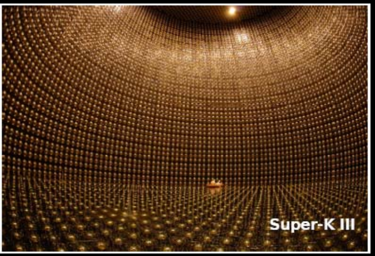
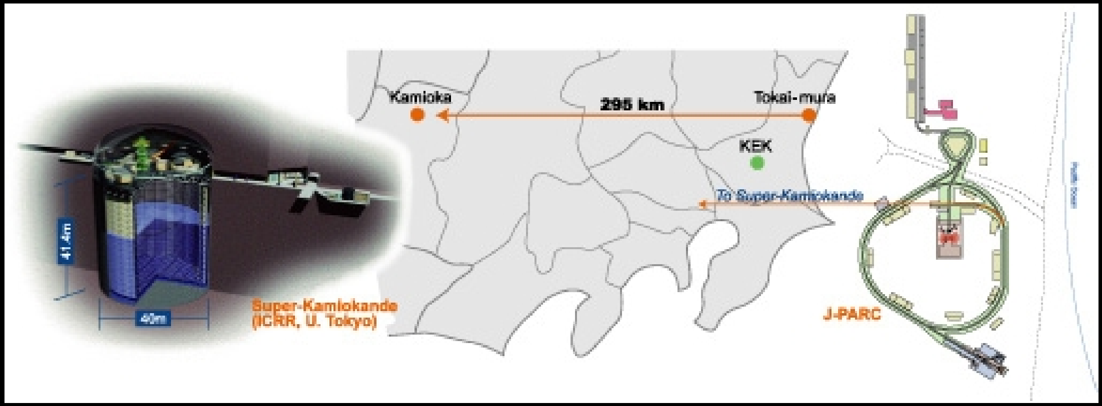
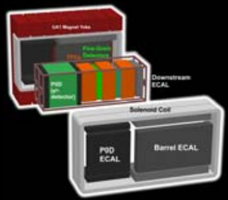
The T2K experiment







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4th International Workshop on Nuclear and Particle Physics

NP08 5 March 2008 Mito, Ibaraki, Japan

The T2K Collaboration

385 members, 64 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

Japan
U. Hiroshima
ICRR
ICRR Kamioka
ICRR RCCN
KEK
U. Kobe
U. Kyoto
U. Miyagi
U. Osaka City
U. Tokyo

Switzerland
U. Bern
U. Geneva
ETH Zurich

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroklaw

S. Korea
N. U. Chonnam
U. Dongshin
N. U. Gyeongsang
N. U. Kyungpook
U. Sejong
N. U. Seoul
U. Sungkyunkwan

Spain
IFIC, Valencia
U. A. Barcelona

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

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova

United Kingdom
Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC/RAL
STFC/Daresbury

Russia
INR

Neutrino mixing

Flavor eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 3} & U_{\tau 3} \end{bmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass eigenstates

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\mathrm{CP}}} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} e^{i\eta_1} & 0 & 0 \\ 0 & e^{i\eta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric
(+ ν_μ Long BL)

ν_μ Long BL
reactor Short BL

Solar
(+ reactor Long BL)

Majorana
??

$$c_{ij} = \cos(\theta_{ij})$$

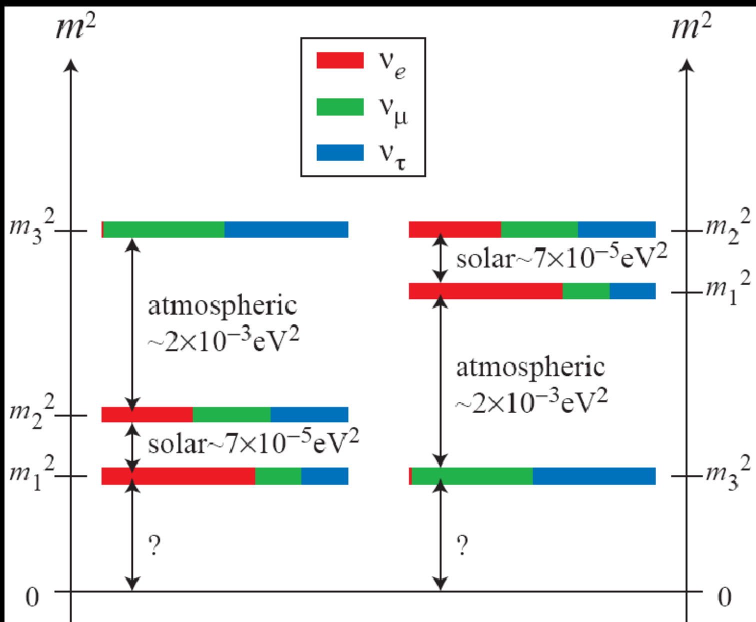
$$s_{ij} = \sin(\theta_{ij})$$

2-neutrino oscillation

$$P_{\alpha\beta} = \delta_{\alpha\beta} - \left(2\delta_{\alpha\beta} - 1\right)\sin^2(2\theta)\sin^2\left(1.27 \bullet \Delta m^2 \bullet \frac{L}{E}\right)$$

Neutrino oscillations today

Mass hierarchy



normal **inverted**

$$\Delta m^2_{21} = 7.67\,^{+0.22}_{-0.21}\,\left(^{+0.67}_{-0.61}\right) \times 10^{-5}\ \mathrm{eV}^2\,,$$

$$\Delta m^2_{31} = \begin{cases} -2.37 \pm 0.15\,\left(^{+0.43}_{-0.46}\right) \times 10^{-3}\ \mathrm{eV}^2 \\ +2.46 \pm 0.15\,\left(^{+0.47}_{-0.42}\right) \times 10^{-3}\ \mathrm{eV}^2 \end{cases}$$

$$\theta_{12} = 34.5 \pm 1.4\,\left(^{+4.8}_{-4.0}\right)\,,$$

$$\theta_{23} = 42.3\,^{+5.1}_{-3.3}\,\left(^{+11.3}_{-7.7}\right)\,,$$

$$\theta_{13} = 0.0\,^{+7.9}_{-0.0}\,\left(^{+12.9}_{-0.0}\right)\,,$$

$$\delta_{\mathrm{CP}} \in [0,\ 360]\,.$$

Errors: 1σ (3σ)

hep-ph 0704.1800v2 16 Oct 2007

- Is θ_{13} non-zero?
- CP violation?
- Is θ_{23} 45^0?
- Which hierarchy?

Main T2K Science Objectives

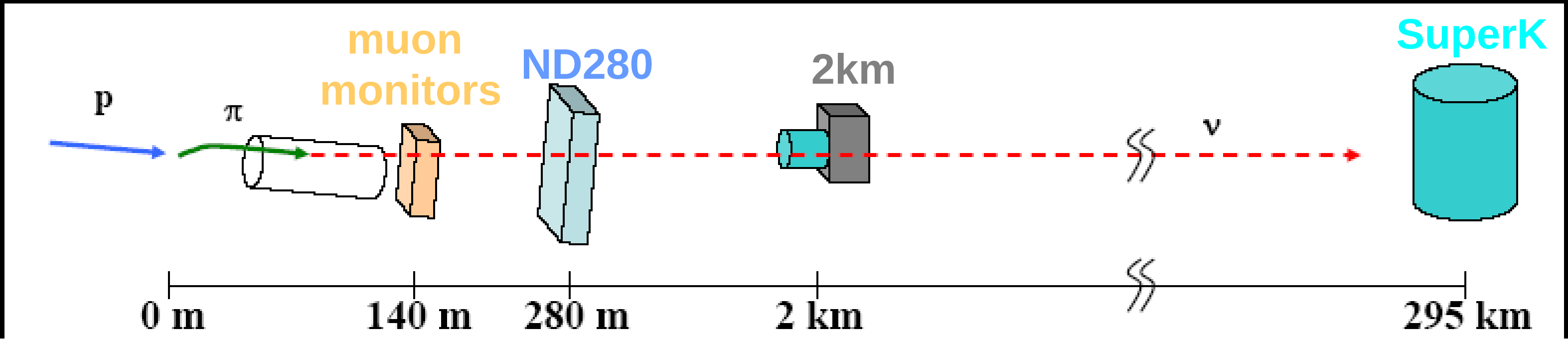
- Discovery: search for non-zero θ_{13}
  - Increase current sensitivity by ~10
  - Outcome crucial for international neutrino programme planning
  - Opens up search for neutrino CP violation and Leptogenesis
- Precision: θ_{23} , Δm^2_{23}
  - World's most precise measurements

    $\sin^2 2\theta_{23} \rightarrow \quad \approx 1\% \qquad \Delta m^2_{23} \rightarrow \quad \approx 2\%$

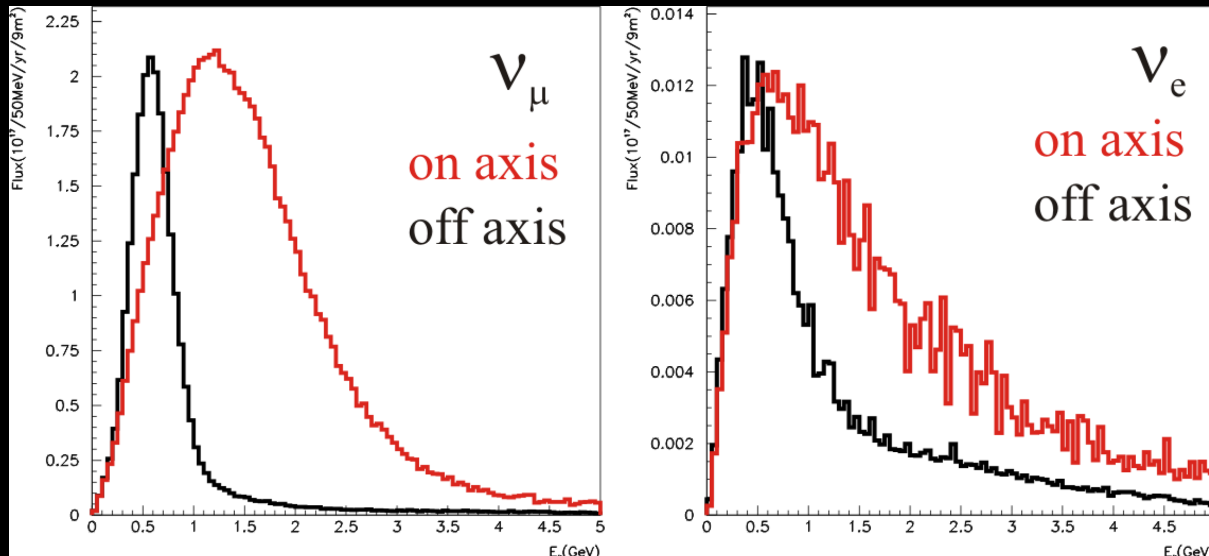
    - Is 23 oscillation maximal?
    - New symmetry of Nature?
- Neutrino scattering below 1GeV
  - Precision measurements necessary to achieve previous goals
  - Interesting physics in itself (nuclear models)
- Clarify mass hierarchy (together with external measurements)

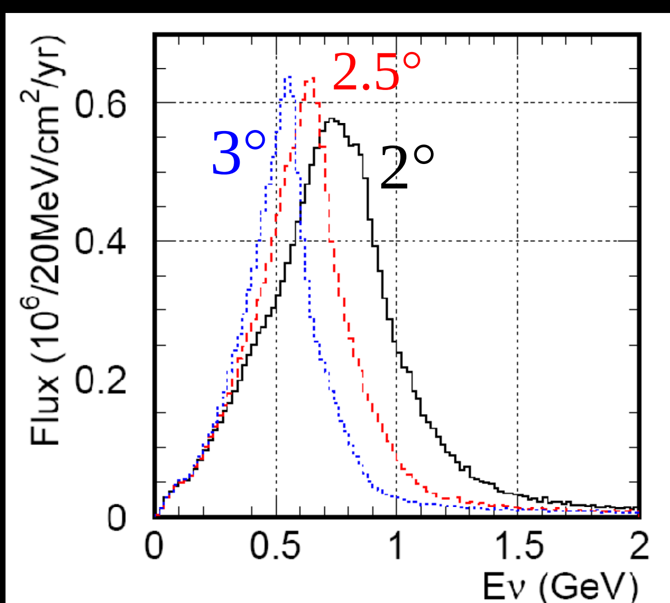
T2K strategy

- Conceptual innovation: off-axis beam
- Technological innovation: highest power pulsed proton beam at J-PARC (5×10^{21} P.O.T., K2K x 50)
- Well-understood far detector: SuperK
- Proven in long baseline mode: K2K
- Powerful Near Detector: ND280
- Extendable: 2km



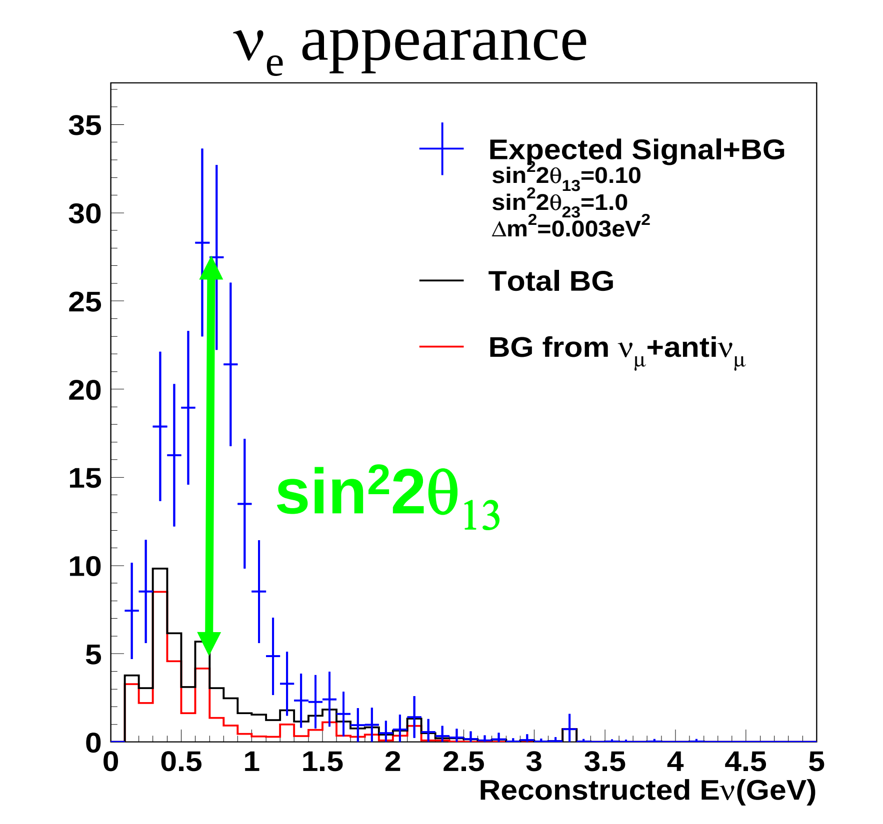
Off-axis neutrino beam

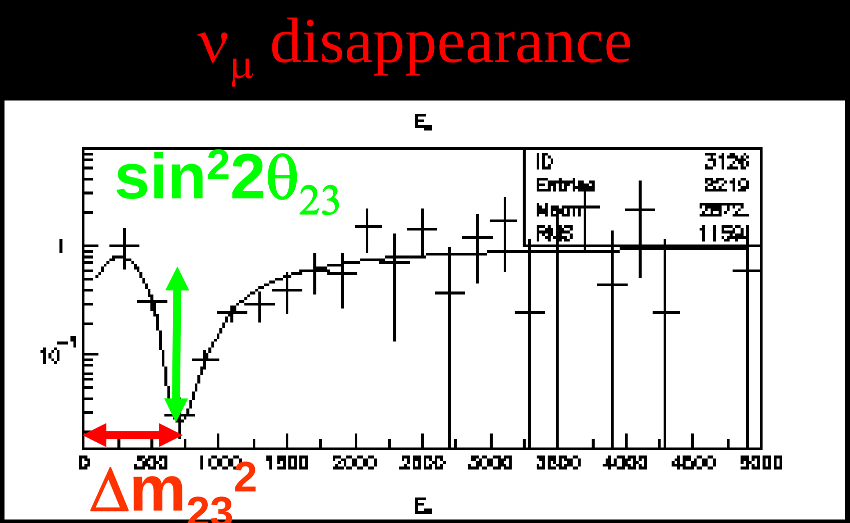




- Quasi-monochromatic ν_μ beam
- L/E tuned for max sensitivity
- Smaller intrinsic ν_e fraction
- Reduced high-E non-CCQE backgrounds

Main T2K measurements

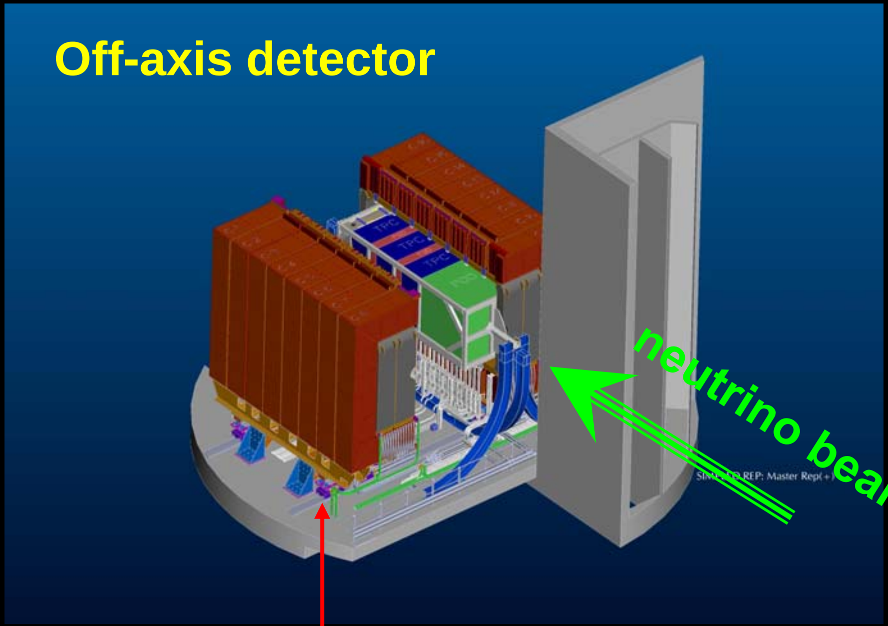


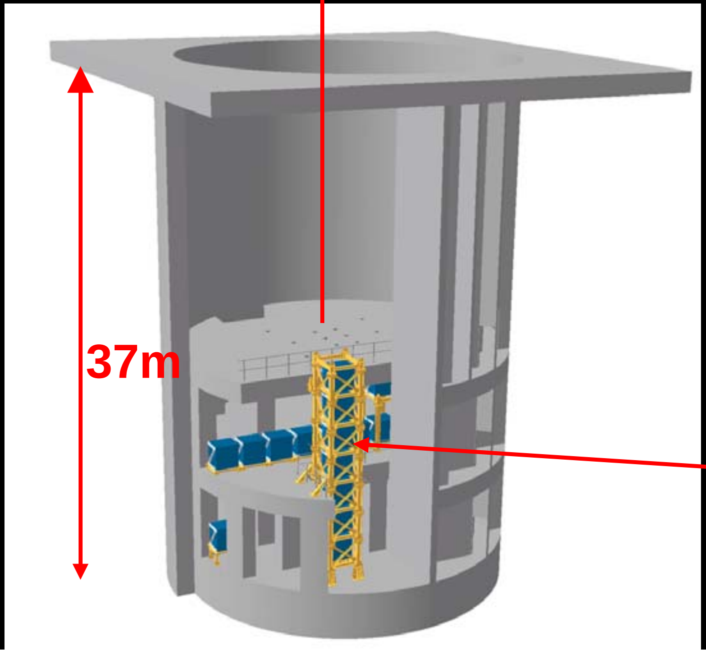


The challenges:

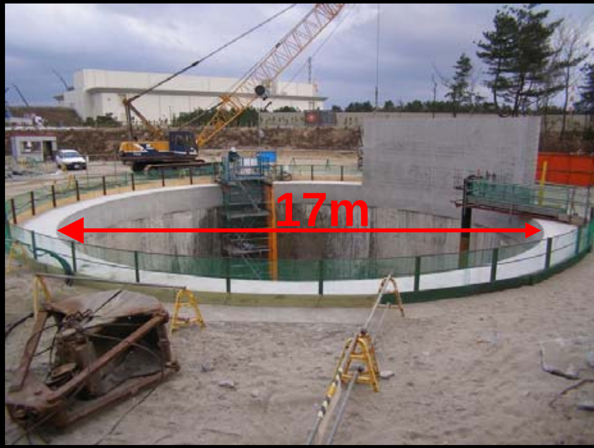
- Knowledge of initial beam content and kinematics
- Knowledge of backgrounds

The near detector: ND280

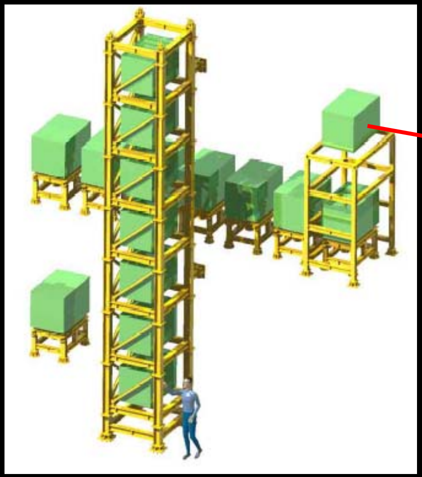


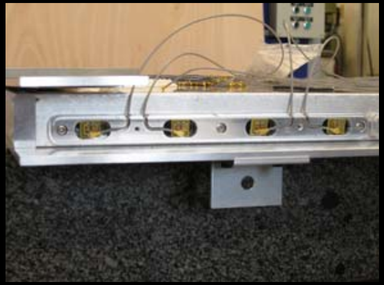


On-axis Detector
INGRID

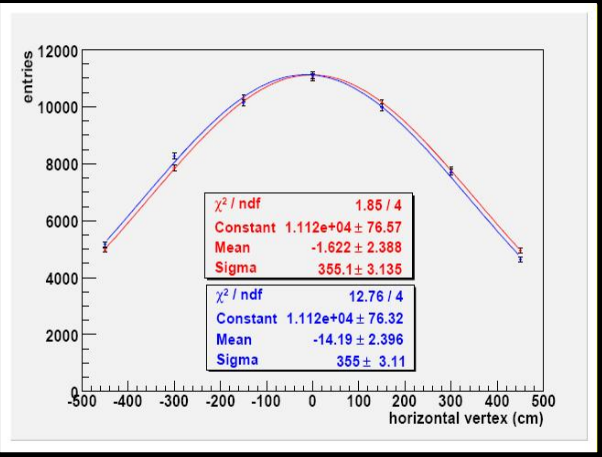


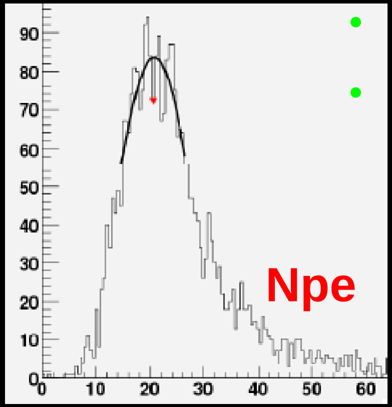
INGRID: beam direction monitor





- 16 modules
- 11 layers scintillator bars
- 10 layers iron
- 2 surrounding veto planes
- 5cm x 1cm bars
- Wavelength-shifting fibre
- 10k events/day, 1mrad resolution
- Hamamatsu MPPC
- TRIP-t electronics
- Tested with 3GeV electrons
- Average light yield: 15p.e. at 50cm from end
- Construction on schedule
- Ready for first neutrino beam in April 2009

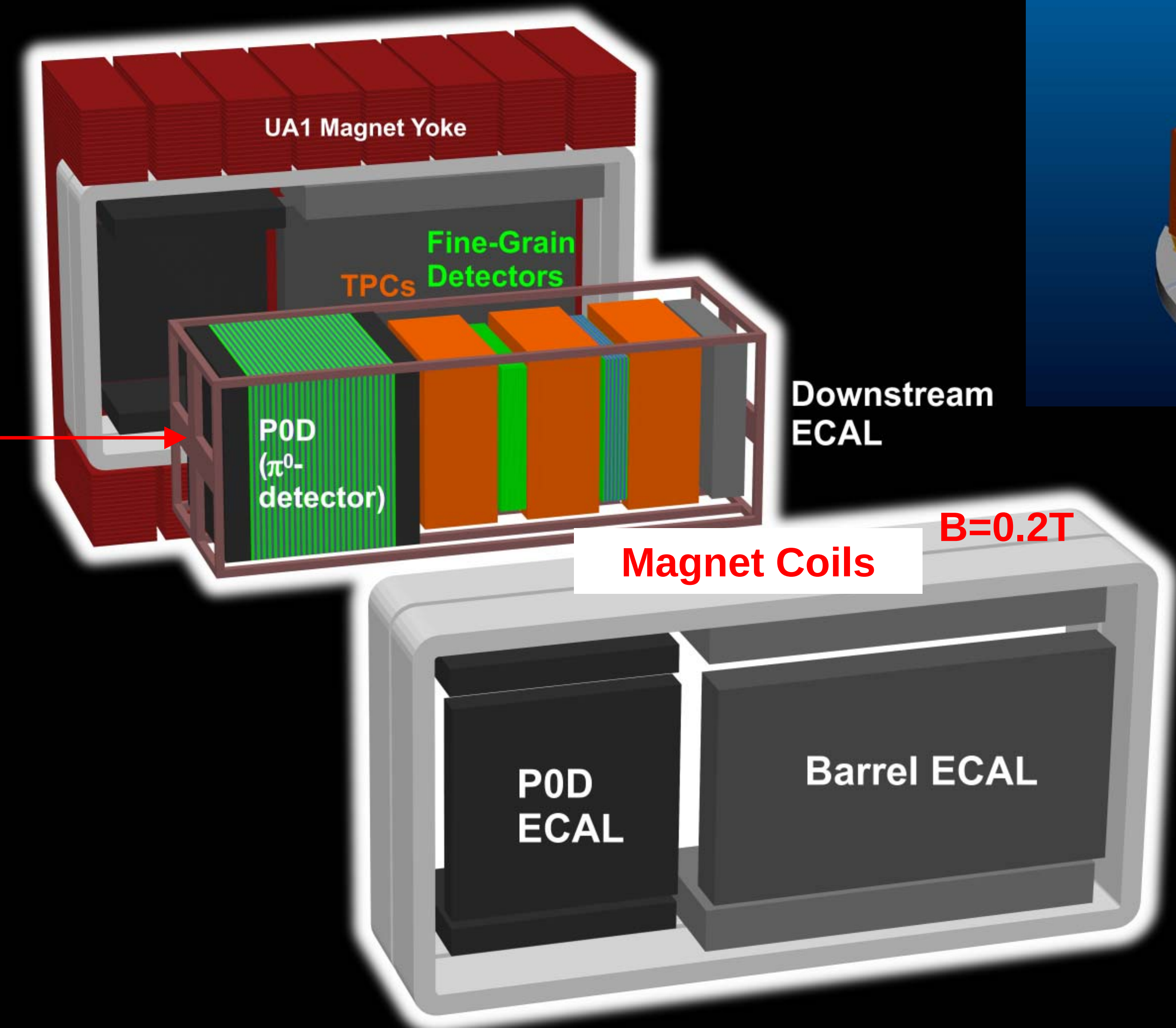


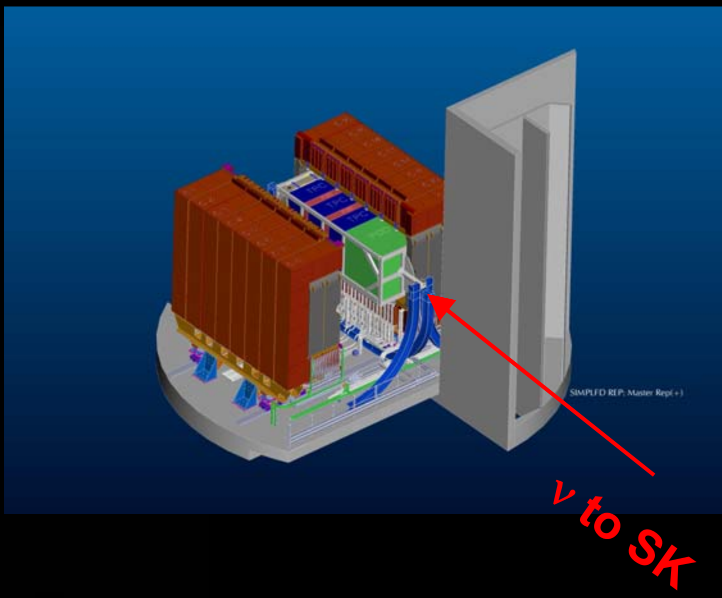


Off-axis Detector

- Measure ν_μ flux: <5%
- Measure ν_μ energy scale: <2%
- Measure intrinsic ν_e content of beam: <10%
- Measure non-CCQE backgrounds for both ν_μ disappearance and ν_e appearance: <10%
- Magnetic field, fine segmentation, excellent tracking
- Major non-Japanese contributions
- High complexity and non-trivial integration

The off-axis detector





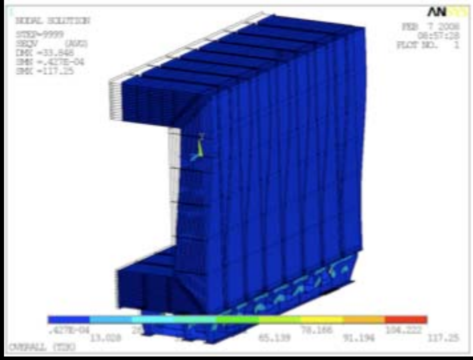
- Instrumented volume: 3.5m x 3.5m x 7.0m
- P0D optimized for NC π^0
- Tracker optimized for CC events
- ECAL on 5 sides
- Muon ranging: instrumented yoke

UA1 magnet

- CHF 6M European contribution
- 8x2 "C"s: 55 ton each
- Dismantled, treated, measured
- 4 Alu coils
- Pressure tested
- New slow control fitted
- Magnet moving system from DESY
- 1,000 tonnes in containers en route to Pousan (Korea), then Hitachinaka
- Installation: May-June 08

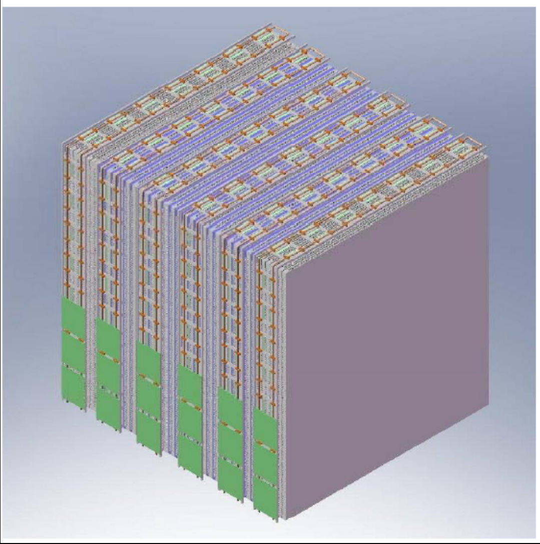
Jan 2007

Jan 2008

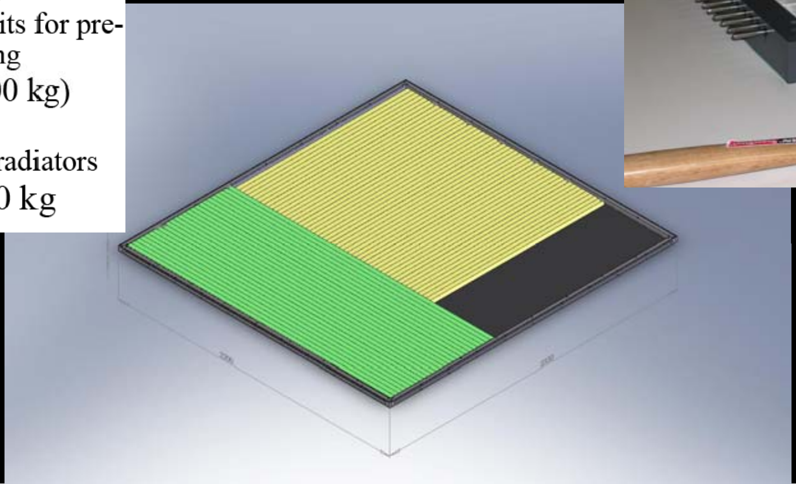


Pi0 Detector

- Scintillator bars – lead/brass sandwich – water targets. Mass: 17.6ton total, 2.9ton water
- Optimized for NC π^0 production measurements
- Runs with/without water: C/H_2O scaling
- 17,000 NC $1\pi^0$ events/year in water
- MINERVA bars, WLS fibres, MPPCs, TRIP-t electronics
- Construction: May-December 2008

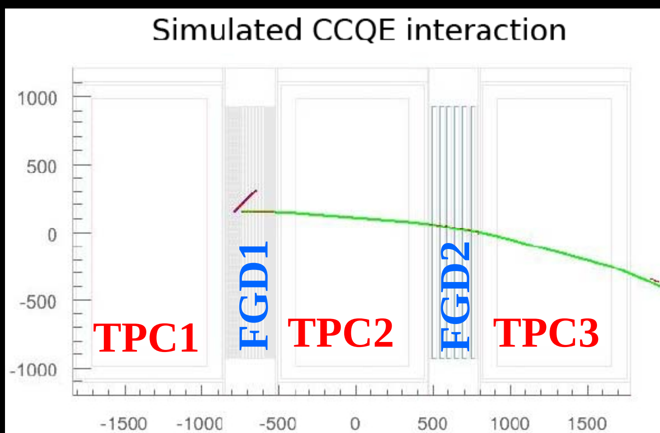


- 3 Super-PØDules
  - Upstream ECAL (3200 kg)
    - 7 PØDules
    - 7 4mm-thick lead radiators
  - Target (11000 kg)
    - 2857.3 kg water
    - 26 PØDules
    - 25 1.6mm brass radiators
    - 25 Water target layers
    - Split into 2 sub-units for pre-installation handling
  - Central ECAL (3200 kg)
    - 7 PØDules
    - 7 4mm-thick lead radiators
- Total Mass is 17600 kg



Fine Grain Detectors

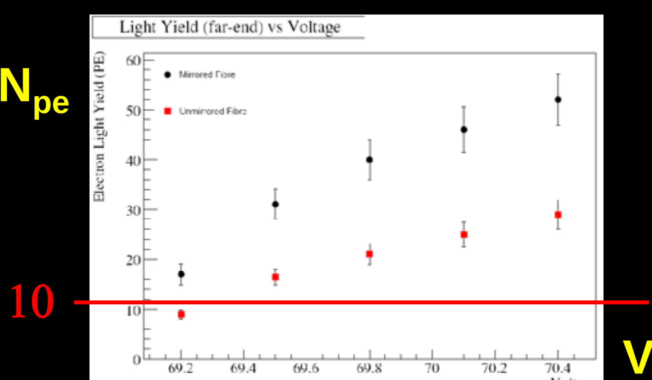
- 2x1ton active target in tracker volume: scintillator bars – water only in FGD2: 40,000 neutrino interactions/year
- Recoiling proton reconstruction
- 1cm x 1cm bars, WLS fibres, MPPCs, AFTER electronics
- Commissioning in second half of 2008 for installation in summer 2009



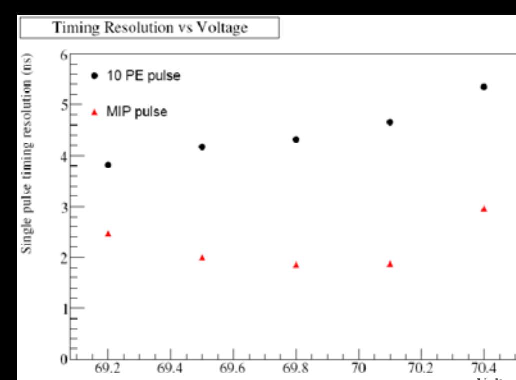
Tracker volume

TRIUMF Beam tests

N_{pe}

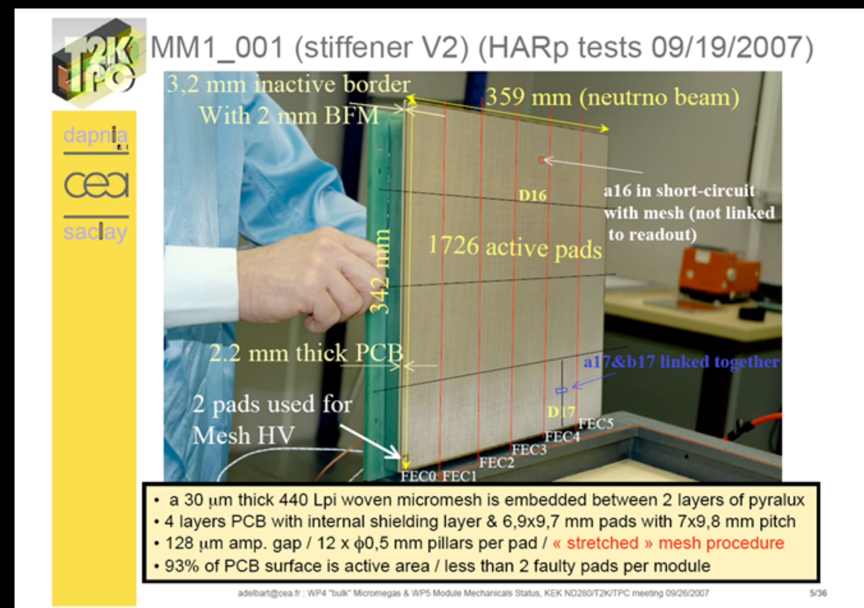


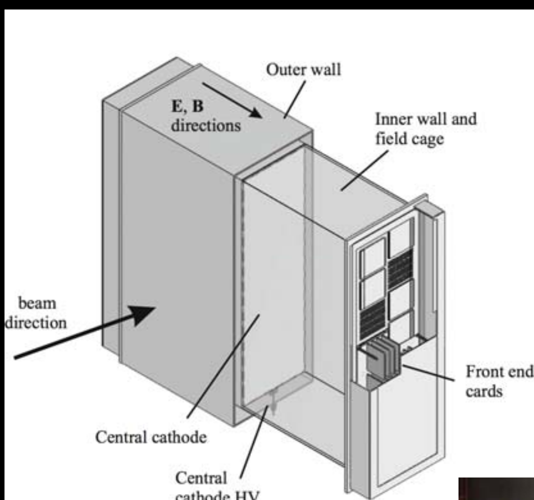
Resolution (ns)

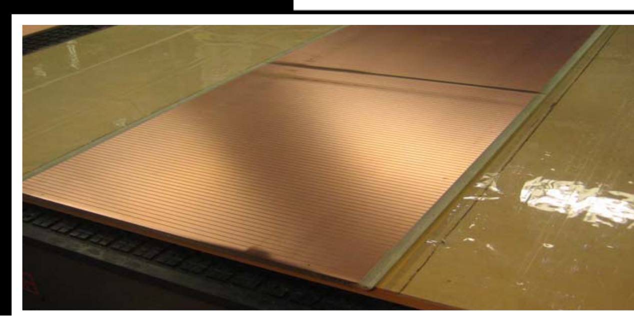


TPCs

- 3 Time Projection Chambers, MicroMegas readout (8mm x 8mm pads)
- 10% momentum resolution for p<1GeV, ~10% dE/dx resolution
- 2,000 neutrino interactions/year in the gas
- MicroMegas prototype tested in HARP TPC, construction at CERN
- 2 TPCs ready for summer 2009, 3rd on critical path

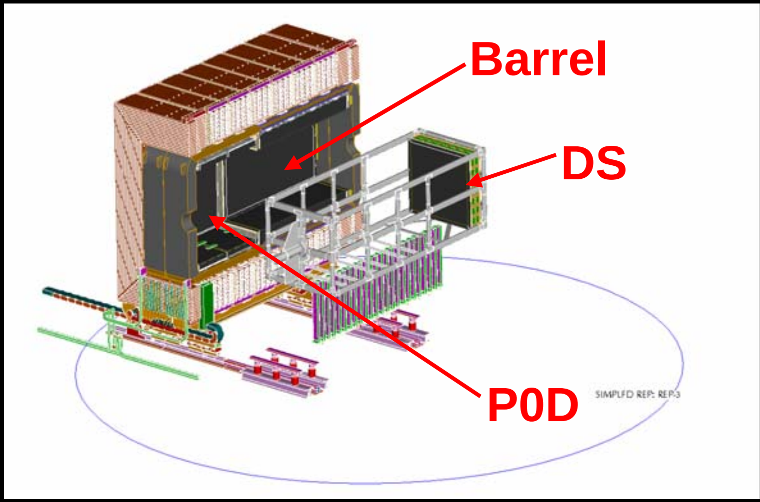


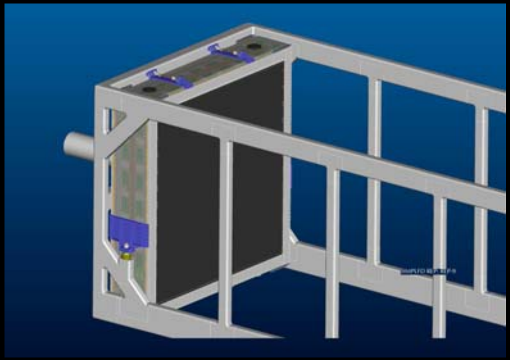


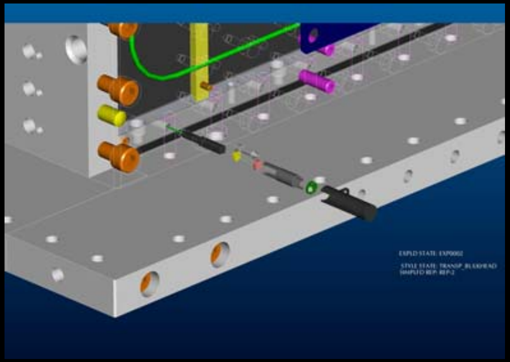


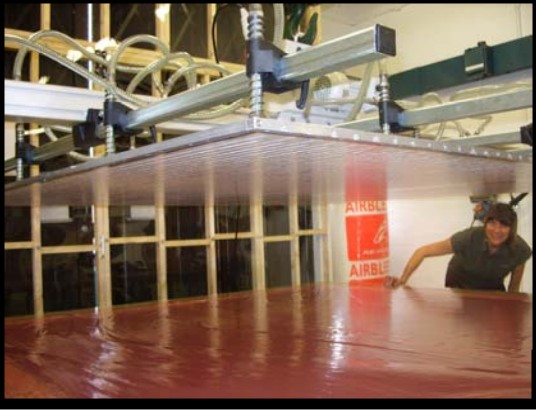
Electromagnetic CALorimeter

- Reconstruct π^0, identify $e/\mu/\pi$
- Lead-scintillator sampling calorimeter
- 4cm x 1cm scintillator, WLS fibre, MPPCs, TRIP-t readout
- 32 layers, 1.75mm Pb, $10X_0$
- DS ECAL ready for installation summer 2009; Barrel in 2010



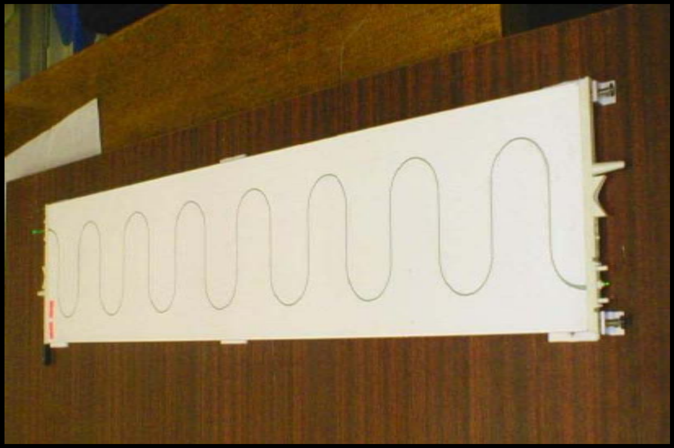
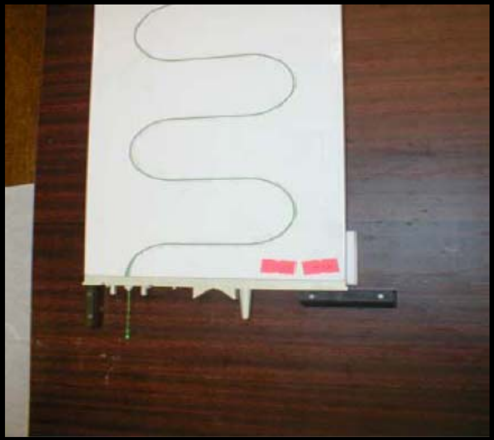






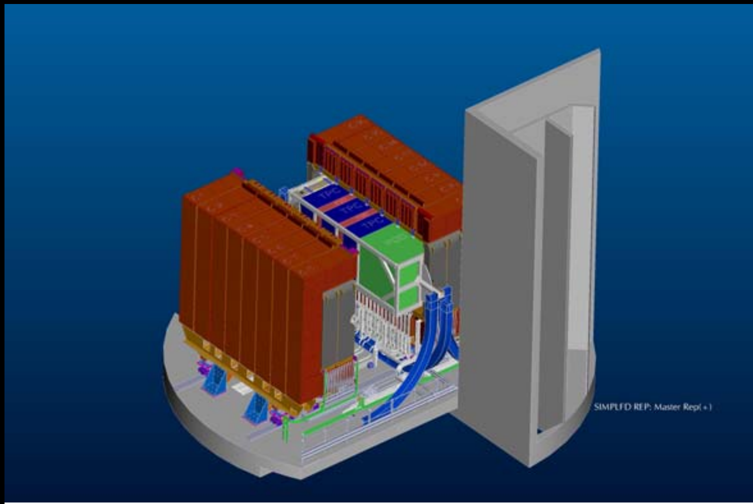
Side Muon Range Detector

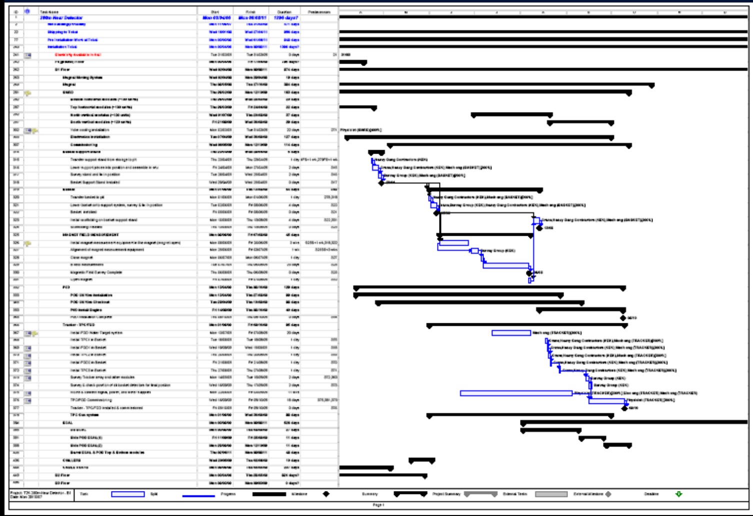
- Scintillator slabs in 1.7cm iron yoke gaps
- Muon detection, incoming activity veto, cosmic trigger
- 7mm scintillator - WLS fibre in surface groove – MPPCs - TRIP-t readout
- Ongoing production, installation summer 2009

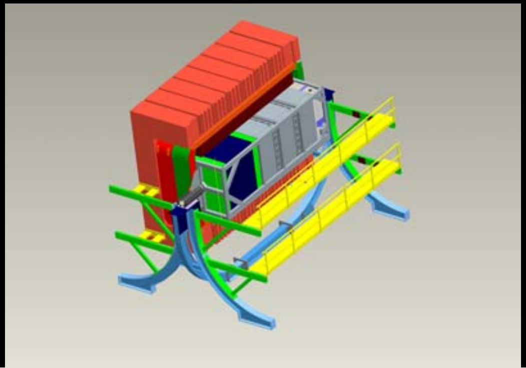



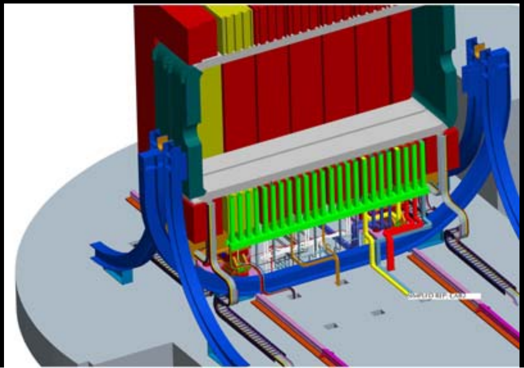

Integration

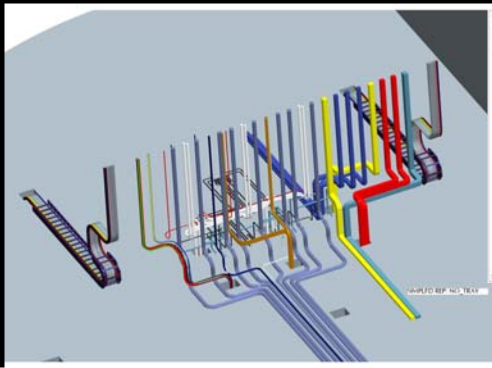
- Complex dependencies and interactions in space and time
- Technical Board, installation co-ordinators
- Central 3-D pit description, including services routing
- Central project file
- Seismic studies
- Environmental studies (temperature, humidity)

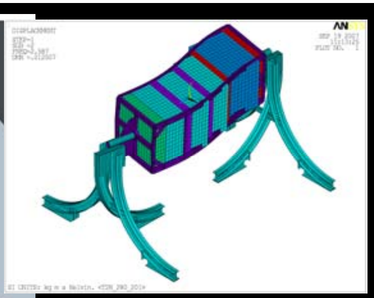






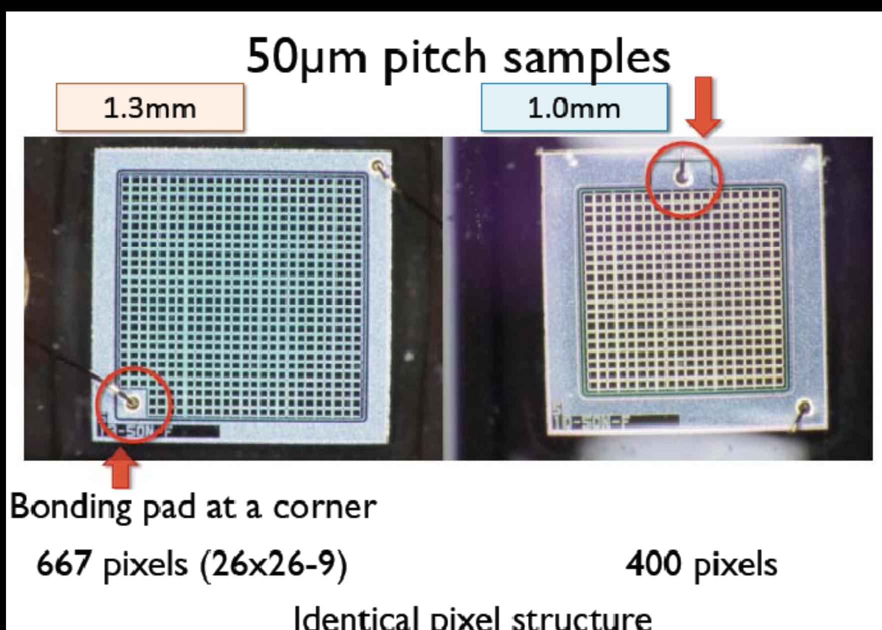


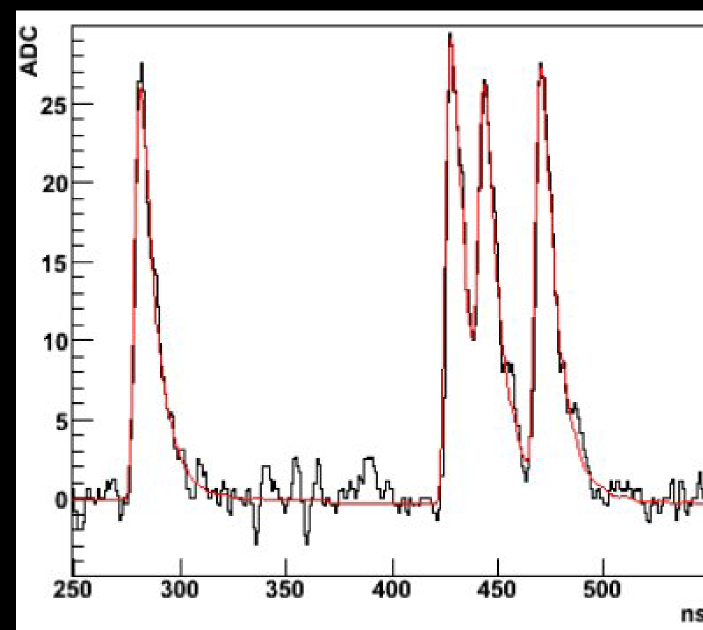




MPPC

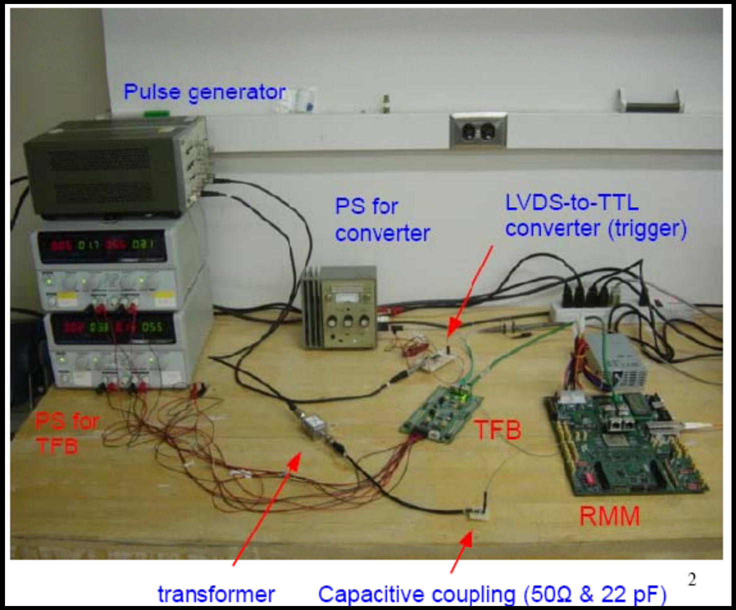
- Multichannel avalanche photodiodes operating in Geiger mode
- HPK MPPC: production started
- Prototype tests in labs and beam tests in Japan, Canada, USA, UK
- Cross-talk, after pulsing measured and included in ND280 simulation



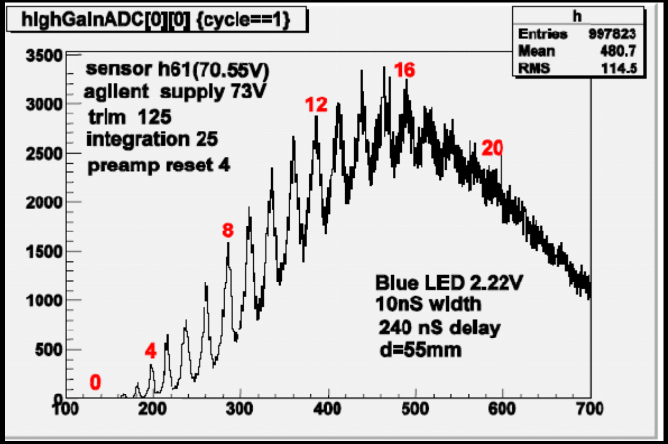


Readout electronics

- Two solutions for Front End Electronics:
  - UK system using FNAL TRIP-t chip: INGRID, P0D, ECAL, SMRD
  - French system using Saclay AFTER chip: FGD, TPC
- Prototypes for both systems operational
- Back End Boards and DAQ system by RAL (common to all)
- Slow Control: MIDAS (TRIUMF)



TFB system in US lab

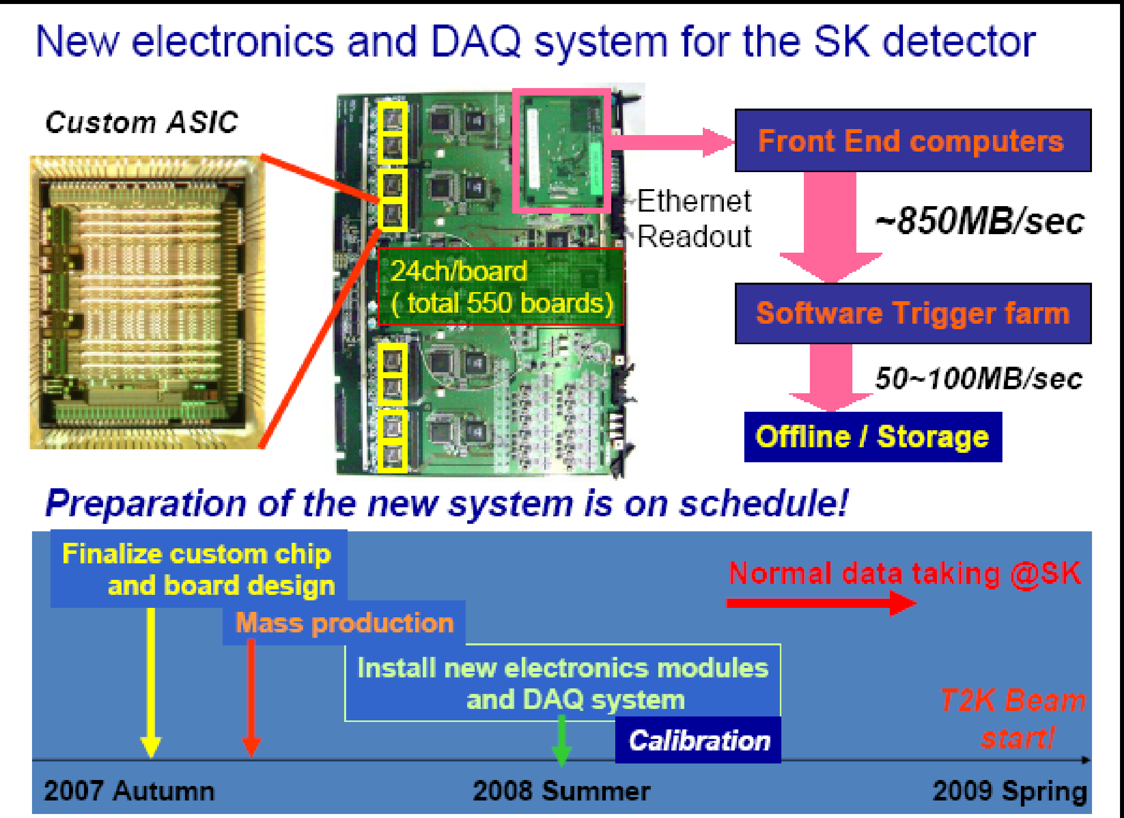


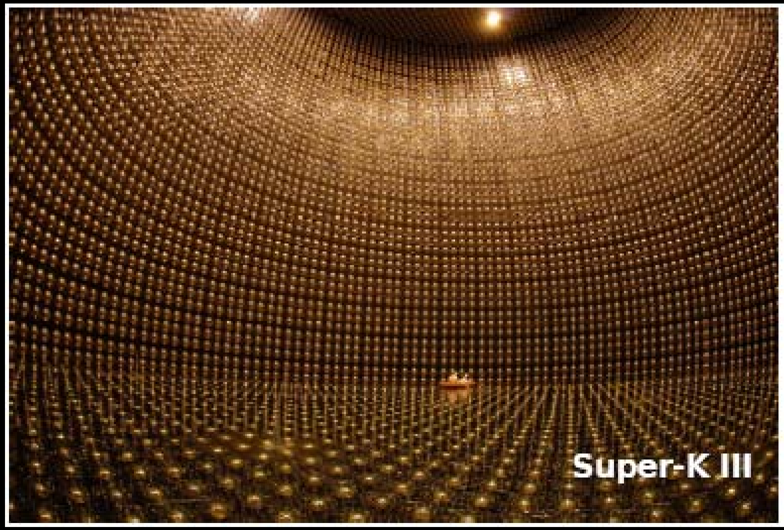
MPPC spectrum with prototype TFB, BEB, and DAQ

AFTER chip and card

SuperKamiokande

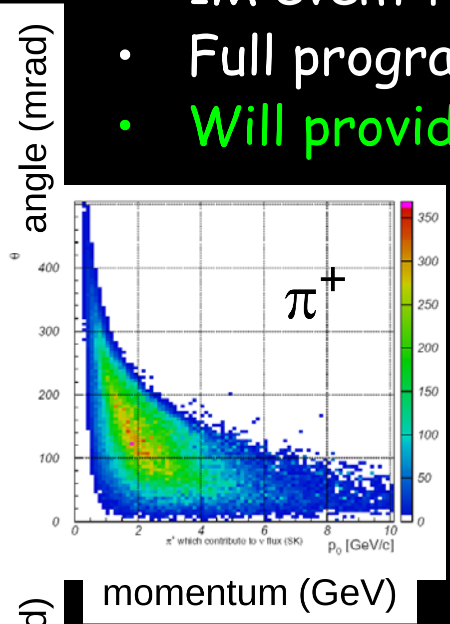
- Refitted SuperK, major next upgrade: electronics (higher dynamic range – faster – no dead time – stability >10 years)
- Installation starting September 2008
- New Online, spill time information transferred from J-PARC over private line, allow to flag and record ±500μs around each spill
- Reconstruction and simulation will be adapted

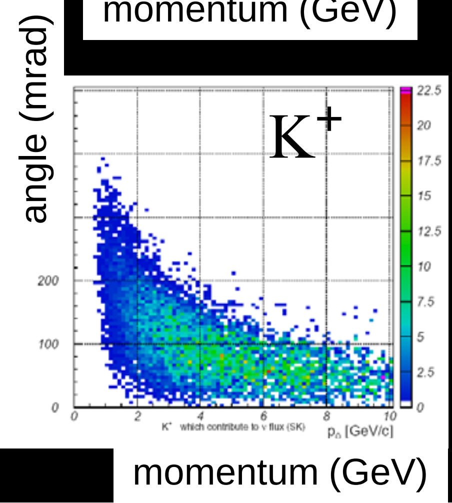


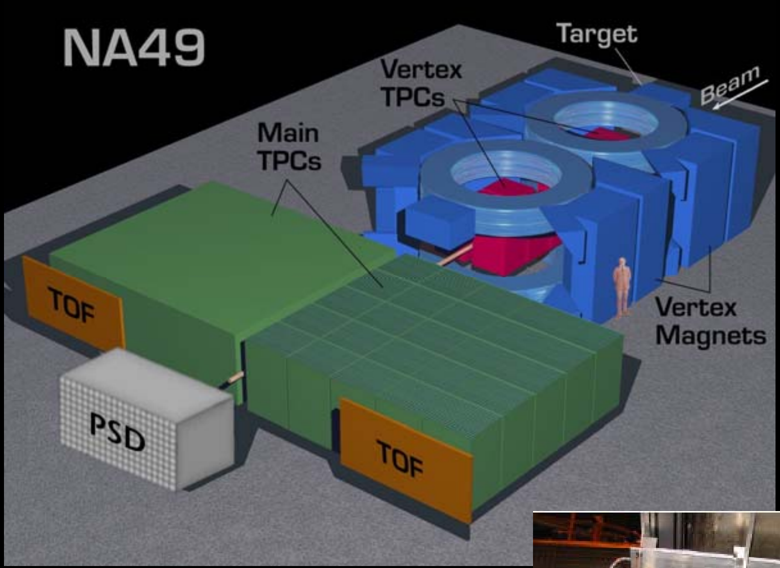


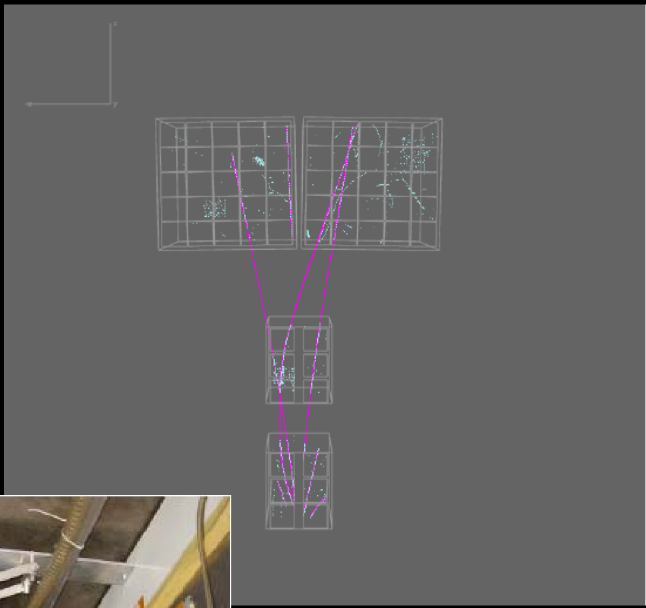
SPS Heavy Ions and Neutrino Experiment

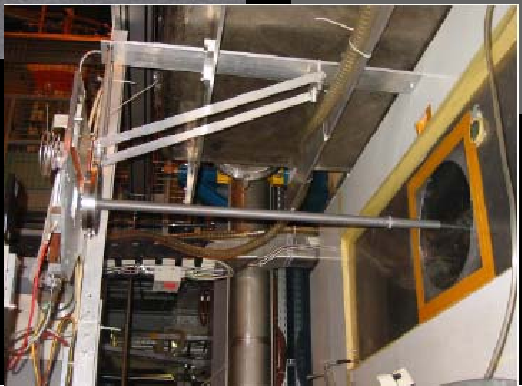
- NA61: dedicated pion/kaon hadro-production experiment using the NA49 detector at CERN SPS and T2K target
- 1M event recorded in 2007 (3 days)
- Full programme planned for 2008 (45 days)
- Will provide 30GeV and 50GeV data for T2K beam simulation





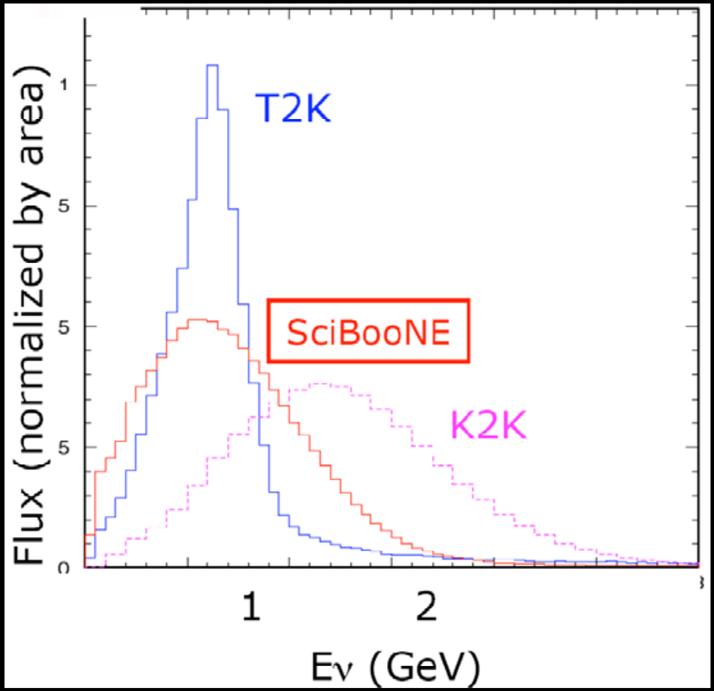


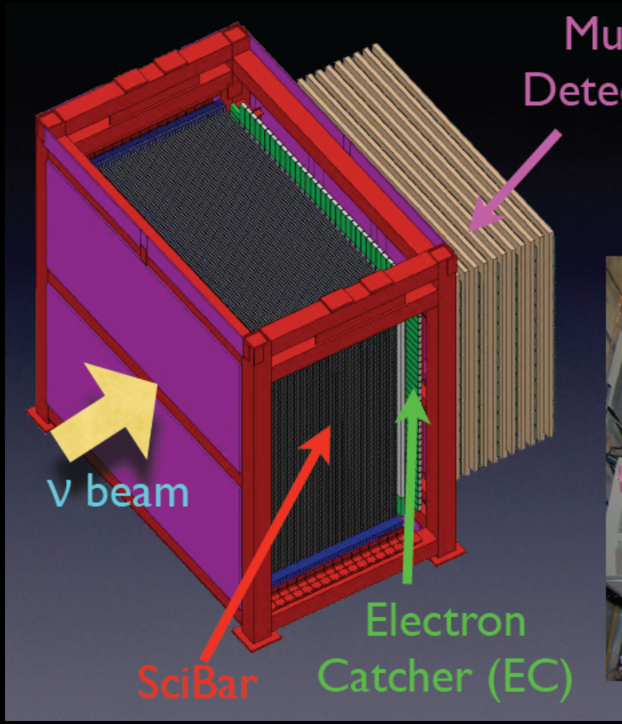




SciBoone

- FNAL E-954, K2K SciBar detector in Booster neutrino beam
- 10^{20} POT, both neutrino and anti-neutrino: half already collected!
- Major input (cross-sections) for T2K
- ND280 software validation!





SciBooNE detectors during cabling

Analysis plans and readiness

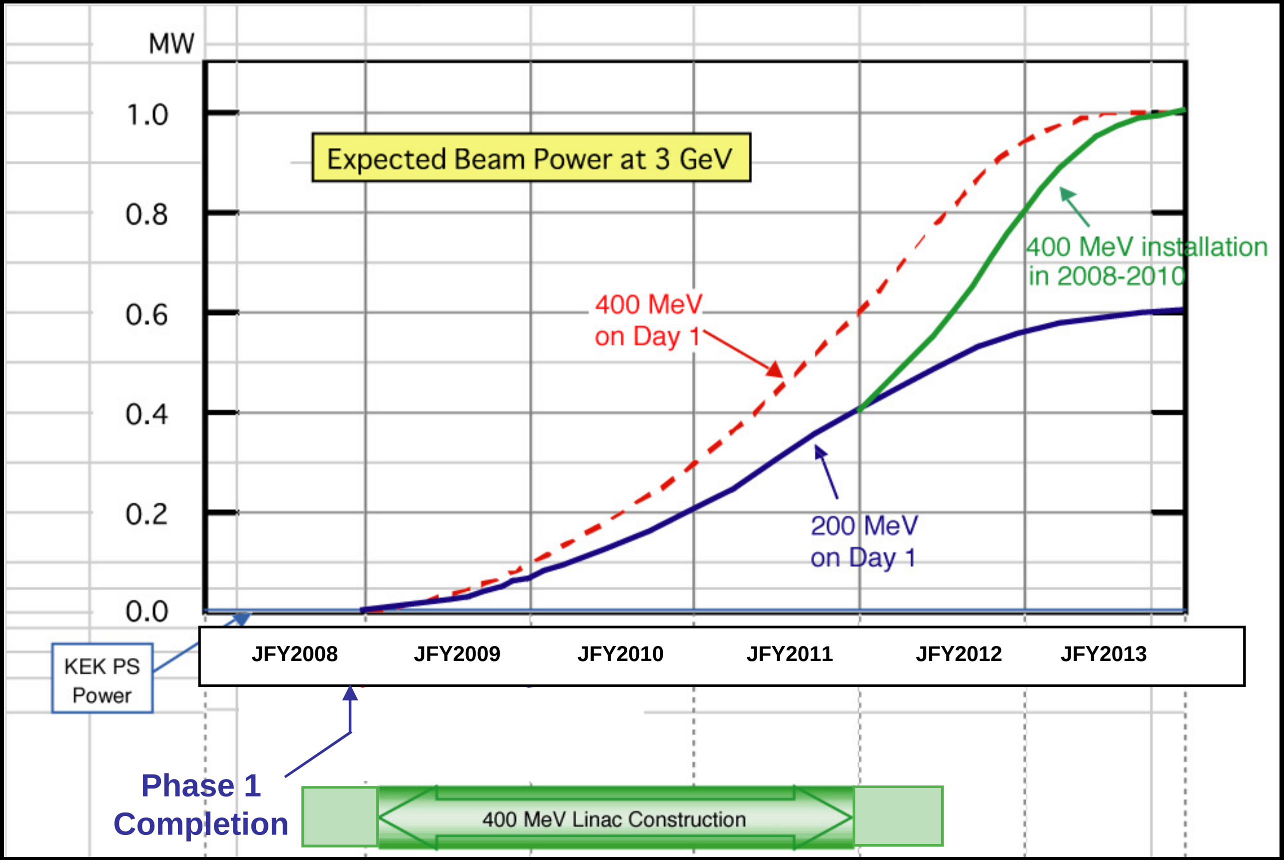
- Integration of simulation, data, and analysis from Beam, ND280, (2km), SK, as well as SHINE, SciBoone
- High statistics regime requires control of systematic errors to unprecedented levels
- Neutrino generators: neut, Genie, more (NUANCE)
- Global Analysis Group, Analysis conveners per group (Beam, ND280, 2km, SK)
- To define T2K physics plan and prepare for timely production of highest quality results
- To co-ordinate manpower and resources for optimal execution of physics plan
- To integrate groups with diverse backgrounds (SK, other neutrino experiments, other high energy physics)
- Already a lot of activity

Conclusions

- T2K has very ambitious programme
- The T2K collaboration is poised to dominate neutrino physics in the next five years and beyond
- Excellent progress in experiment matches that of J-PARC Facility
- Phase 2 could push into CP territory!
- First neutrinos in 2009, first results in 2010
- Stay tuned!

END

Expected flux



Nominal: 10^{21} p.o.t. per year, total 5×10^{21} in five years