Geiger mode APD's for the neutrino oscillation experiment T2K

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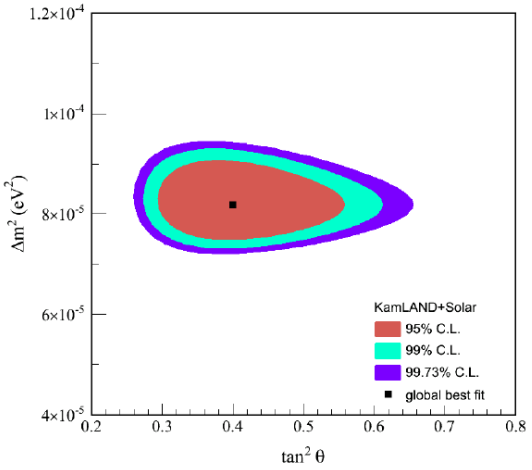
GSI, Darmstadt, 9 February 2008

Current status of neutrino mass and mixings

3 mixing angles (θ_{12}, θ_{23}, θ_{13})
1 CPV phase (δ)
2 (independent) mass differences ($\Delta m^2_{ij}=m_i^2-m_j^2$)

θ_{12}, Δm_{12}^2

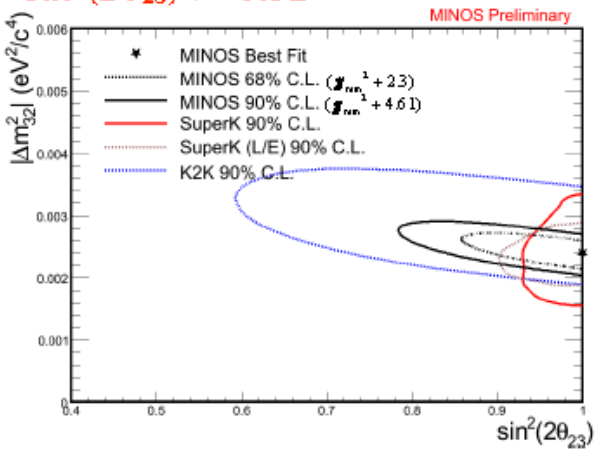
$\Delta m^2_{solar} = 8 \times 10^{-5}$ eV^2
$\sin^2(2\theta_{12}) = 0.86$



Solar + KamLAND

θ_{23}, Δm_{32}^2

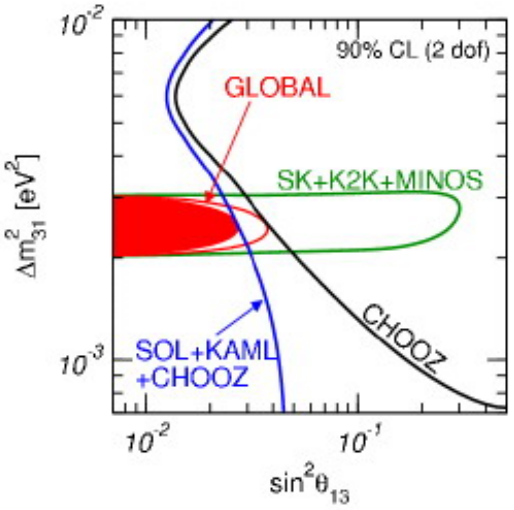
$\Delta m^2_{atm} = (2.2\sim2.6) \times 10^{-3}$ eV^2
$\sin^2(2\theta_{23}) > 0.92$



SK + K2K + MINOS

θ_{13}, Δm_{31}^2

$\theta_{13} \leq 10^0$



Only upper limit on θ_{13}
No information about δ

Yury Kudenko INR-Moscow

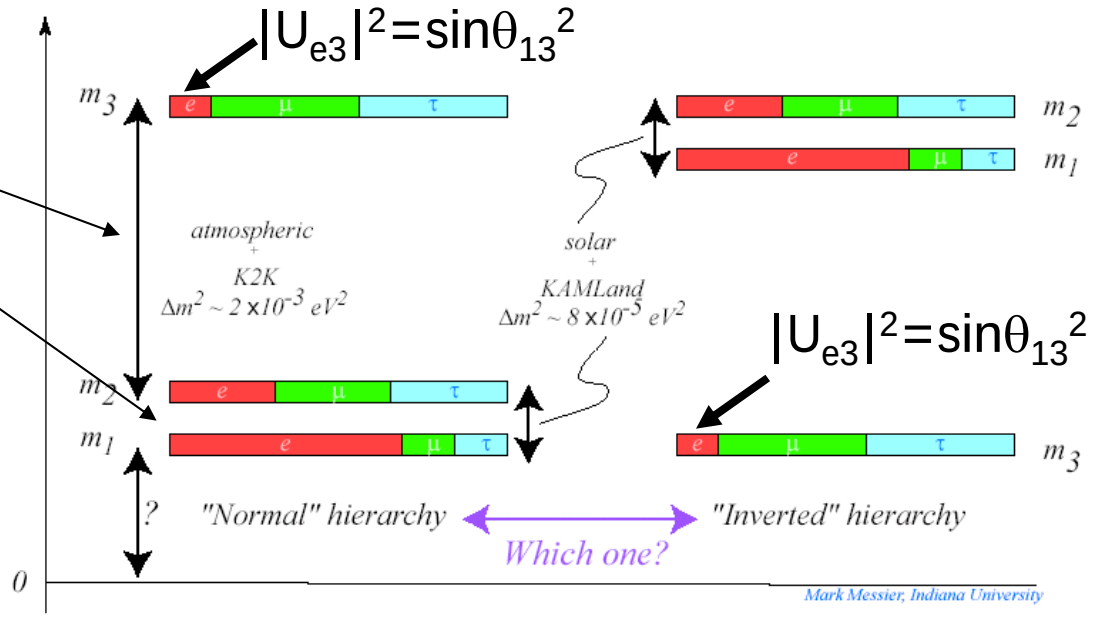
Present knowledge and next steps

$\Delta m^2_{23} \sim 0.0025 eV^2$

$\Delta m^2_{12} \sim 0.00008 eV^2$

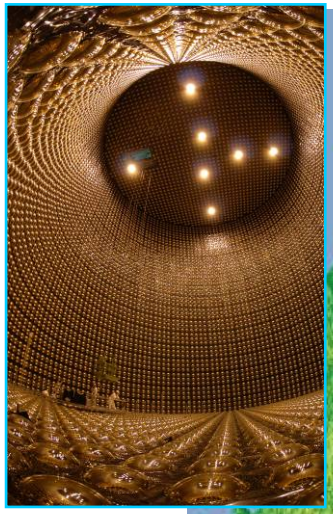
Large mixing { $\theta_{12} \sim 33^o$ $\theta_{23} \sim 45^o$

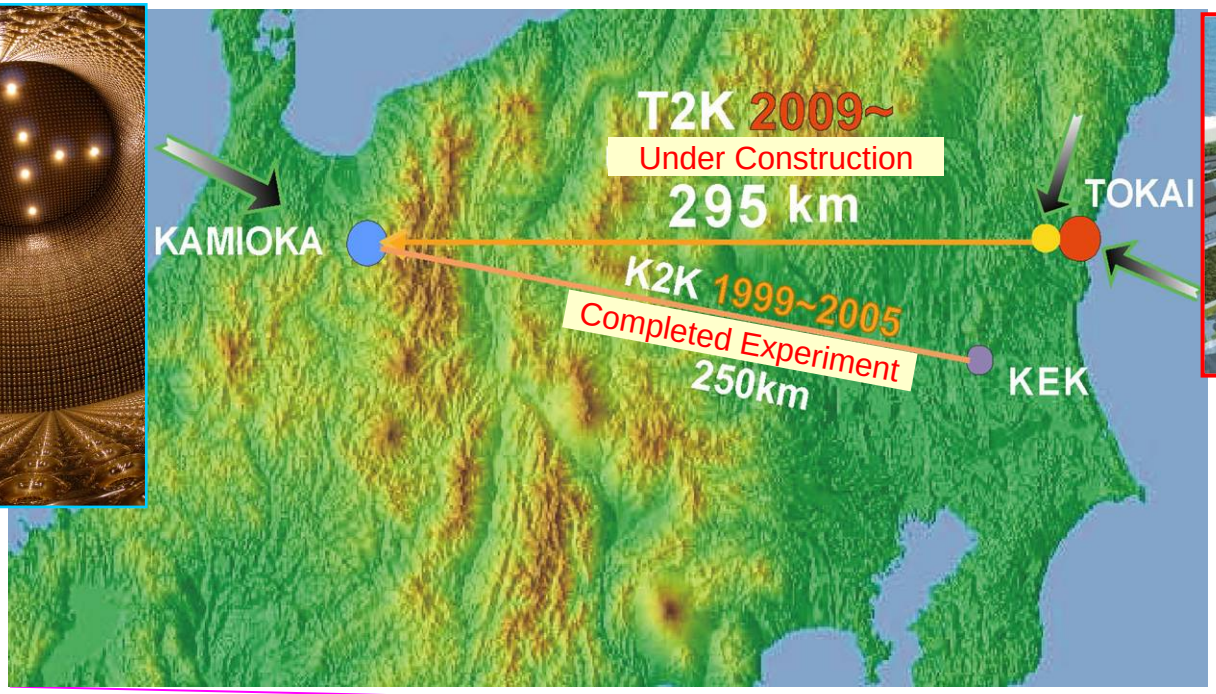
??

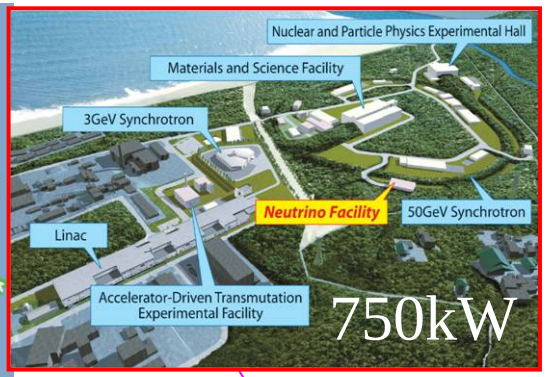


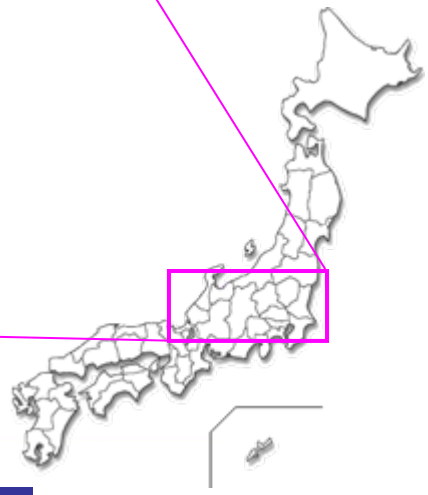
- Mixing angle θ_{13}
- Mass hierarchy (sign of Δm^2_{23} $\rightarrow$ $m_3 > m_1$ or $m_3 < m_1$)
- CP violation
- Absolute mass scale
- Dirac or Majorana
- Approaches
  - LBL experiments: multi purpose (θ_{13}, sign(Δm^2), CPV, θ_{23}, Δm^2_{23})
  - Reactor-based ν_e disappearance: single purpose (θ_{13}), complementary

T2K (Tokai to Kamioka) LBL neutrino experiment

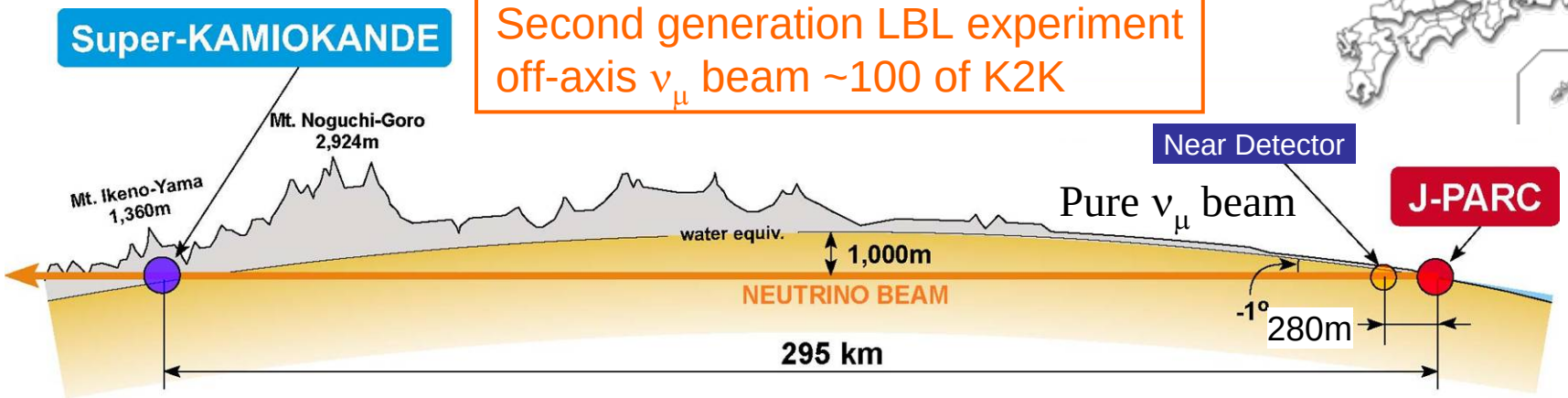








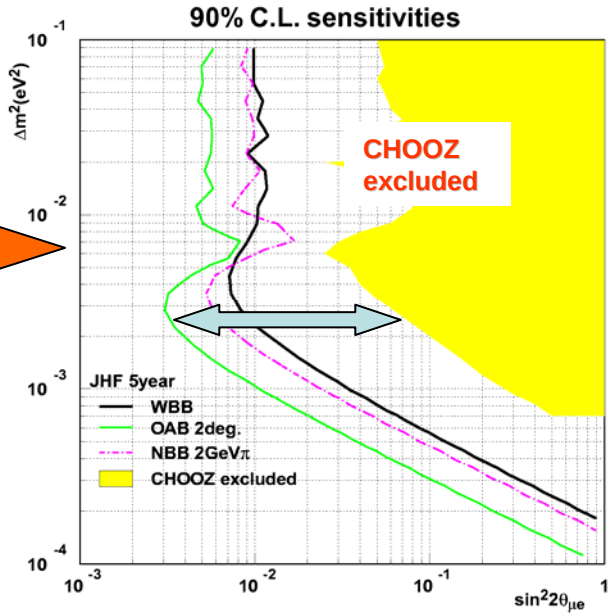
Second generation LBL experiment
off-axis ν_μ beam ~100 of K2K

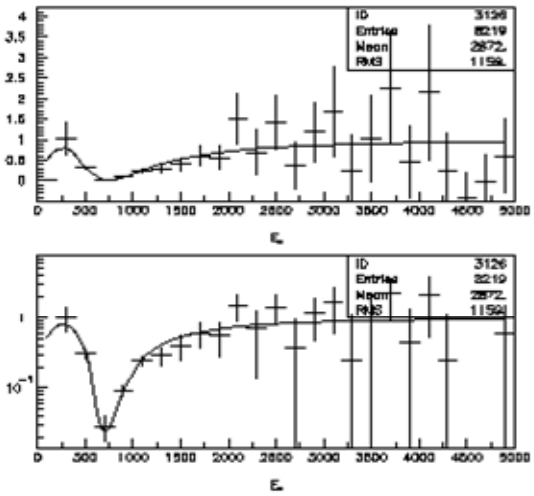


Goals of T2K

- Search for ν_e appearance sensitivity $\sin^2 2\theta_{13} \leq 0.01$

$\nu_\mu \rightarrow \nu_e$





$\nu_\mu \rightarrow \nu_\mu$

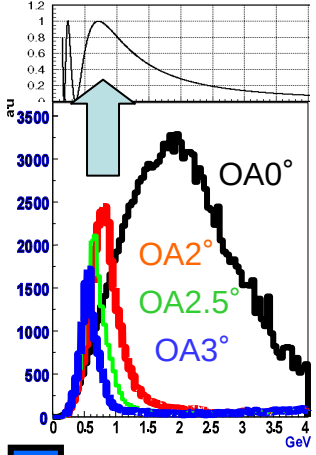
- Measurement of Δm^2_{23} with accuracy 2% and mixing angle with accuracy 1%

$\delta(\sin^2 2\theta_{23}) \sim 0.01$

$\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ eV^2

- Confirmation of $\nu_\mu \rightarrow \nu_\tau$ using NC events

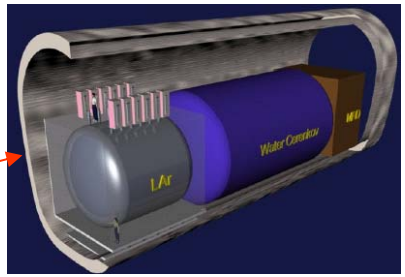
T2K setup



Possible Future

ND280m

ND2km



SK

μ monitor

p

π

off-axis

on-axis

ν

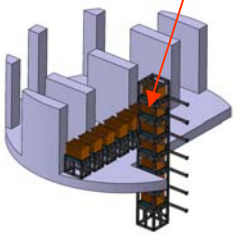
0m

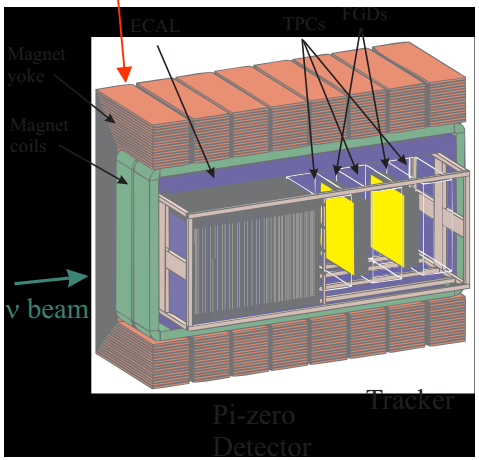
140m

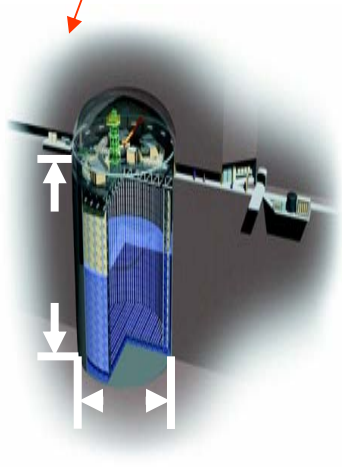
280m

2 km

295 km

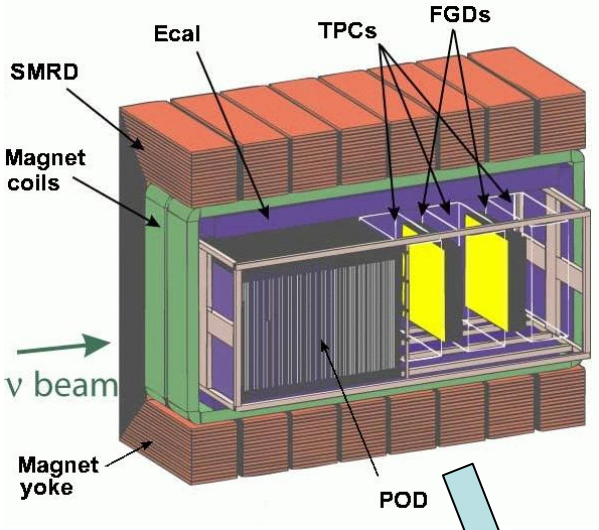




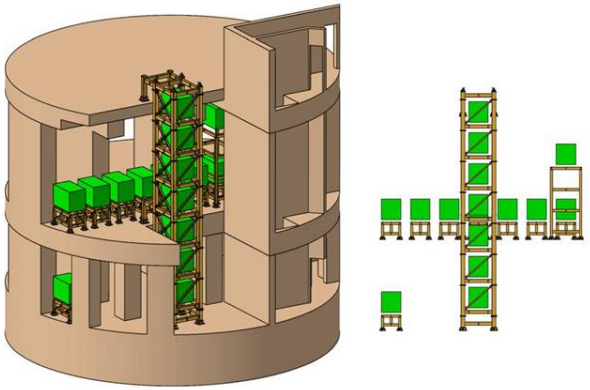


Photosensor issue

Off-axis



INGRID



Scintillator detectors with WLS fibers

- Individual fiber readout

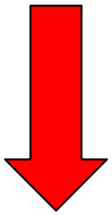
FGD, POD, Ecal, SMRD, INGRID: ~ 60000 readout channels

- Limited space for photosensors

- Magnetic field

T2K requirements for sensor

FROM
- beam energy and time structure
- detector functions and geometry
- long duration of experiment



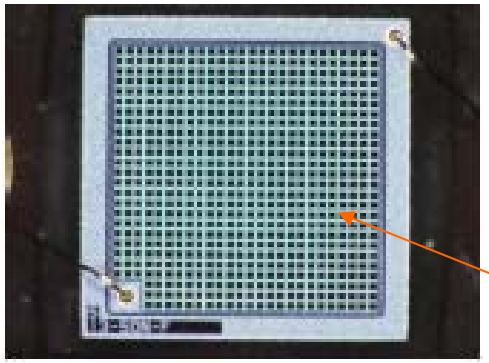
Geiger mode micro-pixel APD

# pixels	**≥ 400**
Active area	**≥ 1.0 mm²**
Gain	**~(0.5-0.7)x10⁶**
PDE	**> 15%**
Dark rate	**≤ 1MHz (th = 0.5 p.e.)**
Pulse width	**≤ 100 ns**
Life time, stability	**very good**
Radiation	**No**

T2K decision in 2004: ND280m baseline photosensor - Multi-pixel Geiger mode avalanche photodiode

T2K photosensor

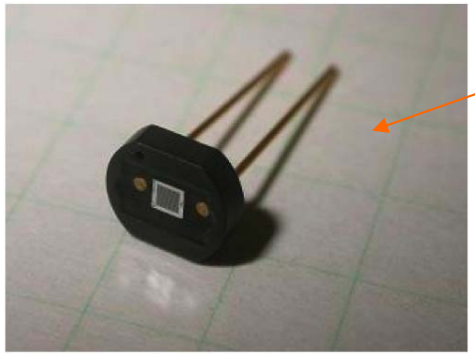
R&D for 3 years with 2 options: MRS APD (CPTA, Moscow)
MPPC (Hamamatsu, Japan)



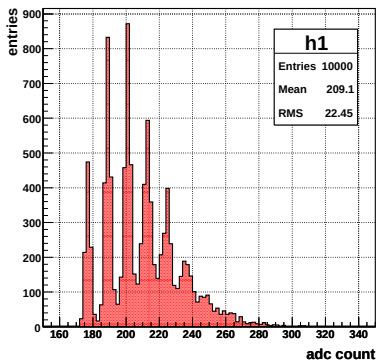
2006

T2K photosensor: MPPC

Hamamatsu MPPC: active area 1.3×1.3 mm^2



HPK311-53-1A-002-1



Number of pixels	667
Pixel size	50×50 μm
Gain	~0.7×10^6
PDE at 525 nm	25-30%
Dark rate, th = 0.5 p.e.,22C	≤1000 kHz
Pulse width	<100 ns
Cross-talk	10-15%
After pulses	10-15%

Macc production for T2K

total number of MPPC's for T2K 63800

mass production/delivery

start February 2008

finish February 2009

all devices are manufactured

almost all tested

less than 0.1% failed to pass tests and rejected

Testing MPPC's

Imperial, Warwick, UK

INR, Russia

CSU,USA

Warsaw, Poland

Kyoto, Japan

LSU,USA

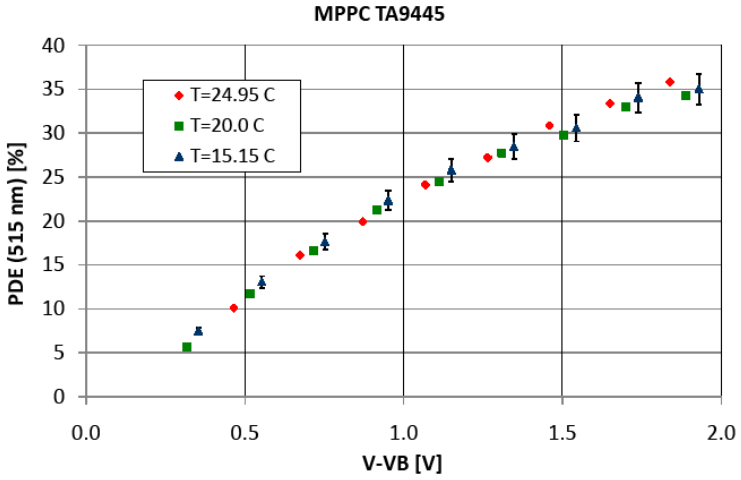
Atlantic Ocean

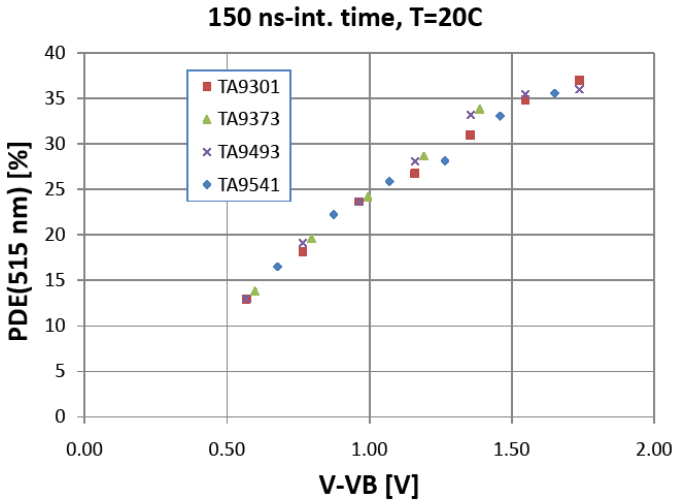
Indian Ocean

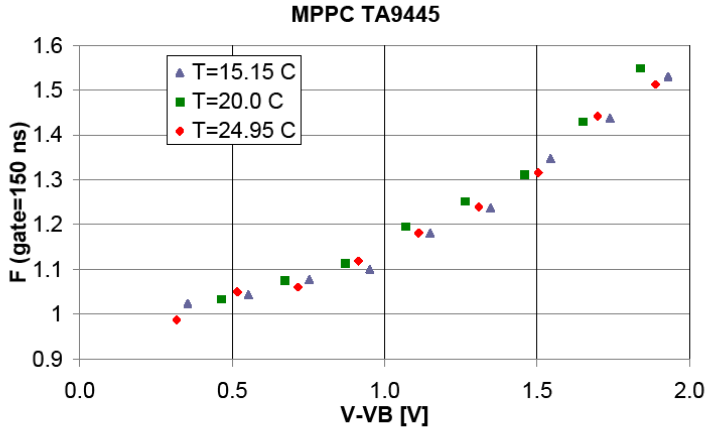
Pacific Ocean

PDE

PDE at 515 nm

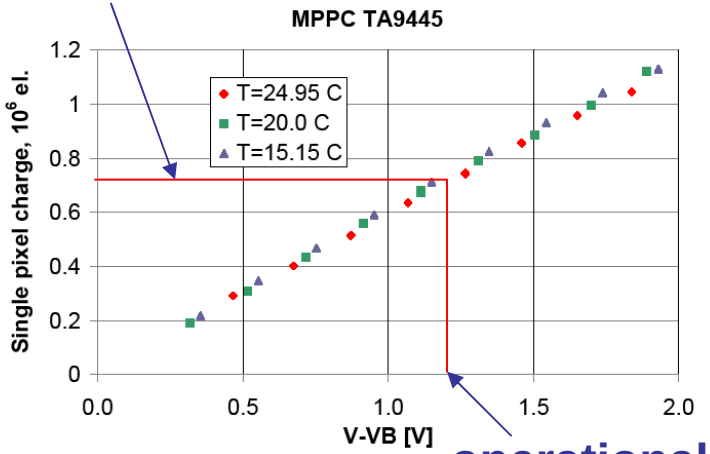






F=dark rate +afterpulses)

Gain ~7x10^5

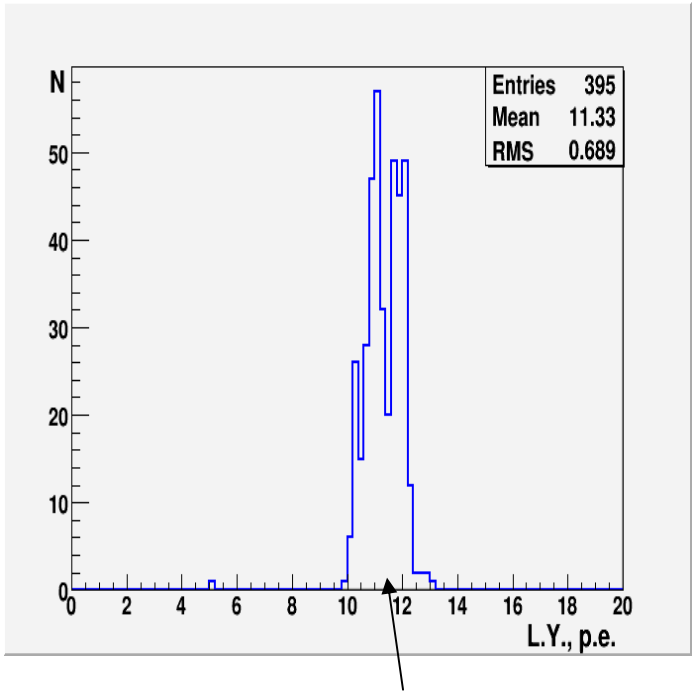


operational ΔV

Uniform sensitivity

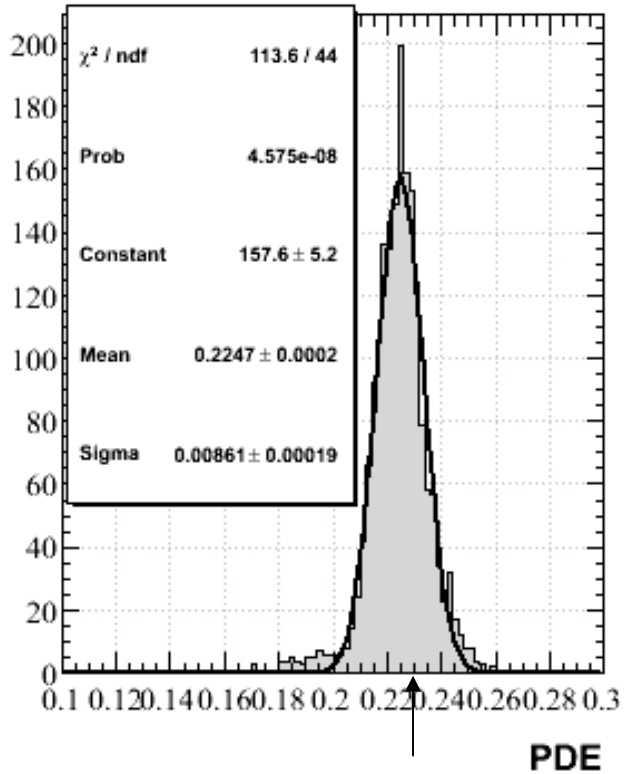
25C, gain~7x10^5, green light

INR



PDE ~25%

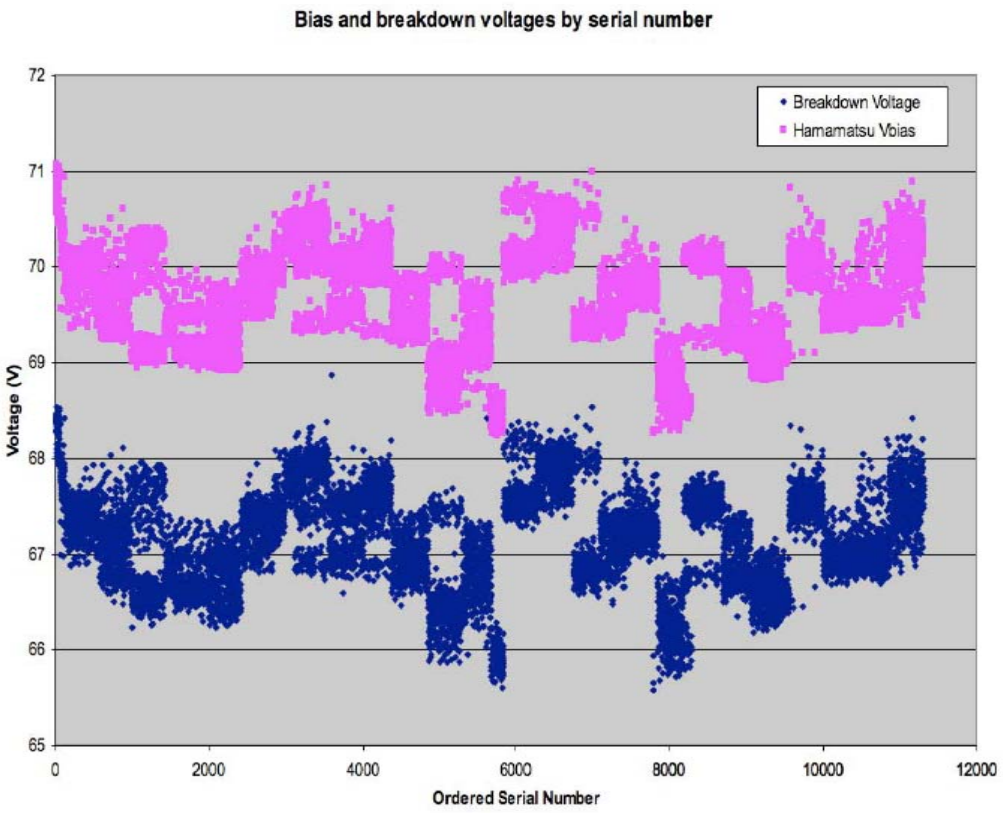
Warwick



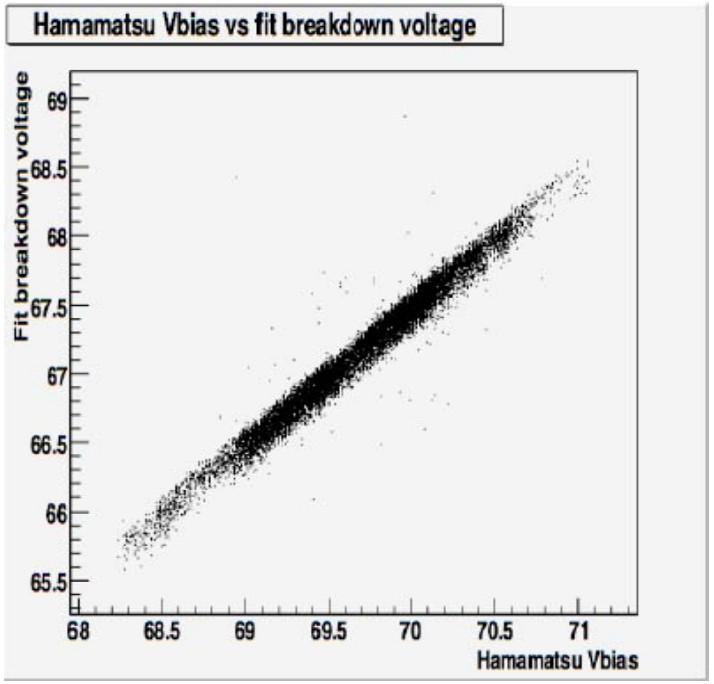
PDE~23%

Breakdown and bias voltages

≥11000 devices



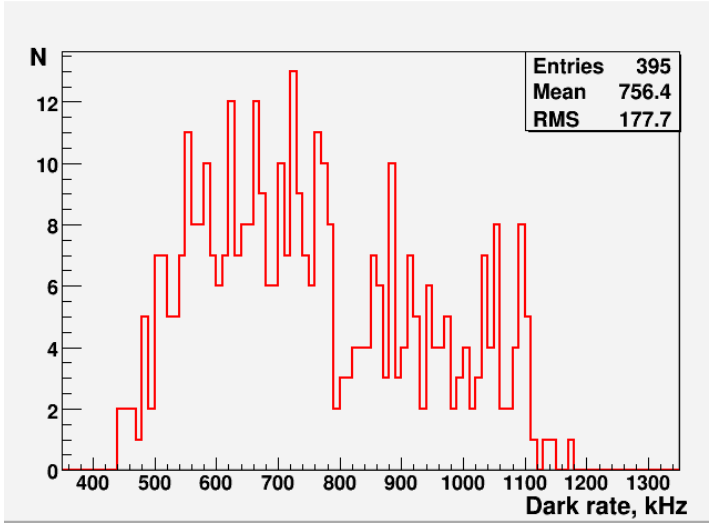
fixed gain



Measurements at CSU

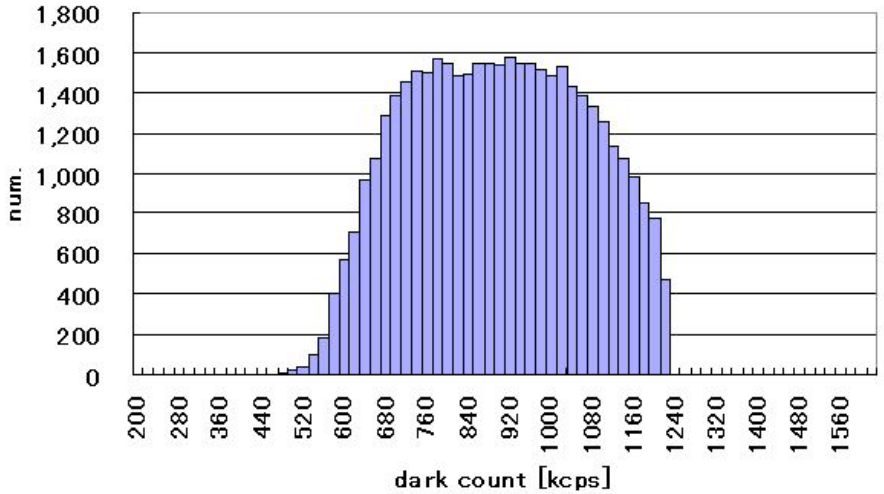
Dark rate

CSU

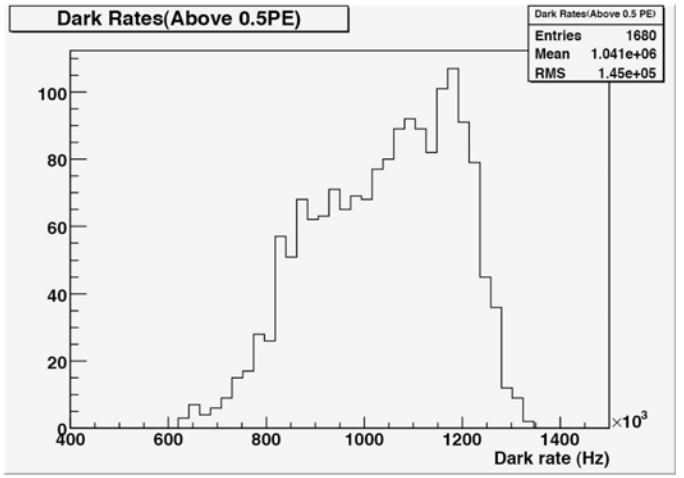


~25C
Th =0.5 p.e.

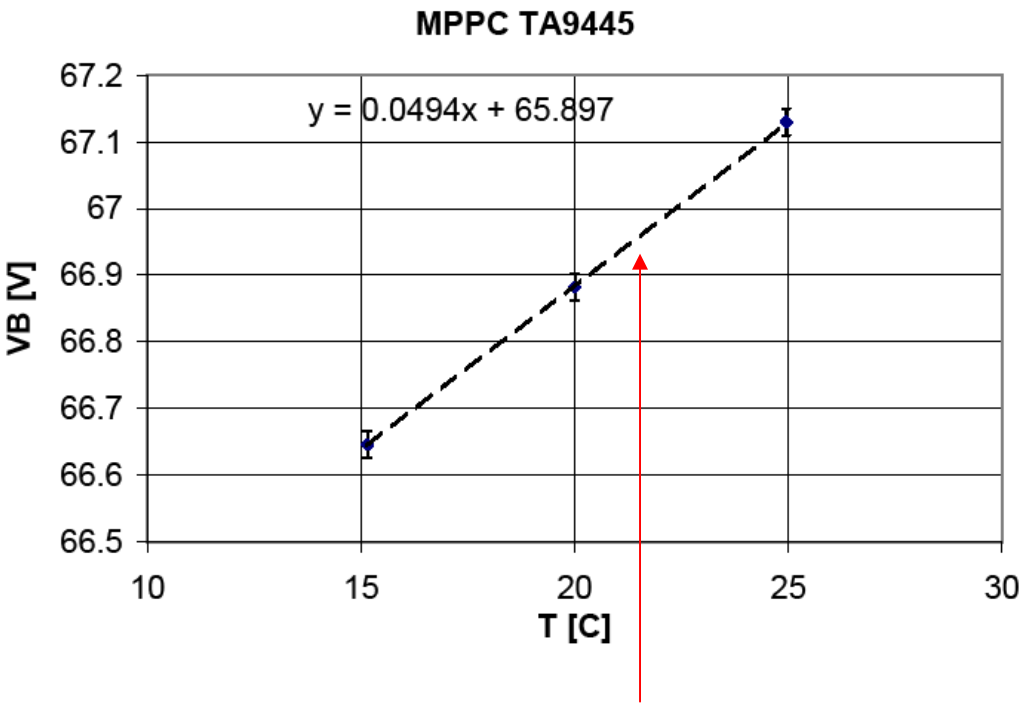
Hamamatsu



INR



V_bd vs temperature



~ 50 mV/deg

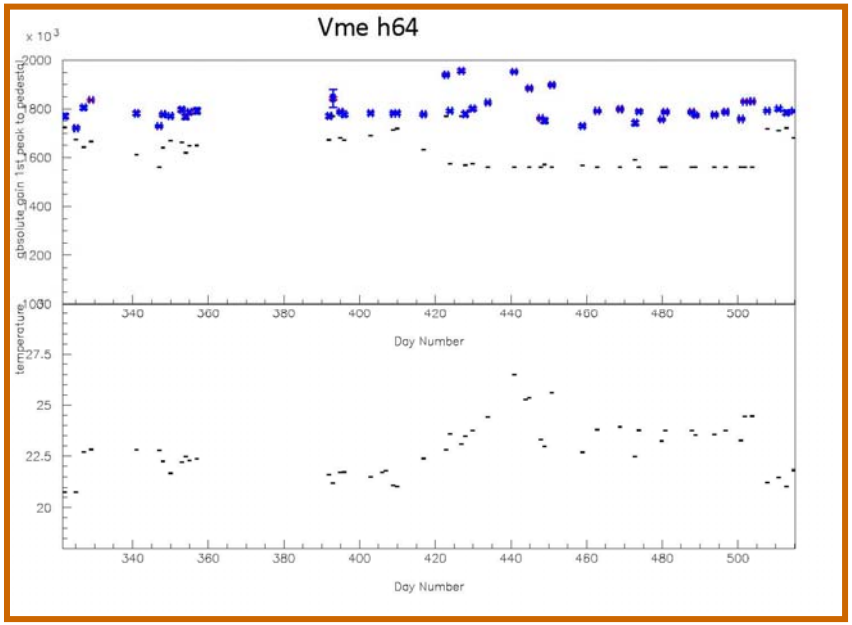
PDE, gain → - 2-4 % per degree

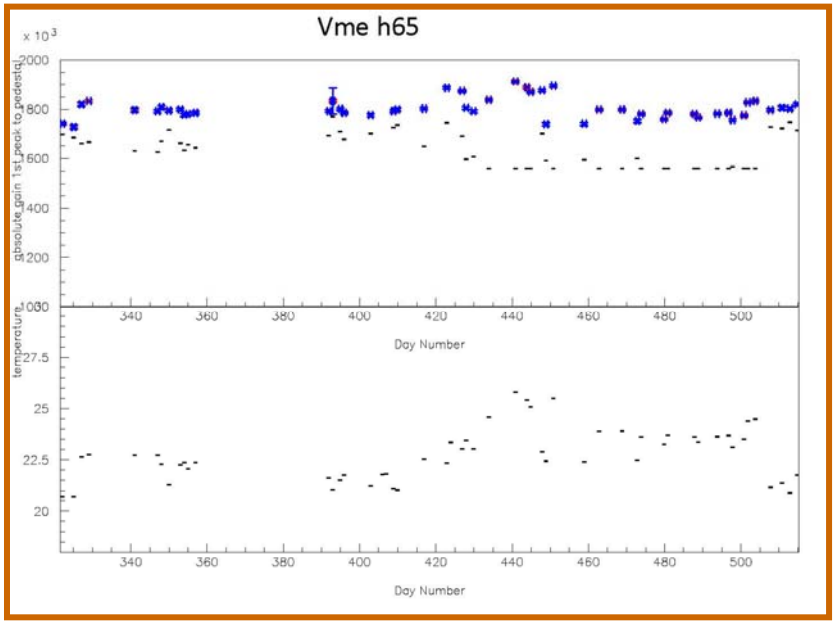
Long term stability

3 MPPC's were tested for long time
21 hrs/24 hrs heating at 80C for 520days

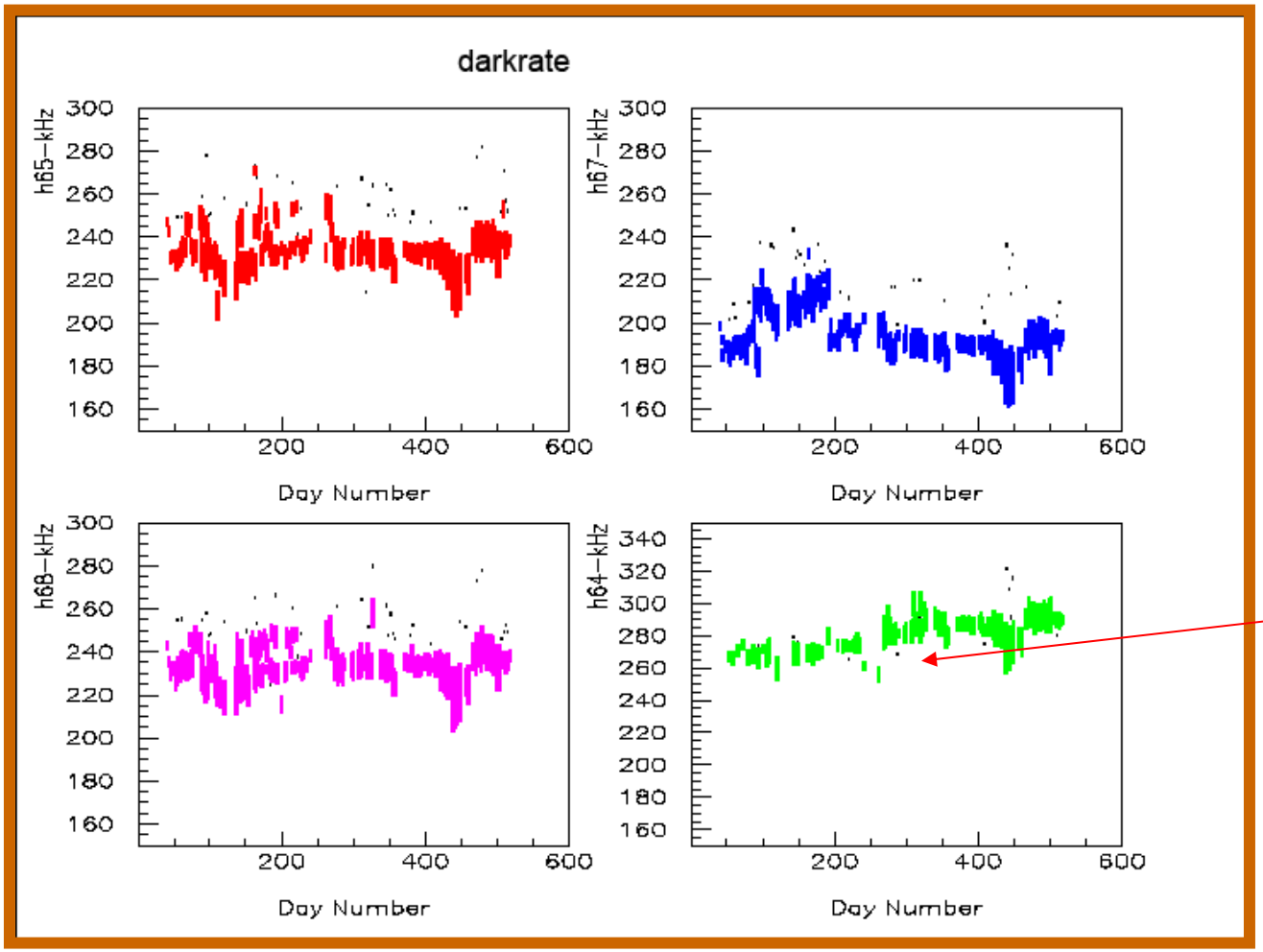
Tests at LSU

gain





Long term stability



Reference,
no heat test

Detector characterization (I)

INGRID strips Kyoto

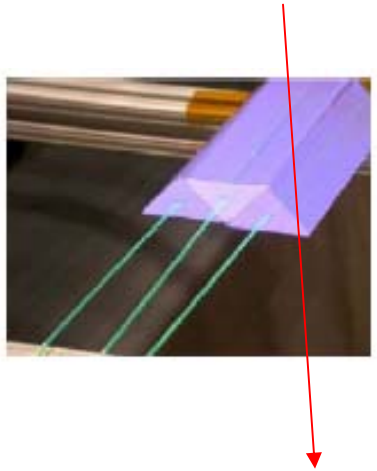
INGRID scintillator strips 1x5x100 cm^3 with Y11 WLS fibers

L.y. = 15 p.e./MeV at 50cm from MPPC (one end readout)

POD elements SBU

Active material length ~ 16mm
on vertical for two bars

cosmic ray muons



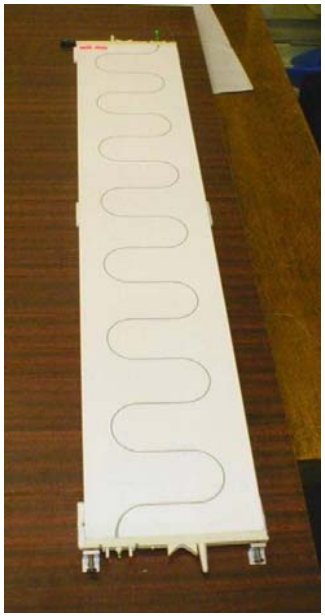
One end readout without mirror

Position (cm)	Yield (p.e.)	p.e./cm	p.e./MeV
25 cm	67.3 +- 0.9	39.6 +- 0.6	19.8 +- 0.3
205 cm	29.7 +- 0.8	17.5 +- 0.3	8.7 +- 0.2

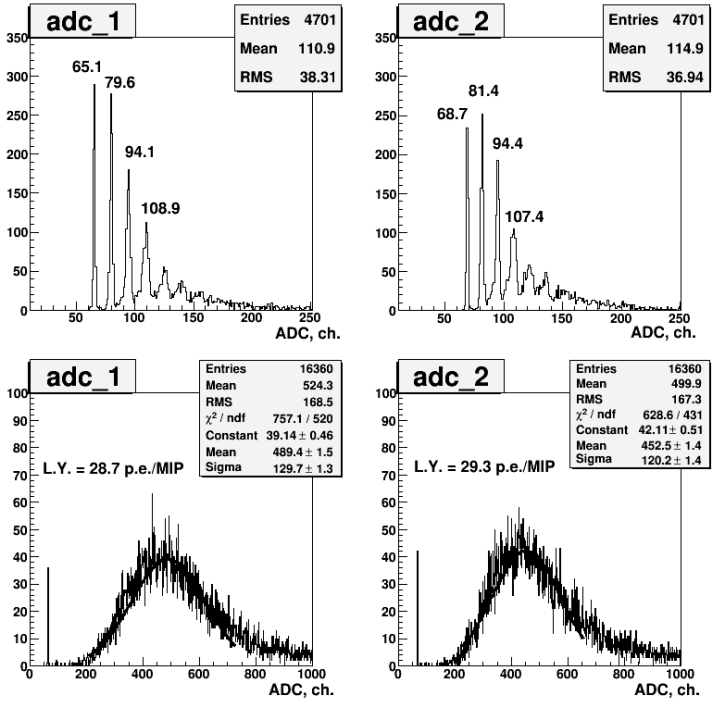
Detector characterization (II)

SMRD detectors INR

Extruded plastics ~7x170x870 mm^3
Y11 fibers embedded in S-grooves



Light yield



MIP detection efficiency	**> 99.9%**
σ_t (MIP)	**~ 0.7 ns**
Spatial resolution	**~ 7 cm**

l.y. (sum of 2 ends) = 58 p.e./MIP

Summary

-Primary goal of **T2K***: discovery of* $\nu_\mu \rightarrow \nu_e$

neutrino beam commissioning *April 2009*

start data taking *December 2009*

- T2K near neutrino detector uses ~60000 MPPC's
(first large scale experiment with Geiger mode APD's)

- Mass production of sensors for T2K completed

- Parameters of MPPC's satisfy the T2K requirements

- Worldwide T2K tests demonstrate
good quality and reliability of MPPC's