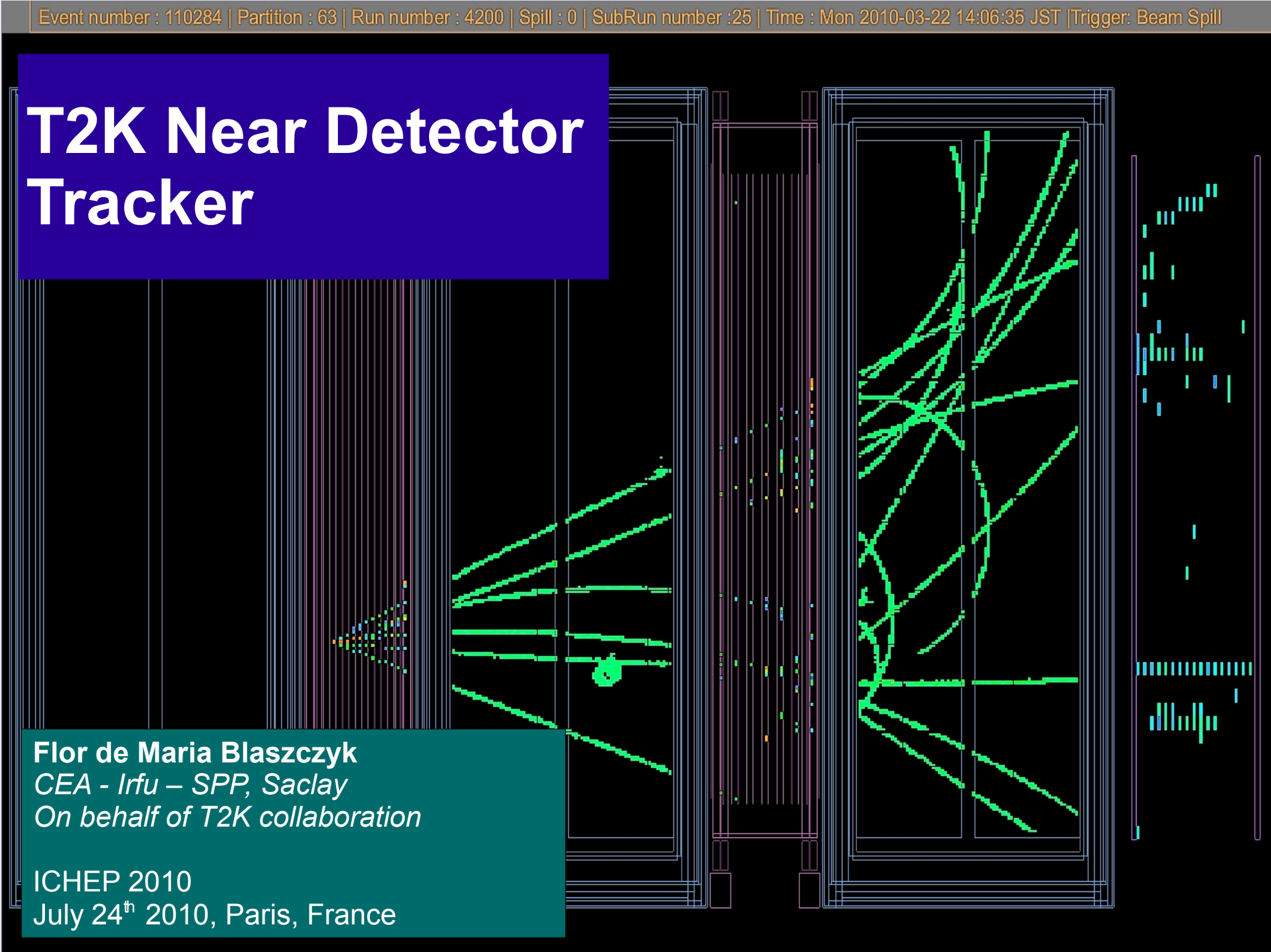


T2K Near Detector Tracker

Flor de Maria Blaszczyk
CEA - Irfu – SPP, Saclay
On behalf of T2K collaboration

ICHEP 2010
July 24th 2010, Paris, France

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. Wroklaw

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

** TPC and FGD groups*

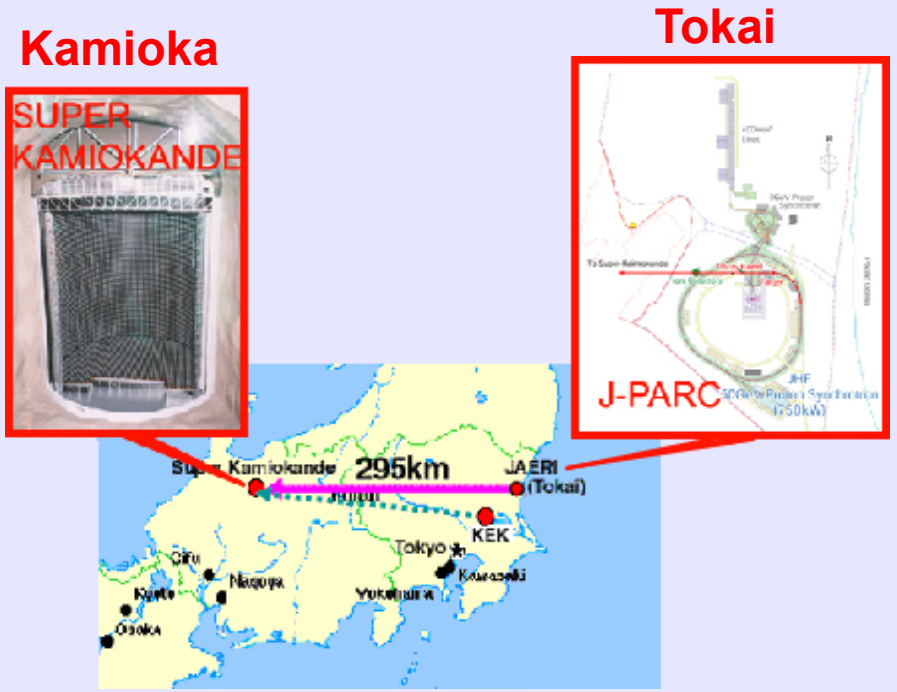
Outline

- The T2K experiment
- Off-axis near detector ND280
- Tracker
  - Fine Grained Detectors
  - Time Projection Chambers
- Conclusion

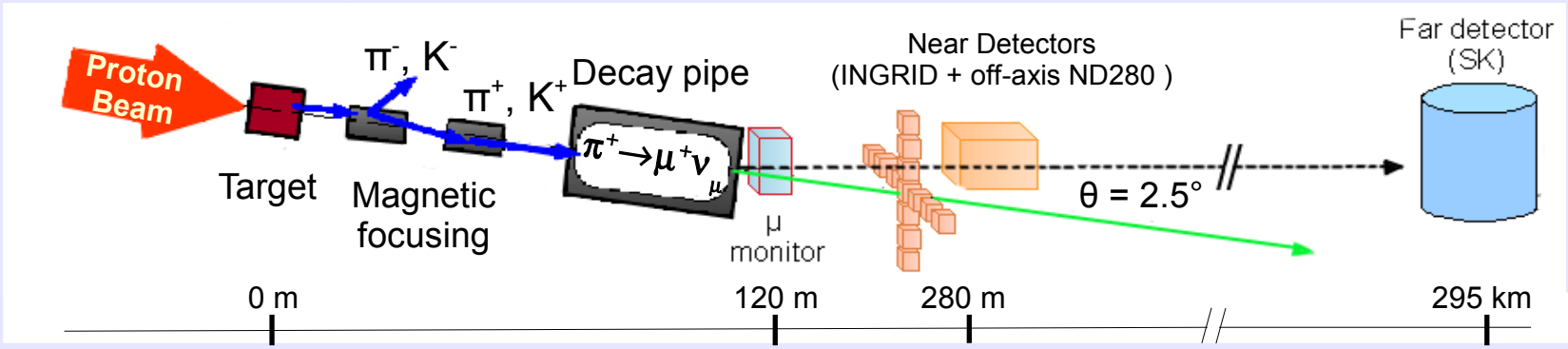
Tokai to Kamioka (T2K)

- **Goals**
  - $\nu_\mu \rightarrow \nu_e$: Measure or improve limit on θ_{13} by at least an order of magnitude;
  - ν_μ **disappearance:** Precise measurement of Δm^2_{23} and θ_{23} .

- **Neutrino oscillation long baseline experiment (Japan)**
  - ν_μ **beam (~600 MeV)** produced at **J-PARC** (Tokai) by a **30 GeV proton beam** ;
  - **Beam monitor OTR** before target and **Muon monitor** at 120 m from proton target ;
  - **Near** detector: **ND280** at **280m**;
  - **Far** detector: **Super Kamiokande** at **295km**.



- 1st beam in April 2009 → data taking started in January 2010.



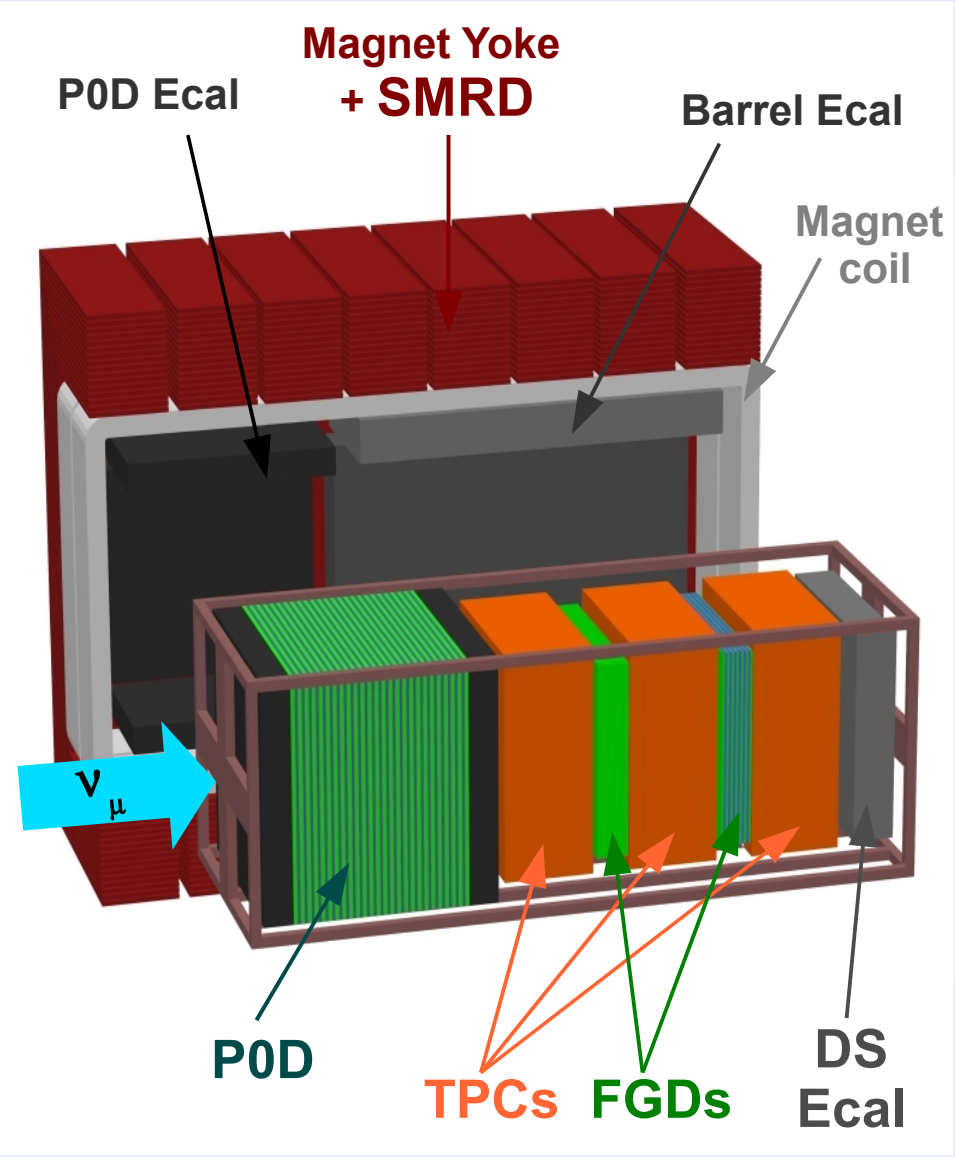
Off-axis near detector

- Located at **280m** from the proton target, off-axis angle of **2.5°**.

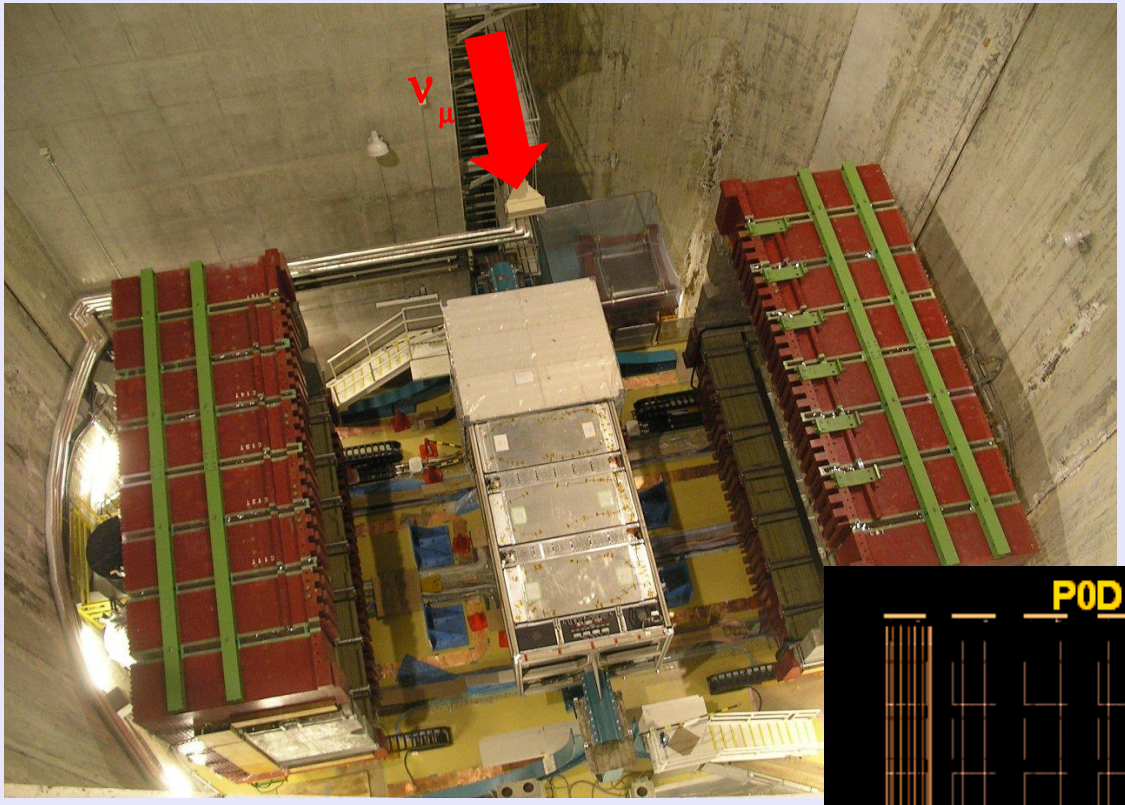
- **Goals:**
  - **characterize** neutrino beam before oscillation
    → flux, spectra, beam composition and direction, cross-section measurements.

- Uses **UA1 magnet: 0.2 T** magnetic field.

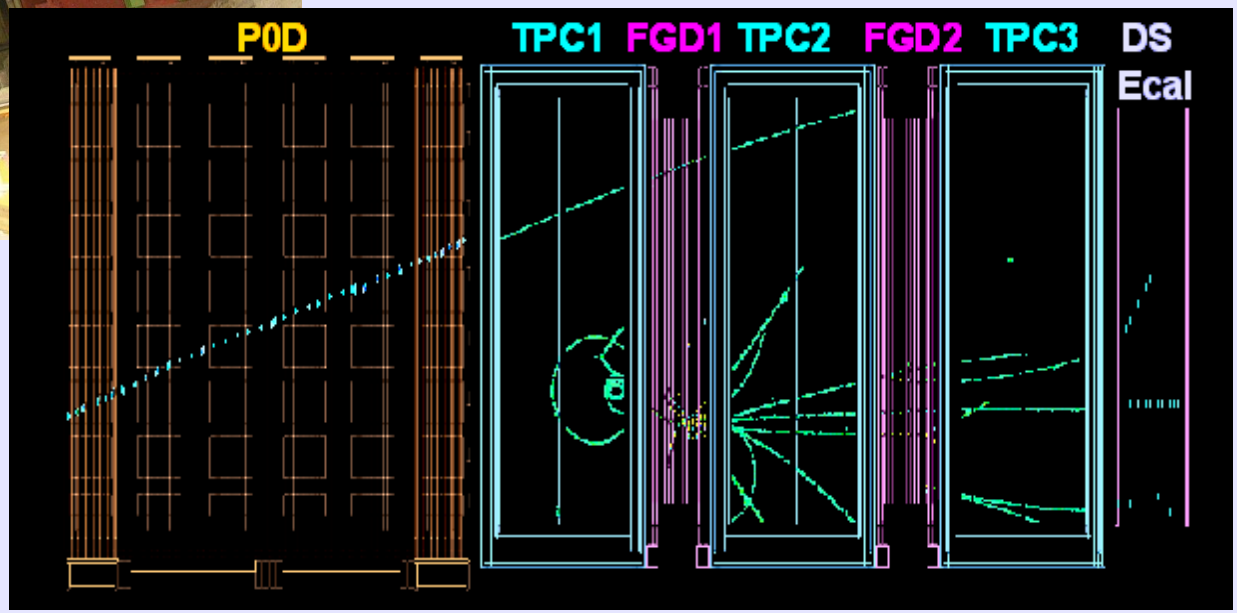
- **Different detector types:**
  - **P0D** (π^0 detector) ;
  - **Tracker**: **3 Time Projection Chambers (TPCs) + 2 Fine Grained Detectors (FGDs)** ;
  - **Ecal** (Electromagnetic calorimeter) ;
  - **SMRD** (Side Muon Range Detector) embedded in the magnet yoke.



T2K off-axis ND280 status



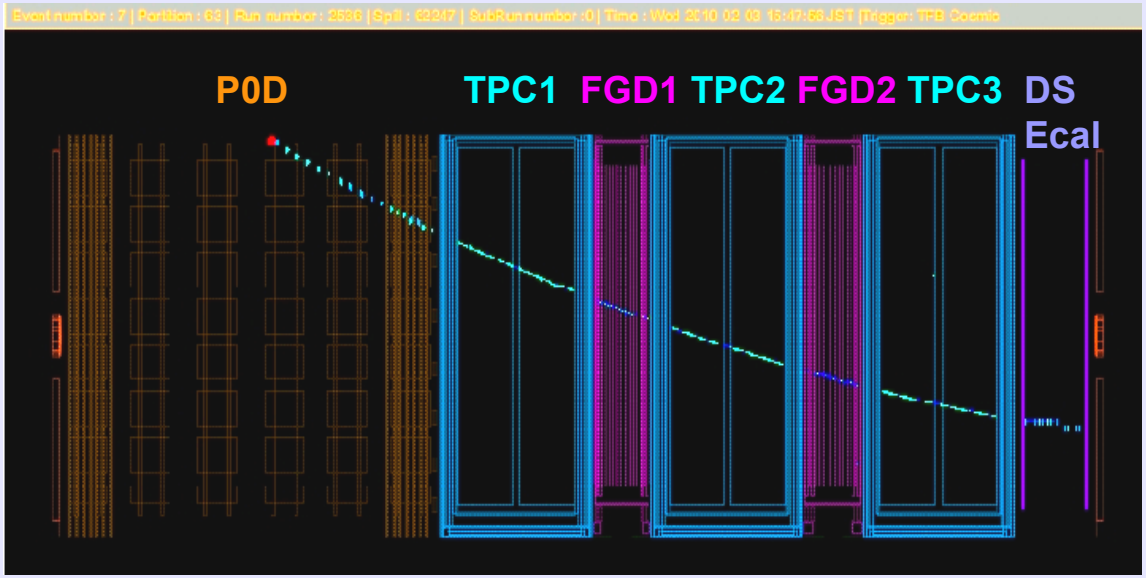
- **Status**
  - Magnet operational, field mapped.
  - All detectors except barrel Ecal installed in the pit.
  - Barrel Ecal installed this summer.
  - **All installed detectors** have been **commissioned** and are **taking data**!

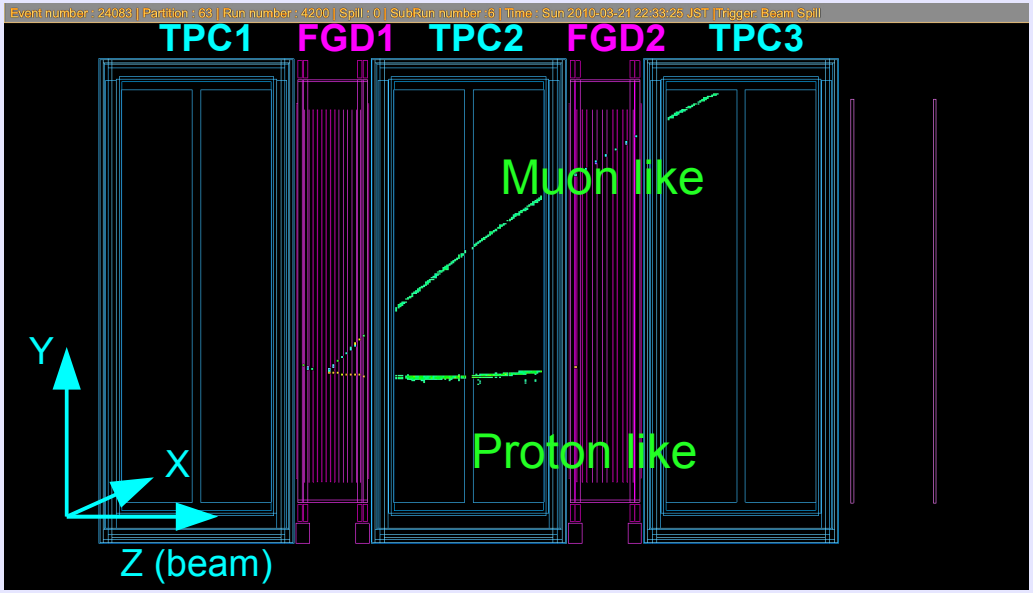


- **Event display:**
  - Sand muon crossing P0D and part of the tracker
  - Neutrino interaction in FGD1 (deep inelastic scattering).

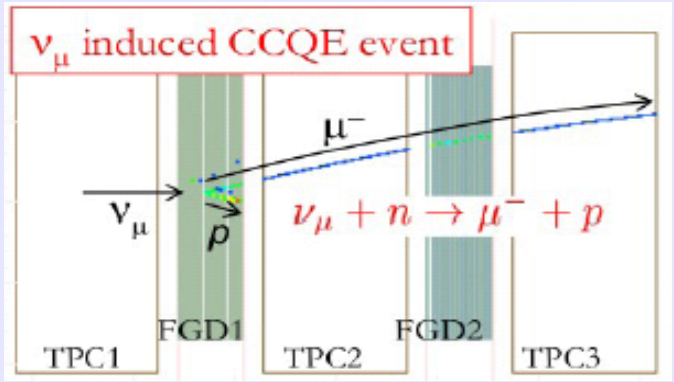
Tracker event display

Cosmic ray event
(entering through the P0D)





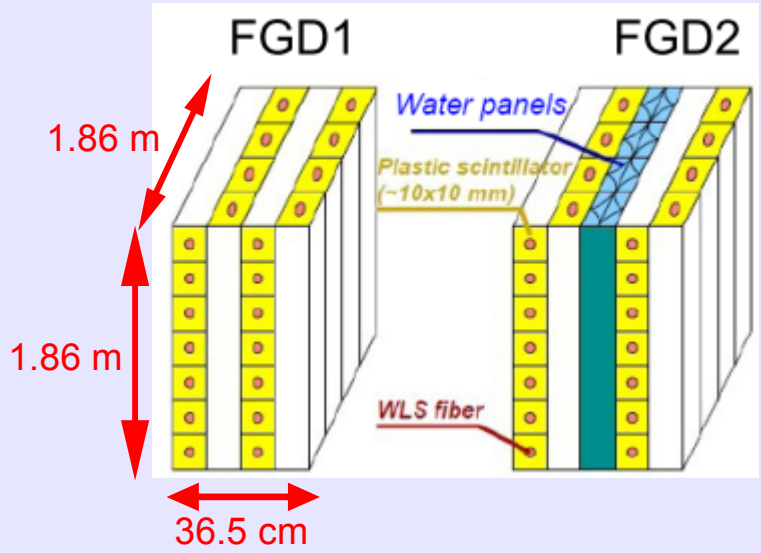
Neutrino CC event candidate
(in FGD1)

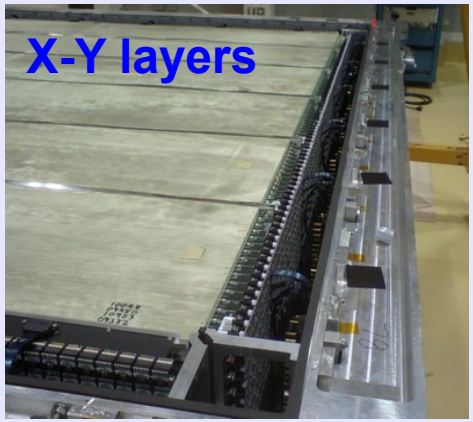


Fine Grained Detectors (FGDs)

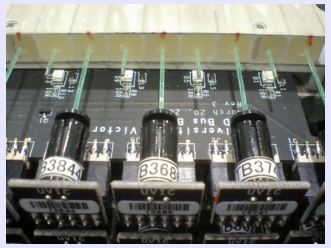
- **Goals:**
  - Provide **target mass** for neutrino interactions (~1 ton per FGD).
  - Measure **neutrino cross sections** in carbon and water (oxygen).
  - Track and vertex **reconstruction, particle identification.**

- **Design:**
  - **Thin scintillator bars** (9.61 x 9.61 x 1864 mm³) organized in X-Y layers to allow tracking.
    → 5760 bars in FGD1, 2688 in FGD2
  - Additional **passive water panels** in FGD2.
  - Scintillation light collected by a **WaveLength Shifting** (WLS) **fiber**, mirrored on one tip (1mm Ø).
  - Fibers transport the light into **Multi Pixel Photon Counters** (MPPCs).
  - **AFTER ASIC** based electronics.
  - LED based **light injection system** for calibration.





Bars
Fibers
MPPCs



Water panels
6 layers of 25 mm
(~ 400 kg)

1st large scintillator based detectors using MPPCs!

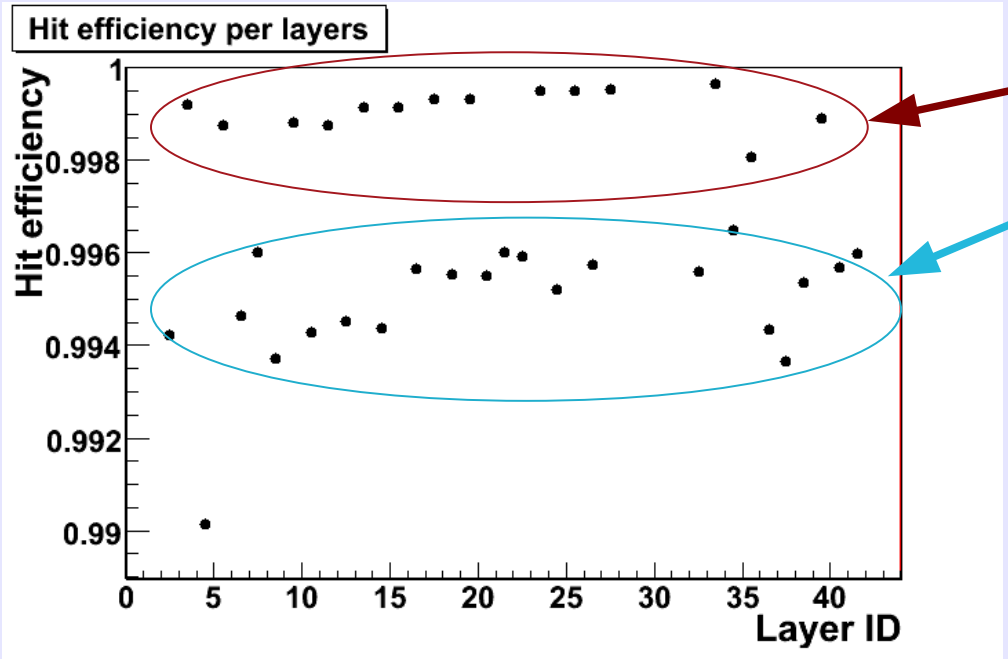
Hit efficiency (cosmic rays)

- Bars yield ~30 pe / MIP
- High quantum efficiency MPPCs (667 pixels)

(by Hamamatsu Japan and Kyoto U.)

→ cf. F. Retière *et al.*, NIM A **610**: 378-380 (2009)

- Hit efficiencies measured with through going cosmics.
- Looking at the middle layer every three hit layers.
- First and last layer of each orientation is omitted.
- **Hit efficiency = # of hits / total layers crossed**.



Horizontal layers (YZ layers)

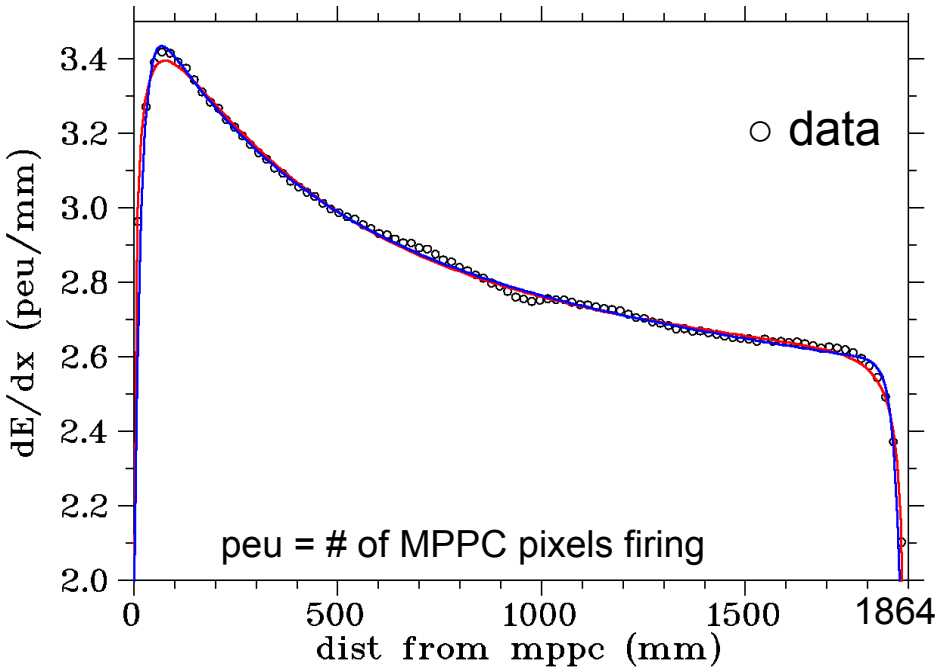
Vertical layers (XZ layers)

- Difference between vertical and horizontal layers is due to a geometrical effect → cosmics are mainly downward going.

Efficiency for all layers better than 99% so better than required

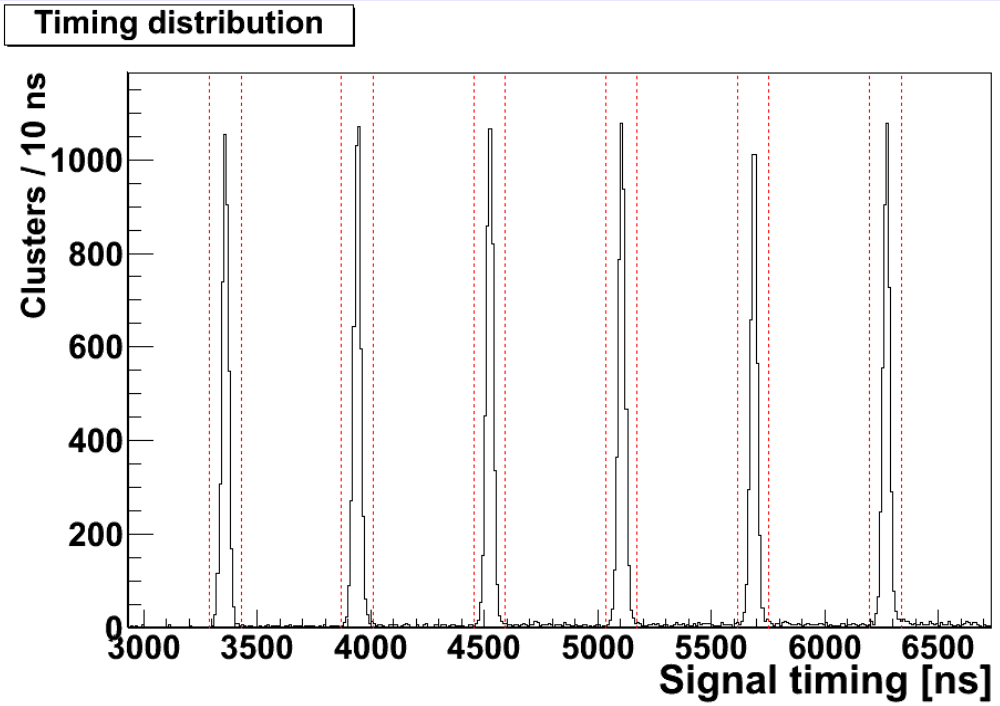
Fiber attenuation (cosmic) / Signal timing (data)

Light yield per path (cosmic rays)



- Cross-talk and afterpulsing are included.
- Modeling of fiber attenuation well understood.
  → Light leaking out of the scintillator bar can be taken into account in 2 different ways (blue and red curve).
- Good agreement with previous measurements.

Neutrino interactions in FGDs reconstructed timing

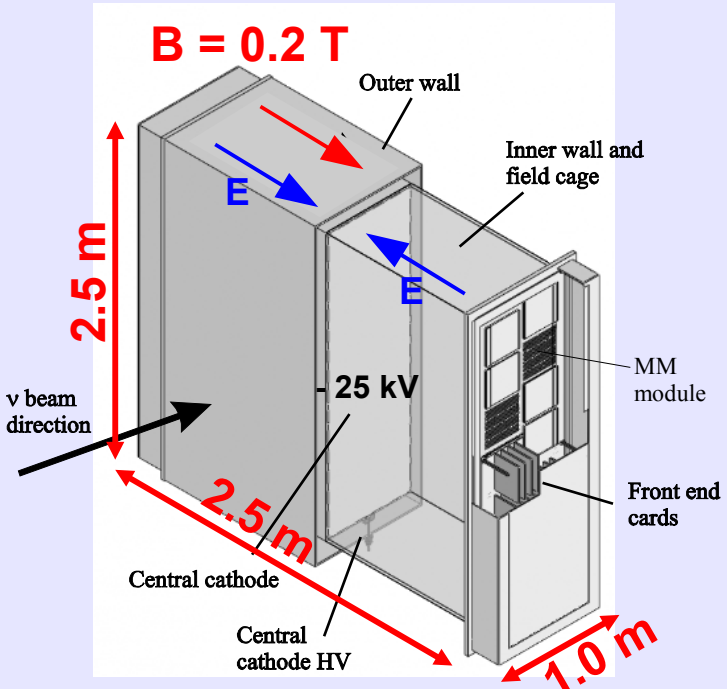


- Beam is delivered in 6 bunches separated by 581 ns, and bunch trains are separated by 3.52 s.
- Bunch structure is clearly visible in the FGDs.

Time Projection Chambers (TPCs)

- **Goals:**
  - **Reconstruct charged particle's tracks**
  - **Particle identification** (dE/dX resolution < 10%)
    → distinguish muons/electrons and protons/pions.
  - **Momentum measurement** (resolution < 10% @1 GeV, momentum scale precision < 2%).

- **Design :**
  - **Double wall** structure (construction @TRIUMF).
  - Read-out plane instrumented with **bulk MICROMEGAS** detectors.
  - Front-end electronics equipped with **AFTER ASIC**.
  - Gas mixture: **Ar (95%) / CF_4 (3%) / iC_4H_{10} (2%)**
  - **Laser system** provides real time calibration.



TPC inner box

Bulk-MICROMEGAS for T2K TPCs

- **All-in-one detector** (anode + mesh)
  → *cf. Jochen Kaminski's talk*

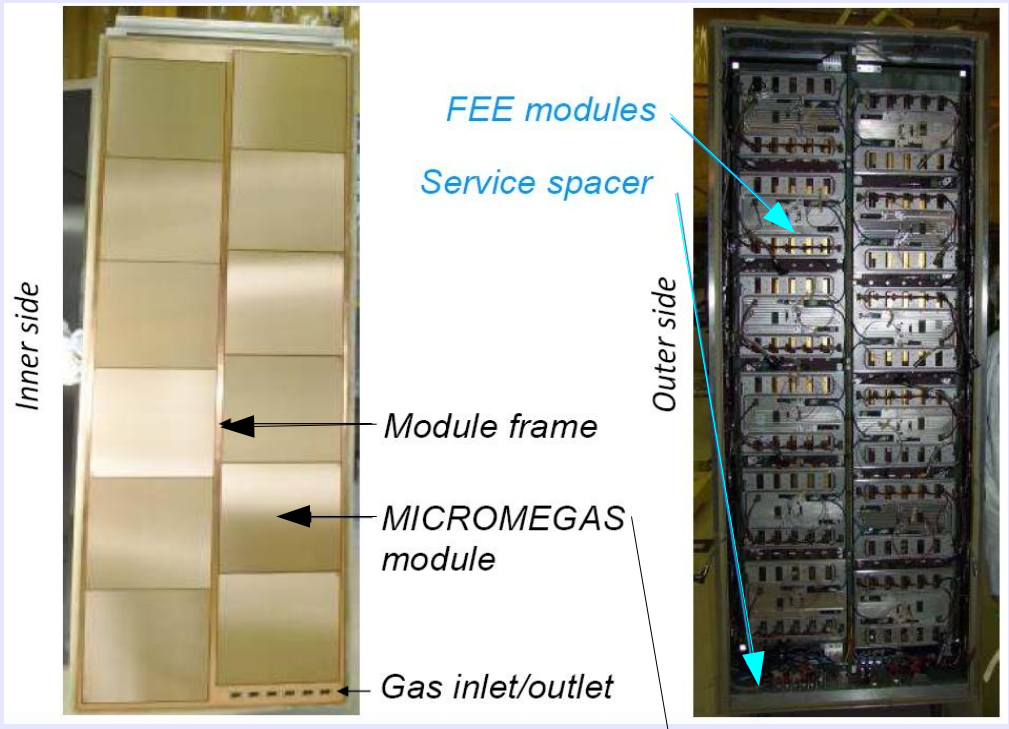
- Saclay design and production by CERN/TS-DEM-PMT, with a dedicated test bench at CERN.

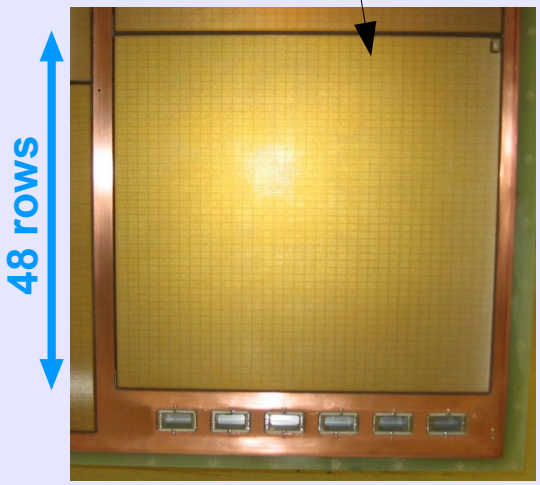
- 12 MICROMEGAS detectors per readout plane
  → **72 MM modules** for all 3 TPCs ;

- Each module is 35x36 cm² and has a **pad pitch of 7.0 mm x 9.8 mm**:

  → **1726 active pads** per module
  → **Total active surface of ~ 9 m²**

- **Gain ~10^3** (128 µm amplification gap, -350V) ;



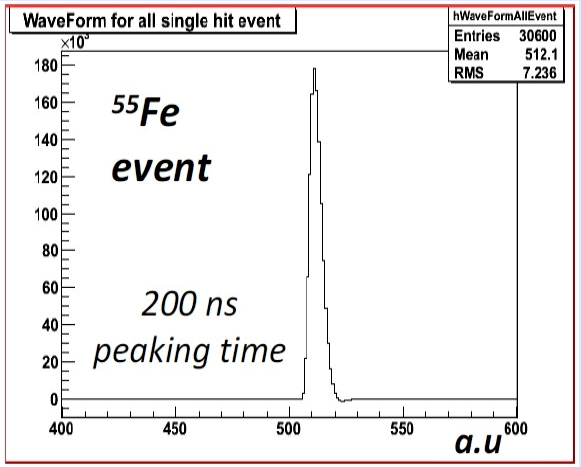


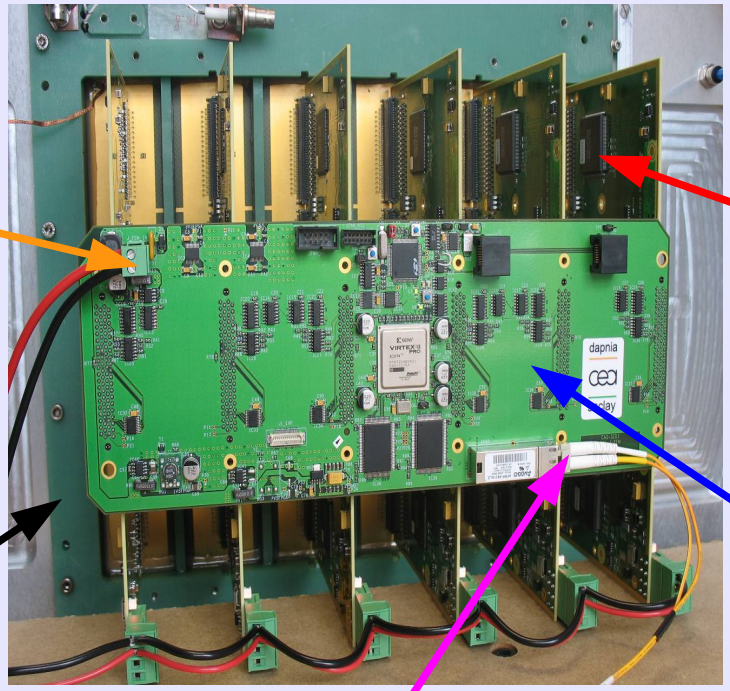
First large size TPCs based on MPGD ! (Micro Pattern Gaseous Detector)

→ cf. S. Anvar *et al.* NIM A **602**: 415-520 (2009)

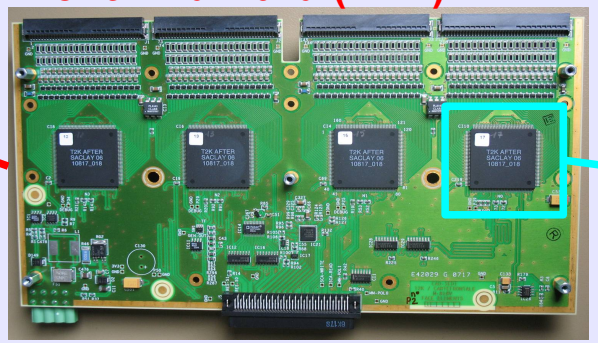
T2K TPCs' Electronics

- **124 272 channels to read out**
- **AFTER ASIC** based electronics (developed at Saclay)
  - Low electronic noise (noise ~ 600 e^-)
  - Sampling frequency up to 50 MHz
  - Adjustable gain
  - Programmable peaking time

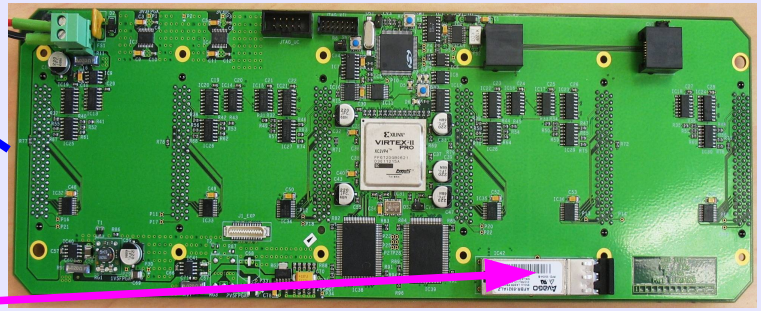




Front-End Card (FEC)



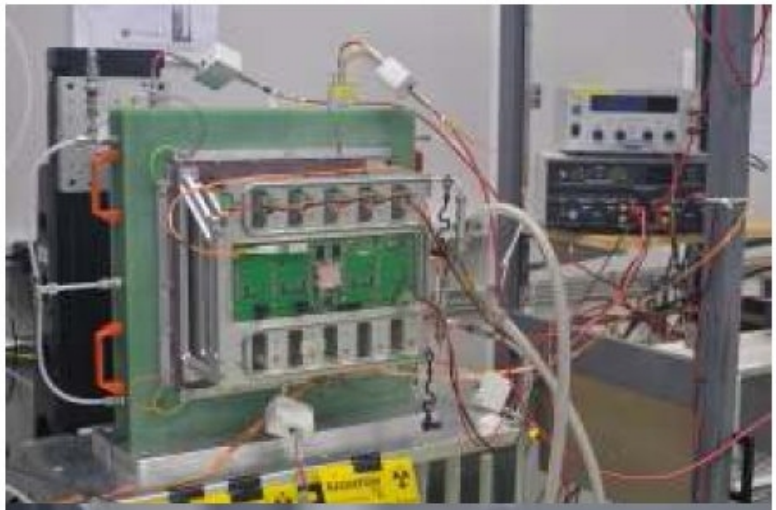
AFTER chip

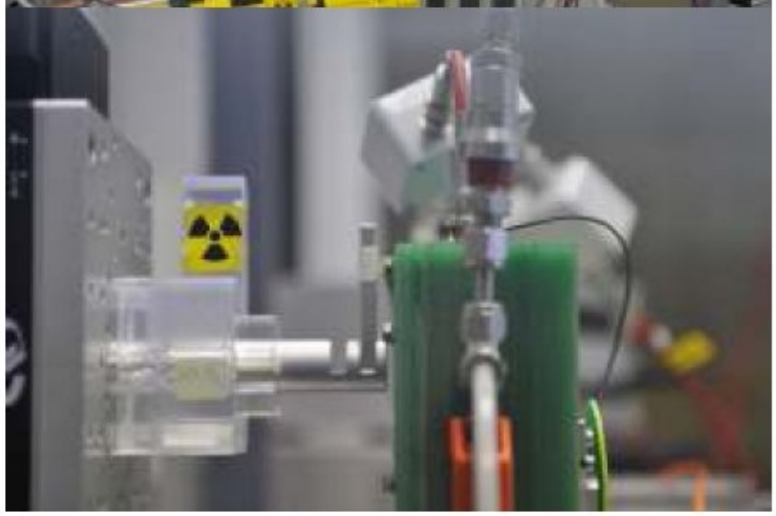


Front-End Mezzanine Card (FEM)

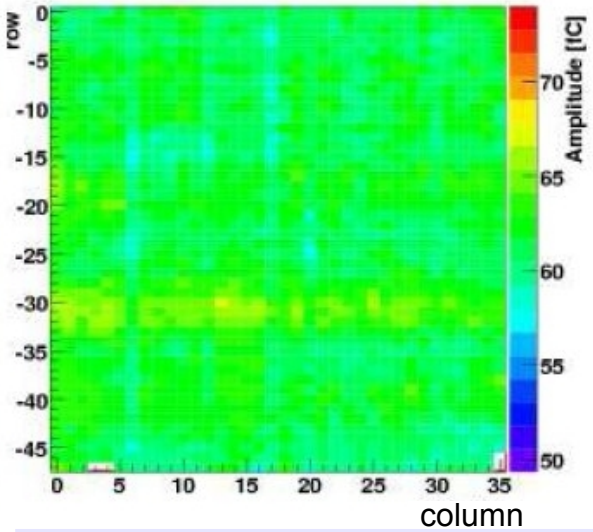
Test bench @ CERN

(X, Y) ^{55}Fe scanning:

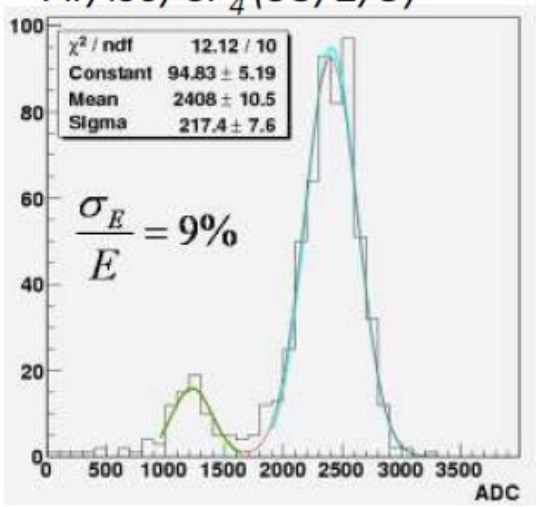




Response uniformity



$Ar/iso/CF_4$ (95/2/3)

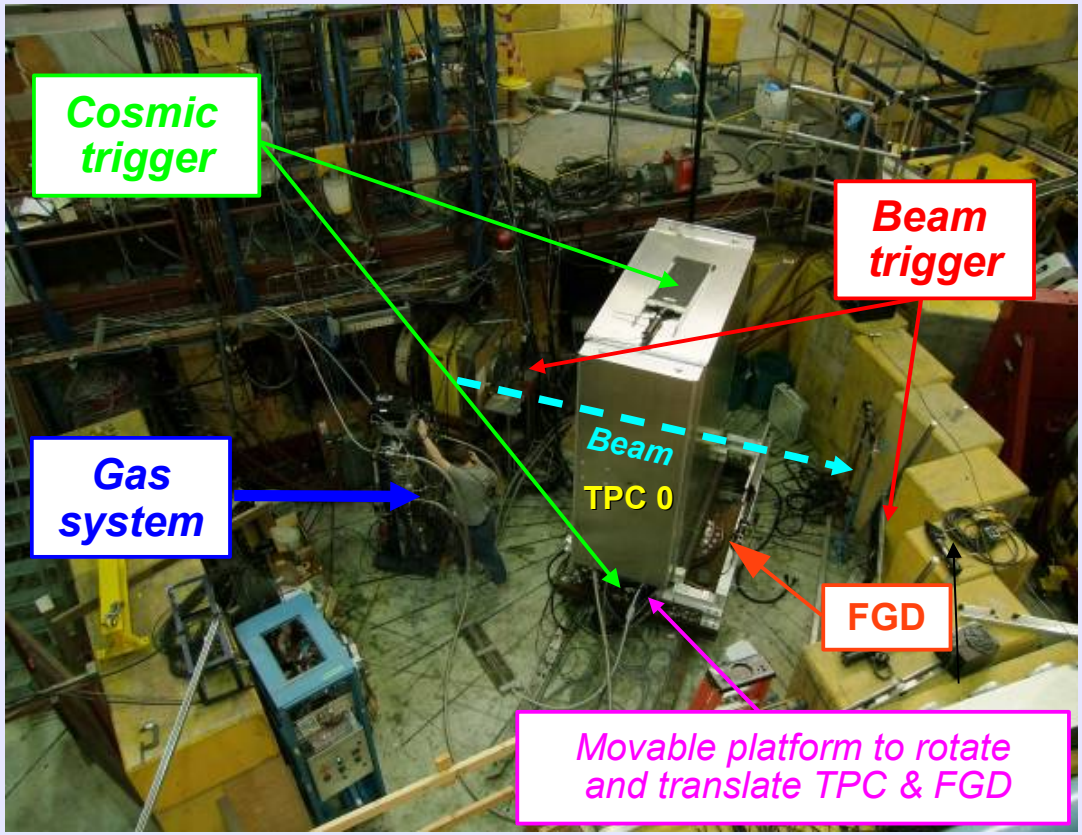


- Quality control check
  - Faulty pads ~ 10 out of ~120 000 pads → < 0.01%
  - Edge effects
- Characterization and calibration pad per pad
  - Energy resolution measurement @ 5.9 keV
  - Gain and resolution uniformity @ nominal gain

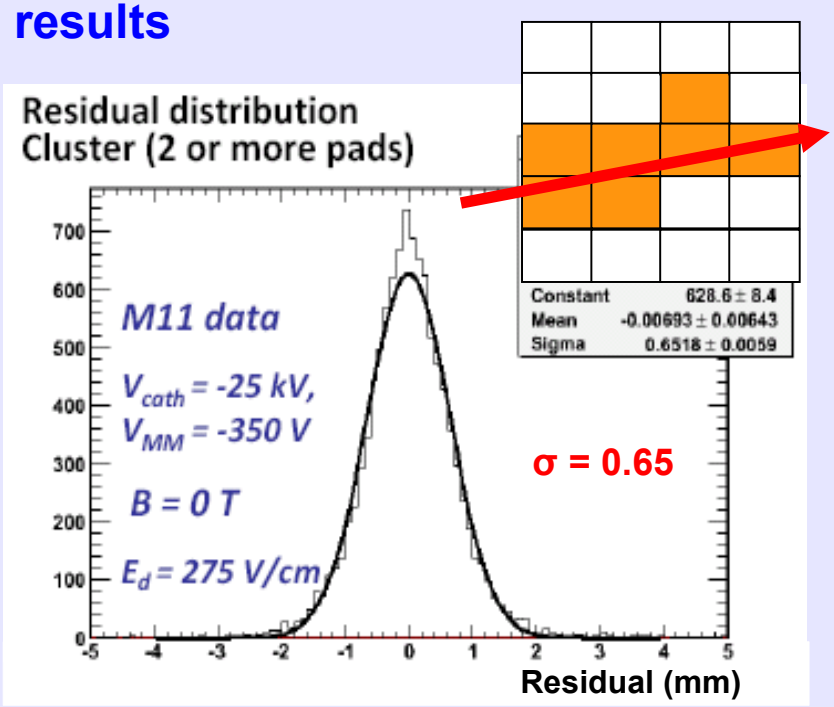
→ Response uniformity of 2%

Beam tests @ TRIUMF

- Beam tests in the M11 area at TRIUMF to study FGD and TPC performances (energy and spatial resolution).
- Beam provides e, μ, π (momentum < 400 MeV/c).
- e, μ, π tagging done by a Time Of Flight system.
- Each track crosses 2 MicroMegas modules.



TPC spatial resolution results



- Spatial resolution is measured by the residual distribution:

  → resolution is better if more than one pad per column is illuminated.

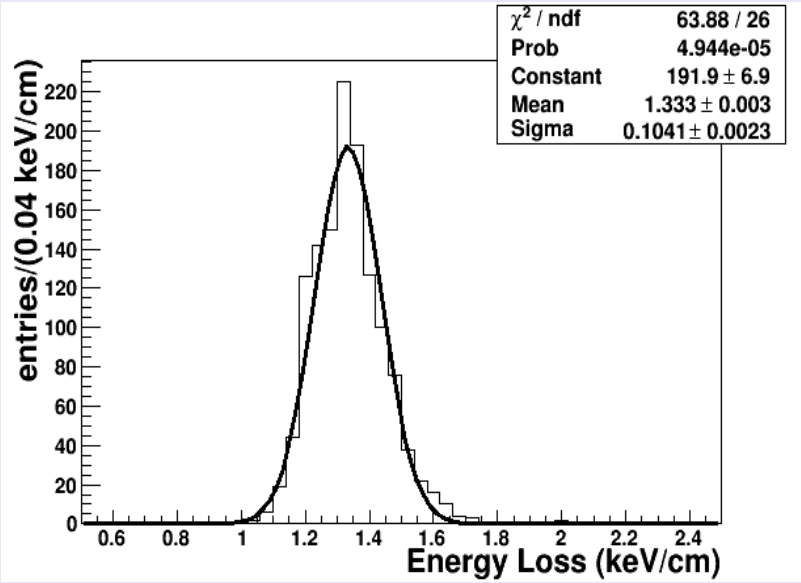
Spatial resolution is 650 μm @ 75cm drift

→ good enough to have a momentum resolution < 10% @ 1 GeV.

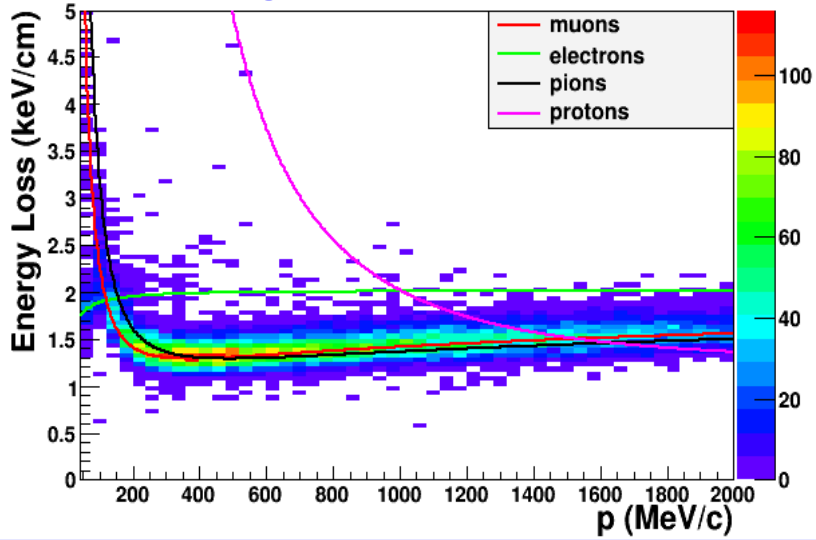
Energy loss (neutrino data, Tokai)

- **Particle Identification (PID)** is based on the **deposited energy (dE/dx)** by the charged particles.
- A **truncated mean method** is used.
- **Resolution** on dE/dx is **7.8 ± 0.2%** (goal was 10%)
- Negative particles: mainly muons, some low energy e^-.
- Positive particles: mainly pions and protons, some low energy e^+.

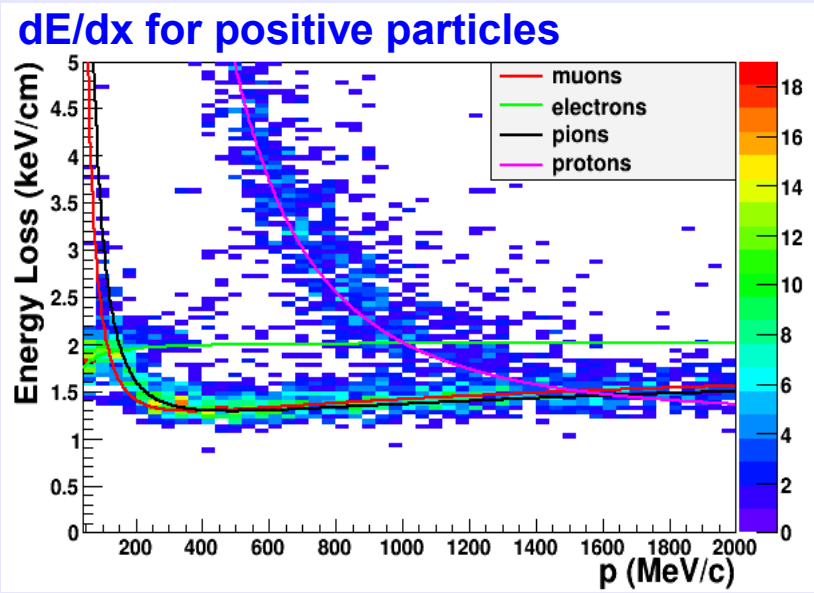
Energy loss distribution for negative particles with 400 < p < 500 MeV/c



dE/dx for negative particles



dE/dx for positive particles



Conclusion

- Beam line and detectors constructed and commissioned → 1st physics run January → June 2010. Next run will start in November 2010.
- ND280 (INGRID, P0D, FGDs, Ecal and SMRD) is the 1st large scintillator based detector instrumented with MPPCs → ~35 000 MPPCs installed and working!
- FGDs have a hit efficiency higher than 99% and cross-section measurements on carbon and water will be important for Super Kamiokande measurements since it's a water Cerenkov detector.
- T2K TPCs, 1st large TPCs instrumented with MPGDs have met the requirements set by T2K.
- dE/dx resolution is 7.8% → achieved the resolution goal.

Tracker performances' requirements have been reached.
More refined studies are under way and physics analyses have started!


Event number : 110284 | Partition : 63 | Run number : 4200 | Spill : 0 | SubRun number :25 | Time : Mon 2010-03-22 14:06:35 JST |Trigger: Beam Spill
Thank you for your attention!

Back up

Neutrino physics

- Neutrino: neutral lepton, 3 families (ν_e, ν_μ, ν_τ), small cross-section
- Flavour (interaction) eigenstates ≠ Mass (propagation) eigenstates

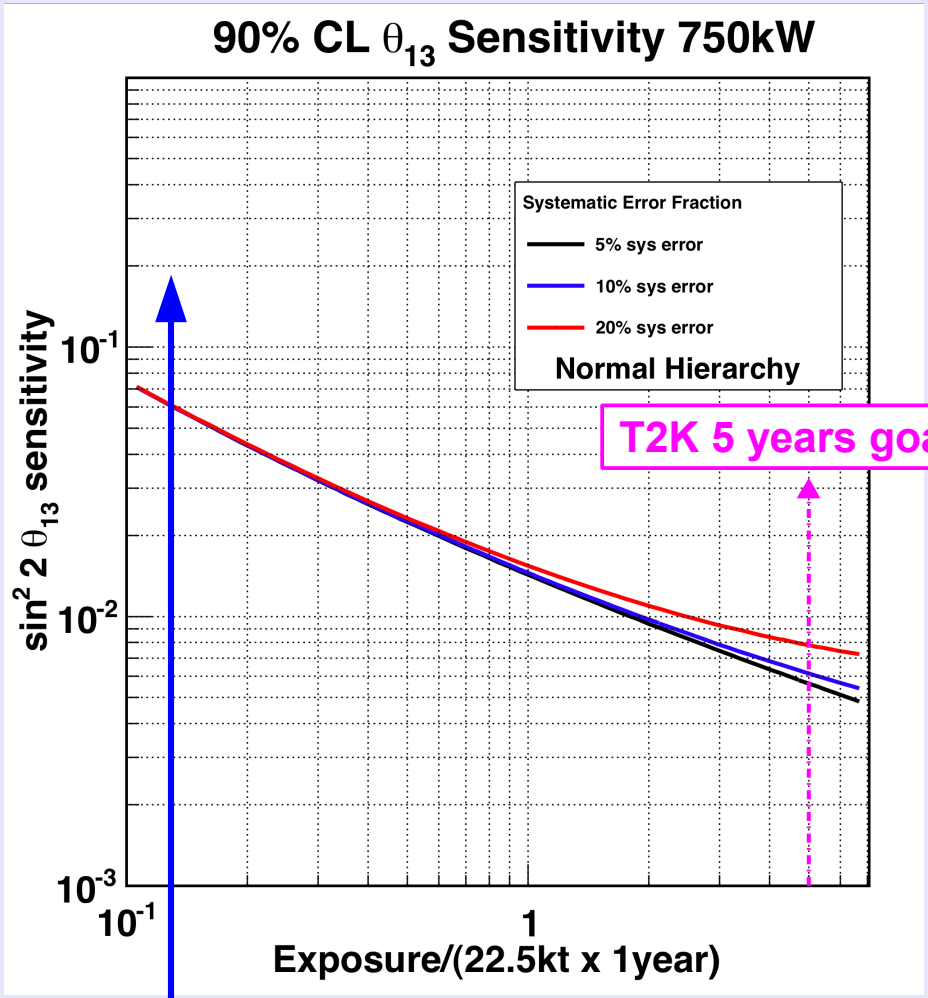
→ oscillation given by PMNS matrix:

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

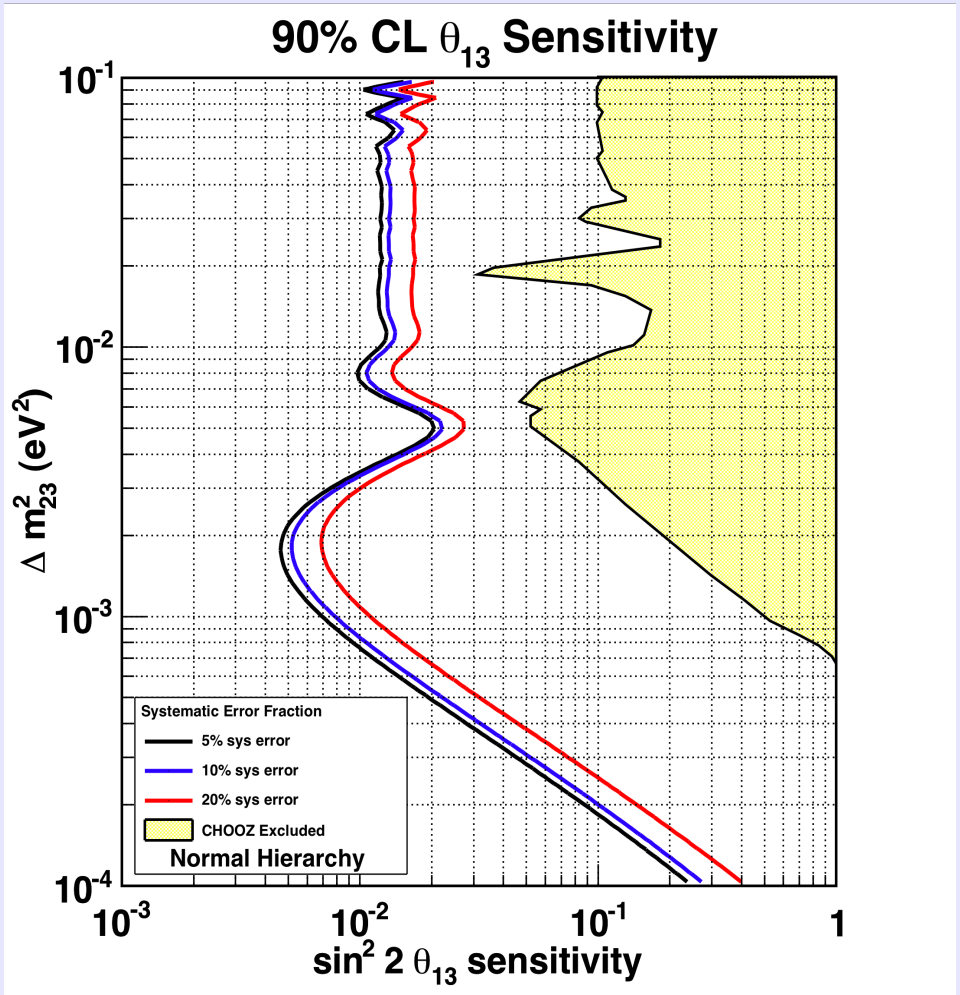
$c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$, δ = CP violation phase

- All parameters have been measured except θ_{13} and δ.
- If θ_{13} and $\delta \neq 0$, there is CP violation in the leptonic sector, which could explain the matter-antimatter asymmetry observed in the Universe (leptogenesis theory).

T2K $\sin^2 2\theta_{13}$ sensitivity

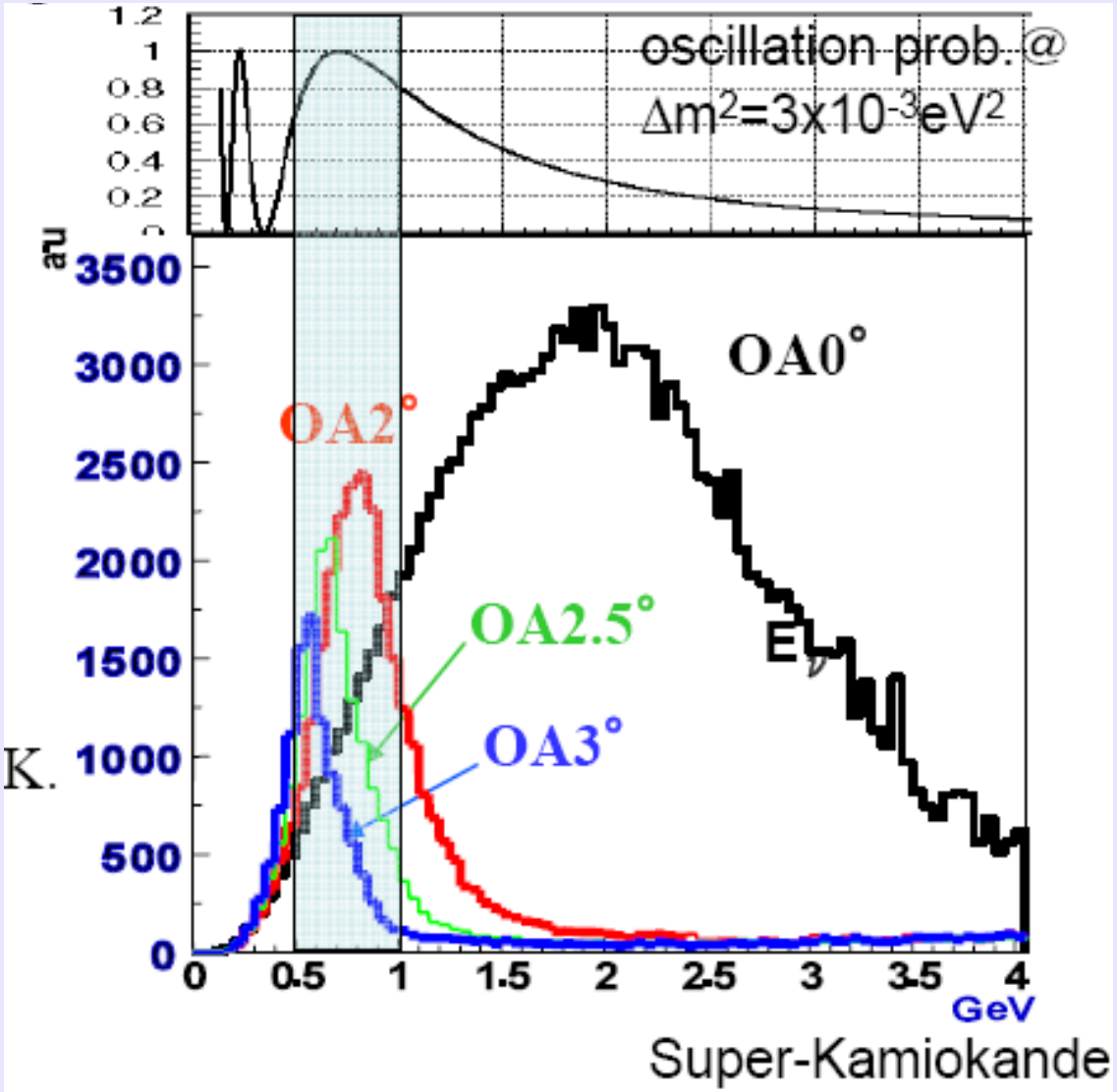


100 kW for 10^7 s (1 nominal year)



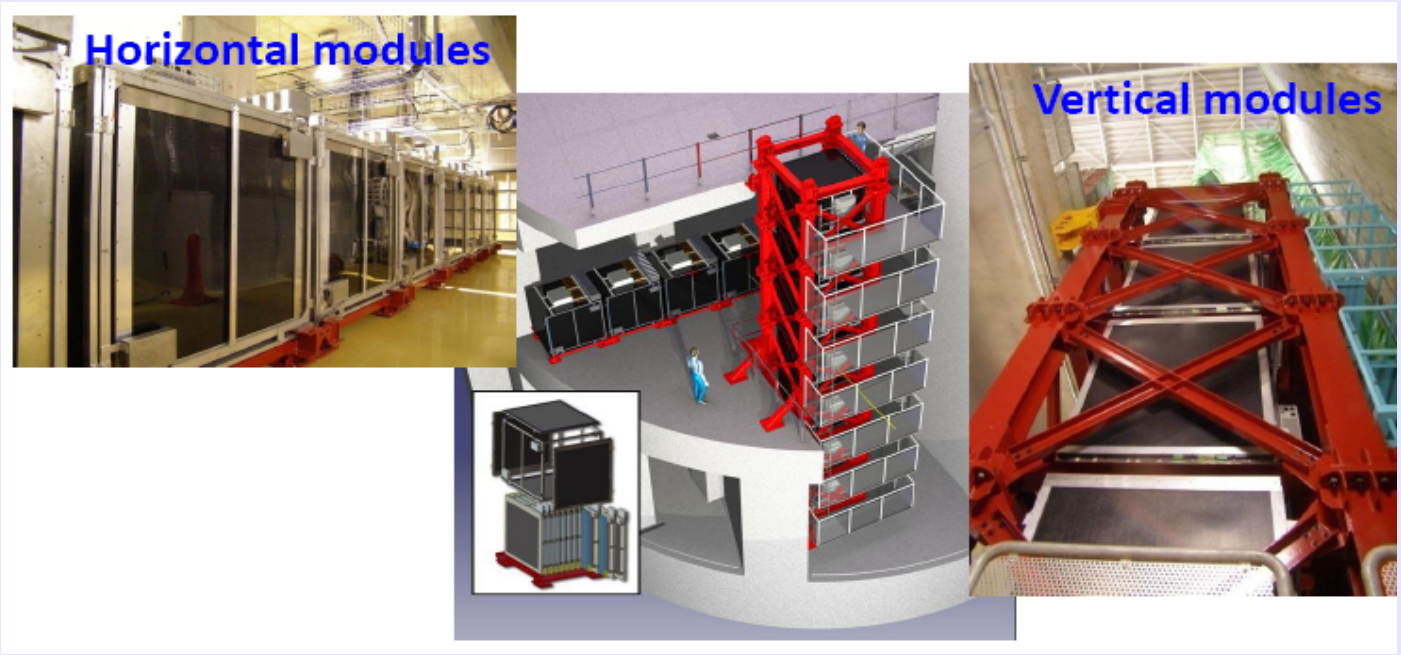
0.008 @ $\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV^2, $\delta_{CP} = 0$
and normal hierarchy 20% sys. error

Why off-axis?



- Quasi-monochromatic beam
- Tuned at expected oscillation maximum

On-axis near detector: INGRID

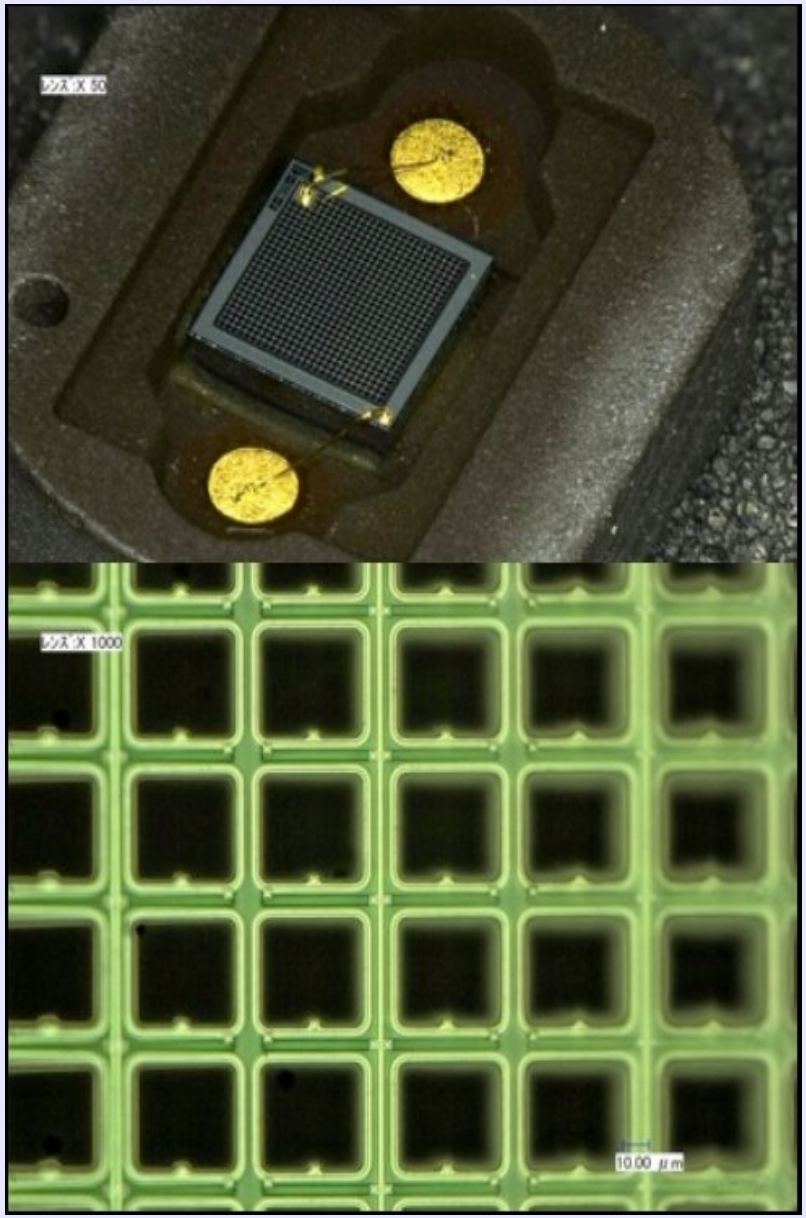


- *Located at* **280m** *from the proton target, on-axis.*
- **Goals:**
  - **High-precision beam direction monitoring** ($\sin^2 2\theta_{23}$ ~1% ⇒ 1mrad)
  - Measure **beam profile** and **intensity**.
- **Design:** 7 vertical modules and 7 horizontal modules, layed out in a cross-shape, centered at the neutrino beam center + 2 off-axis modules.

Multi Pixel Photon Counters

MPPC, solid-state Multi-Pixel Photon Counter:

- Developed and produced by Hamamatsu Japan and Kyoto University.
- 1.3 x 1.3 mm² modules, specifically designed for T2K
- Suited for 1 mm diameter fiber
- 667 pixels: 26x26 50 μm pixels (-9 in the corner for lead)
- Dark noise: < 1.2 MHz at nominal voltage
- Gain: 7.5 x 10^5 at 25°C.
- Photon detection efficiency: ~30% at nominal voltage
- Dead channels in FGDs: ~30 out of ~ 8500 (< 0.4%)



Calibration in-situ: Fiber attenuation

- Major effect in the middle of the fiber described by:

$$I = Af(x)$$

$$f(x) = e^{-x/L} + (B/A)e^{-x/S}$$

→ x = distance, S (short) and L (long) attenuation coefficients.

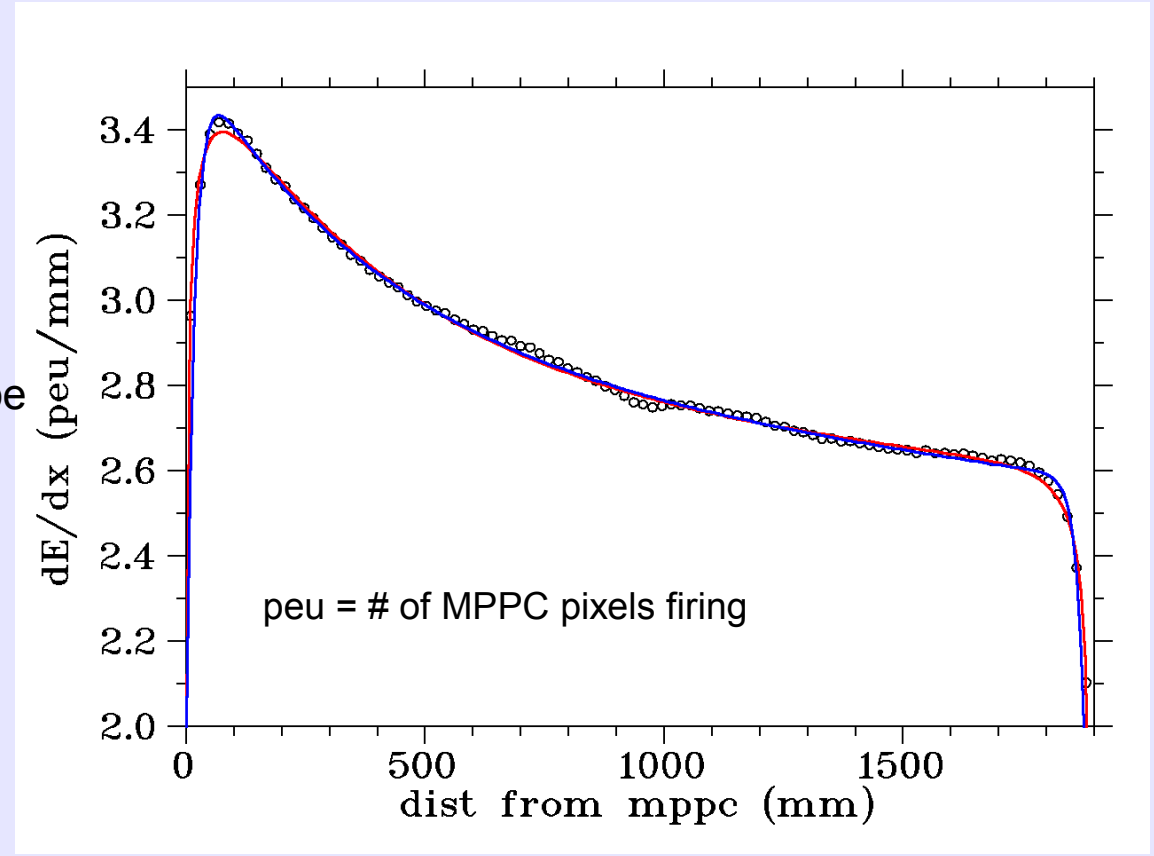
- Light leaking out of the scintillator bar can be taken into account in 2 different ways (blue and red curve).

$$I = Af(x)g(x)$$

$$g(x) = 1 - \frac{1}{2}\left(e^{m(D-x)} + e^{-mx}\right) \quad \text{or}$$

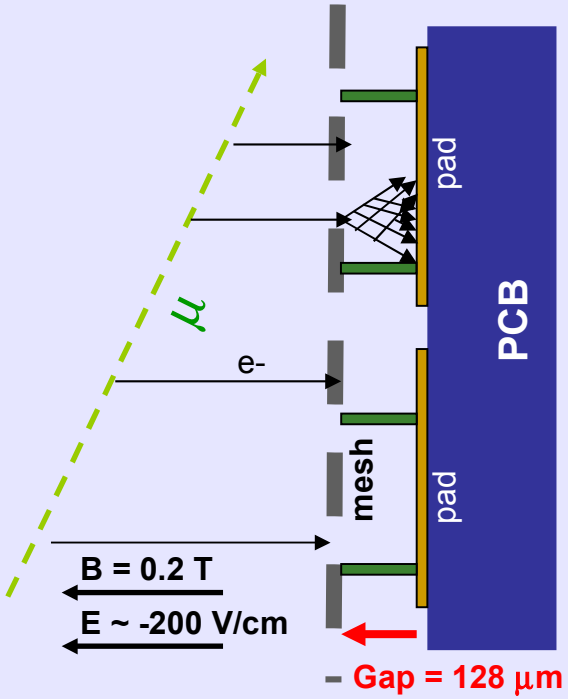
$$g(x) = 1 - \frac{1}{2}\left(e^{-m\sqrt{(D-x)}} + e^{-m\sqrt{x}}\right)$$

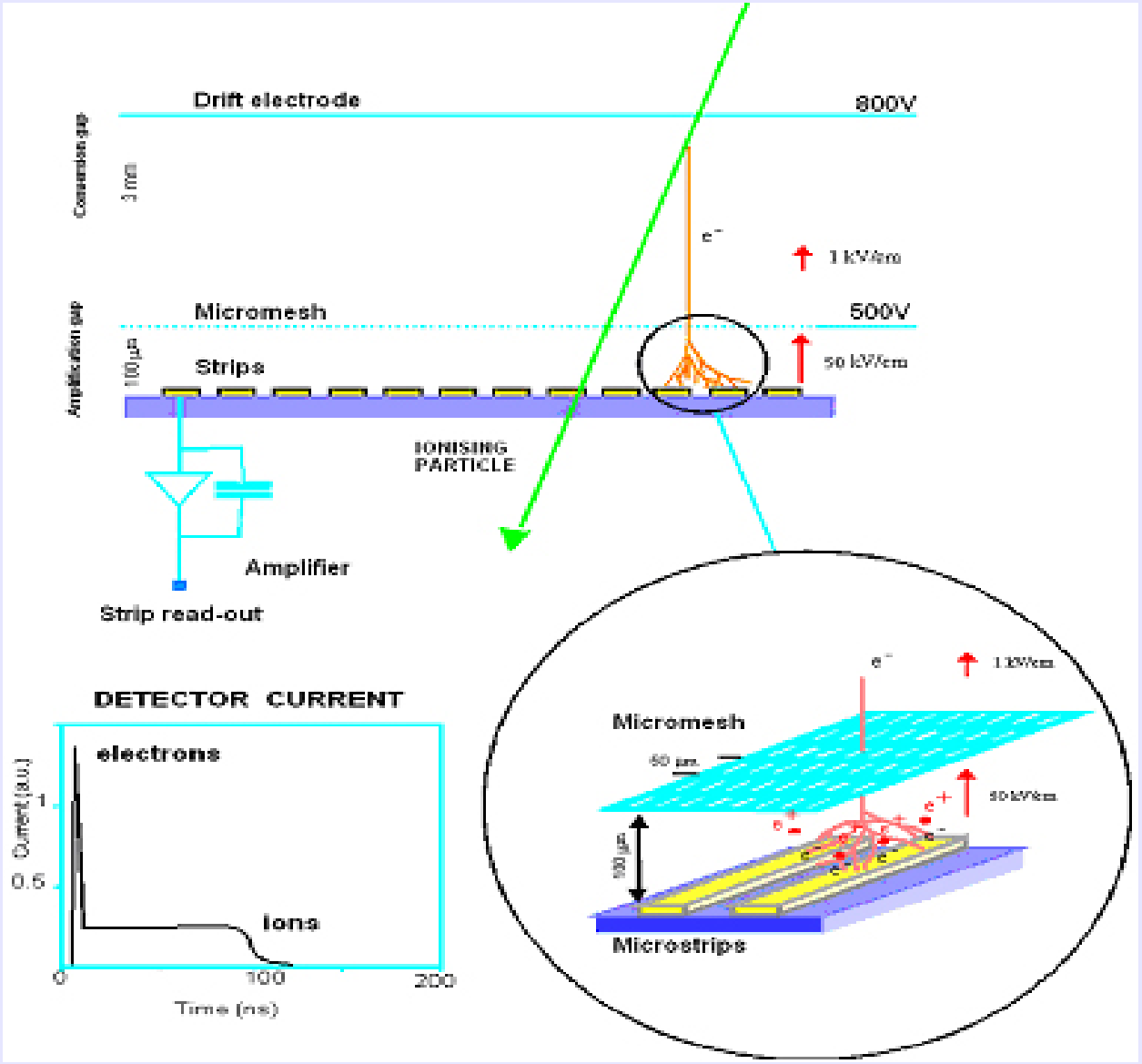
Light yield per path (cosmic rays passing through the FGD)



The effective fiber attenuation curve derived from cosmics for these (mirrored) fibers agrees well with ex-situ measurements

MICROMEGAS


μ
e-
pad
PCB
mesh
pad
B = 0.2 T
E ~ -200 V/cm
Gap = 128 μm


Drift electrode
800V
3 mm
e⁻
1 kV/cm
Micromesh
500V
100 μm
Strips
50 kV/cm
IONISING PARTICLE
Amplifier
Strip read-out
DETECTOR CURRENT
electrons
ions
Current (a.u.)
1
0.5
0
100
200
Time (ns)
Micromesh
50 μm
50 kV/cm
100 μm
Microstrips

Laser calibration system

- Targets on the central cathode
- Illuminated by **UV laser light** to measure:
  - Field distortion calibration (in situ)
  - Electron drift velocity