Physics of the near detectors of T2K

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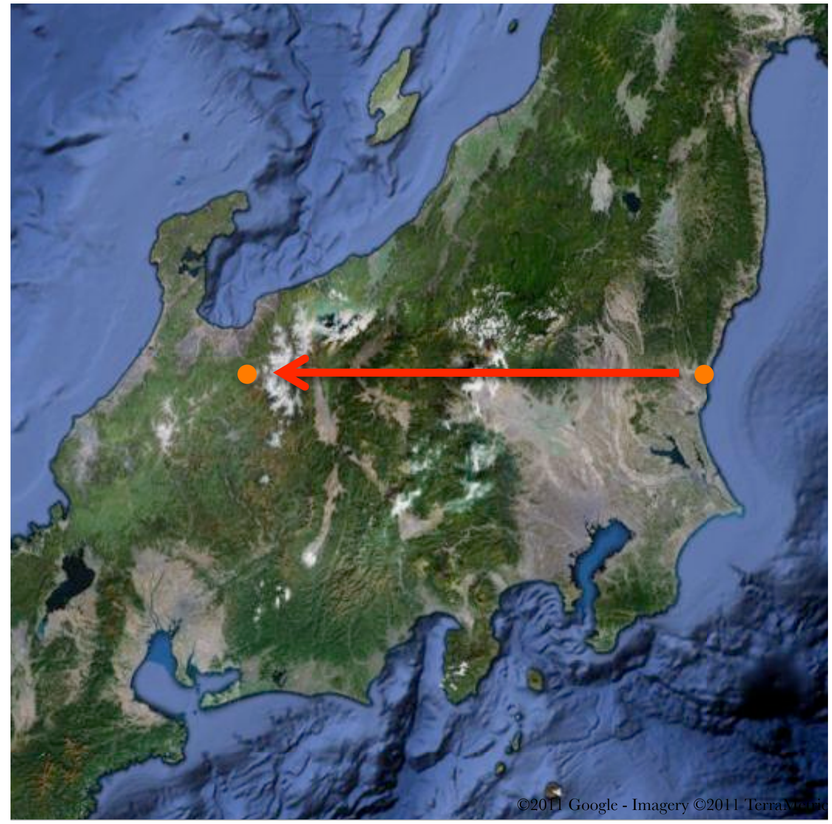
TRIUMF

For the T2K collaboration

T2K

The Tokai-to-Kamioka (T2K) experiment

Produce a beam of ~1 GeV/c muon neutrinos (ν_μ) produced in Tokai-mura, Japan
and observe them 295km away in Kamioka

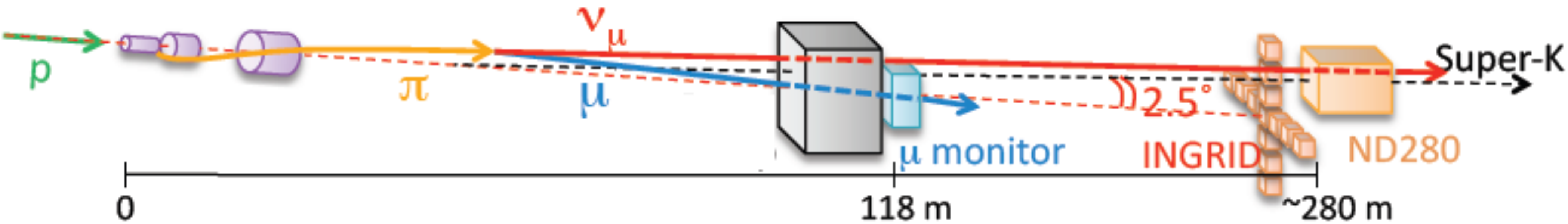


T2K is designed to make precision measurements of neutrino oscillation:

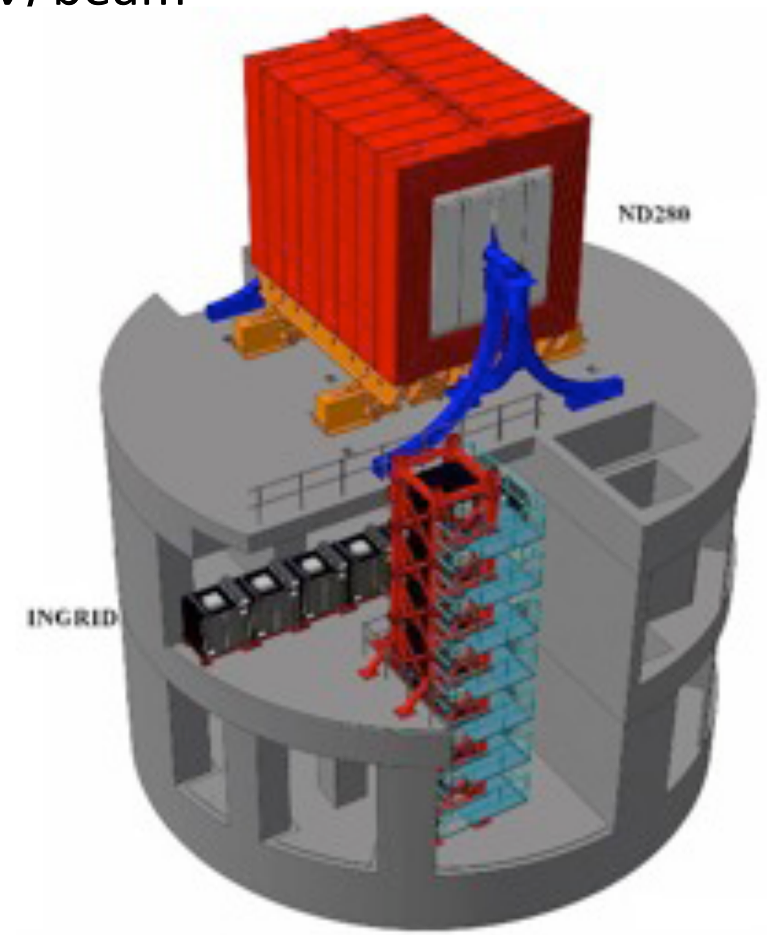
Observe a change to the ν_μ energy spectrum in rate and shape (ν_μ disappearance)

If the as-yet-unseen mixing angle θ_{13}
is large, then observe more ν_e than produced (ν_e appearance)

Overview of the T2K experiment



Neutrinos are produced from a tertiary (p -> π/K -> ν) beam



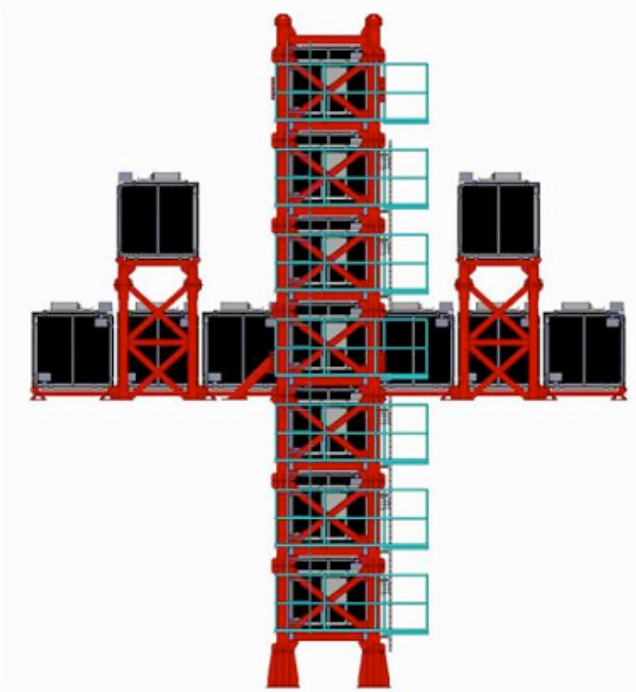
T2K uses a novel off-axis beam technique:

- Idea originally developed at TRIUMF for a long baseline proposal at BNL (E889)

Flux prediction depends upon:

- Initial proton beam properties (proton beam monitors)
- Hadron production within target (NA61 experiment)
- Meson focusing (horn current, field map and alignment)
- On axis direction (Interactive Neutrino GRID) near detector)

Constraint of beam direction with INGRID



16 iron-scintillator modules arranged in a cross

- X-Y scintillator layers, 7.1 tons each

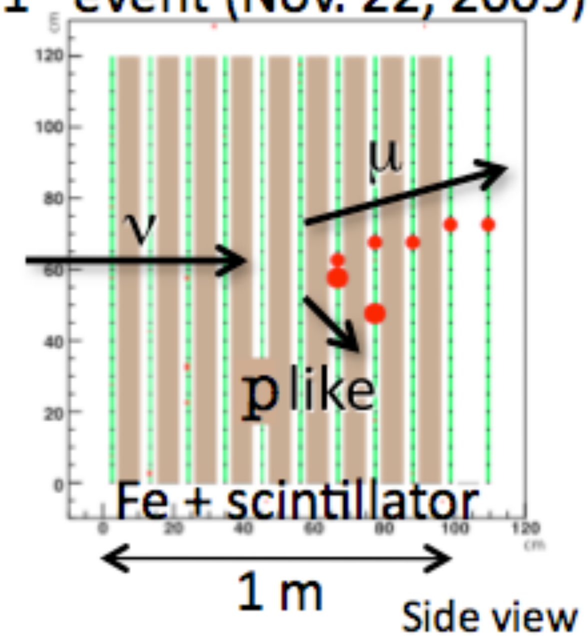
Count neutrino interactions in each module to determine neutrino rate vs. position

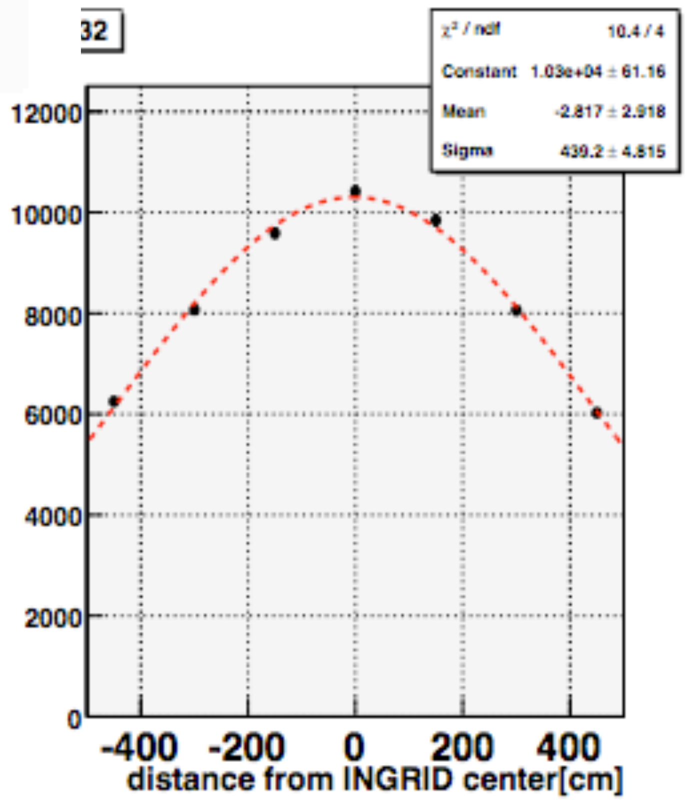
Extract beam direction better than 0.5 mrad

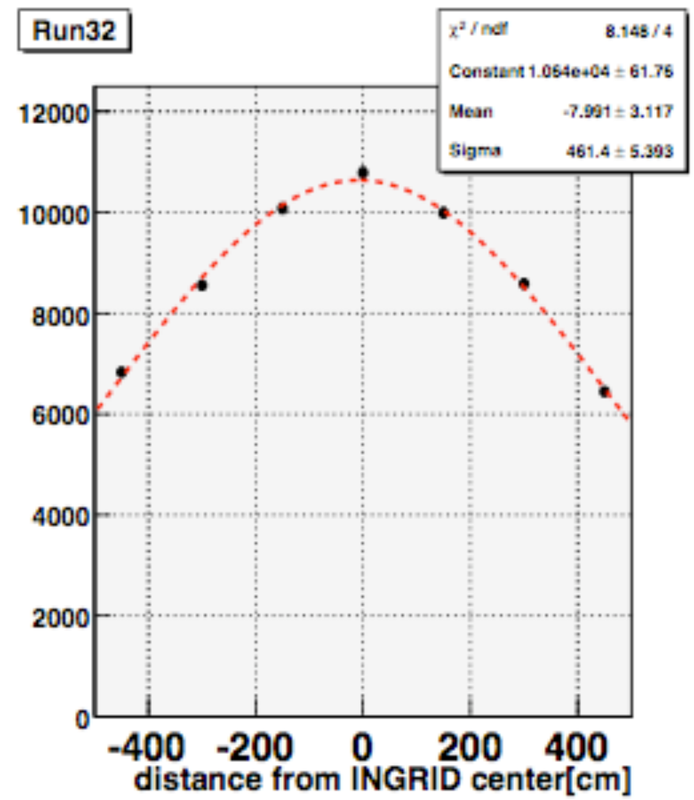
Monitor of neutrino beam vs. time

- ~1.5 ν / 10^{14} protons on target
- ~10,000 events / day

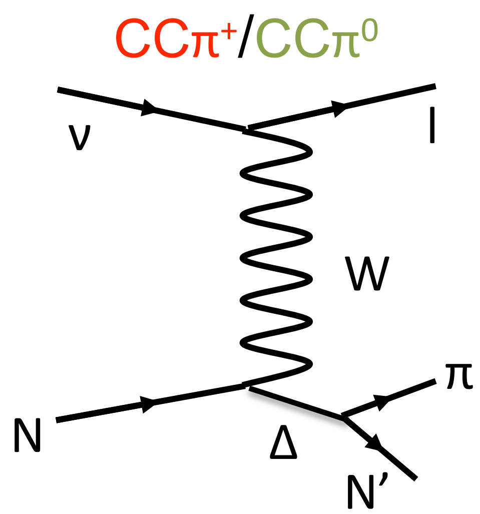
1st event (Nov. 22, 2009)

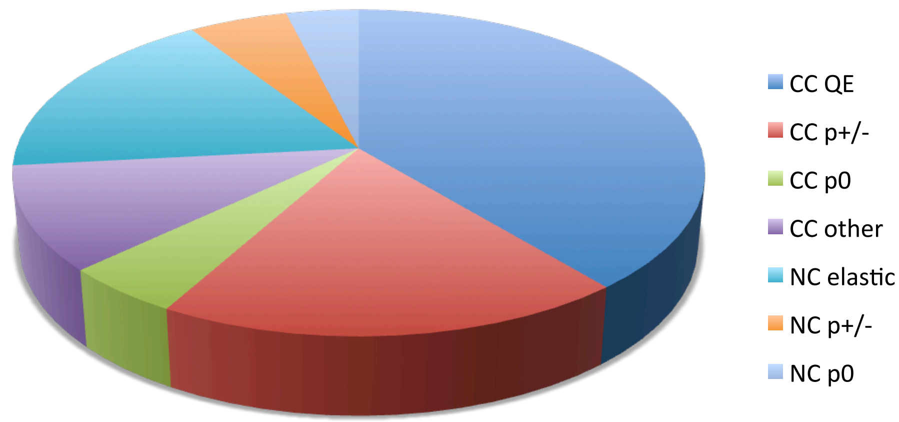


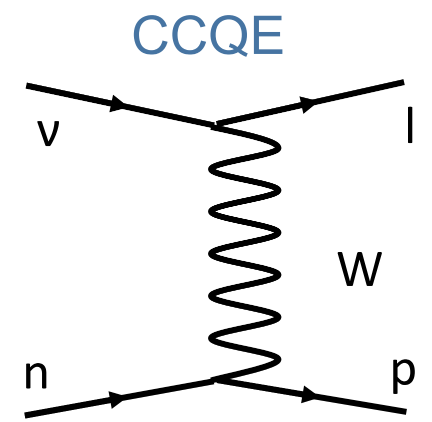




Neutrino interactions at T2K

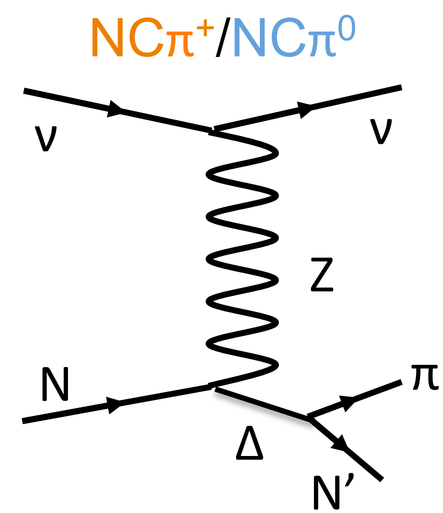






Primary interaction is Charged Current Quasi-Elastic events

- Reconstruct neutrino energy from outgoing lepton
- Need e-μ separation, lepton momentum measurement



CCπ (single pion production) and NCπ are backgrounds

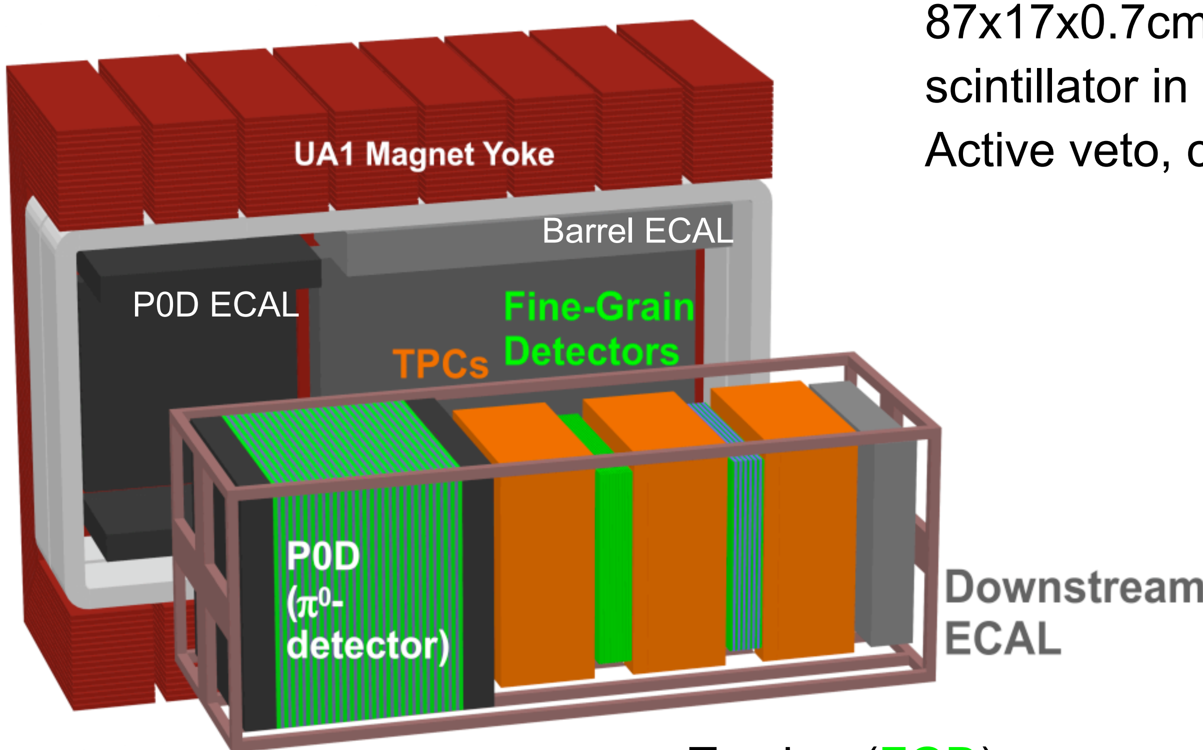
- ν_μ disappearance: Same as CCQE if pion is not identified
- ν_e appearance: NC backgrounds are flux dependant
- Need to be able to observe π^0, π^+
- Final state interactions alter the underlying event to what is observed

ND280 designed to:

- Check unoscillated rate prediction and reduce uncertainties on oscillated rate
- Dedicated cross section physics

ND280 detector complex

Suite of near detectors sit within UA1 (B=0.2T, 850 tons) magnet 280m from neutrino beam production target



Side Muon Range Detector

87x17x0.7cm instrumented scintillator in magnet yoke

Active veto, cosmic trigger

Electronmagnetic Calorimeters

X-Y Pb/scintillator planes

P0D, Barrel, TPC3

Tag photons, e from Tracker and P0D

Pi-zero Detector (P0D)

Pb/brass/scintillator planes with water bags (13.3 tons)

Neutrino interaction target ($C+H_2O$)

Photons, electrons shower separable from MIPs

Tracker (FGD)

2 Fine Grained Detectors

XY scintilator sandwich

Neutrino interaction target

(C, $C+H_2O$, 1.1 tons each)

Detailed vertex information

Particle ID from energy loss

Tracker (TPC)

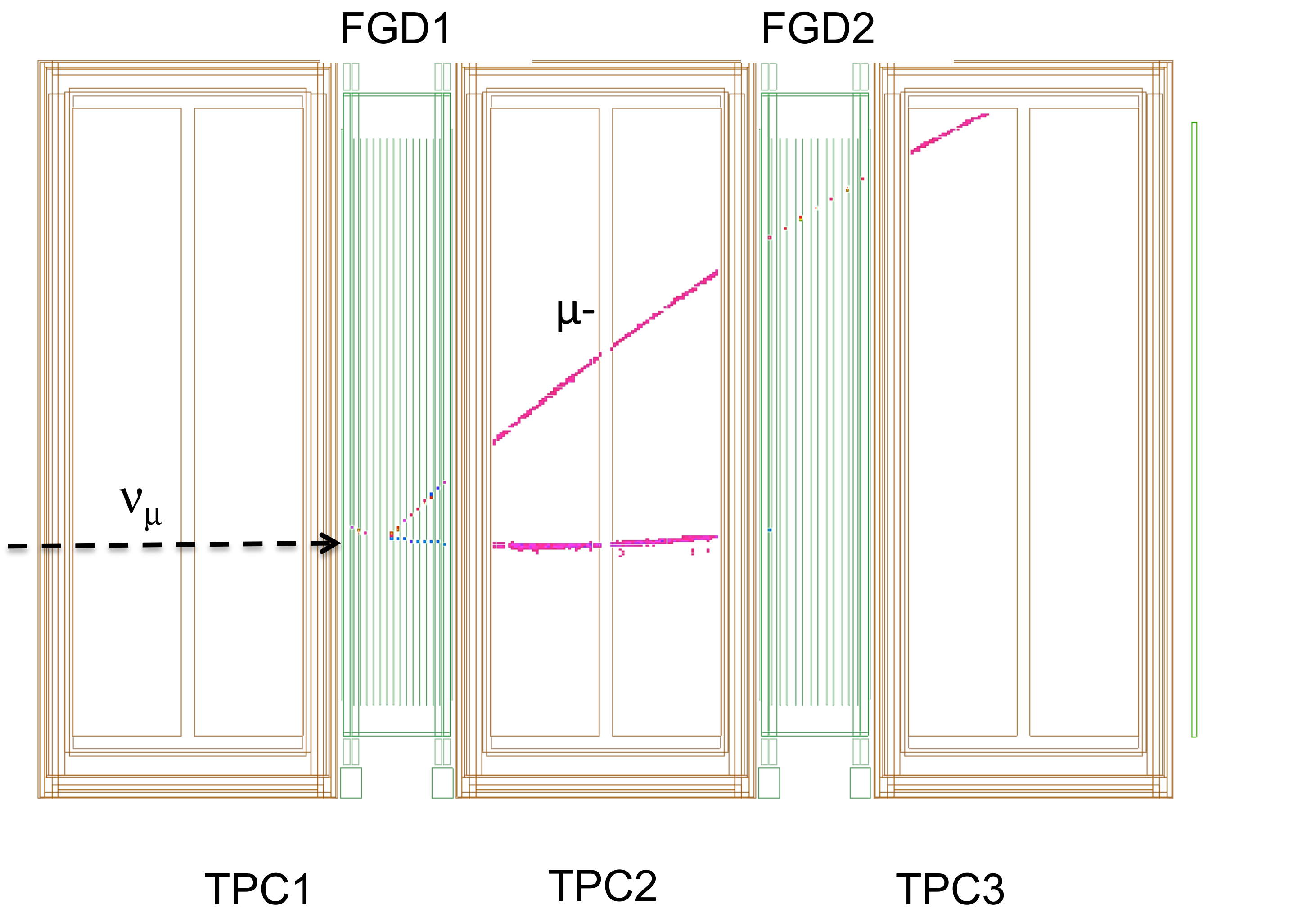
3 Time Projection Chambers

Field cage within a box filled with 95% Ar 3% CF_4 2% isobutane

Momentum from curvature

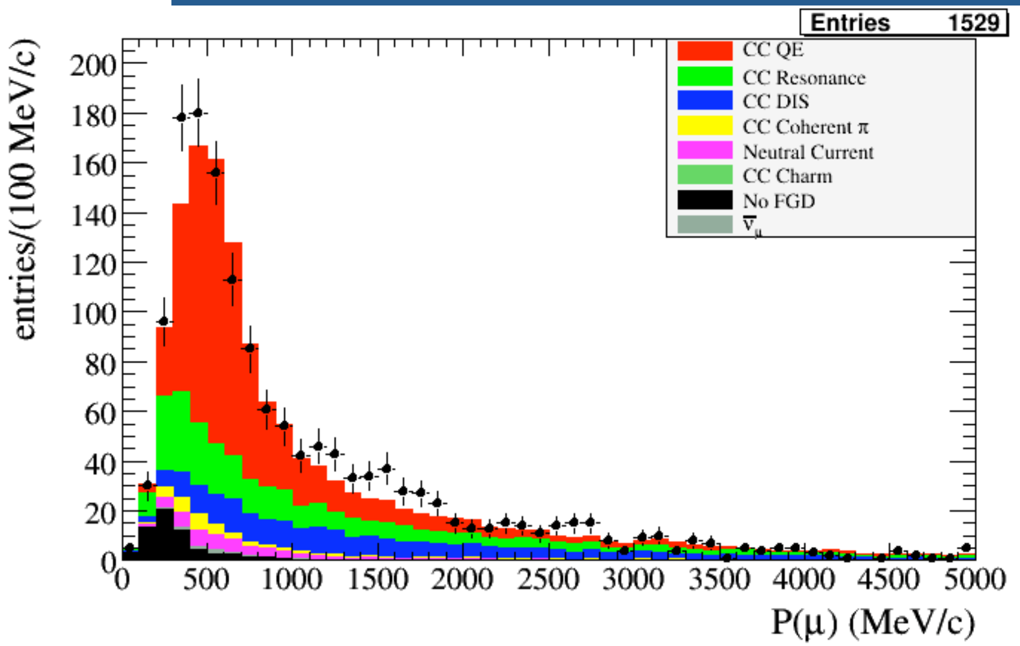
Particle ID from energy loss

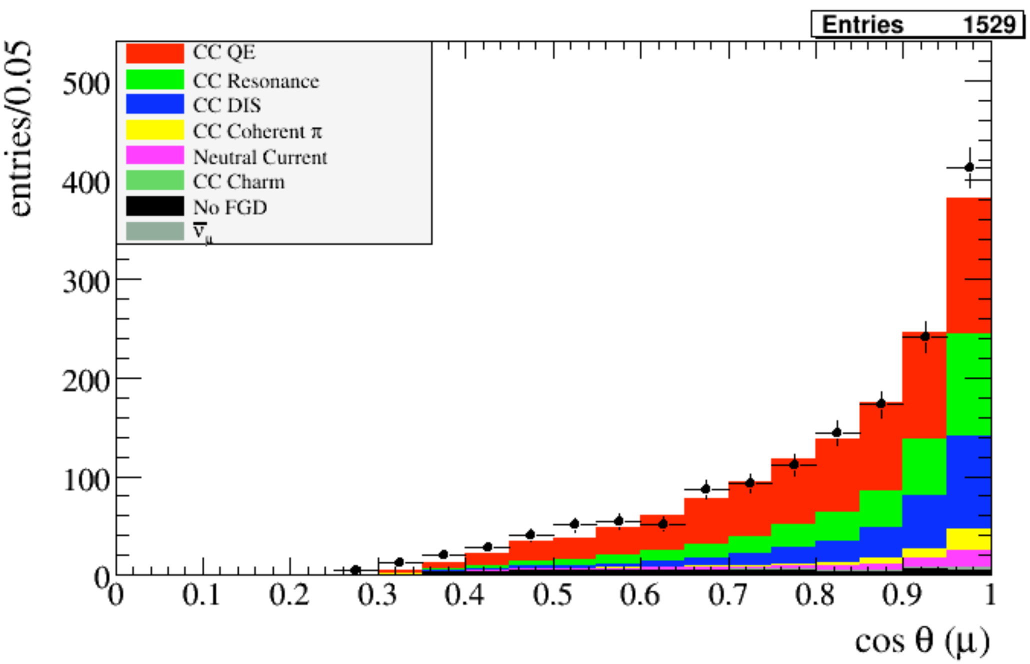
Basic CC ν_μ selection in ND280



1. Select neutrino events: Use TPC1 as a veto (no tracks in TPC1)
2. Select events which originate in FGD1 or FGD2 fiducial volume
3. Use the highest momentum, negative TPC2 or TPC3 track
4. Select μ from TPC dE/dx information

ND280 CC ν_μ sample





Dataset shown here: 2.88×10^{19} POT

Reconstructed momentum and angle of the CC ν_μ candidates after selection

CC ν_μ purity: 91%

CCQE purity: 49%

No tuning to flux or cross section applied

R(data/MC) = 1.036 ± 0.028 (statistics) $^{+0.044}_{-0.037}$(det systematics) ± 0.038 (xsec model)

Rate used to normalize expected number of events at far detector

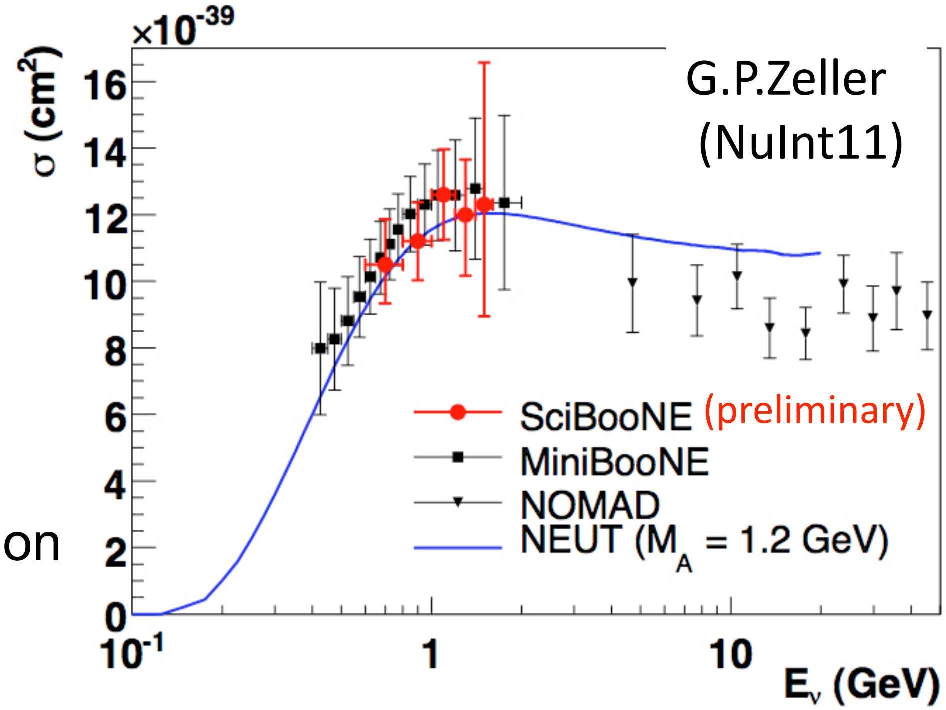
Flux uncertainties on ν_e appearance analysis reduced by 2 from rate constraint

Future work will use momentum, angular information in extrapolation

Measuring the CCQE cross section

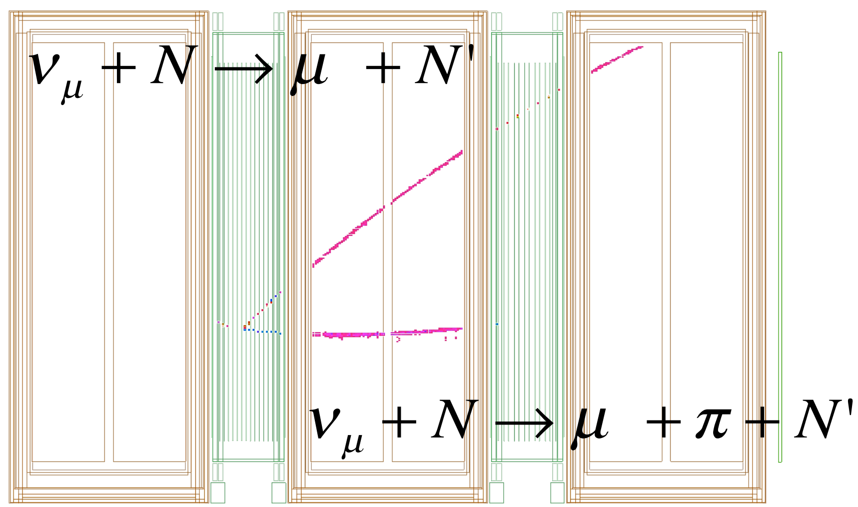
Signal channel for ν_μ disappearance, simplest cross section process

Disagreement between high and low energy for CCQE ν on C indicative of possible deficiencies in xsec model



Add more information with ND280:

- Multiple (C, H_2O) targets
- Final state particle (p,μ) kinematic information



<u>CCQE selection</u>

Select 1 or 2 track CC ν_μ candidates

Require 2nd track not pion-like to reject $CC\pi^+$ background:

- No π -> μ -> decay e signal

Additional capabilities:

- Energy loss in FGD consistent with p
- Positive track/energy loss in TPC

Measuring the NC π^0 cross section

Background to ν_e appearance analysis: ν_μ NC π^0

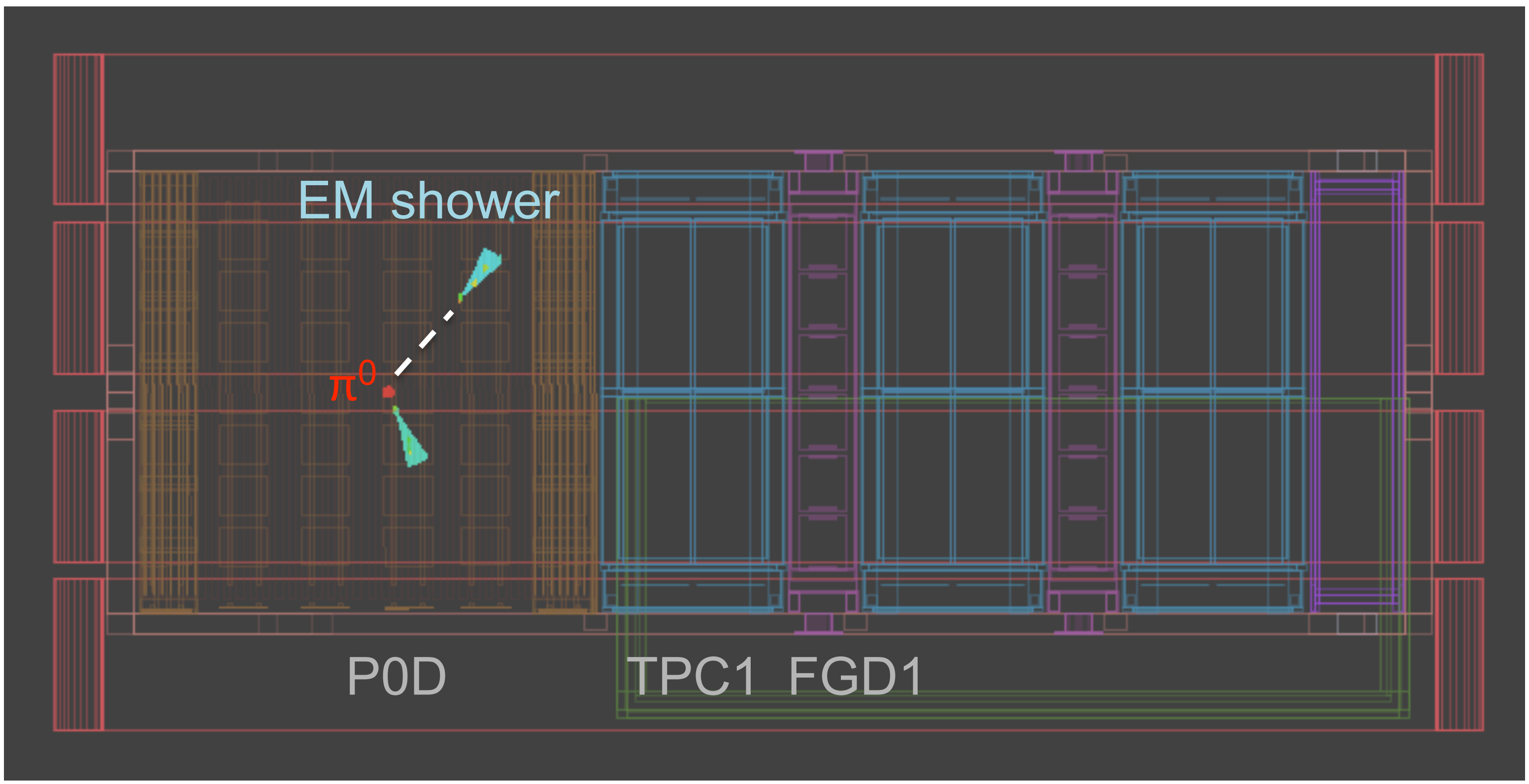
$$\nu_\mu + N \rightarrow \nu_\mu + \pi^0 + N'$$

π^0 decays to two photons, one photon may be not reconstructed or unobserved

Photons look like electrons (and therefore signal) in Cherenkov far detector

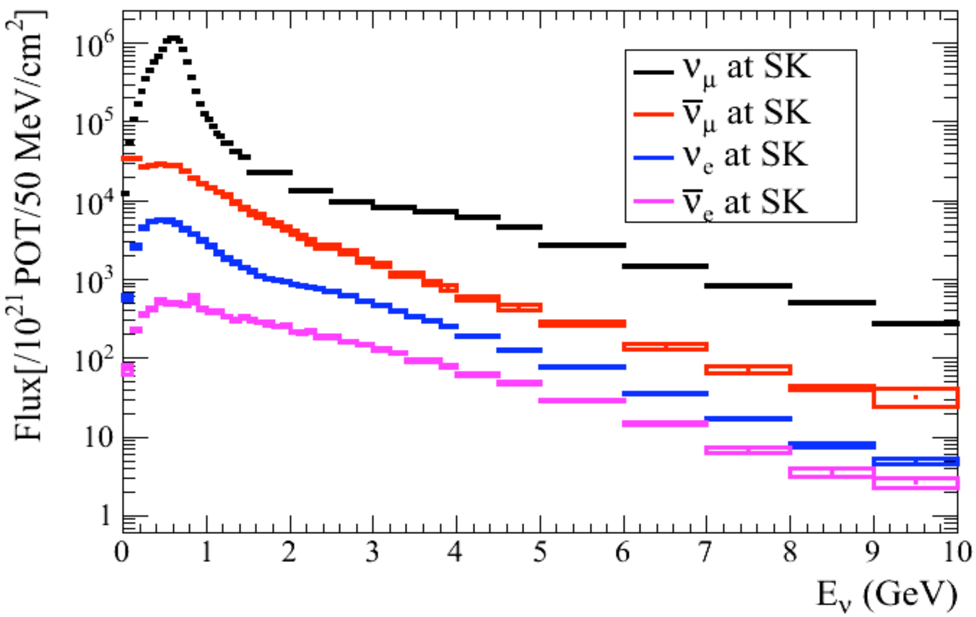
Observe two photon showers in P0D to select NCπ^0 in ND280:

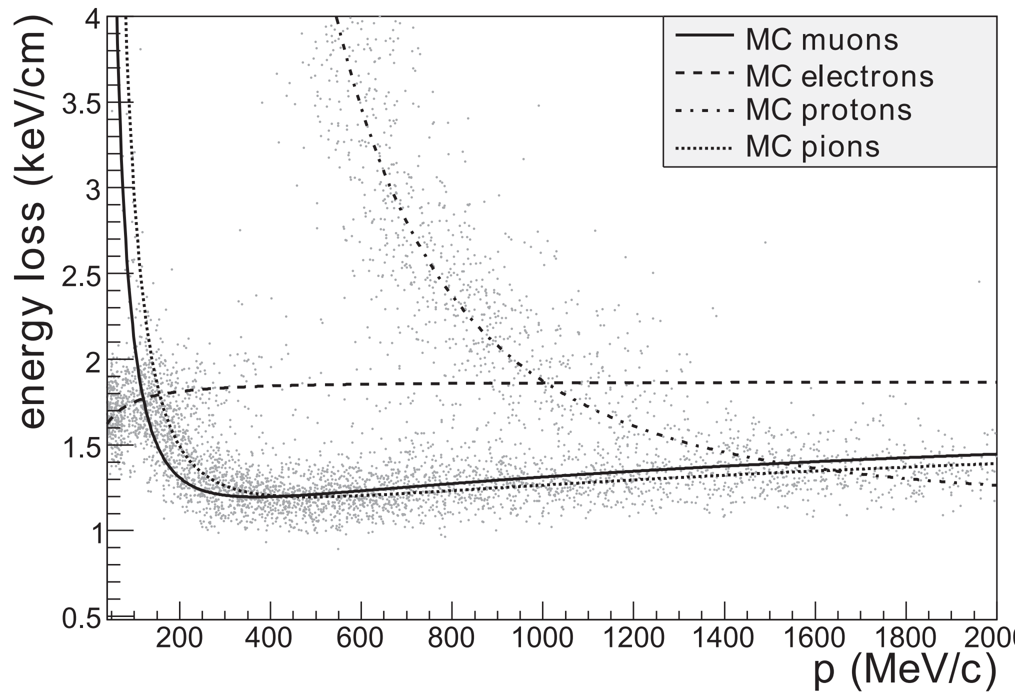
- Reject muon/pion tracks (no decay electron, EM-like shower)
- Combine tracks to form invariant mass, select around peak



Constraint of beam ν_e

Background to ν_e appearance analysis: ν_e already present the beam





Select CC ν_e candidates like CC ν_μ :

Require highest momentum negative track to be electron-like using TPC dE/dx information

- Advantage: low probability of muon misidentified as electron
- Challenge: reject photon events (e+/e- pairs where e- is selected)

Summary

The near detectors of the T2K experiment, INGRID and ND280 have been successfully built, commissioned, and operated since 2009

INGRID has been used to monitor the neutrino beam direction and stability

ND280 has produced an overall CC ν_μ rate used to constrain the oscillated event rate at the far detector

In the future, ND280 will be used to:

- Provide the unoscillated spectrum of CCQE, CCπ^+ ν_μ events
- Constrain backgrounds in ν_e appearance analysis: CC ν_e and NCπ^0
- Extract cross sections for neutrino and antineutrino interactions at E_ν ~1GeV

Backup slides

The T2K Collaboration

59 institutions in 12 countries

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

France
CEA Saclay
IPN Lyon
LLR E Poly
LPNHE-Paris

Russia
INR

Korea
Chonnam Nat'l U
Dongshin U
Seoul Nat'l U

Spain
IFIC, Valencia
IFAE, Barcelona

Poland
A Soltan, Warsaw
HNiewodniczanski
T U Warsaw
U of Silesia
Warsaw U
Wroclaw U

Switzerland
Bern
ETH Zurich
U of Geneva

UK
U of Oxford
Imperial C London
Lancaster U
Queen Mary U of L
Sheffield U
STFC/RAL
STFC/Daresbury
U of Liverpool
U of Warwick

Japan
ICRR Kamioka
ICRR RCCN
KEK
Kobe U
Kyoto U
Miyagi U of Ed
Osaka City U
U of Tokyo

Italy
INFN Bari
INFN Roma
Napoli U
Padova U

USA
Boston U
BNL
Colorado State U
Duke U
Louisiana State U
Stony Brook U
U of California, Irvine
U of Colorado
U of Pittsburgh
U of Rochester
U of Washington

Germany
RWTH Aachen U

Earthquake in Japan

On March 11th, 2011, Japan experienced a severe earthquake followed by a tsunami

No reported injuries to members of the T2K collaboration or JPARC employees

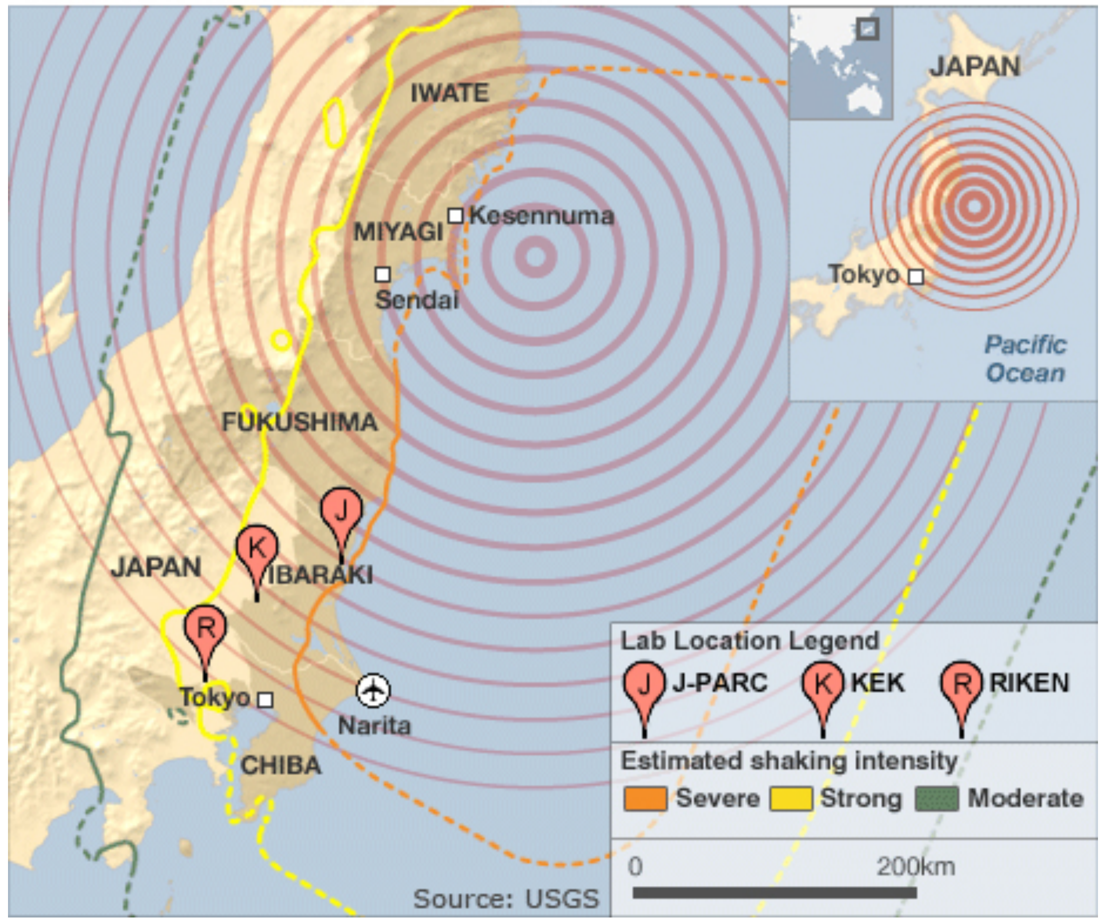
All foreign collaborators have returned home safely

The tsunami did not reach JPARC

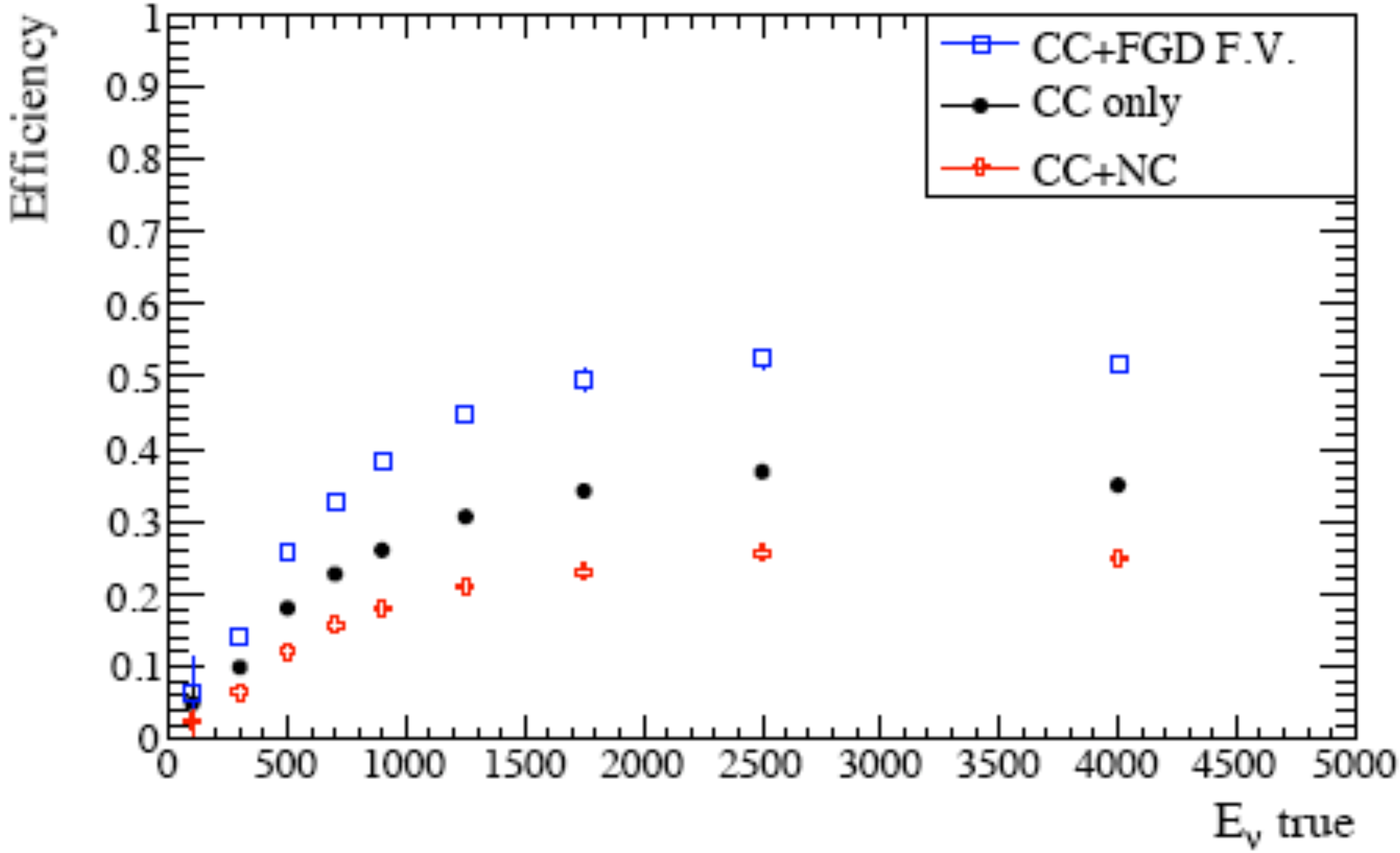
Inspection of the lab is ongoing

Priority is to restore water, power, and gas systems

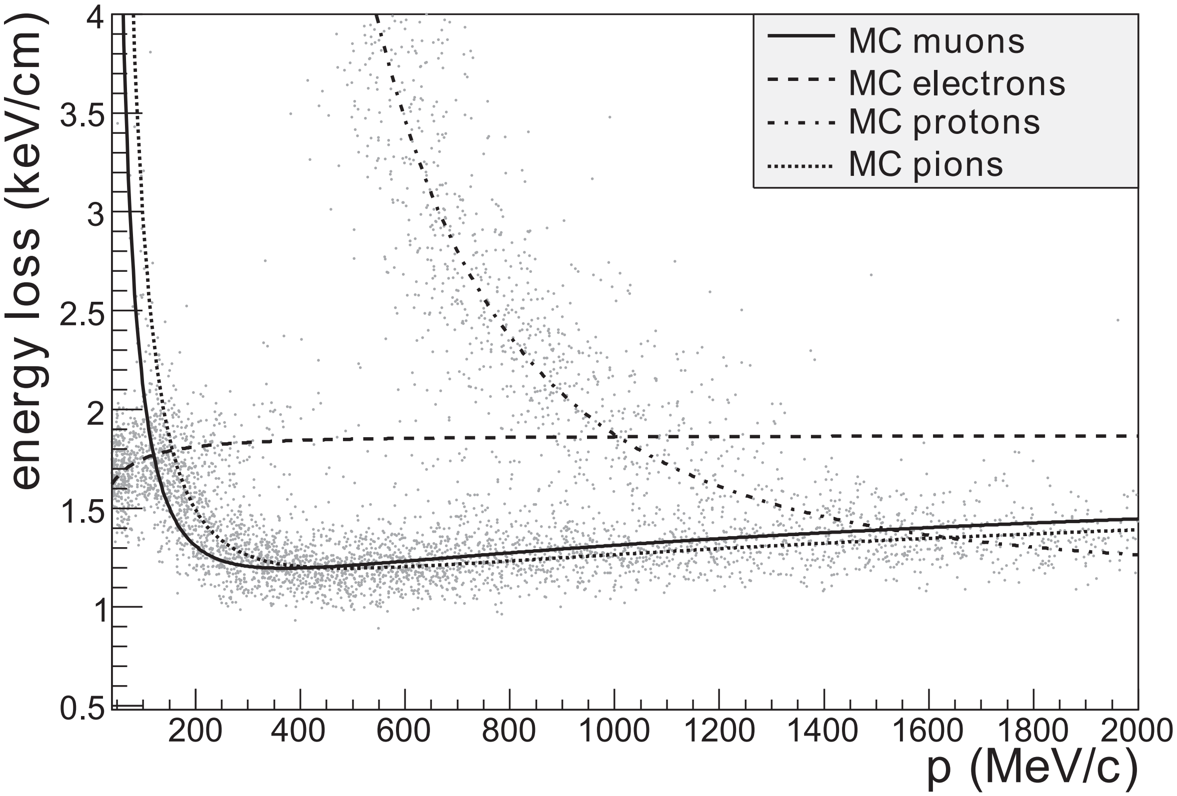
Areas affected by the quake

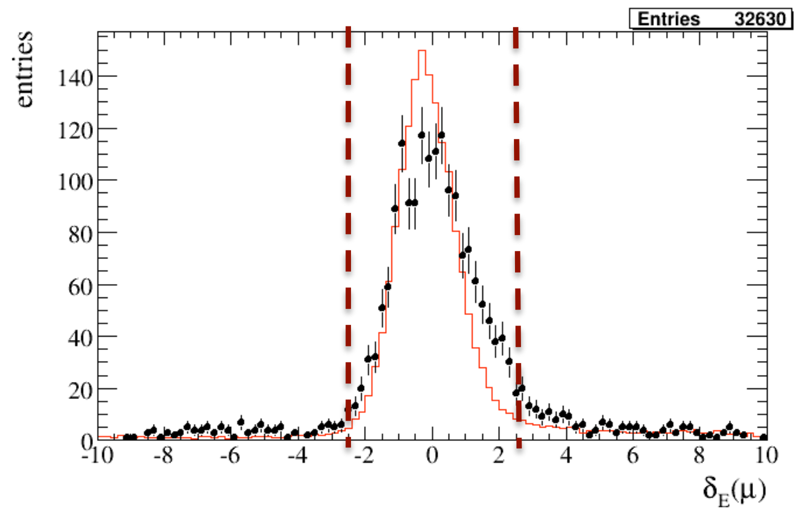


Efficiency of CC ν_μ events



TPC dE/dx particle ID





PID "pull" variable

Energy loss of the particle (dE/dx) can be used to separate particle type

dE/dx resolution for MIPs is 8%

Probability for a muon between 0.2 and 1.0 GeV to be identified using dE/dx as an electron is less than 0.2%

Constraint of beam direction with INGRID

On-axis beam center vs. time

Statistical errors only