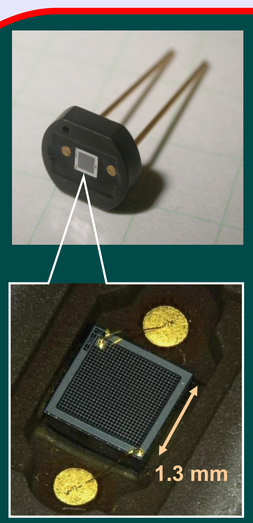
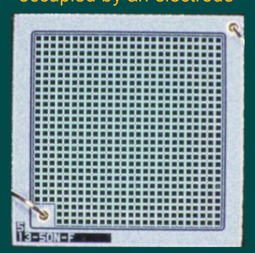
Characterization and performance of multi-pixel photon counters in T2K experiment

Oleg Mineev (INR RAS, Moscow, Russia) on behalf of the T2K collaboration

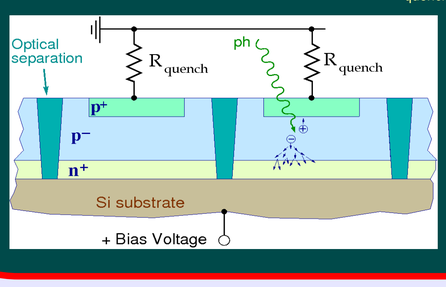
MPPC (Multi-Pixel Photon Counter)
Multi-pixel Geiger mode photodiode

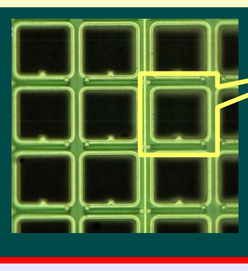




Hamamatsu type :	S10362-13-50C
Number of pixels :	667
Pixel size :	50 x 50 μm²
Total sensitive area :	1.3 x 1.3 mm²
Operational bias voltage :	~ 70 V
Operational overvoltage ΔV :	~ 1.3 V
PDE at 520 nm (ΔV =1.3 V):	~ 28 %
Gain at ΔV =1.3 V :	0.75 x 10^6
Dark rate (thr=0.5 pe) :	0.5 – 1.2 MHz
Recovery time τ :	13.4 ns
Optical crosstalk :	9 – 12 %
Afterpulsing :	14 – 16 %
$V_{breakdown}$ temp. coefficient:	52 ± 4 mV/deg

Bias voltage is larger than the breakdown value but no current through a diode until first carrier arrives in the p-n junction area.
Geiger avalanche is quenched by a voltage drop across R_{quench}

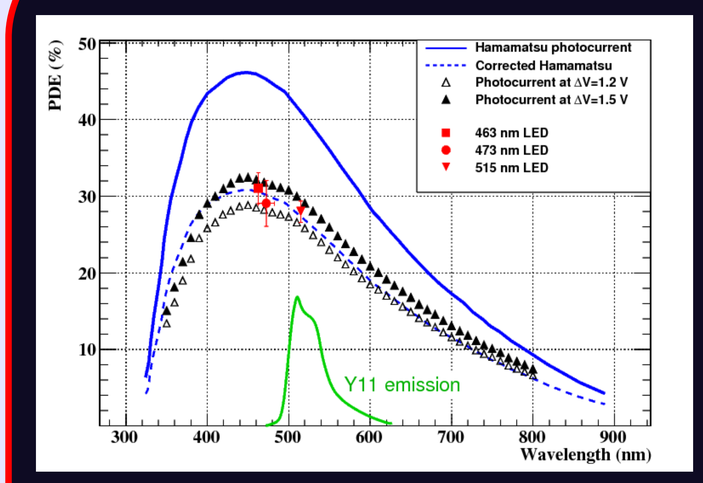




Single pixel: 50x50 μm²
C_{pix} = 90 fF
R_{quench} = 150 ± 2 kΩ

Recovery time for a pixel:
$\tau = C_{pix} * R_{quench}$

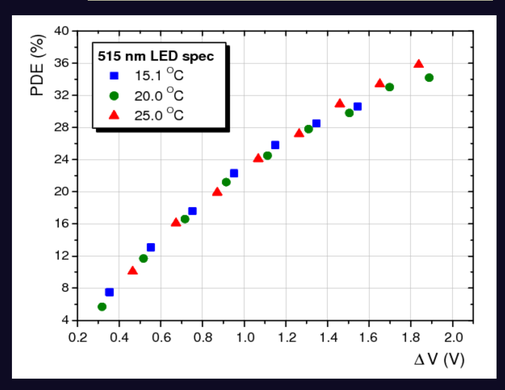
Photon detection efficiency (PDE)



PDE of MPPC peaks in blue wavelength region.
PDE is about 25% for average emission spectrum of Kuraray Y11 fiber at overvoltage ΔV=1.3 V.

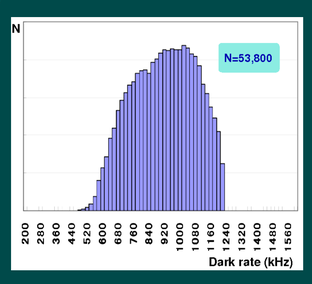
Hamamatsu PDE results (catalogue data) include contributions from crosstalk, afterpulsing, etc.

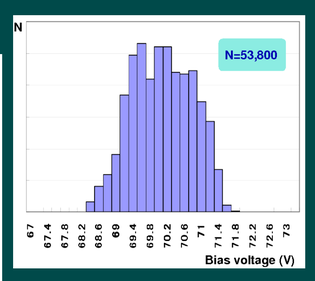
PDE = QE(λ) * ε_{pixel} * ε_{Geiger}
QE (λ) ~ 80% at 500 nm
ε_{pixel} = 62 – 64% (active pixel area)
ε_{geiger} ~ 55% (Geiger discharge)



PDE depends almost linearly on ΔV within operational range of 1.0-1.6 V.
No temperature dependence at a fixed ΔV.

Quality Assurance and Failure Rate





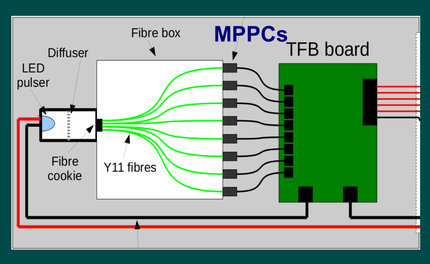
Step 1. Tests of MPPCs by Hamamatsu

Development of MPPCs by Hamamatsu started in 2005.
The mass production for T2K has started in February 2008.

Hamamatsu tested all MPPCs before shipping them to T2K.
The plots show the dark rate and bias voltage distributions among 53800 MPPCs at 25°C.
Hamamatsu has specified the bias voltages to have the same gain of 7.5 x 10^5 for each MPPC.

Step 2. All MPPCs were tested by T2K groups

Typical test bench scheme at Warwick



MPPCs were irradiated by LED pulser. Measured parameters include breakdown voltage value, gain, dark rate, light output at 25°C. Each T2K group had set the own rejection criterion.

T2K groups	Tested MPPCs	Rejected MPPCs
Kyoto (Japan)	17695	9
CSU (USA)	11500	14
LSU (USA)	1717	11
LLR (France)	3158	0
Warwick (England)	1820	0
ICL (England)	1897	0
T. U. Warsaw (Poland)	1202	4
INR (Moscow, Russia)	924	1

Average rejection rate is 0.1%

MPPC failure rate in beam runs (December 2009 – March 2011)

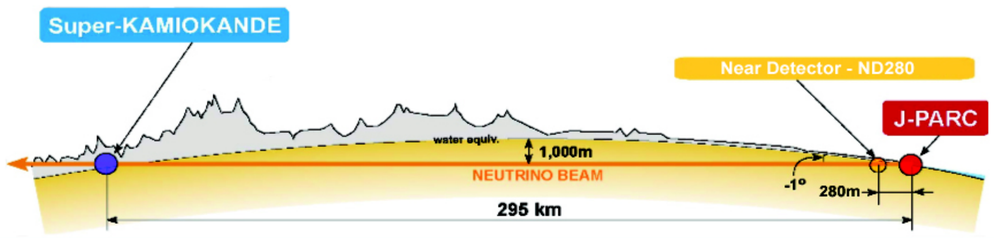
Detector	Number of MPPCs	Failed channels	Fraction
INGRID	10796	18	0.17 %
P0D	10400	7	0.07 %
FGD	8448	20	0.24 %
SMRD	4016	7	0.17 %
DS ECAL	3400	11	0.32 %

Failure in readout of a channel includes all possible reasons: MPPC, cabling, front-end electronics.

MPPC failure rate is less than the presented numbers.

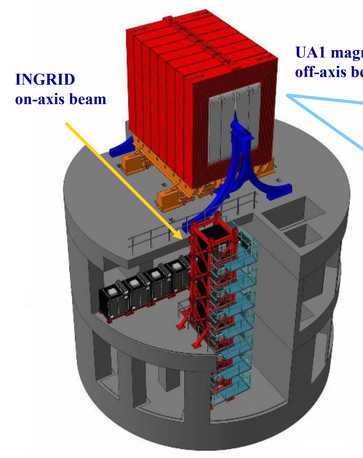
First T2K result on June 15, 2011:
Indication for $\nu_\mu \rightarrow \nu_e$ appearance

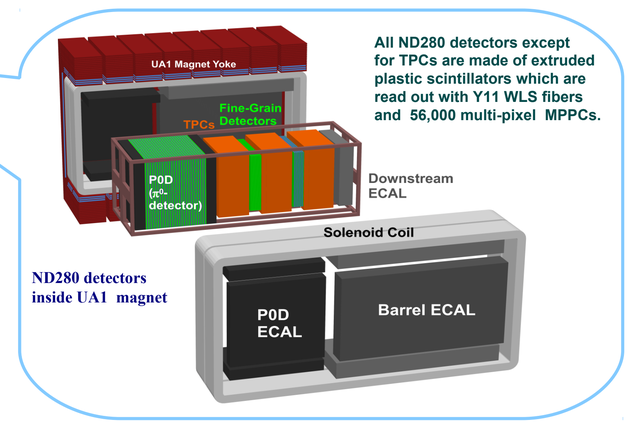
Tokai to Kamioka (T2K) experiment

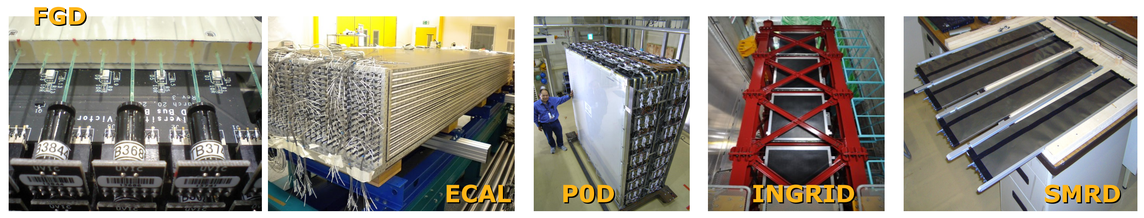


T2K is a long base-line neutrino oscillation experiment. Near detector complex ND280 is built at a distance of 280 m from the target.

ND280 Near Detectors in T2K



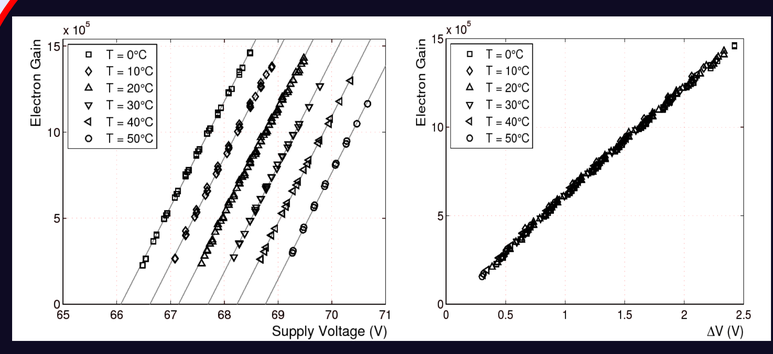




First large scale application of multi-pixel Geiger mode photodiodes MPPCs

ND280 scintillator detectors	Number of channels
• Fine-Grained Detector (FGD) – tracker :	8448 MPPCs
• Electromagnetic Calorimeter (ECAL) :	22336 MPPCs
• Pi-Zero Detector (P0D) – π^0 detector :	10400 MPPCs
• SMRD – muon detector within magnet yoke gaps :	4016 MPPCs
• INGRID – on-axis neutrino beam monitor :	10796 MPPCs

Parameters of MPPC

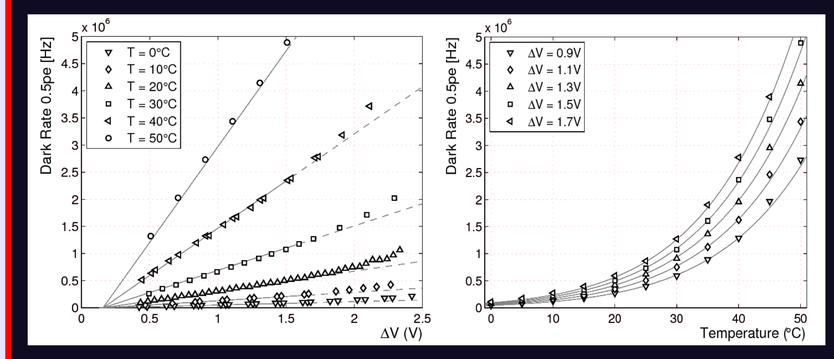


Gain

MPPC gain can be defined as the charge produced in a single pixel avalanche: $G = C_{pix} * \Delta V$.

Overvoltage ΔV is calculated by:
$\Delta V = V_{bias} - V_{breakdown}$
V_{bias} is supply voltage, $V_{breakdown}$ is the measured parameter.

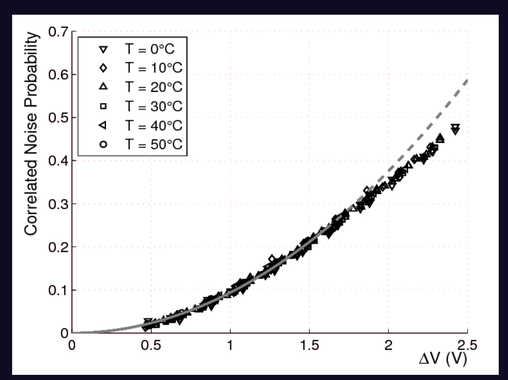
No gain vs temperature dependence at a fixed ΔV.



Dark rate

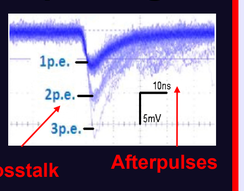
Dark rate consists mainly of single pixel avalanche pulses caused by thermal generation. Larger amplitudes are generated by optical crosstalk and afterpulsing.

Dark rate for MPPC samples is distributed in range 0.5–1.2 MHz at t = 25°C and ΔV =1.4 V



Crosstalk and afterpulsing

Crosstalk is caused by optical photons generated in an avalanche and propagated in the neighboring pixels. **Afterpulsing** is caused by the trapping and late releasing of charge carriers within the same pixel.



Combined crosstalk and afterpulse probability is shown in the plot vs overvoltage ΔV. The probability is fitted :
$P = 0.094*\Delta V^2$ (within operational range of 0.5–1.6 V)

Independent measurements also yielded:
Afterpulse probability $P = 0.08*\Delta V^2$
Crosstalk probability $P = (0.05 – 0.08)*\Delta V^2$

References

1. A. Vacheret et al., arXiv:1101.1996
2. M. Yokoyama et al., Nucl. Instr. Meth. A622 (2010) 567.
3. F. Moreau et al., Nucl. Instr. Meth. A613 (2010) 46.
4. A. Vacheret, Nucl. Instr. Meth. A623 (2010) 201.
5. Y. Dua and F. Retière, Nucl. Instr. Meth. A596 (2008) 396.