The Electromagnetic Calorimeter of T2K's Near Detector

Roberto Sacco

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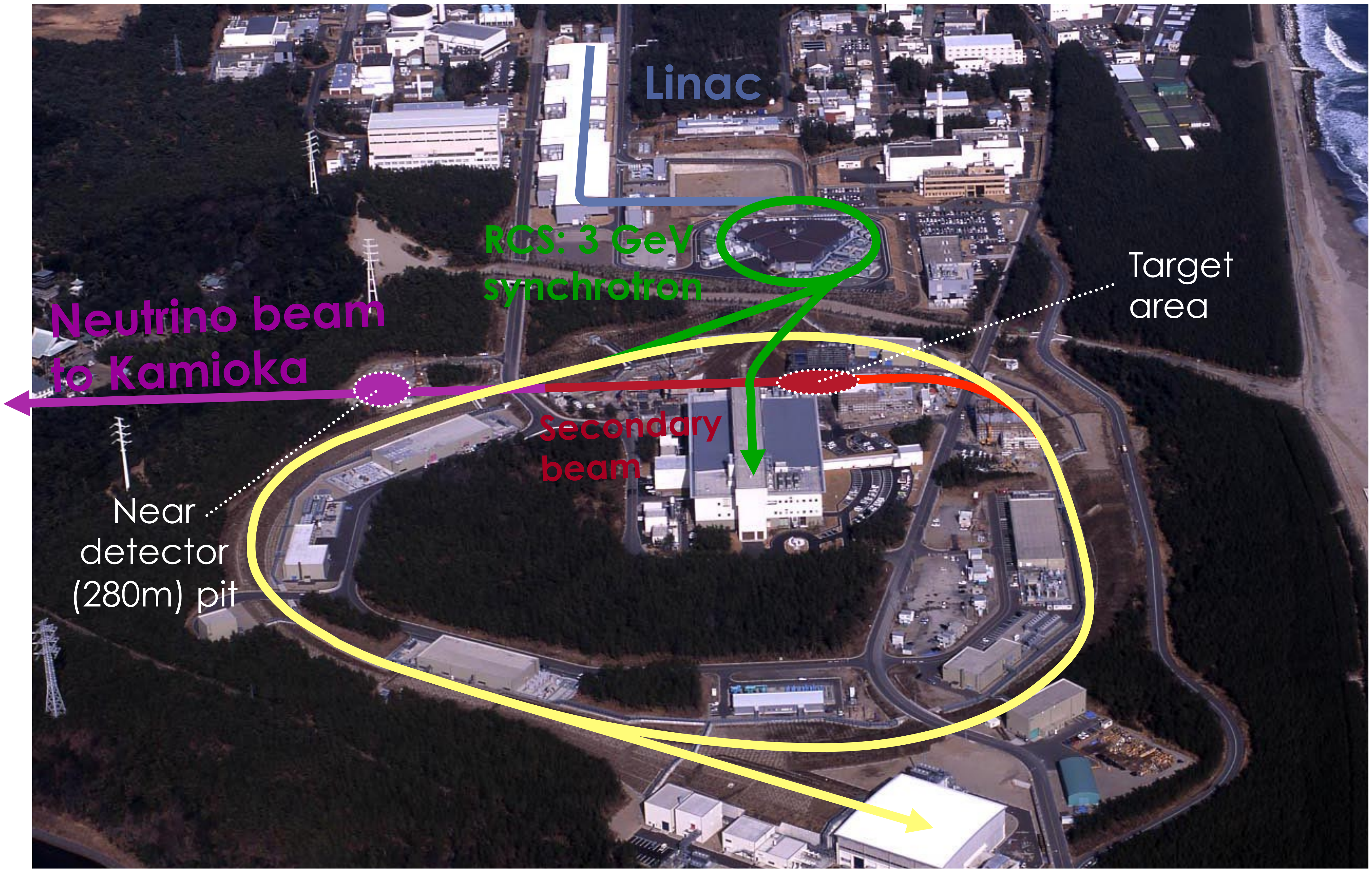
T2K

Queen Mary
University of London

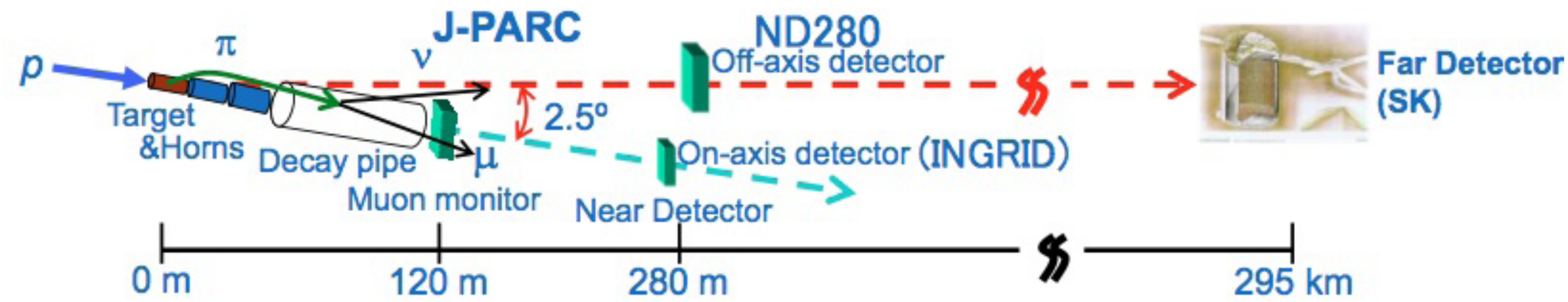
The T2K Experiment

First LBNE experiment built for θ_{13} measurement

Accelerator complex provides a 30 GeV proton beam with a design power of 0.75 MW, currently delivering ~135 kW



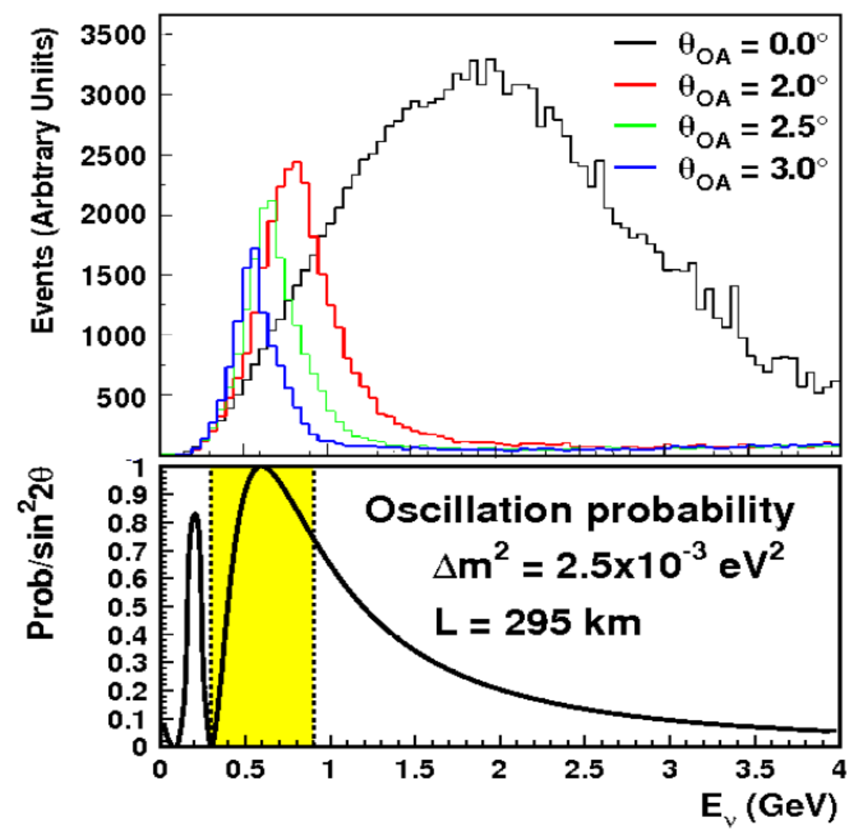
The T2K Experiment



8 (6 in early 2010) bunches strike a Φ2.6 × 91.4 cm Helium-cooled graphite target

Spill cycle: 3.04 (3.52) s

3 Magnetic Horns at 250 kA focus positively charged hadrons

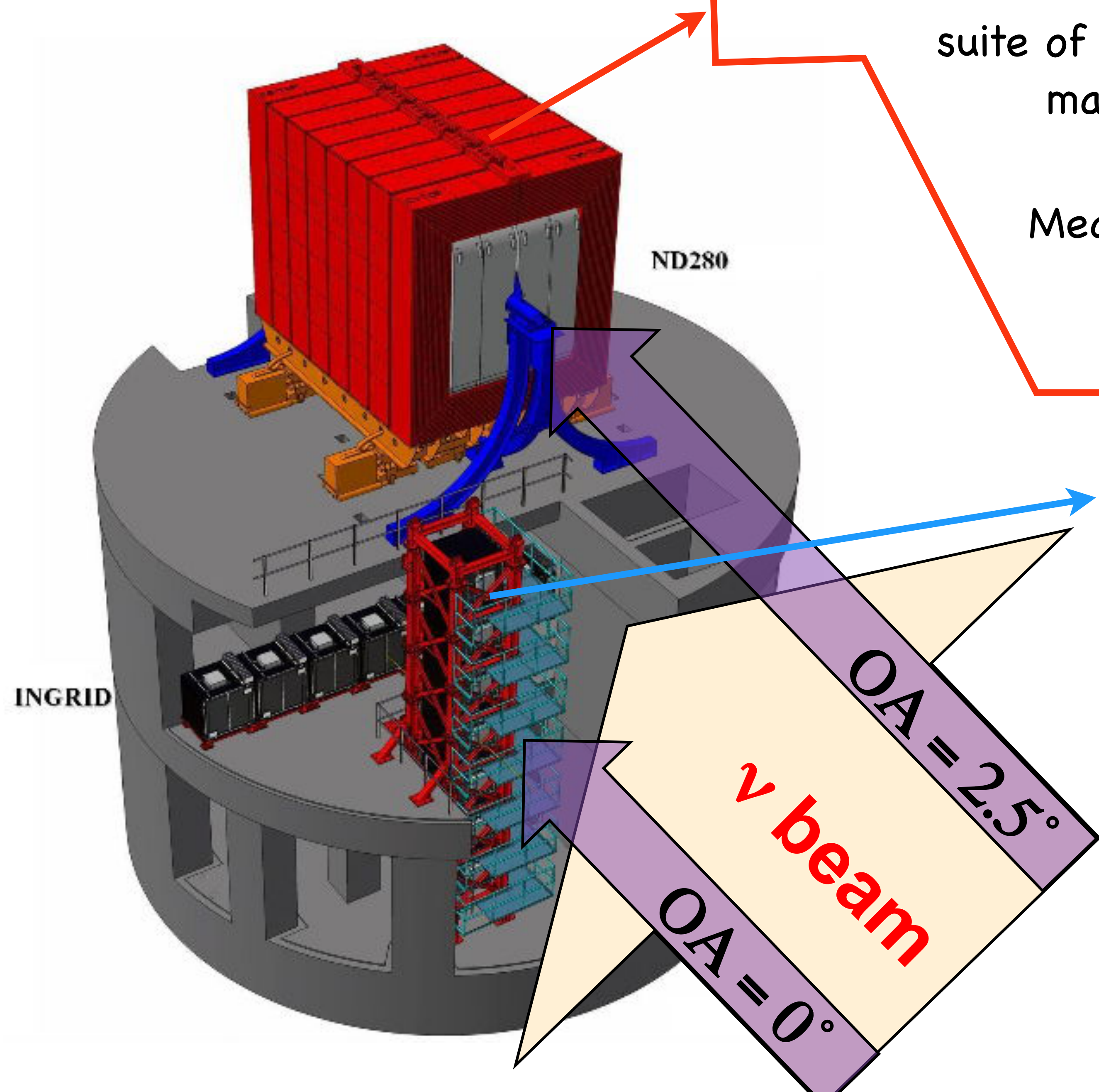


The far detector and part of the near detectors are positioned off-axis (2.5°)

ν beam energy peaked at 1st max E≈600 MeV

What kind of Near Detector?

In principle, we want the near and far detectors to be "identical". In practice, there are too many differences (size, event rate, geometry with respect to the beam, backgrounds,...) so we might as well make it more complex and capable with a different technology.



Off-Axis (ND280)

suite of fine-grained detectors/tracker in a 0.2T magnetic field (old UA1/NOMAD magnet)

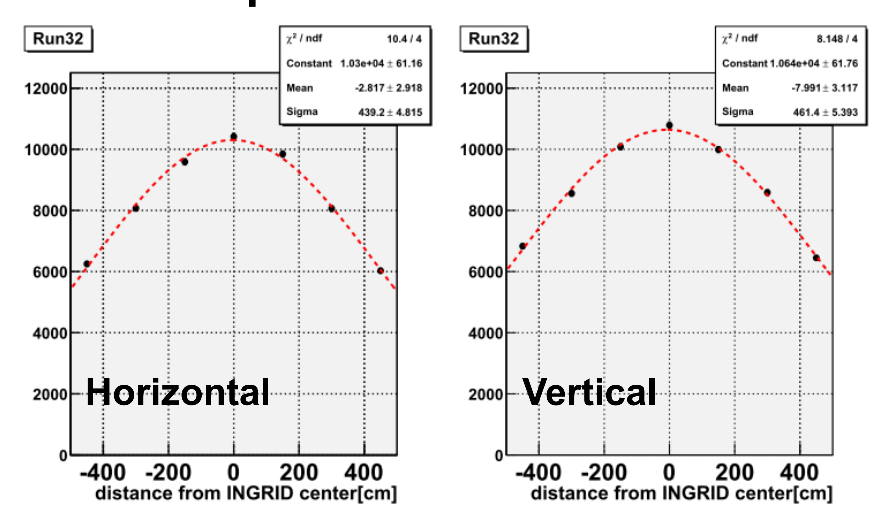
Measurement of: CC ν_μ events (normalisation, E_ν spectrum), NC π^0, CC ν_e events (background to ν_e appearance), neutrino cross-sections

On-Axis (INGRID)

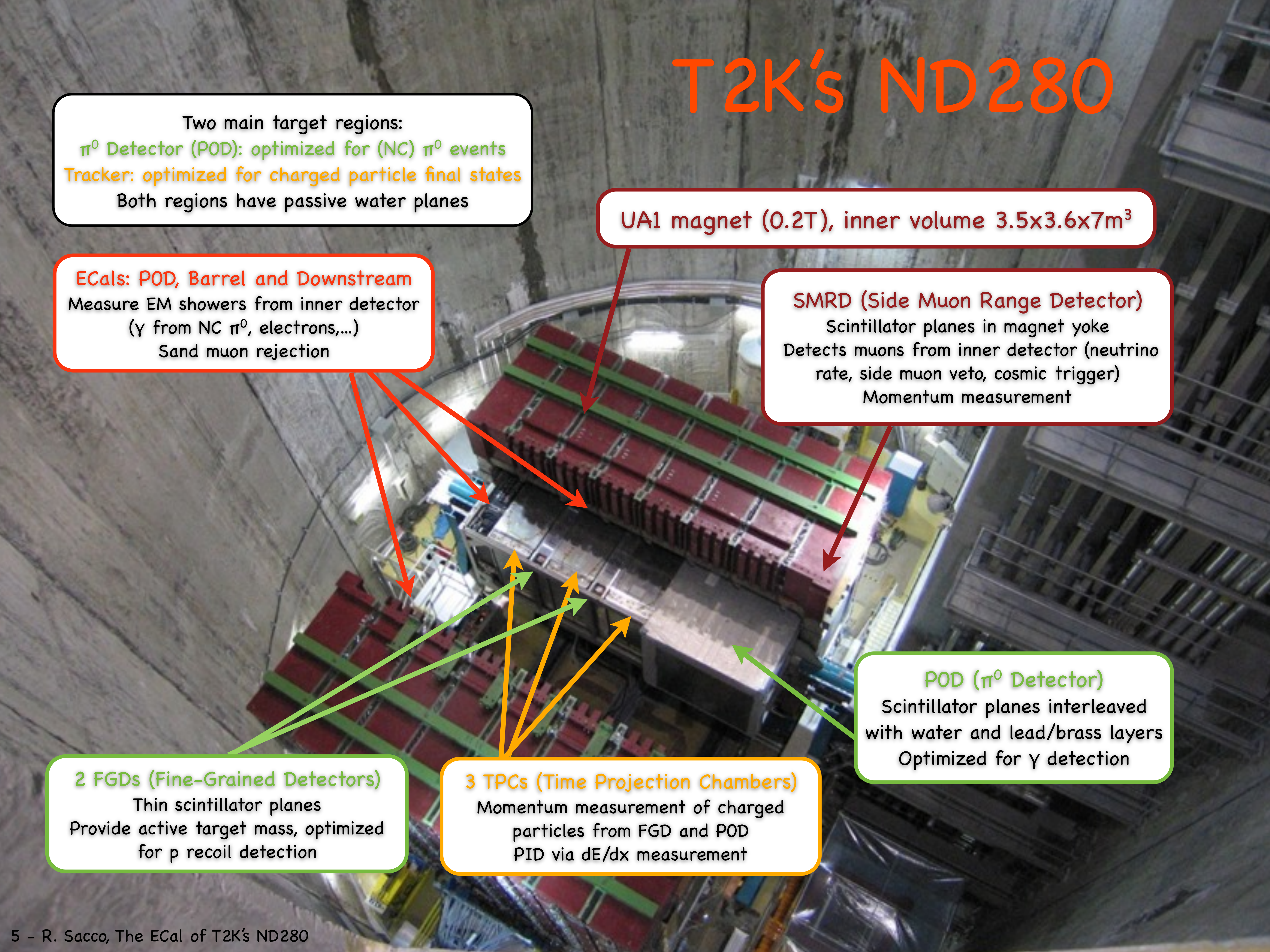
scintillator-iron detectors

Measurement of beam direction and profile

ν beam profile



T2K's ND280

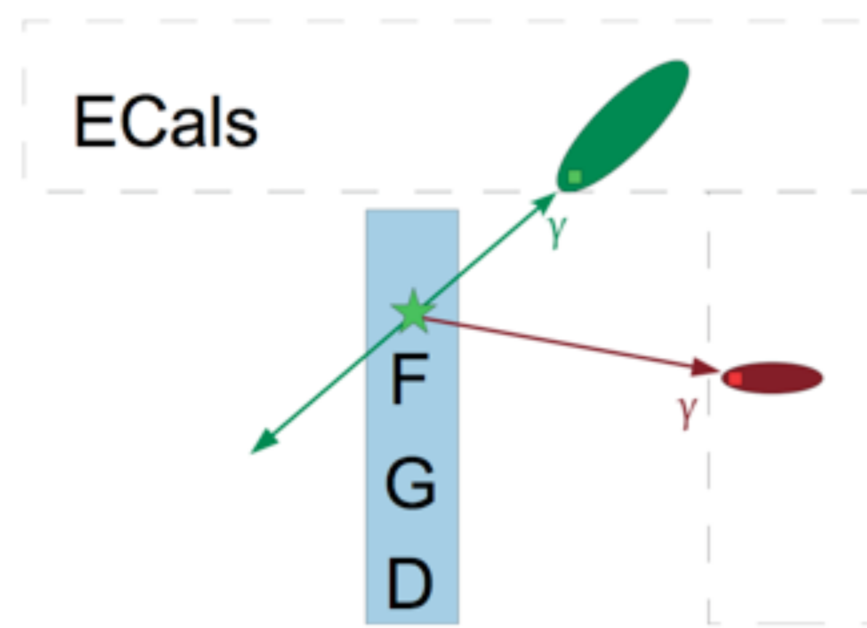

Two main target regions:
π^0 Detector (P0D): optimized for (NC) π^0 events
Tracker: optimized for charged particle final states
Both regions have passive water planes
UA1 magnet (0.2T), inner volume 3.5x3.6x7m^3
ECals: P0D, Barrel and Downstream
Measure EM showers from inner detector
(γ from NC π^0, electrons,...)
Sand muon rejection
SMRD (Side Muon Range Detector)
Scintillator planes in magnet yoke
Detects muons from inner detector (neutrino rate, side muon veto, cosmic trigger)
Momentum measurement
P0D (π^0 Detector)
Scintillator planes interleaved with water and lead/brass layers
Optimized for γ detection
2 FGDs (Fine-Grained Detectors)
Thin scintillator planes
Provide active target mass, optimized for p recoil detection
3 TPCs (Time Projection Chambers)
Momentum measurement of charged particles from FGD and P0D
PID via dE/dx measurement

What kind of ECal?

Main role: complement the inner detectors in full event reconstruction through the detection of photons and measurement of their energy and direction

detection of charged particles and the extraction of information relevant for their identification (electron-muon-pion separation)

reconstruction of π^0's produced in neutrino interactions inside the tracker detectors (especially important for NC1π^0 cross-sections)



In the case of π^0 production inside the P0D, the P0D-ECal complements the P0D reconstruction with information on escaping energy.

ND280's ECal

The ND280 ECal is a plastic scintillator/lead sampling electromagnetic calorimeter surrounding the inner detectors (PØD, TPCs, FGDs).

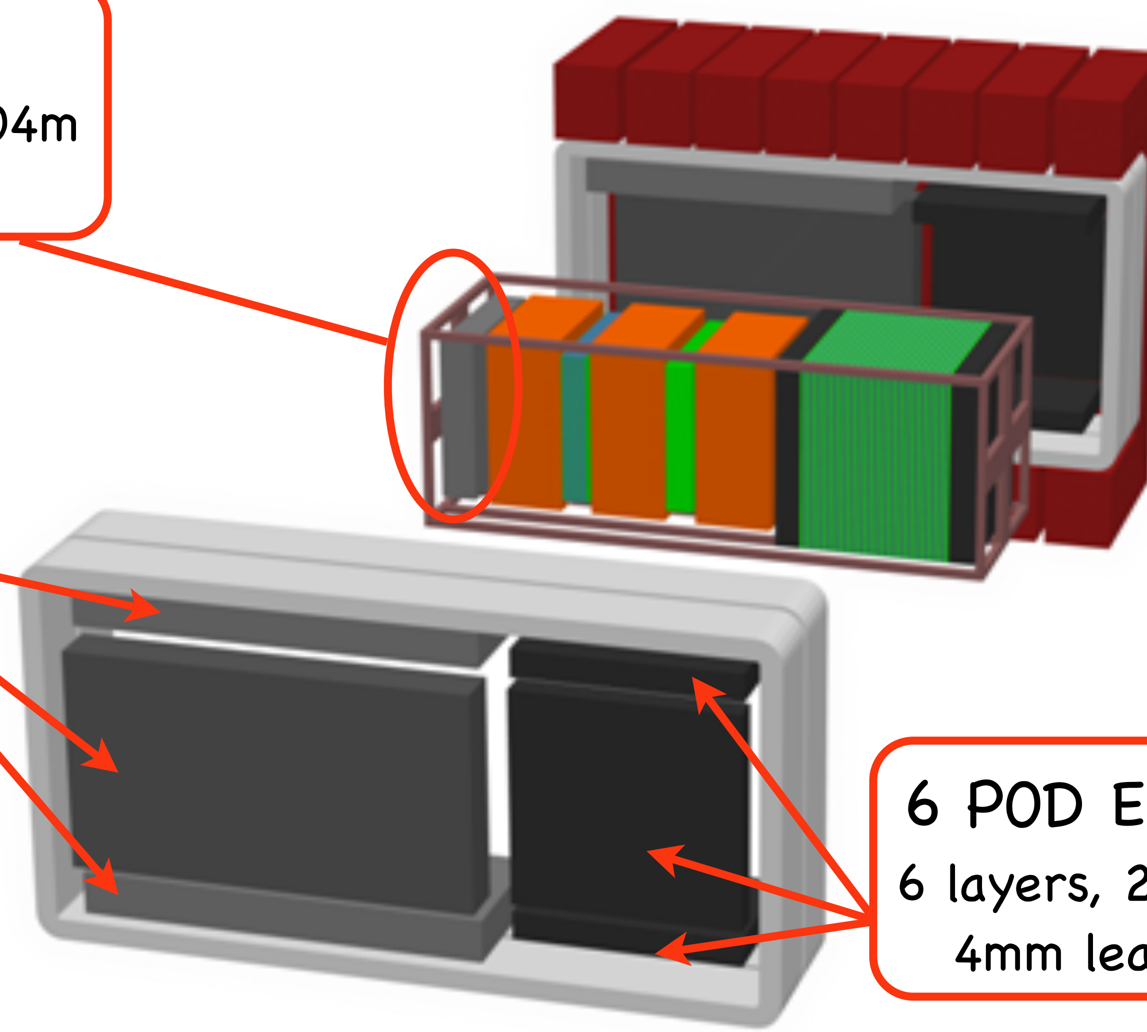
It consists of 13 independent modules:

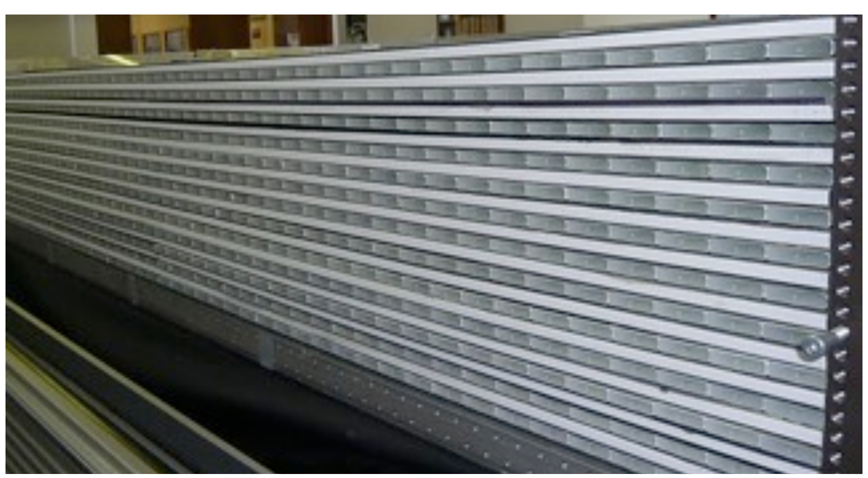
Downstream ECal

34 layers, each 50 scintillator bars 2.04m long and 1.75mm lead sheet: $10.6X_0$

6 Barrel modules

31 layers, 3.84m or 1.52 m bars and 1.75mm lead sheet: $9.7X_0$





6 P0D ECal modules

6 layers, 2.34m bars and 4mm lead sheet: $3.6X_0$

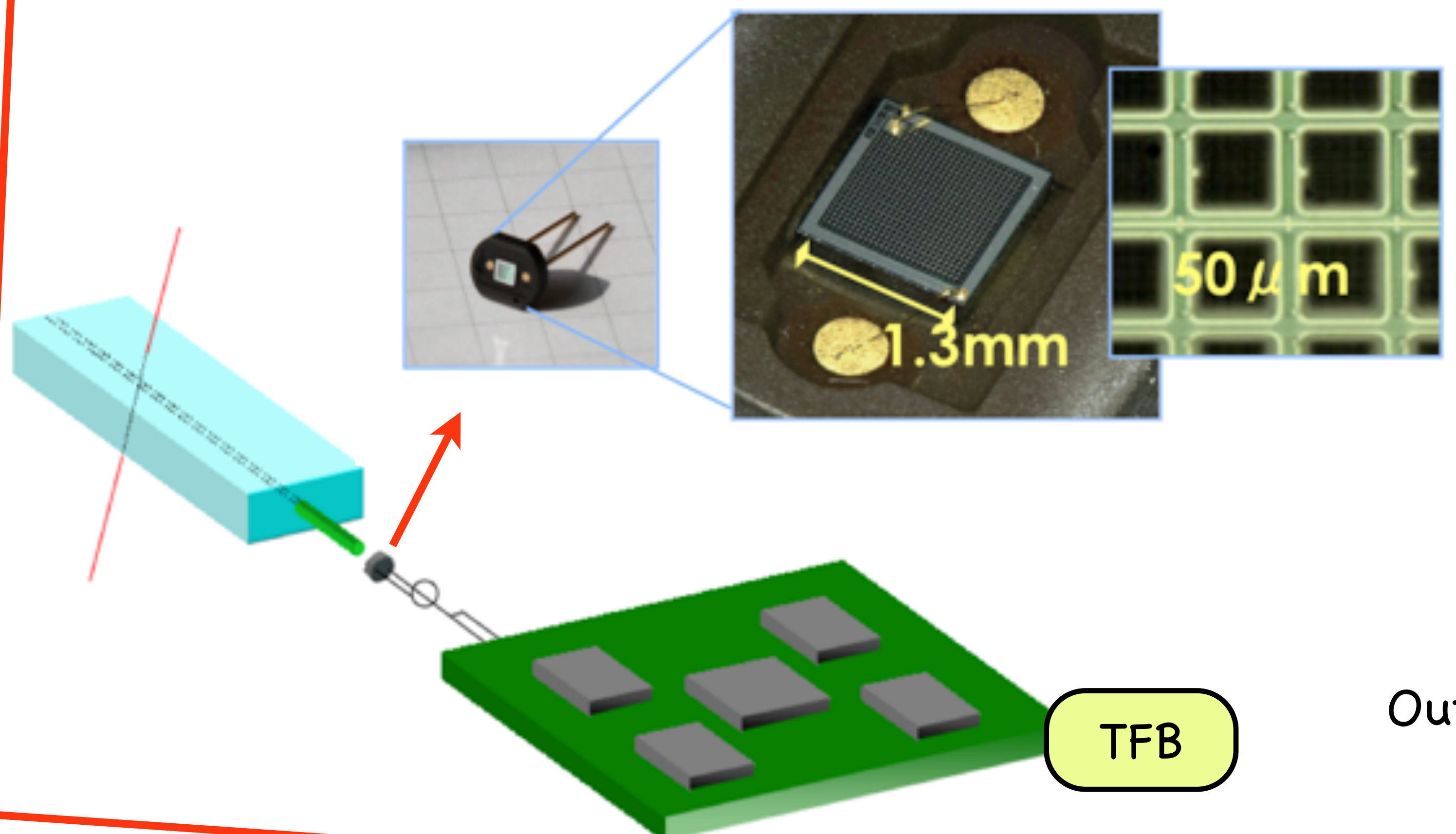
Scintillator bars have a 4.0cm × 1.0cm section with a 1.0mm × 2.0mm elliptical hole running along their full length in the middle, to allow insertion of WLS fibers

ND280's MPPCs

Innovative readout

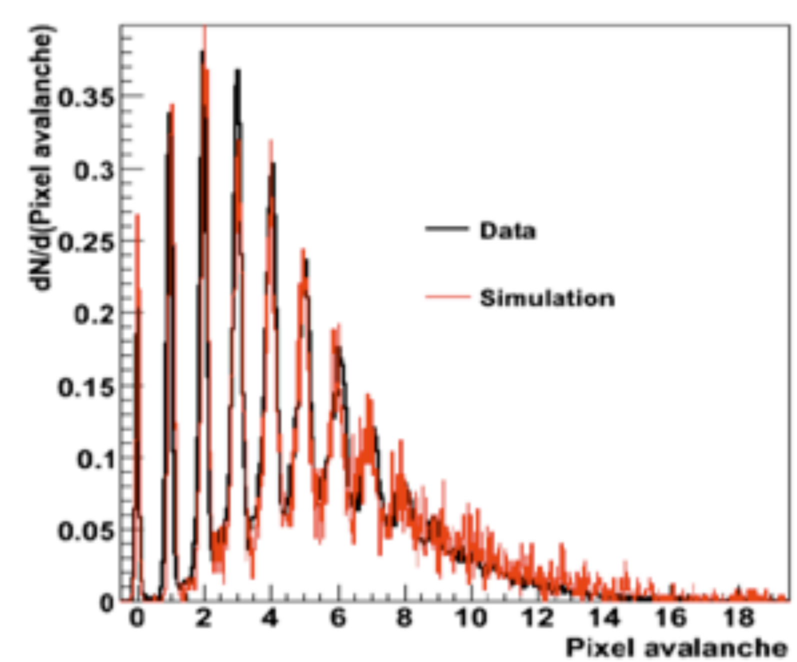
Scintillators+WLS Fibers are read out by Multi-Pixel Photon Counters (MPPC)

array of Si diodes, just above breakdown V, developed by Hamamatsu for T2K



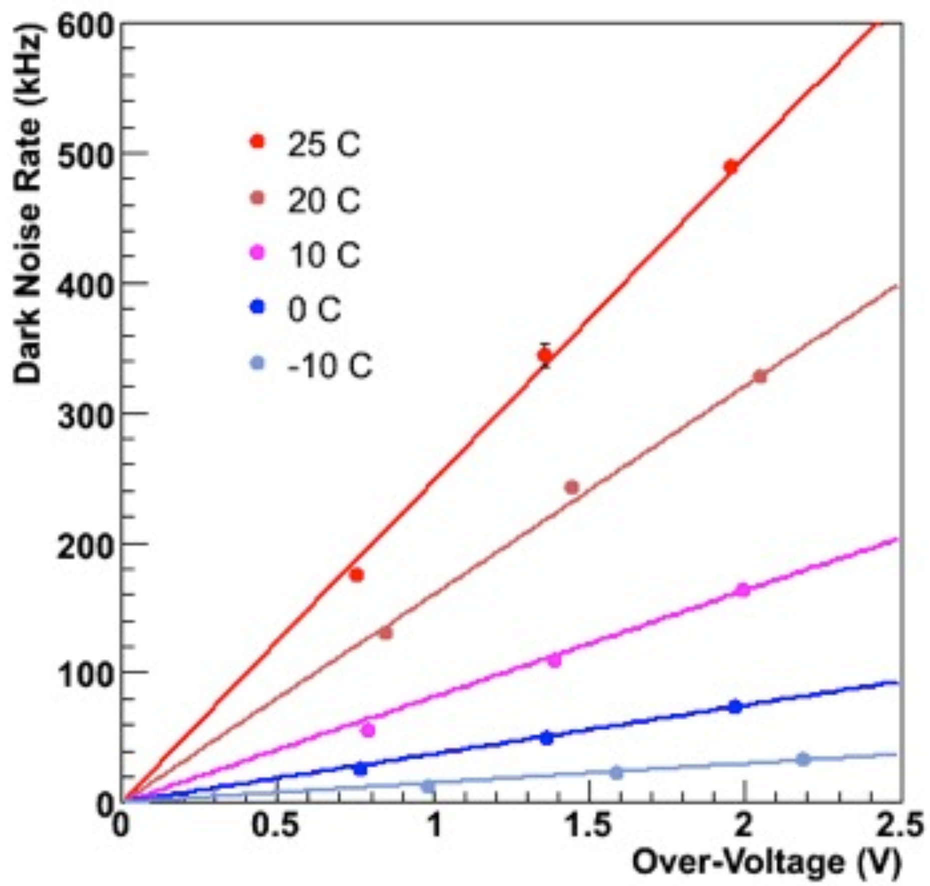
Number of pixels	667
Active area	1.3×1.3 mm^2
Pixel size	50×50 μm^2
Operational voltage	68 – 71 V
Gain	~ 10^6
PDE at 525 nm	26 – 30%

Output is sum of charges from pixel avalanches:



Can isolate single photoelectrons
Low operating voltage and power consumption
Gain similar to conventional PMTs
Insensitive to magnetic field

ND280's MPPCs



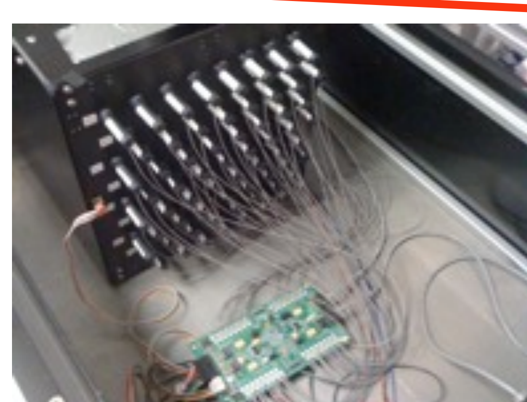
High dark noise rates: ~0.3-0.5 MHz
Cross-talk/afterpulsing effects

All quantities depend strongly on temperature and over-voltage.

need to keep T stable within a few degrees

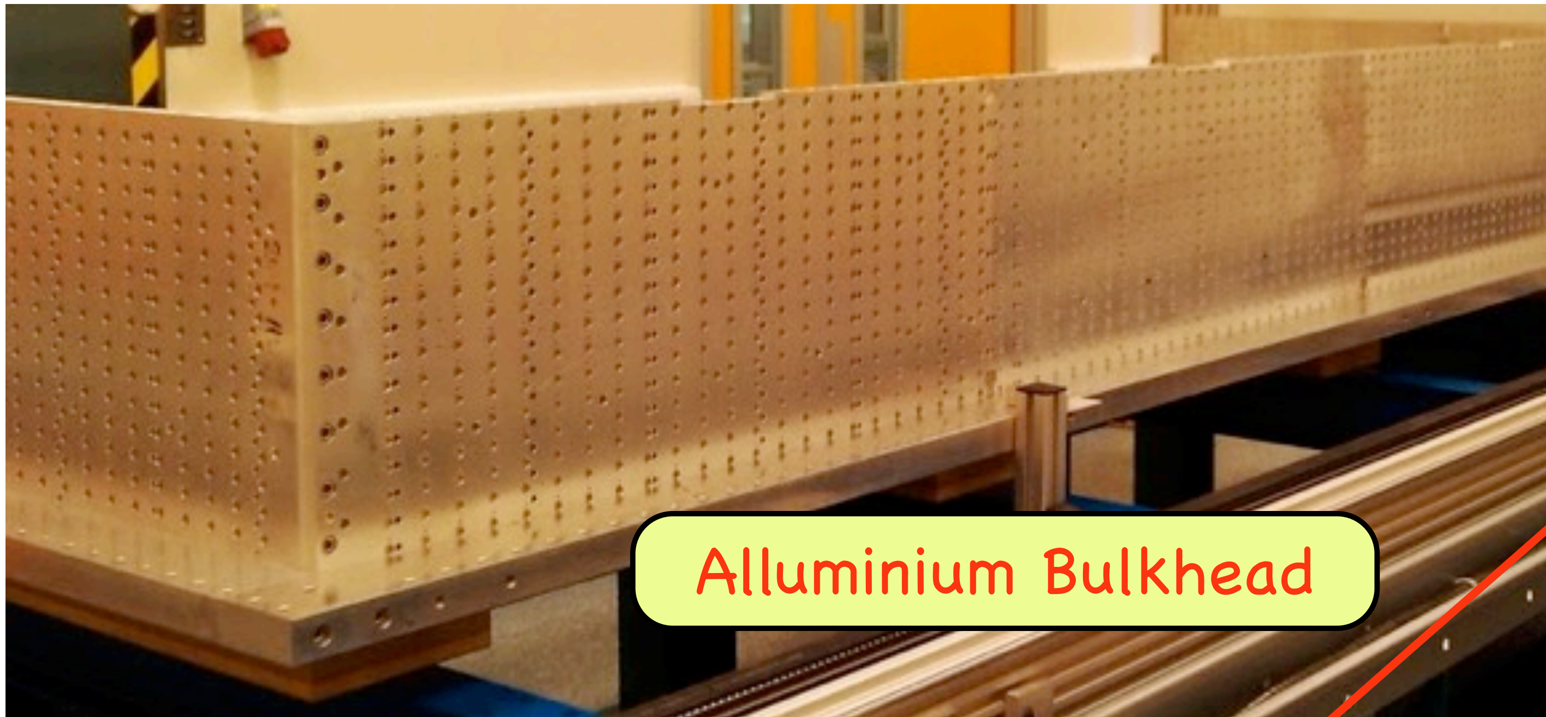
Large variation in breakdown voltage:
Bias voltage has to be adjusted individually for each channel

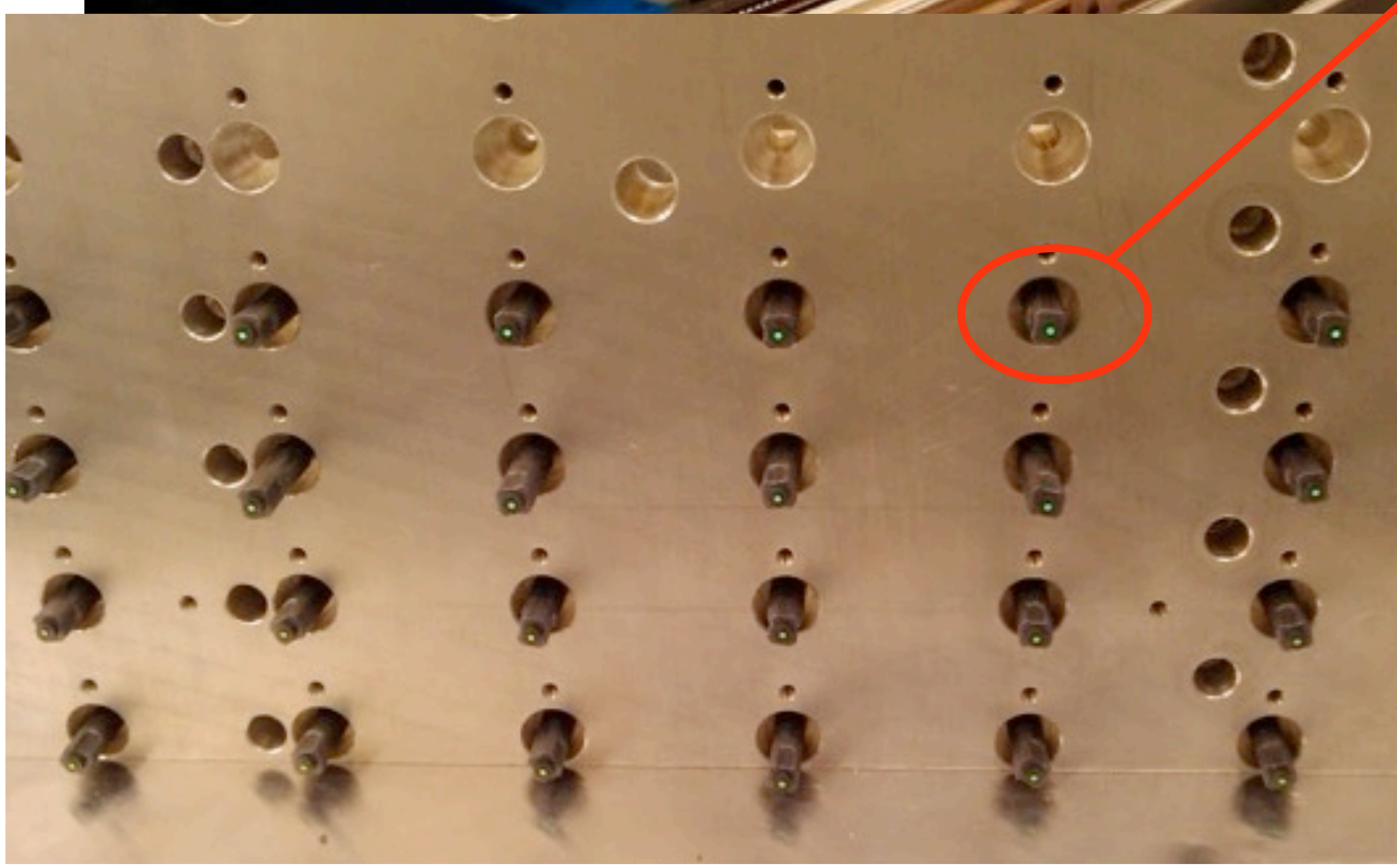
Quality Assurance prior of installation: excellent results
Ageing/Stability
Tested MPPCs at elevated T (~80C) with no obvious ill-effects.
First year of operation with MPPCs has been very positive; few-to-none have failed.

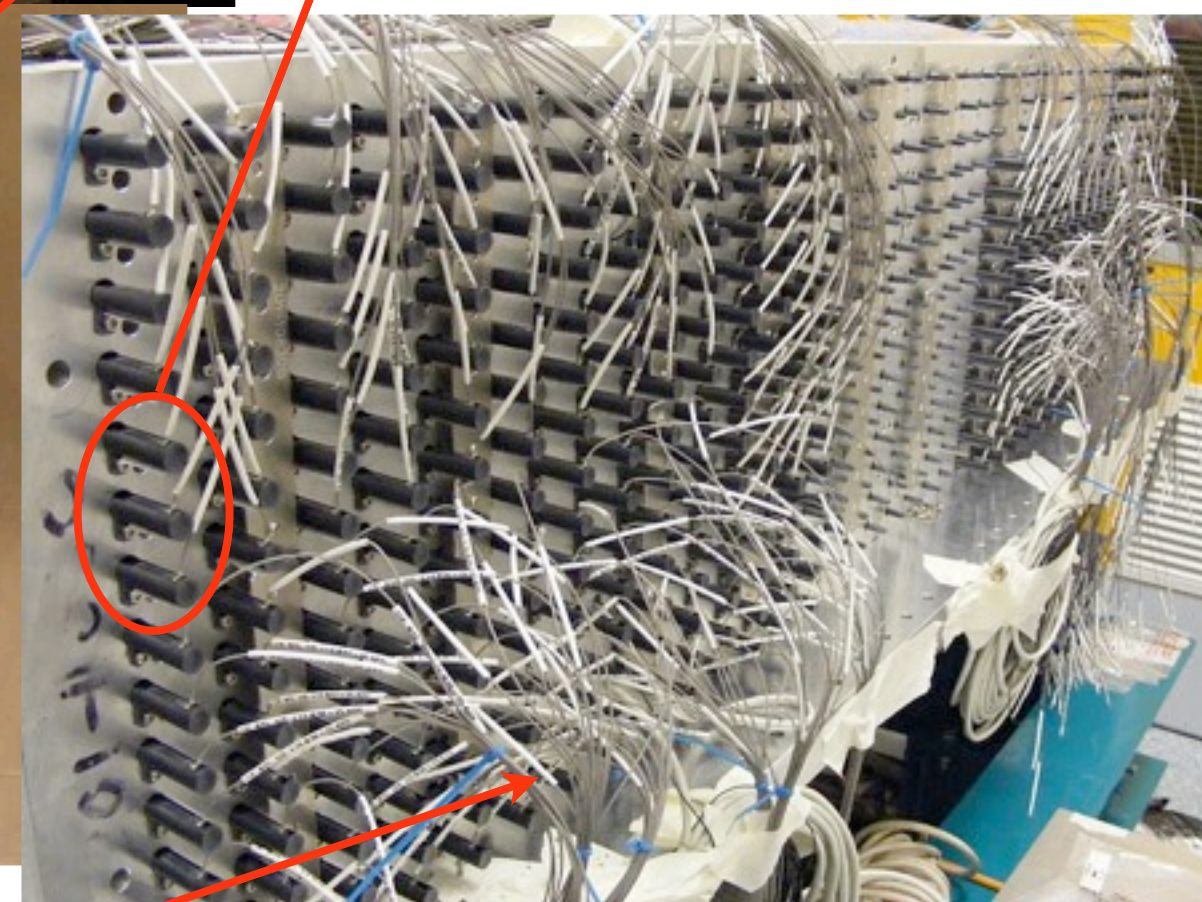


The ECal is instrumented with more than 22300 MPPCs read out by 366 front-end boards

ND280's ECal



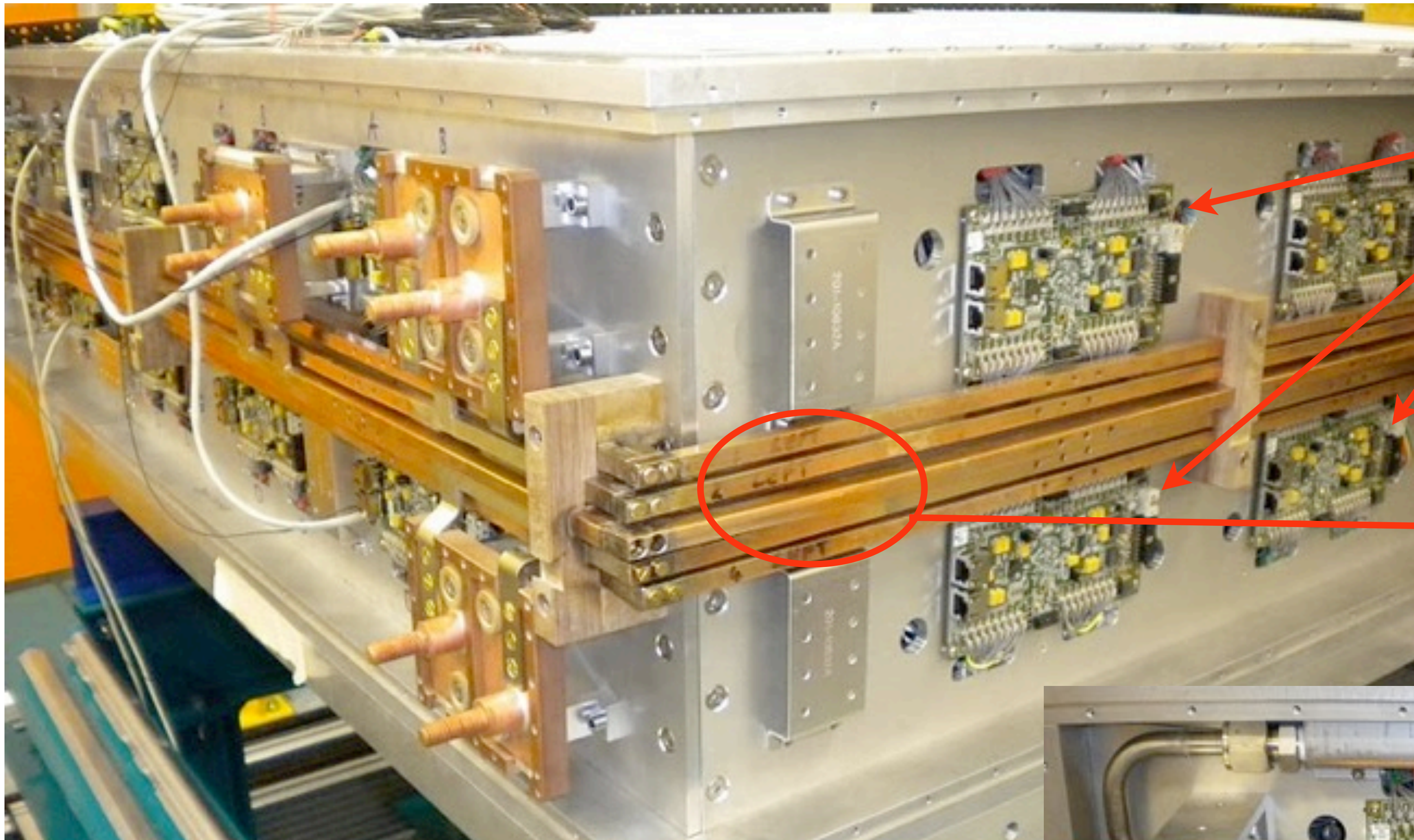




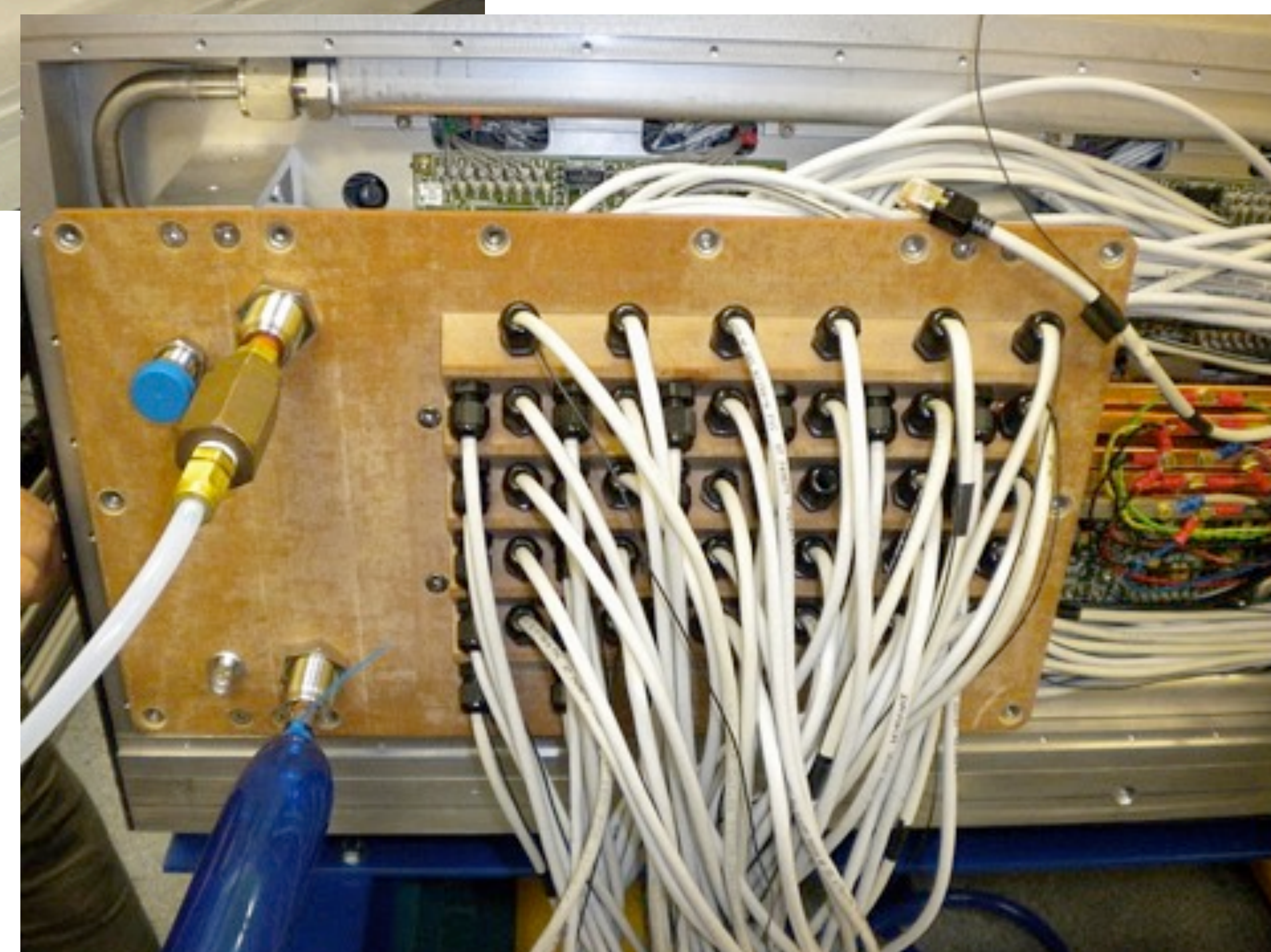
Fiber-MPPC optical coupling:
A ferrule is glued to the fiber end and secures inside an MPPC holder

Connection to front-end electronics with micro-coaxial cables

ND280's ECal

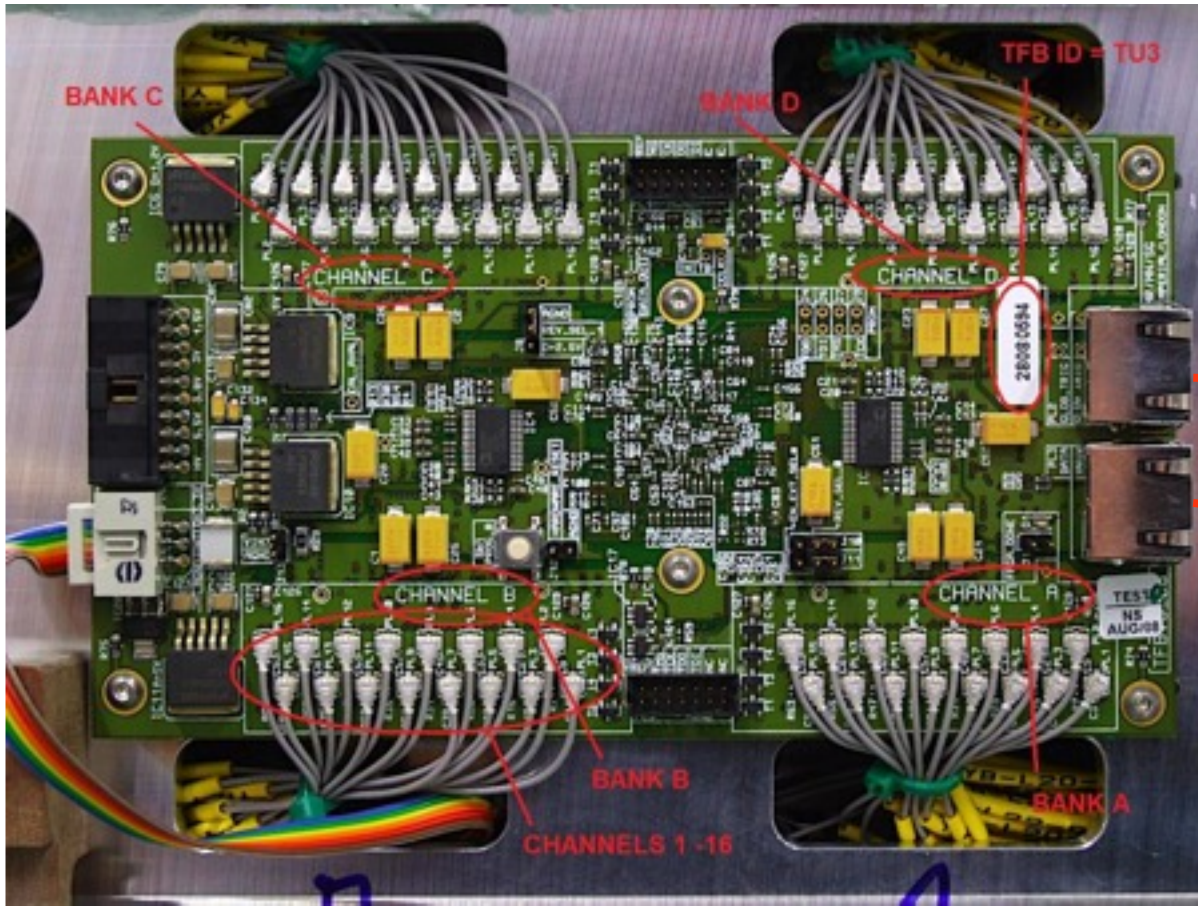


Each module is sealed shut and light-tight, services and communication with the electronics happens via a feed-through



ND280's ECal

The Trip-T Frontend Board



4 Trip-T chips are mounted on a TFB

Up to 16 MPPC signals (high and low gain) digitized in one Trip-T chip

to Master Clock Module (MCM)

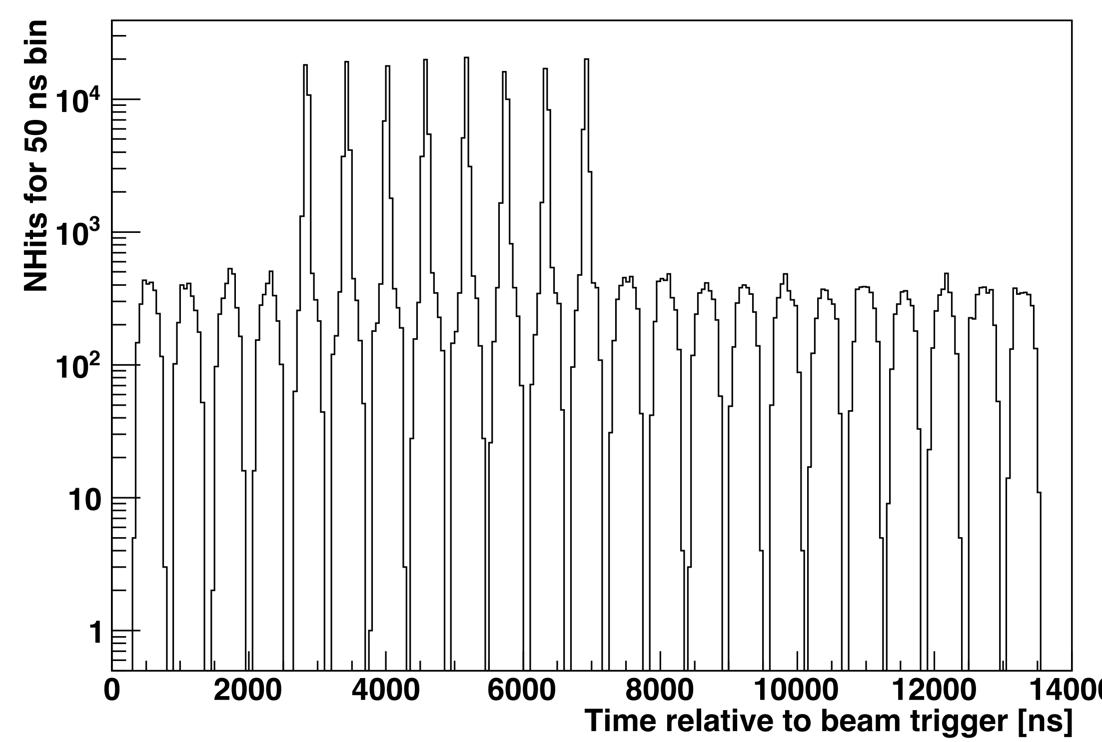
to Cosmic Trigger Module (CTM)

Charge integrated in 23 cycles

480ns long, 100ns reset time

synchronized with the beam

Timestamping accuracy: 2.5ns



ECal Performance

Very successful data-taking so far

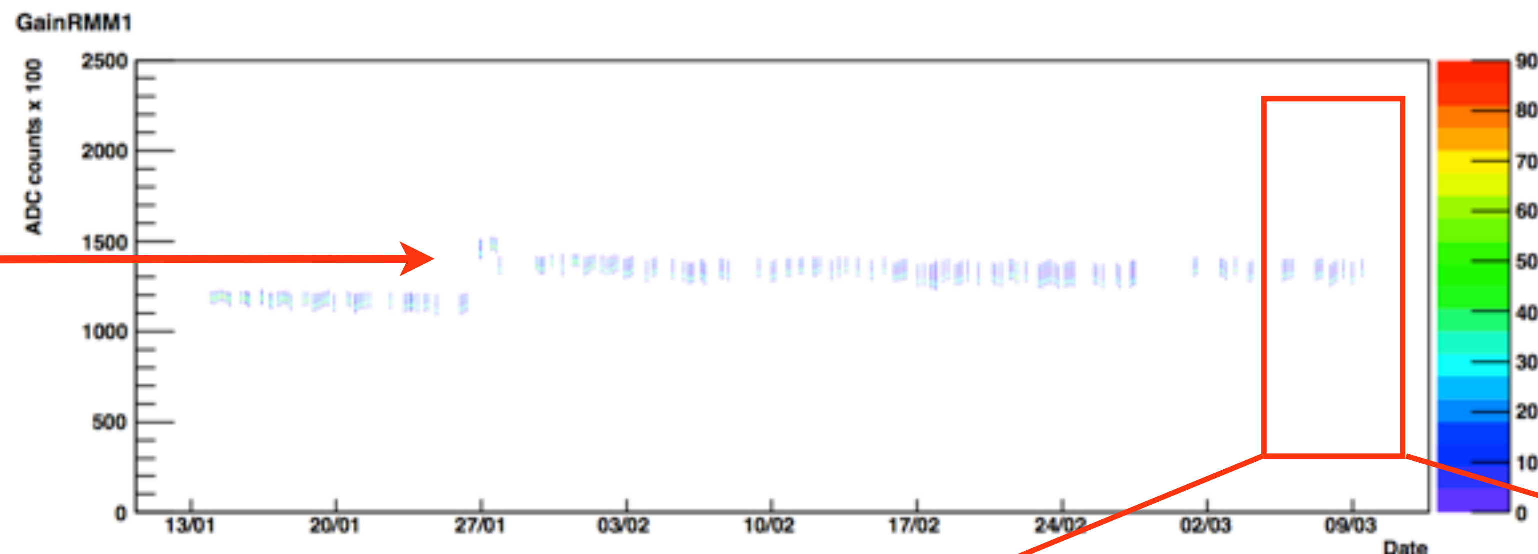
DSEcal: November 2009 - March 11th 2011

Barrel and POD ECal: November 2010 - March 11th 2011

46 dead channels (out of 22300)

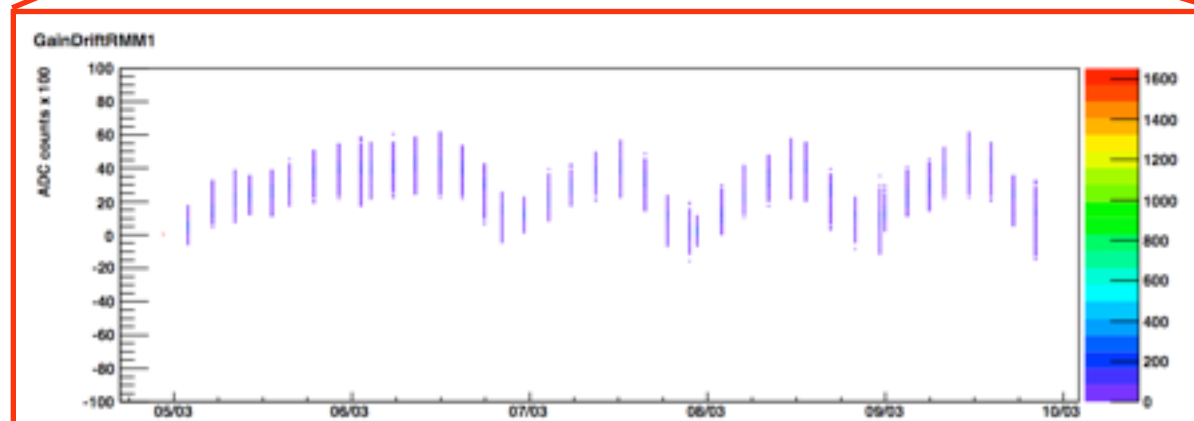
Gain stability plot from fit of MPPC spectra for each channel (2011 data)

14 ADC counts



ECal stable for the full data-taking period until March 11th

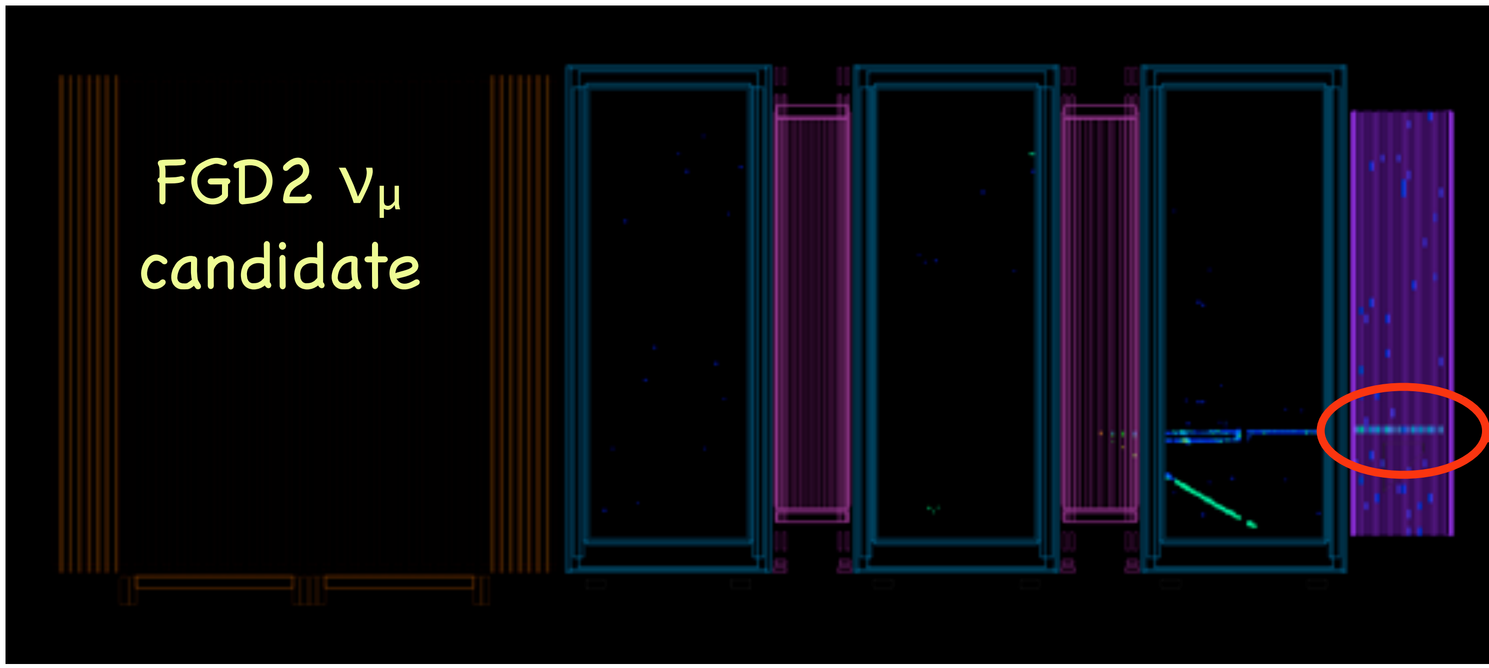
Did not contribute significantly to ND280 down time!



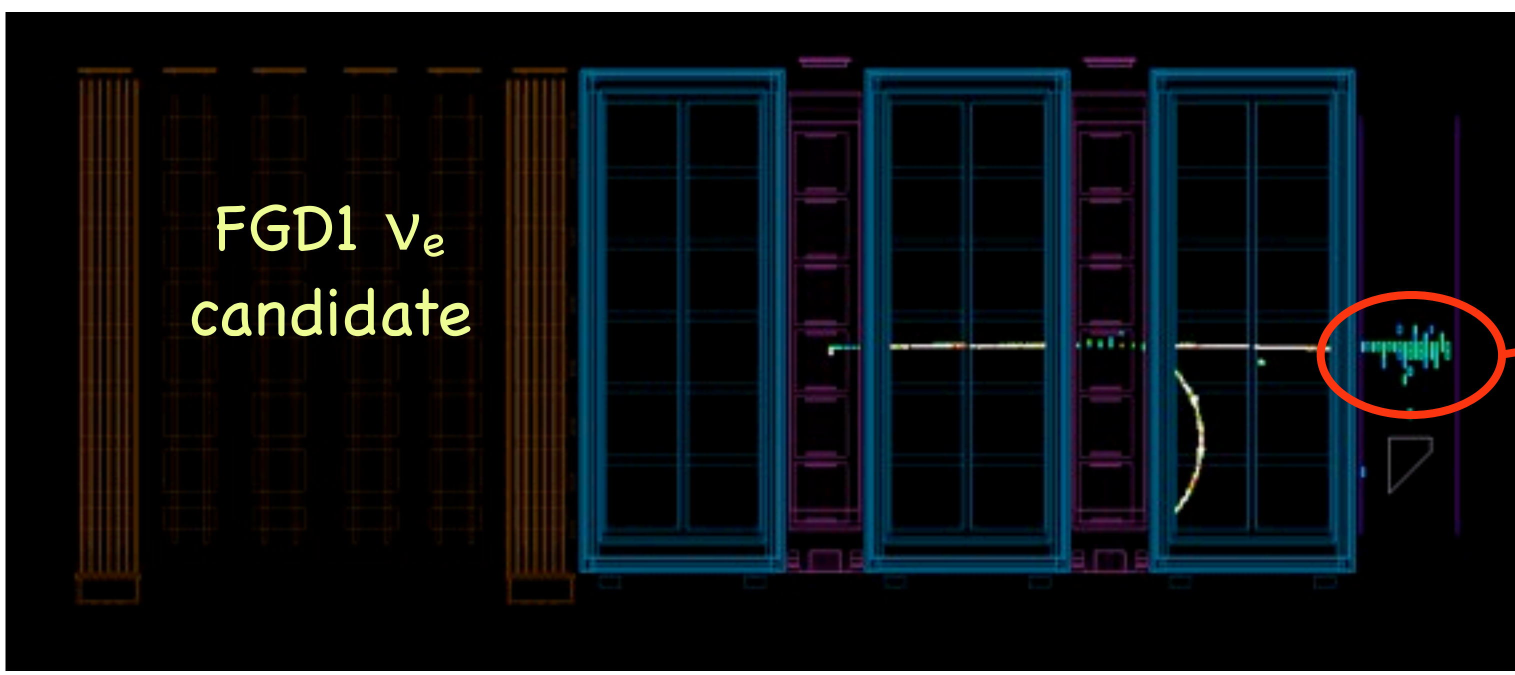
ECal Performance

We are developing a Neural Network algorithm that calculates a Track-or-shower particle identification (PID) parameter

Independent analysis of signal purity and reconstruction systematics

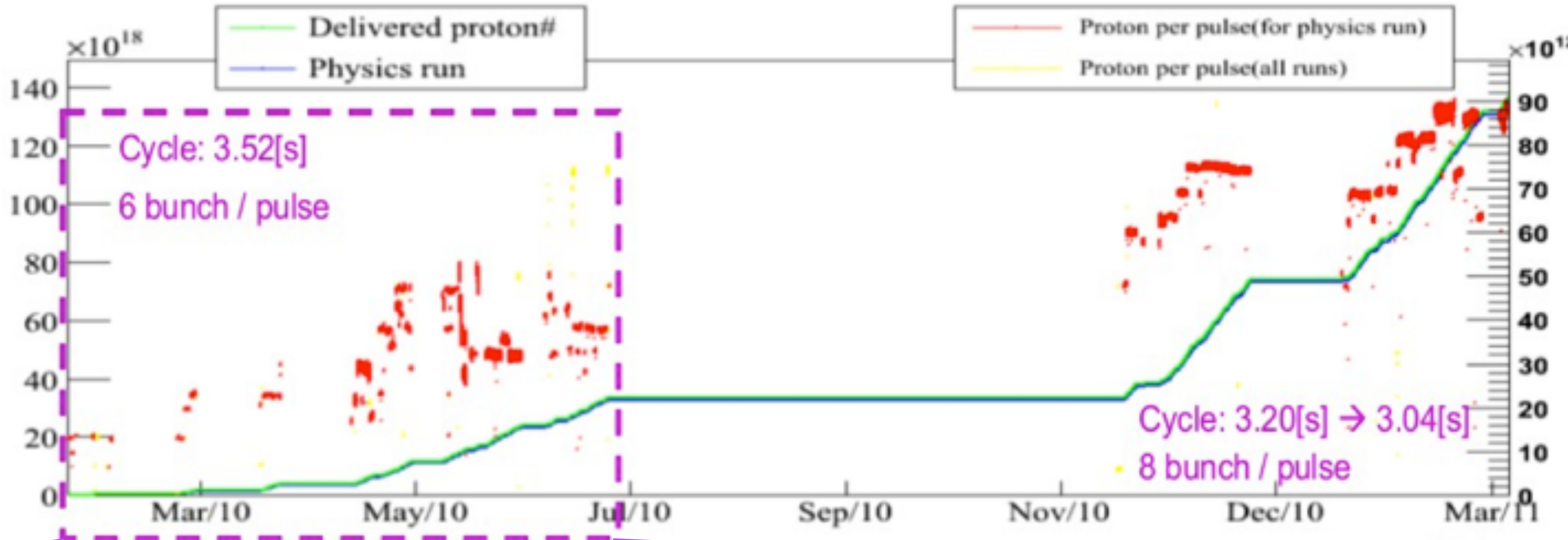


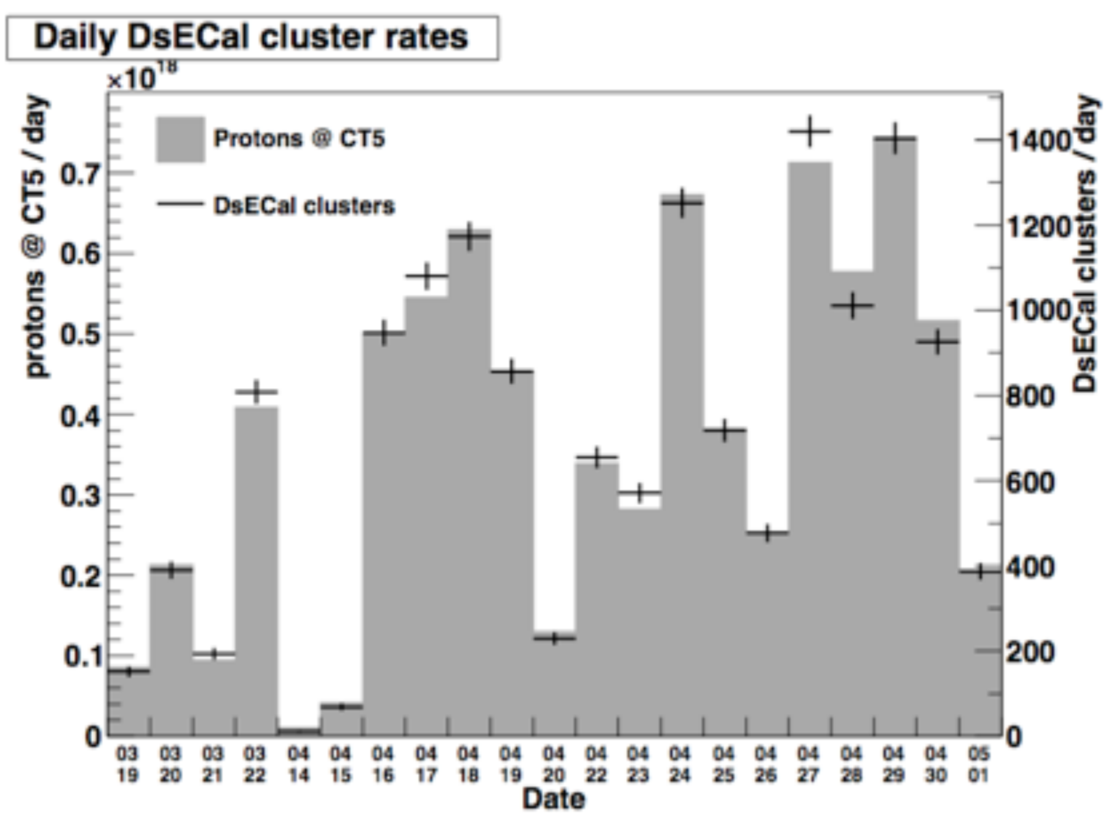
tagged as a track by TPCs and ECal

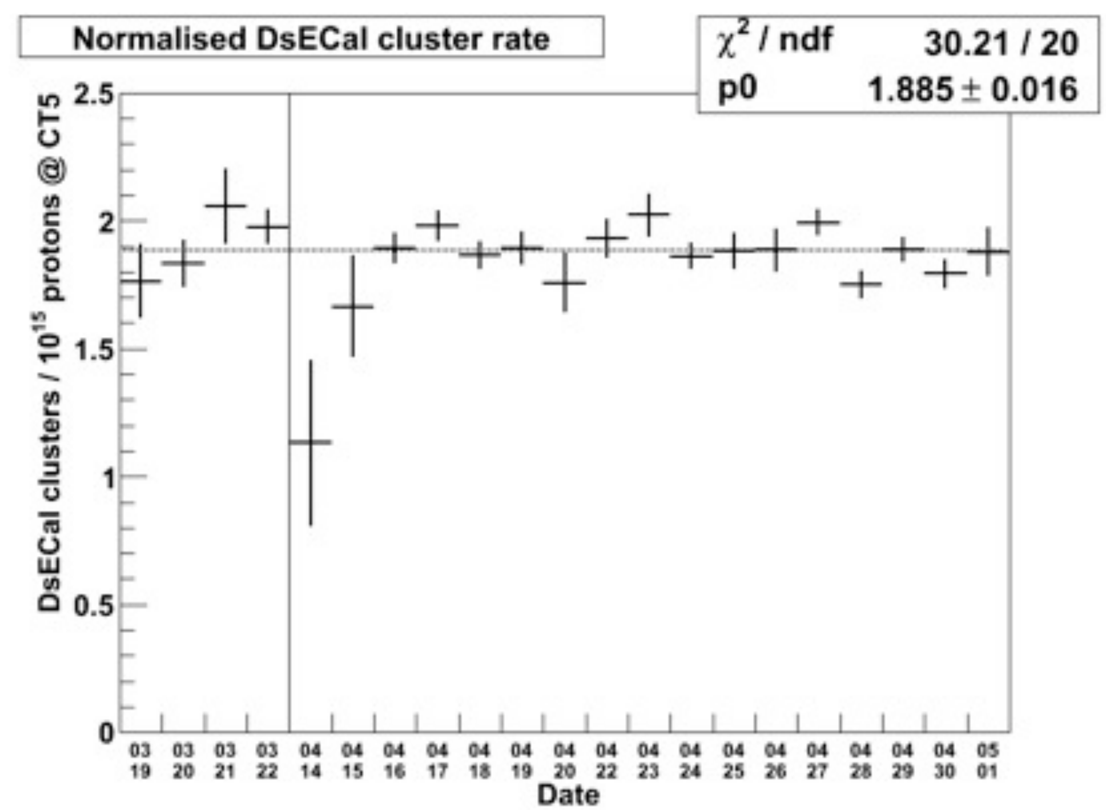


tagged as an electron by TPCs and ECal

ECal Performance







Conclusions

13 Modules of ND280's ECal, instrumented with more than 22300 MPPCs, have been installed at J-PARC between 2009 and 2010

Operations have been smooth, with collection of good quality data, that are being analysed, and no significant down time - until the March 11th earthquake

We are now in the process of fully assessing the damage to proceed with repairs, if needed