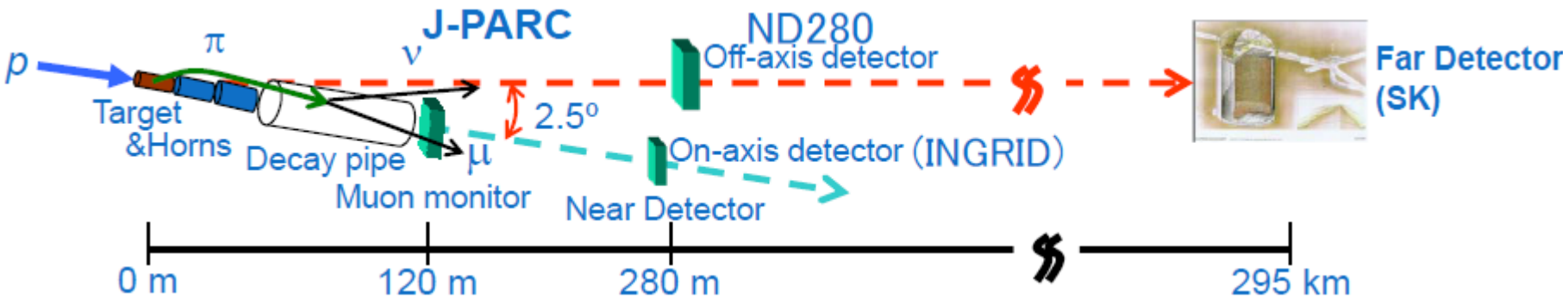
- Long baseline neutrino oscillation experiment in Japan
- **J-PARC**: Intense proton accelarator (design value = 750kW)
  - K2K: 5.2kW, NuMI for MINOS: 400kW, CNGS: 500kW
- **Super-Kamiokande**: Large water cherenkov detector
  - Fiducial volume = 22.5 kton (c.f. MINOS = 5.4 kton)

T2K goals

- Measure last unknown mixing angle θ_{13} using $\nu_\mu \rightarrow \nu_e$ appearance
  - Potentially open up δ_{CP} search in lepton sector

- Measure precisely the atmospheric parameters θ_{23} and Δm_{32}^2 using $\nu_\mu \rightarrow \nu_\mu$ disappearance
  - Is there a symmetry between 2nd and 3rd generation?

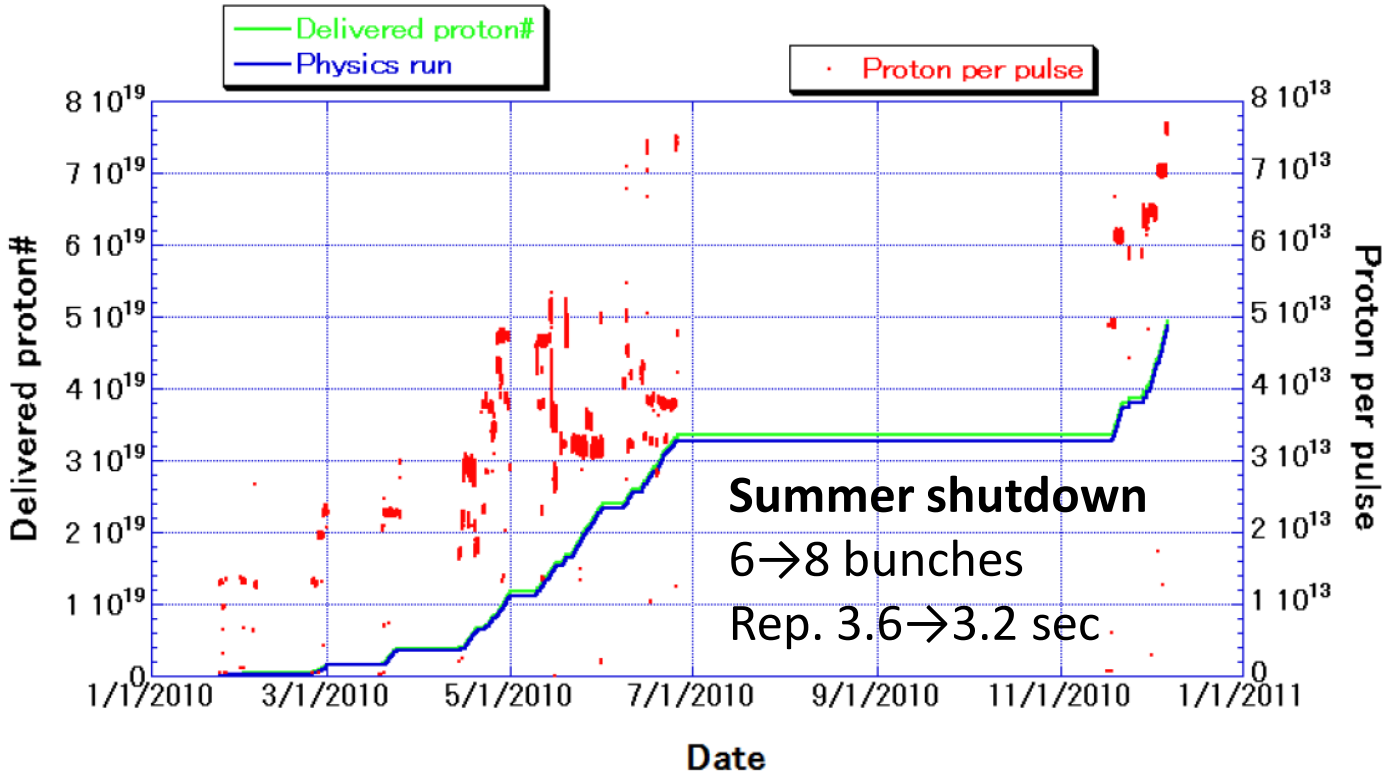
T2K schematic



- **Beam monitoring**
  - Primary beam monitors (intensity, position, profile)
  - Muon monitor (MUMON) after the decay pipe
  - On-axis neutrino detector (INGRID) at 280 m from the target
- **Beam characterization and cross section measurements**
  - (2.5˚) off-axis neutrino detectors at 280 m from the target
- **Neutrino flavor and flux measurement at far site**
  - Super-K at 295 km from the target (2.5˚ off-axis)

T2K status

Accumulated protons

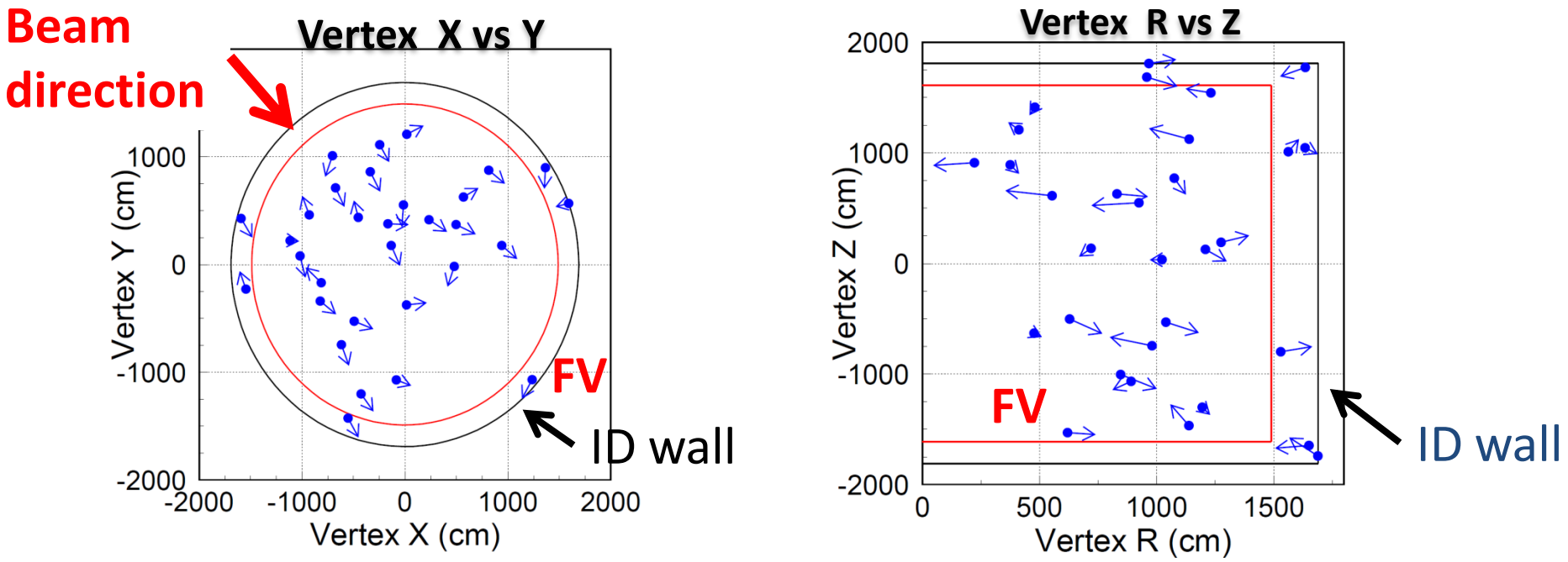


- **First run** (January to June 2010)
  - ~50 kW stable operation; 3.23×10^{19} protons for physics analysis
- **Second run** started on Nov. 16
  - Rapid ramp up to current 115 kW

T2K events in Super-K (1)

Jan-June 2010	# of events
Fully-Contained (FC)	33
+ fiducial volume cut + visible E > 30 MeV (FCFV)	23

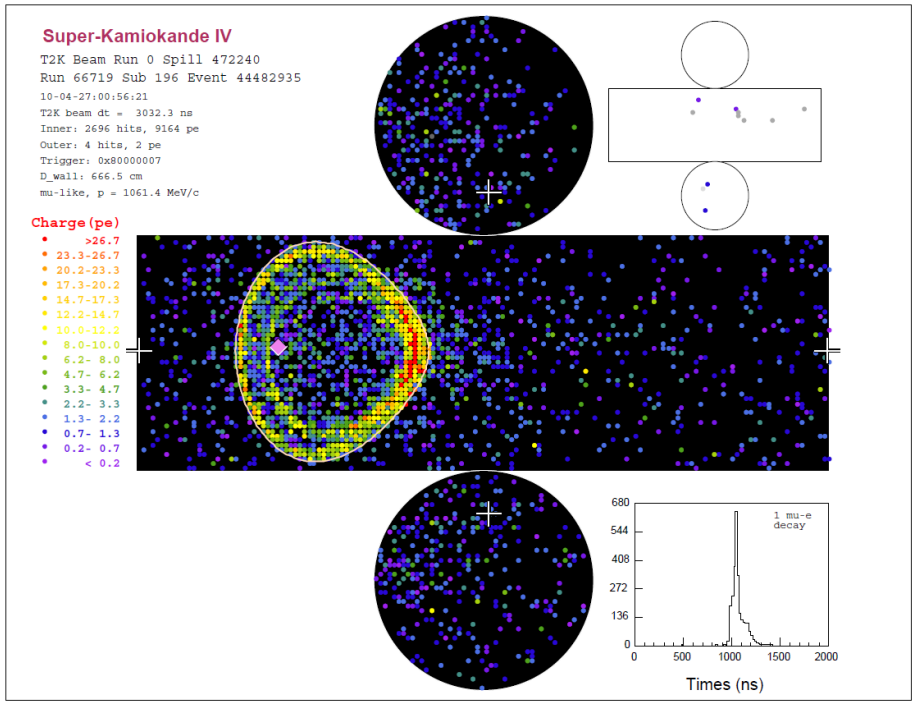
Vertex and direction (FC, Evis>30MeV)



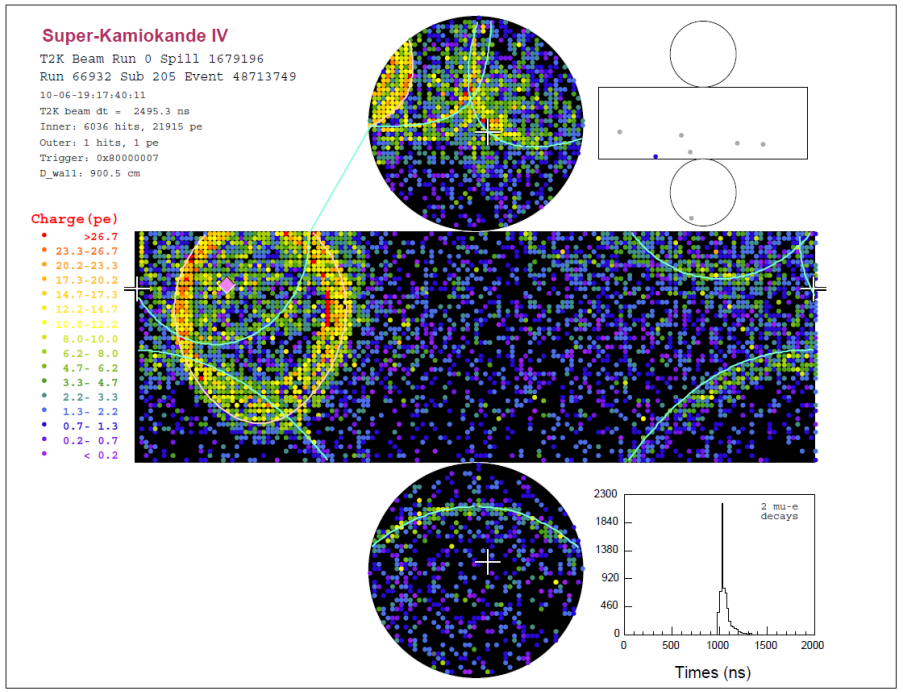
Points: Reconstructed event vertex, **Arrow**: 1st-ring direction

T2K events in Super-K (2)

single-ring μ-like



multi-ring μ-like



Pμ = 1061 MeV/c

1 decay-electrons

Pμ = 1438 MeV/c

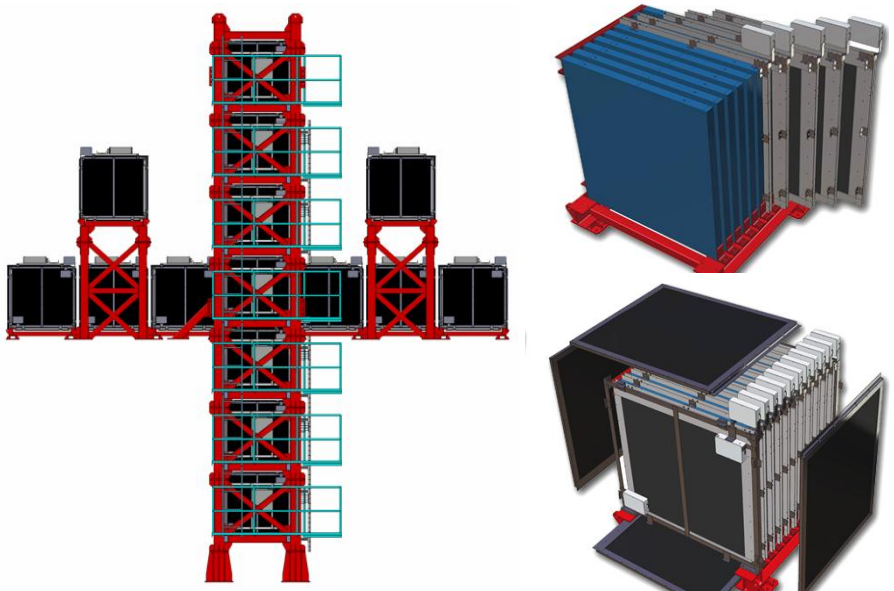
2 decay-electrons

Expect first results by winter 2011 conferences.

T2K near detectors and MPPC

INGRID on-axis neutrino detector

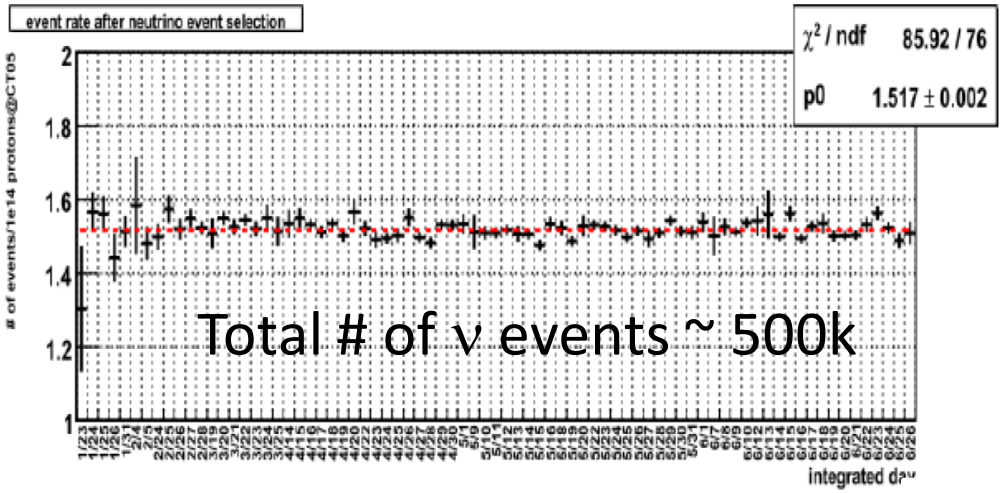
- On-axis detector is crucial for off-axis measurements
  - Monitor beam direction, intensity and mean energy
  - Beam coverage ~ 10×10 m^2
  - Off-axis angle measurement accuracy goal is 1 mrad (< 15 MeV shift on off-axis peak energy)
  - 10k ν interactions per day at full power (750 kW)



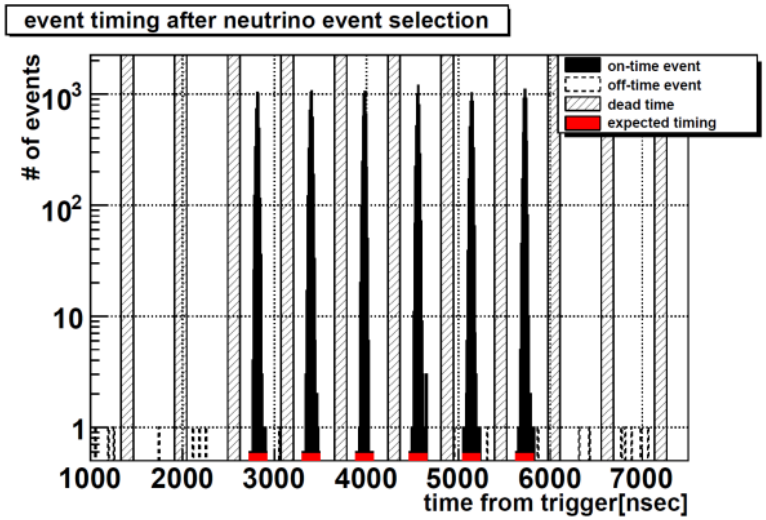
INGRID "cross" is formed with 14 identical modules + 2 diagonal modules made of plastic scintillator planes and iron targets surrounded by VETO planes.

INGRID measurements

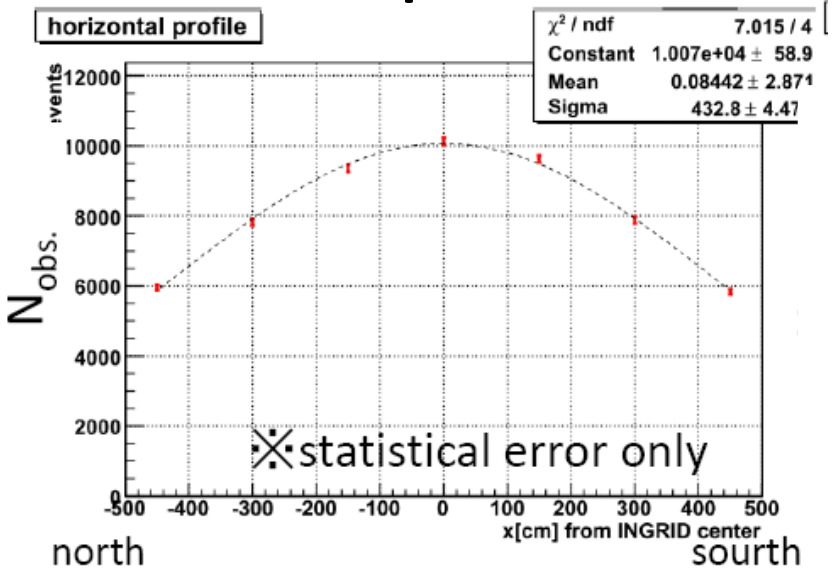
of ν events/1e14 POT



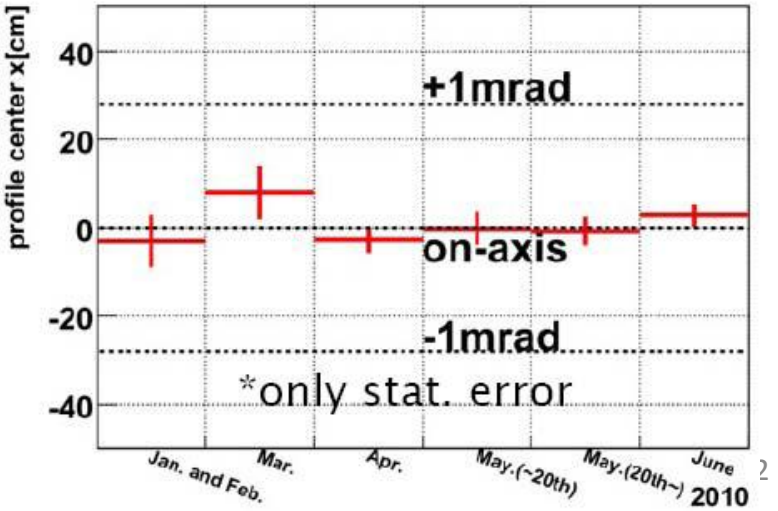
Six bunch beam structure



Beam profile X



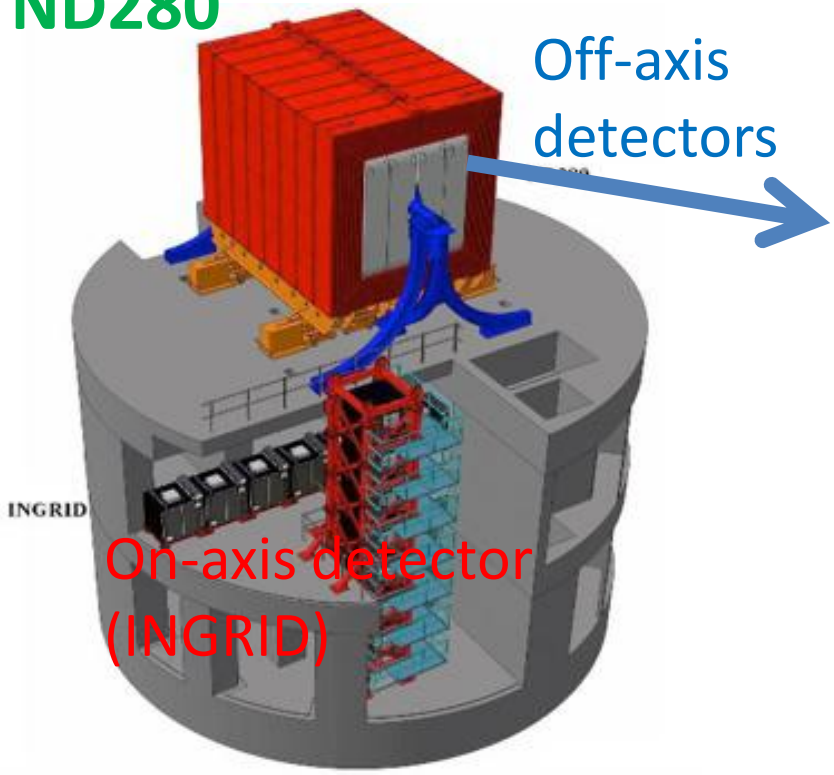
Beam profile center X

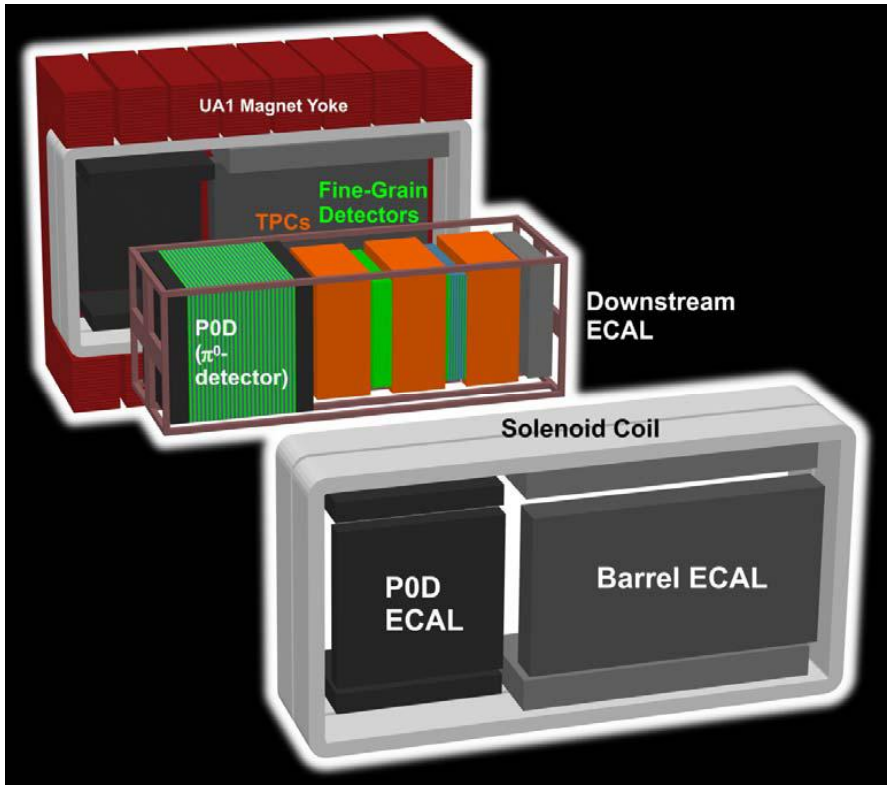


T2K off-axis near detectors

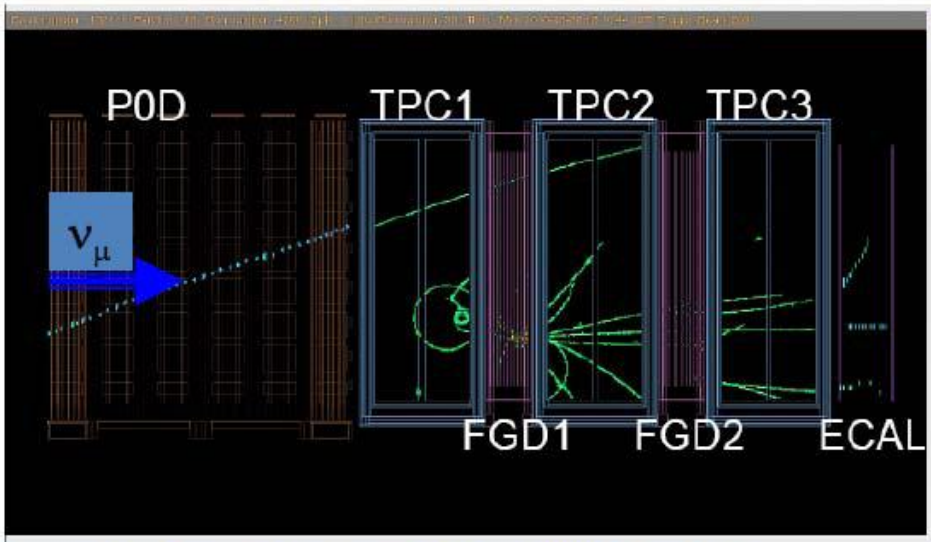
- The off-axis near detectors provide
  - Off-axis beam measurement based on CCQE
  - Beam ν_e contamination
  - Super-K background measurements (NCπ^0)
  - Precise cross-section measurements with very large statistics

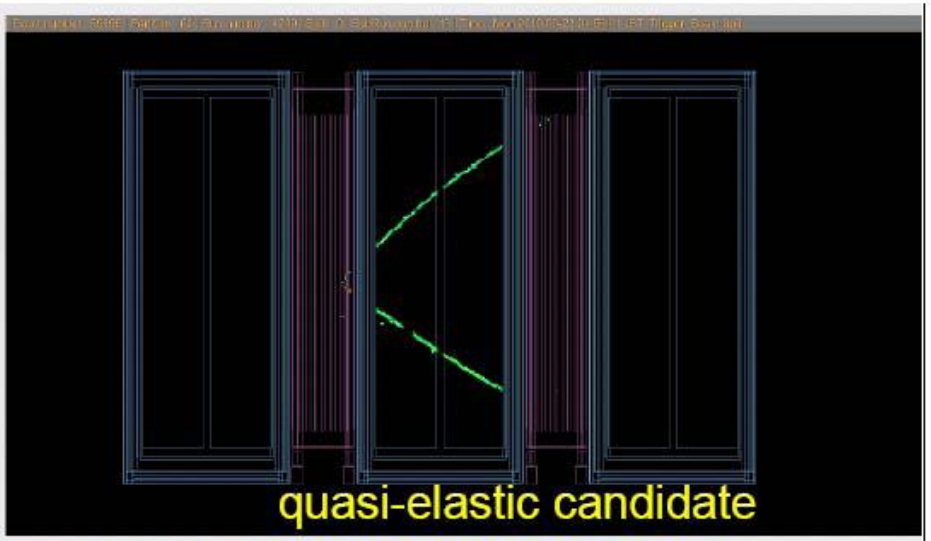
ND280

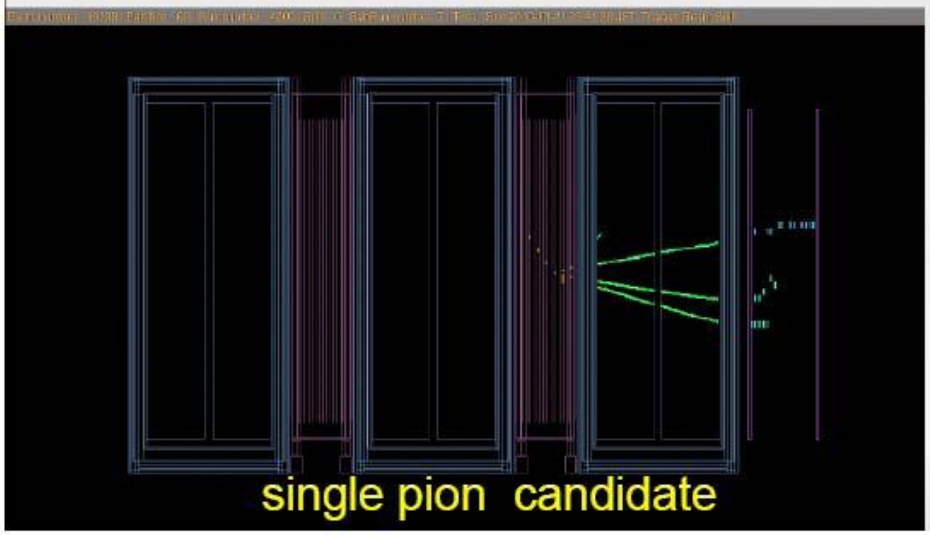


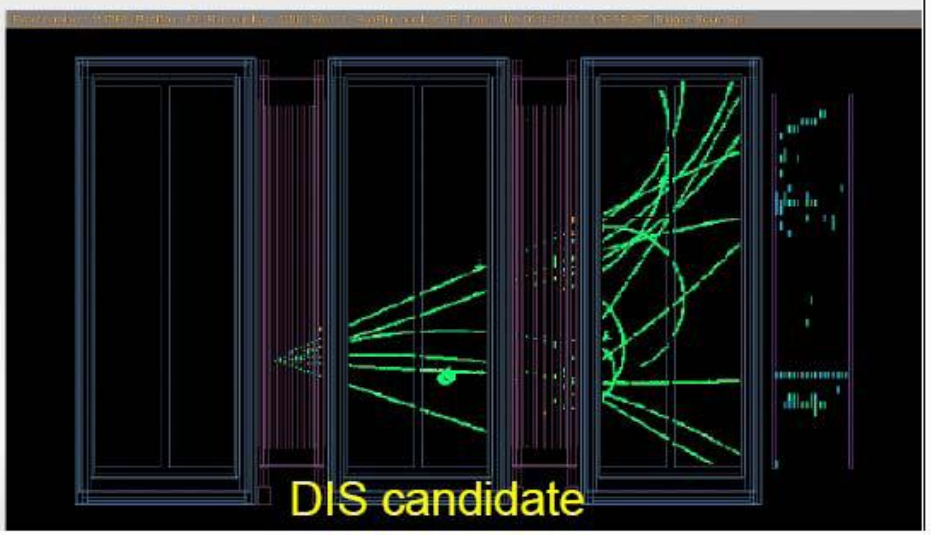


Off-axis near detectors measurements









ND280 photosensor requirements

- **Operational in magnetic field B=0.2T** (UA1 magnet)
- **Very tight space constraints**
  - Compact
- Low light yield at the end of Y-11 fibre (λ_{att} = 3.5 m)
  - Photo detection efficiency > PMT @ 550 nm
- Large number of channels (56000)
  - Low price
- Detector operation for five years

MPPC development for T2K: a fast R&D!

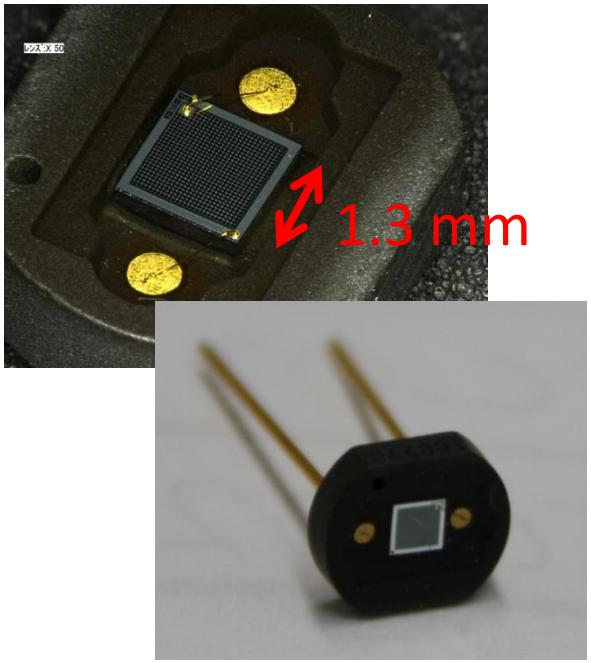
- **2004-2005**: First study of photon-sensor options
  - MA-PMT, MCP-PMT, APD, GM-APD arrays
  - First tests of MRS-APD from CPTA by ND280 groups
- **End of 2005**: Decision to use GM-APD arrays
  - In November, we met with Hamamatsu Photonics K.K.
- **2006**: R&D of MPPC by Japanese groups (T2K, ILC etc)
  - Other SiPM candidates were also tested
- **2007**: First MPPC on Hamamatsu catalogue ($1 \times 1 mm^2$)
- **End of 2007**: $1.3 \times 1.3 mm^2$ 50μm pitch (667 pixels) ceramic package type MPPC is adopted for all ND280
  - Delivery of 63500 MPPCs (inc. spares) was completed in Feb. 2009!

T2K MPPC specifications

Item	Spec
Active area	1.3 x 1.3 mm^2
Pixel size	50 x 50 μm^2
Num. of pixels	667
Operation voltage	70 V (typical)
PDE @ 550nm	~ 25 %
Dark count (Gain = 7.5 x 10^5)	< 1.35 Mcps @ 25 deg. (Thre. = 0.5 p.e.)
Num. of device	56,000

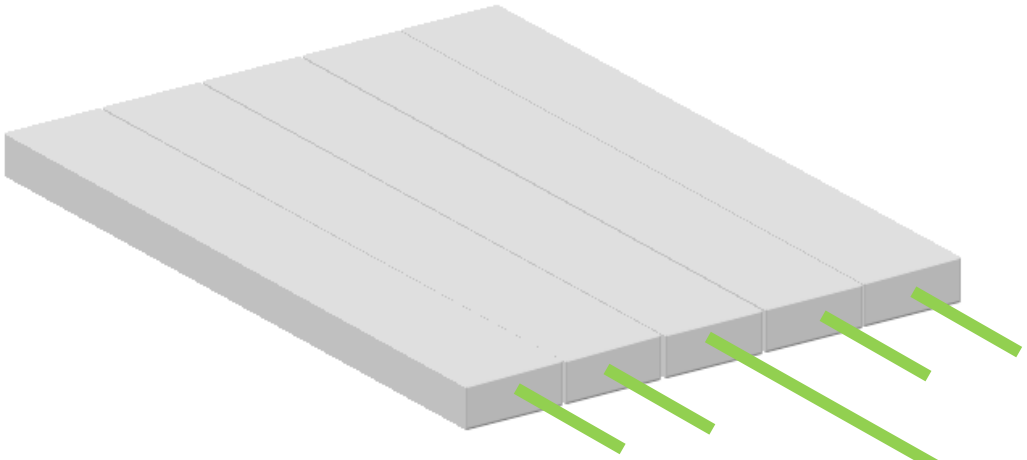
S10362-13-050C

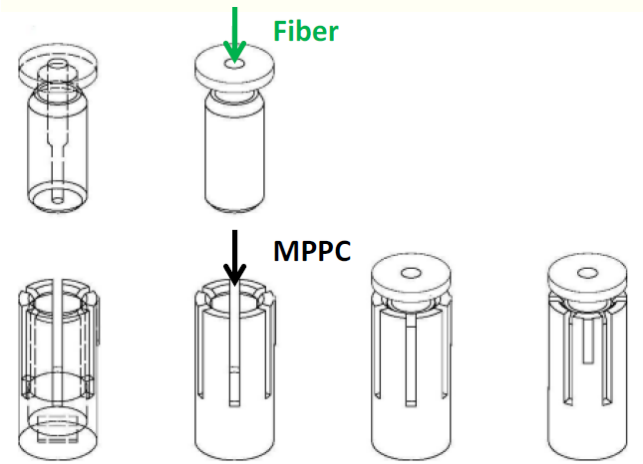
Developed for T2K



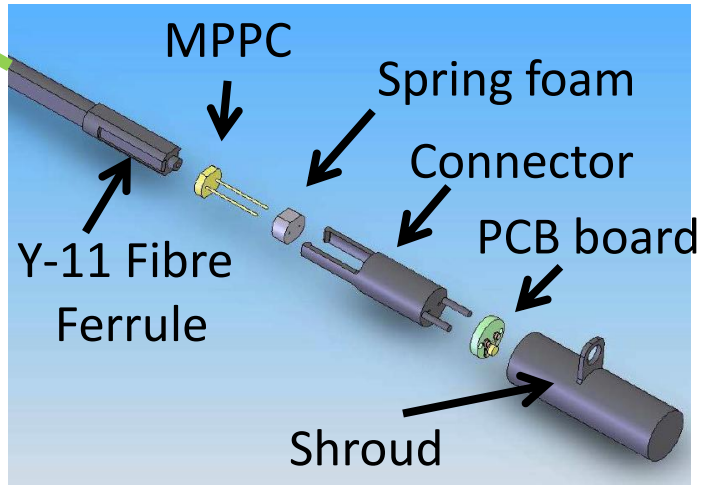
Produced by Hamamatsu Photonics

MPPC in T2K near detectors





Connectors for INGRID/FGD

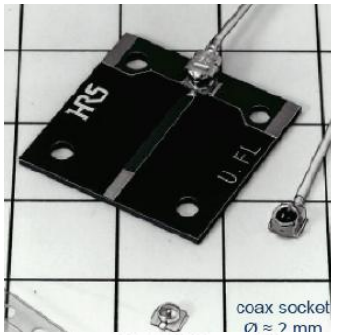


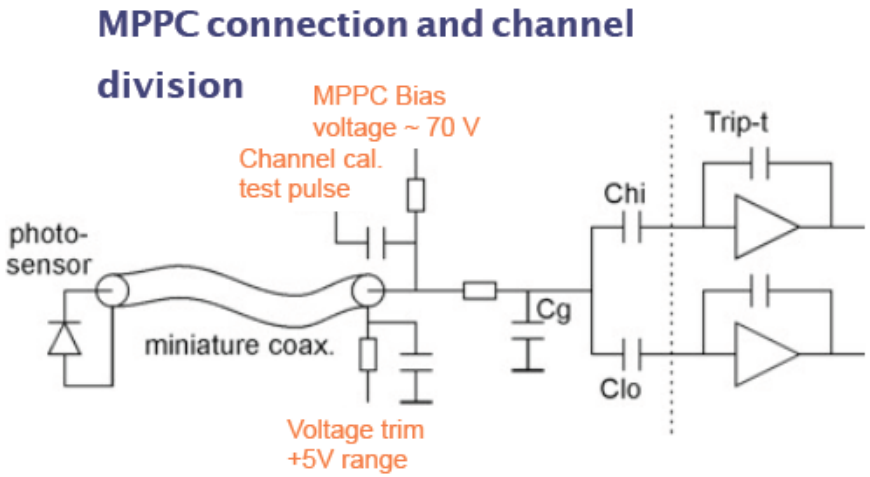
Connectors for P0D/ECAL/SMRD

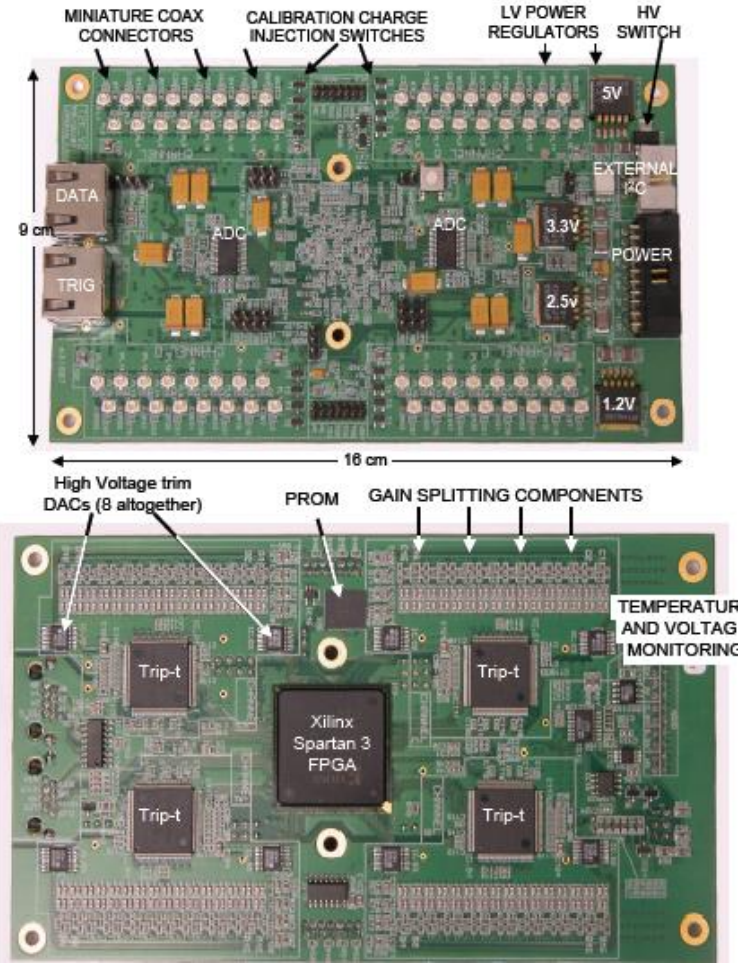
- Basic element of the near detector scintillator subsystem (INGRID, P0D, FGD, ECAL, SMRD)
  - Extruded scintillator bar with embedded Y-11 fibre read out by individual MPPC in coupler
  - 56000 channels in total

Readout electronics

Trip-T electronics

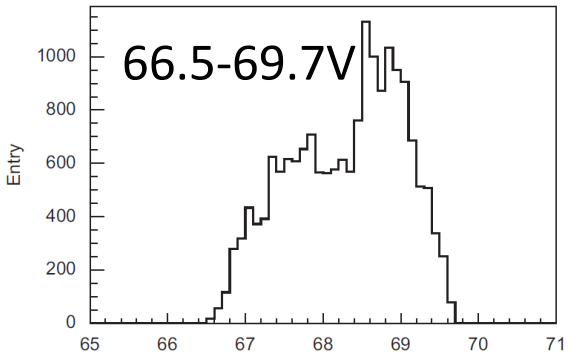




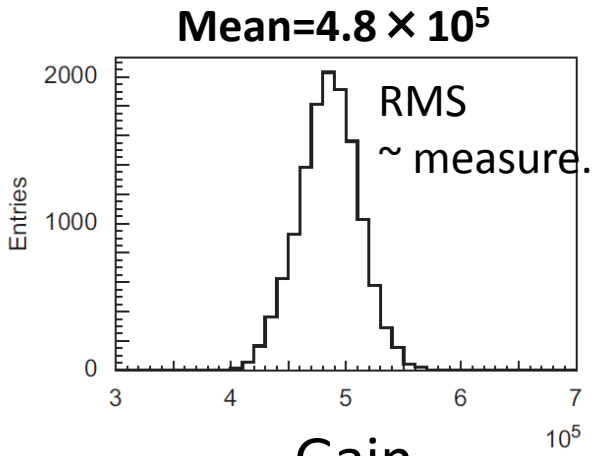


- 64 Hi/Lo gain ADC and TDC
- Individual HV trim (8bit, 5V range)
- On board charge injection circuit
- Temperature sensors

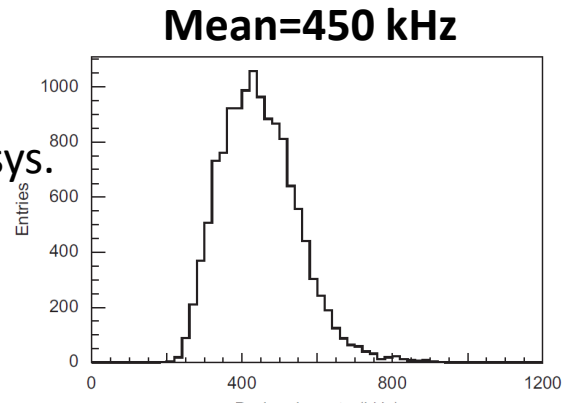
Kyoto large scale test (17686 MPPCs)



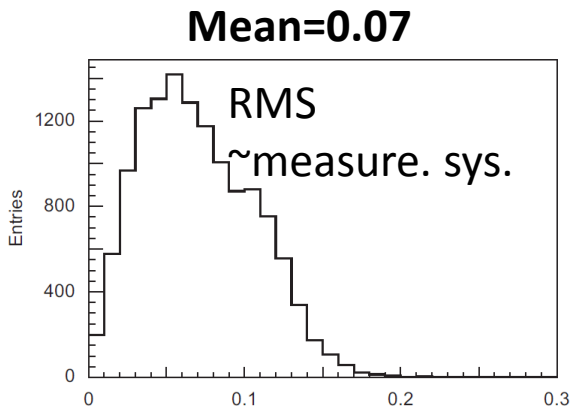
V_{bd} at 20˚C



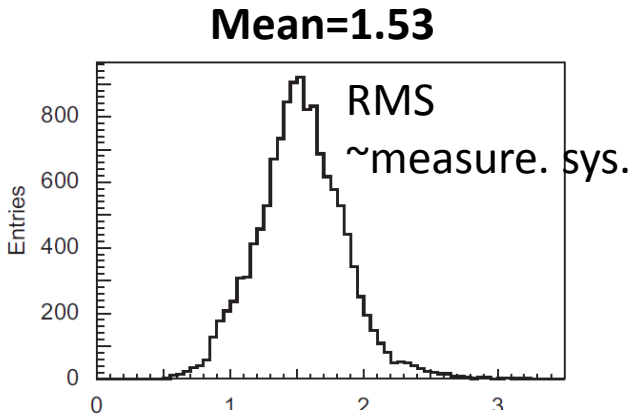
Gain



Dark rate (kHz)



AP + CT prob.



PDE (xPMT)

<u>ΔV = 1.0V and 20˚C</u>

Failure rate < 0.05 %

M. Yokoyama et al.,
NIM A 622 (2010) 567-573

<u>Device uniformity itself is considered to be much better.</u>

Bad channels (after ~2 year operation)

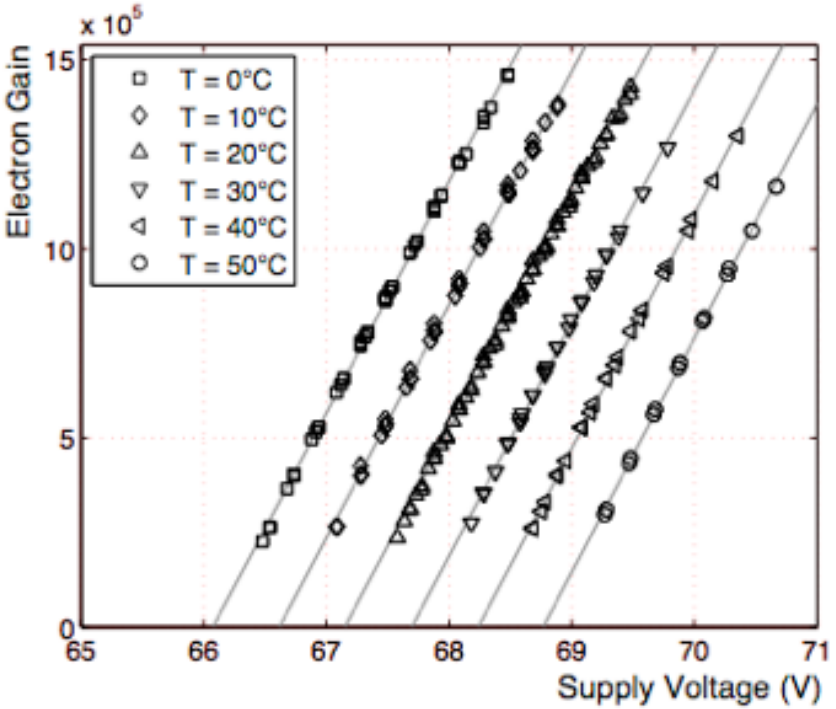
System	Channels	Bad channels	Fraction
ECAL (DSECAL)	22336 (3400)	35 (11)	0.16% (0.32%)
SMRD	4016	7	0.17%
P0D	10400	7	0.07%
FGD	8448	20	0.24 %
INGRID	10796	18	0.17 %
Total	**55996**	**87**	**0.16 %**

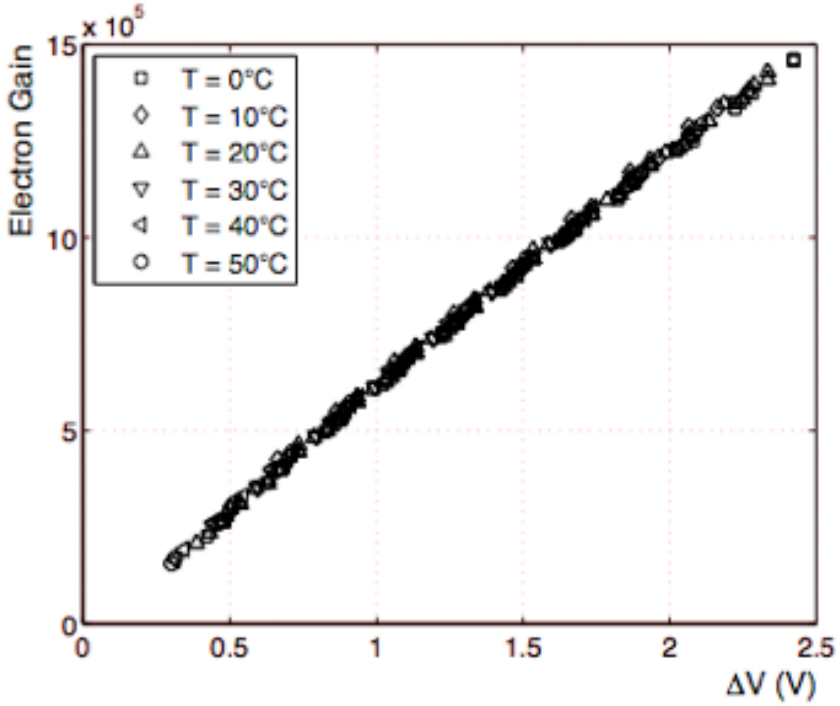
Bad channel does not necessarily mean problem with the MPPC, it could be electronics, cable or connection problem as well.

MPPC characterization

Gain and temperature dependence

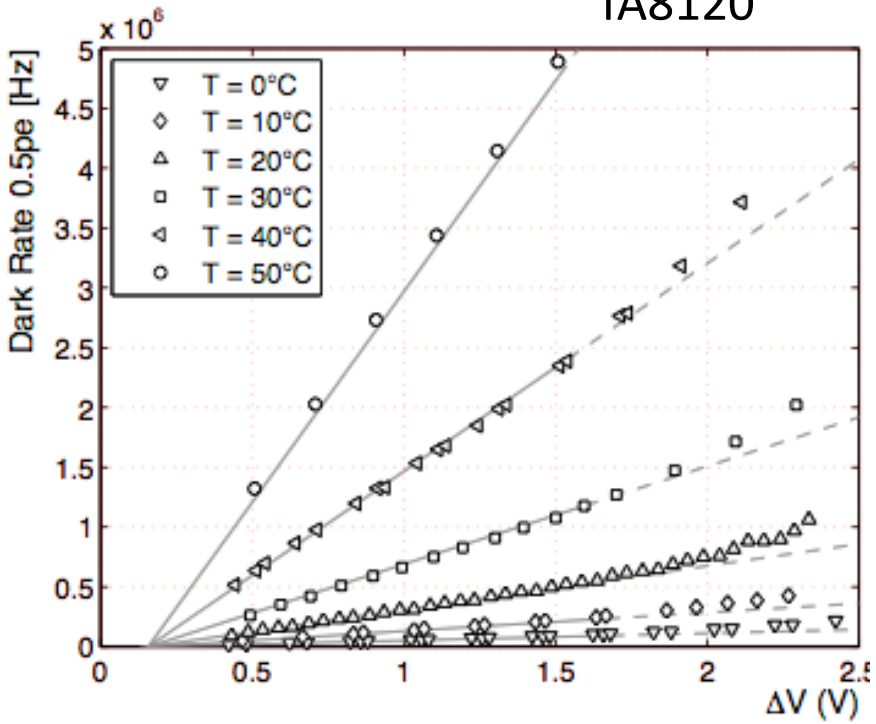
- Gain proportinal to overvoltage
- Breakdown voltage changes with temperature



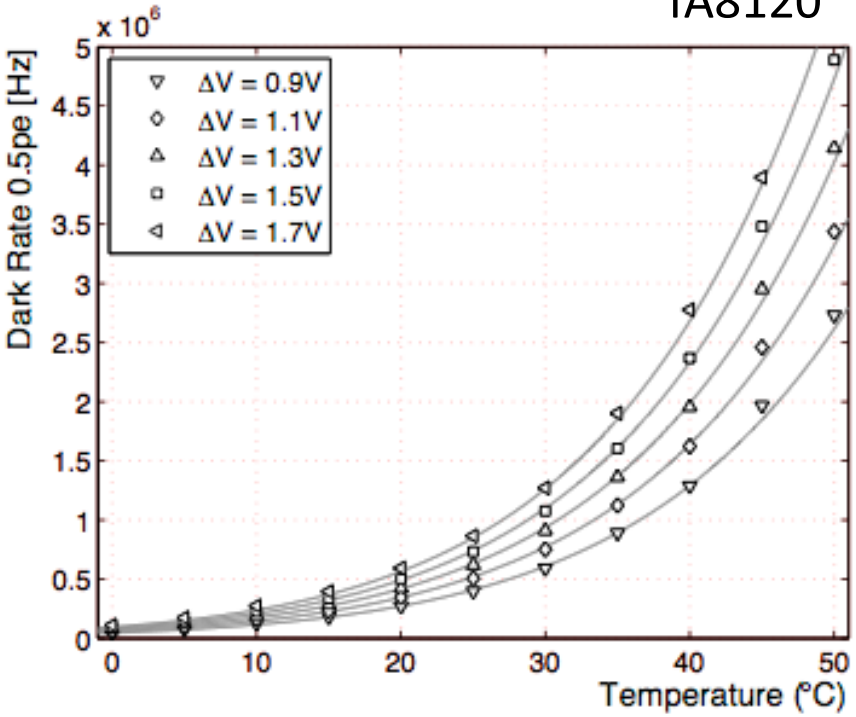


Dark count rate

TA8120



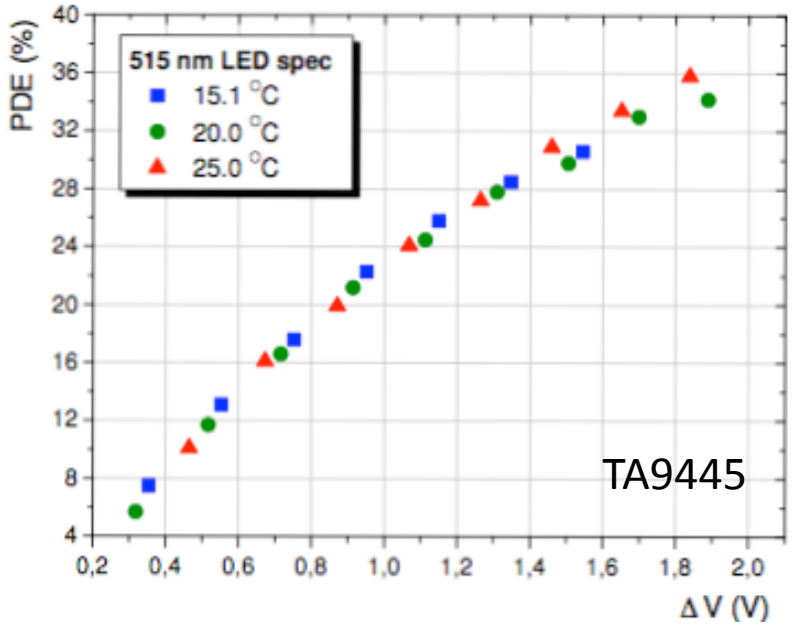
TA8120

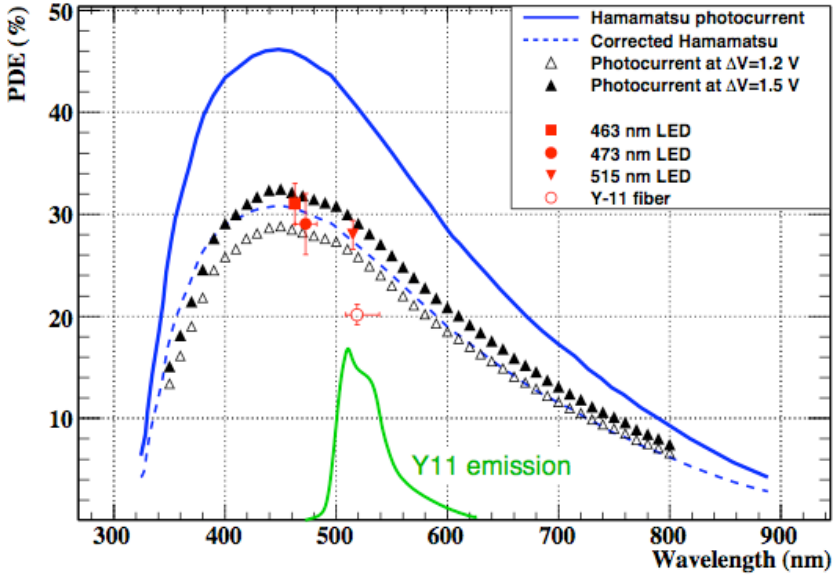


- Dark count is proportional with overvoltage
- Increase exponentially with temperature

Photon detection efficiency

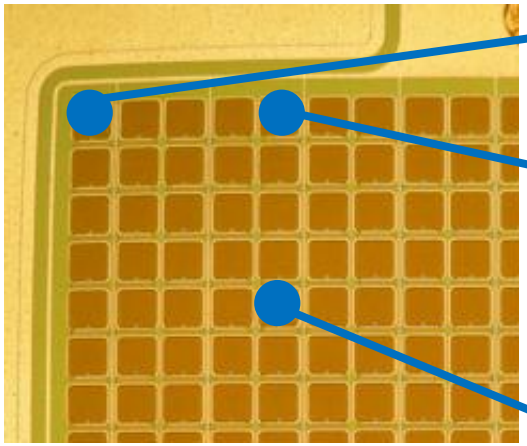
INR, Imperial College, Sheffield University

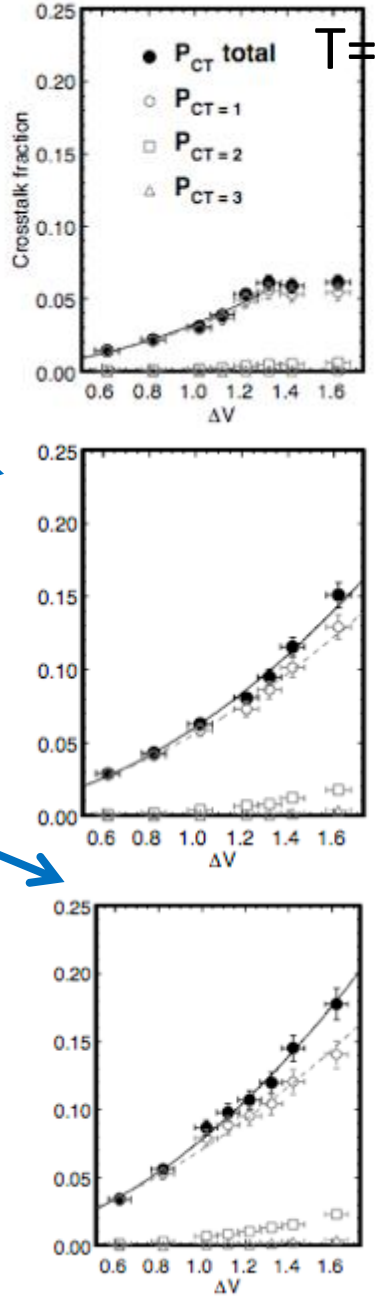




- PDE was measured at different wavelength using Poisson zero probability method
  - Insensitive to crosstalk and afterpulse
- PDE=20-25% for green light at nominal gain
- Good agreement in variation with wavelength with Hamamatsu

Pixel to pixel cross talk





- Pixel cross talk measured with optical microscopy set up, fast amplifier and laser LED
  - Beam spot width 5μm
  - 3 specific pixels: corner[1:1], side[1:5] and inside[5:5] to study position dependence of cross talk
- Probability scales consistently with random crosstalk generation in pixel

What next?

Once we find finite θ_{13},

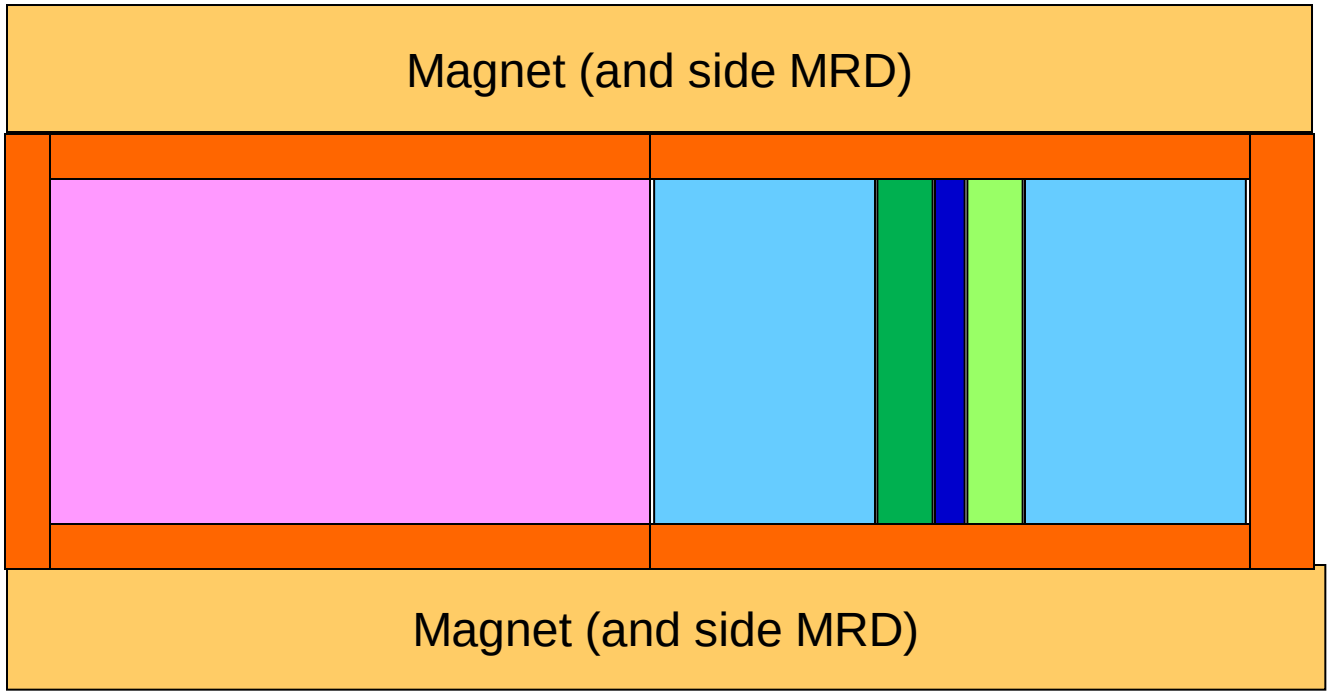
Next goal:
Discovery of CP violation in lepton sector

- $\nu_\mu \to \nu_e$ in LBL most promising channel
- Two strategies
  1. Compare neutrino and anti-neutrino
  2. Compare 1st and 2nd oscillation maxima

A Conceptual Design of the T2K-ND280m Detector Upgrade

(**no relation to the T2K collaboration**)

T. Nakaya @ GLA2010
March 28-31, 2010,
Tsukuba.



One vague idea of TN

Electron calorimeter

Fine Grained detector

FGD w/ water scintillator

Gas TPC

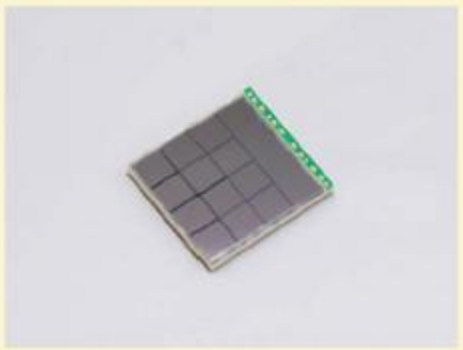
Lq. Ar TPC

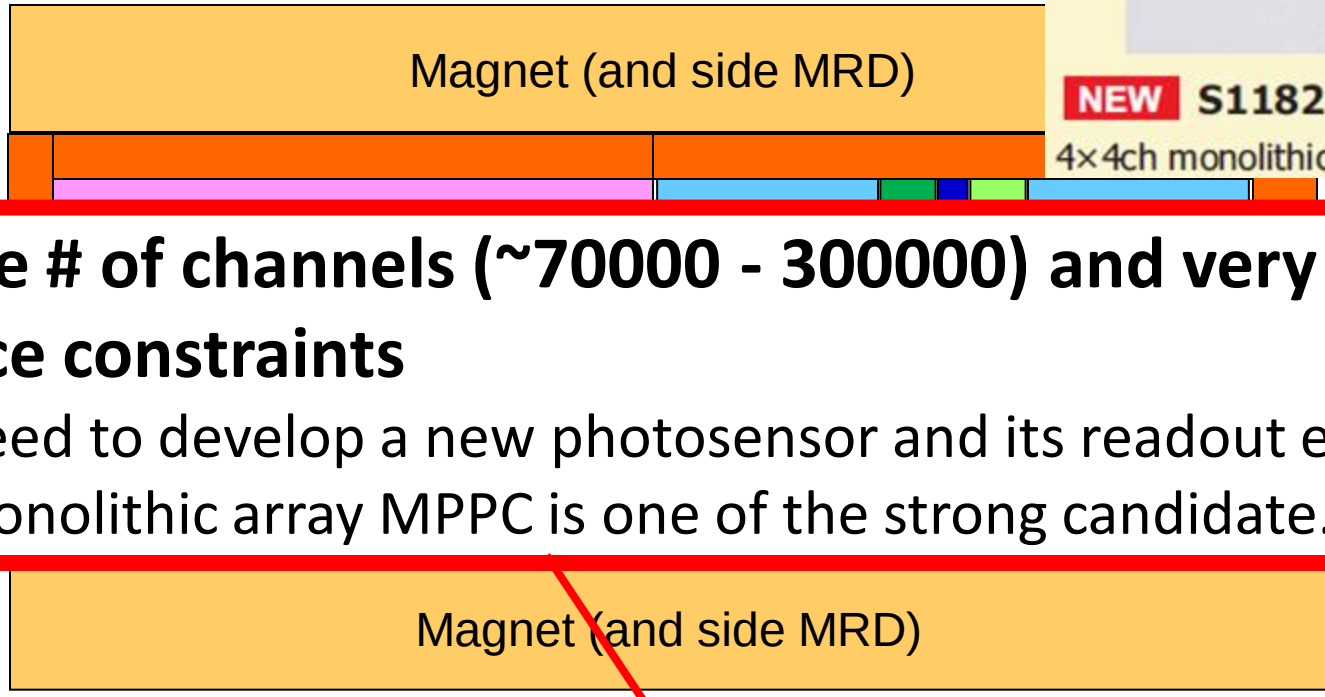
Scintillating fiber camera (1~2mm fiber)

Idea (2010?) → Realization/Operation 2016?~

A Conceptual Design of the T2K-ND280m Detector Upgrade

(**no relation to the T2K collaboration**)





Huge # of channels (~70000 - 300000) and very tight space constraints

-> Need to develop a new photosensor and its readout electronics

-> Monolithic array MPPC is one of the strong candidate.

Idea (2010?) → Realization/Operation 2016?~

Summary

- Development, commercialization and large production of MPPC for T2K near detectors completed
  - Very fast R&D and delivery on schedule of 62500 MPPC for T2K by Hamamatsu with <0.1% of devices rejected by QA
  - T2K near detectors are the first large scale application of MPPC to a real experiment
- Operation at T2K has been very stable for ~2 years
  - Very small number of bad channels (<0.2%)

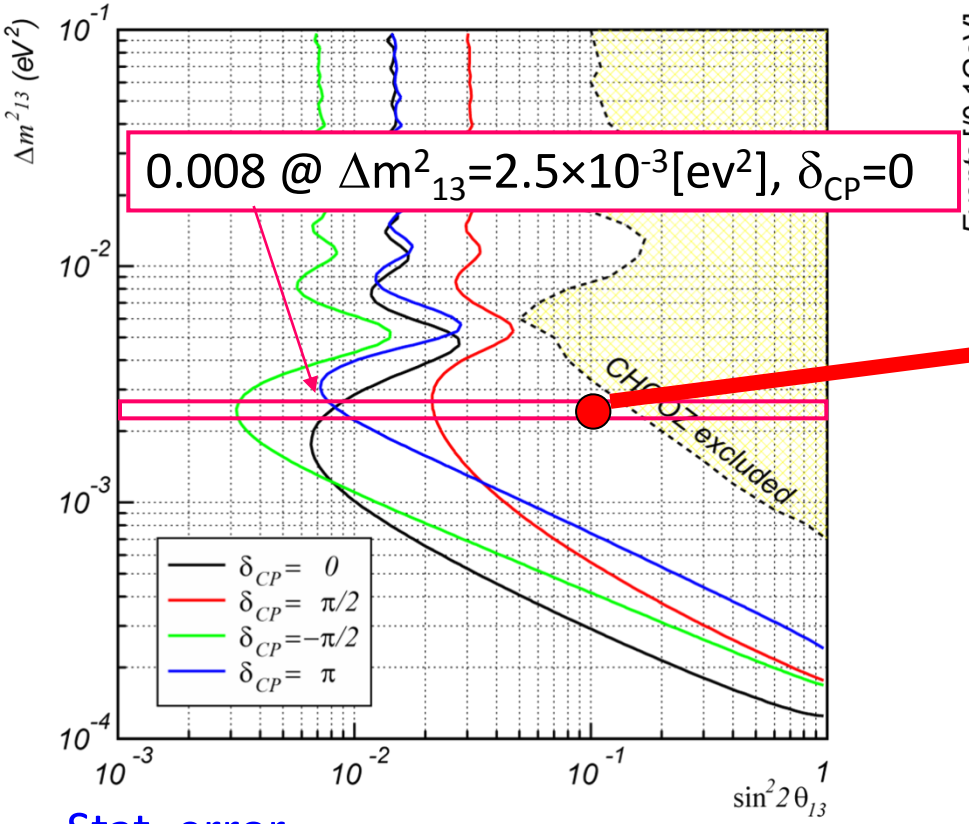
Backup

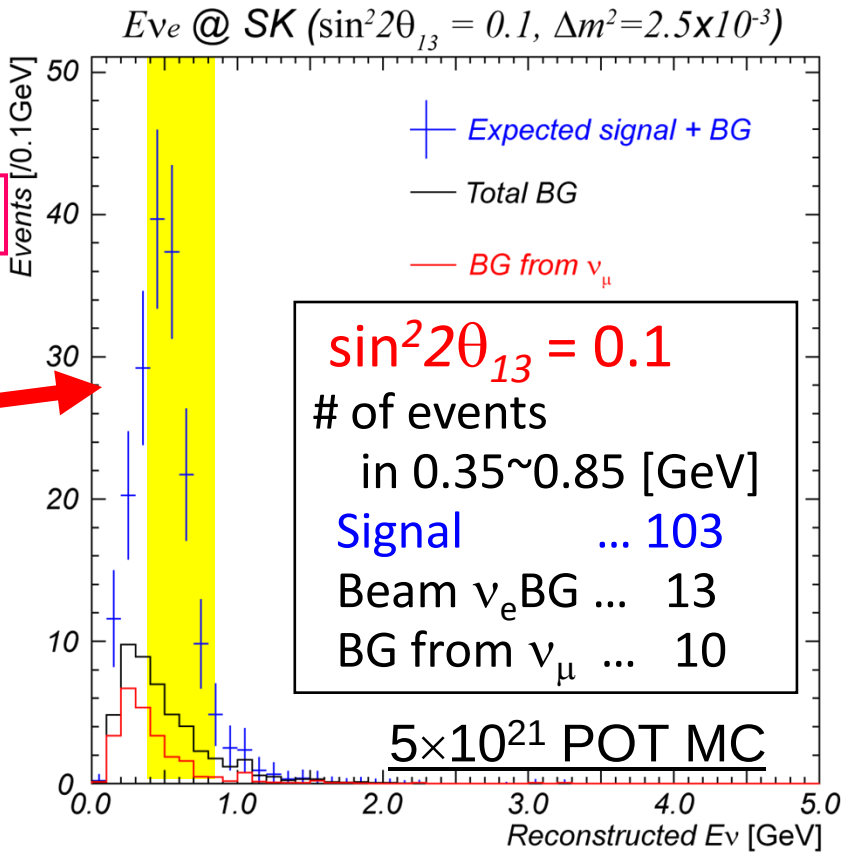
T2K θ_{13} sensitivity (normal hierarchy)

90% C.L. sensitivity

$\sin^2 2\theta_{23}$ = 1.0 is assumed.

5×10^{21} POT ~ 5 years@ full intensity





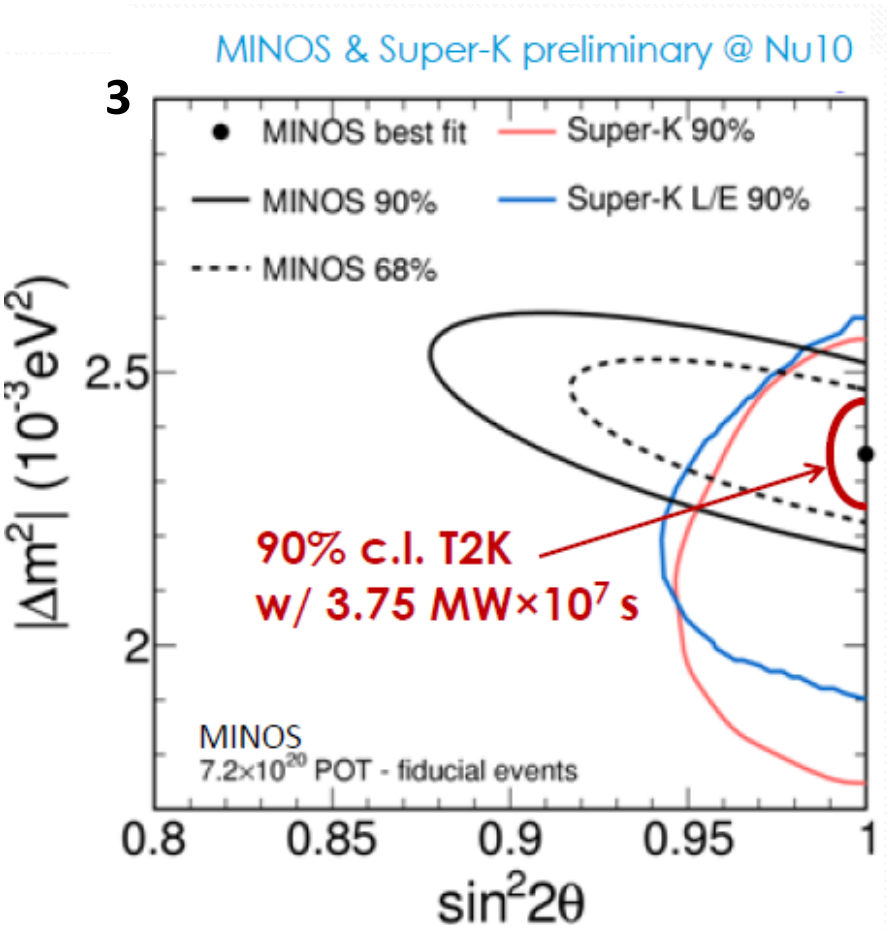
Stat. error

+ Syst. error for BG subtraction (10%)

T2K atm. parameters sensitivity

- Narrow band spectrum centered on oscillation maximum
  - Good sensitivity to atmospheric parameters

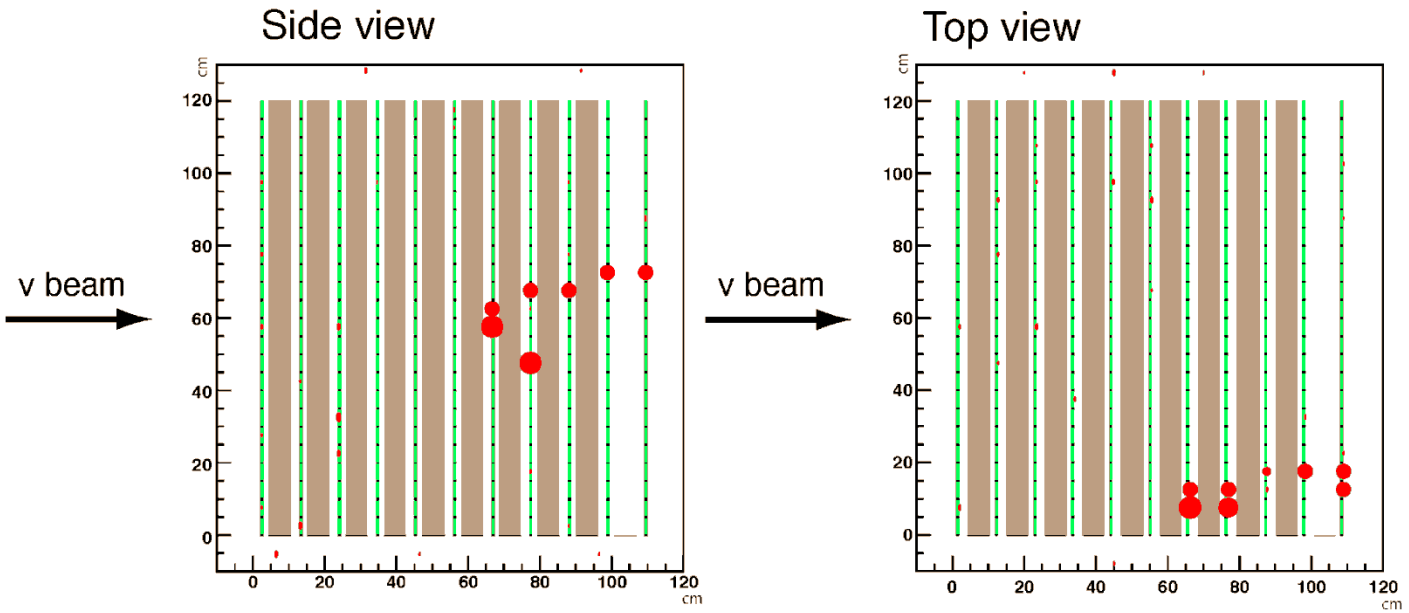
- **Expected sensitivity**
  - **$\Delta\sin^2 2\theta_{23} \sim 0.01$**
  - **$\Delta m^2_{23} < 1.0 \times 10^{-4} eV^2$**



INGRID on-axis neutrino detector

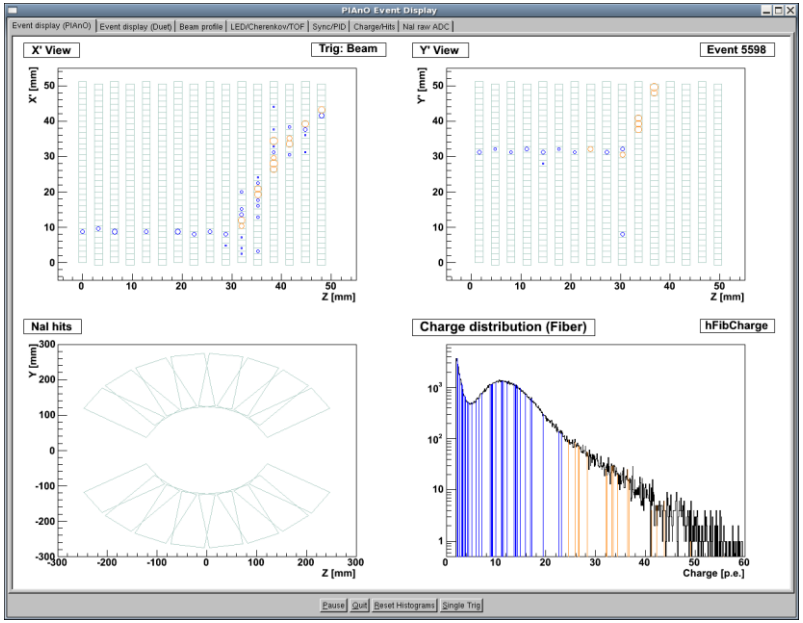
- On-axis detector is crucial for off-axis measurements
  - Monitor beam direction, intensity and mean energy
  - Beam coverage ~ 10 × 10 m^2
  - Off-axis angle measurement accuracy goal is 1 mrad (< 15 MeV shift on off-axis peak energy)
  - 10k ν interactions per day at full power (750 kW)

First ν event
Nov. 22, 2009
20:25:48 JST



PIAnO

- Measure charged π cross section with 10% sys. errors
  - Traker size: $5 \times 5 \times 5$ cm^3
  - 1.5 mm scintillation fibers + MAPMTs
  - 150–300 MeV π beam at TRIUMF



Pixel to pixel cross talk