RESULTS FROM THE FIRST T2K PHYSICS RUN

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INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
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Results from the first T2K physics run

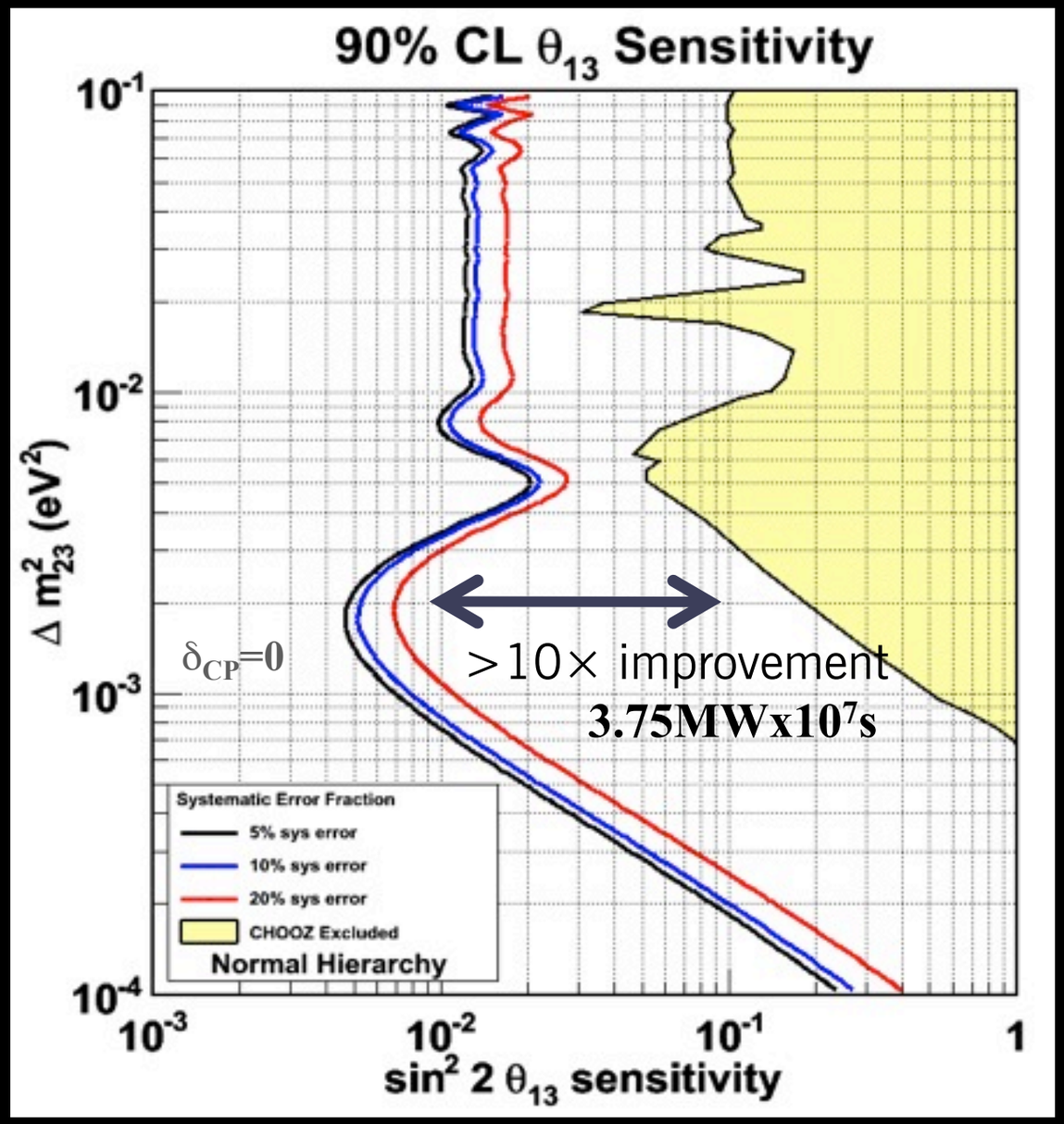
- T2K: physics goals
- Design of the experiment
- Commissioning and first operation
- The first physics data

T2K physics goals

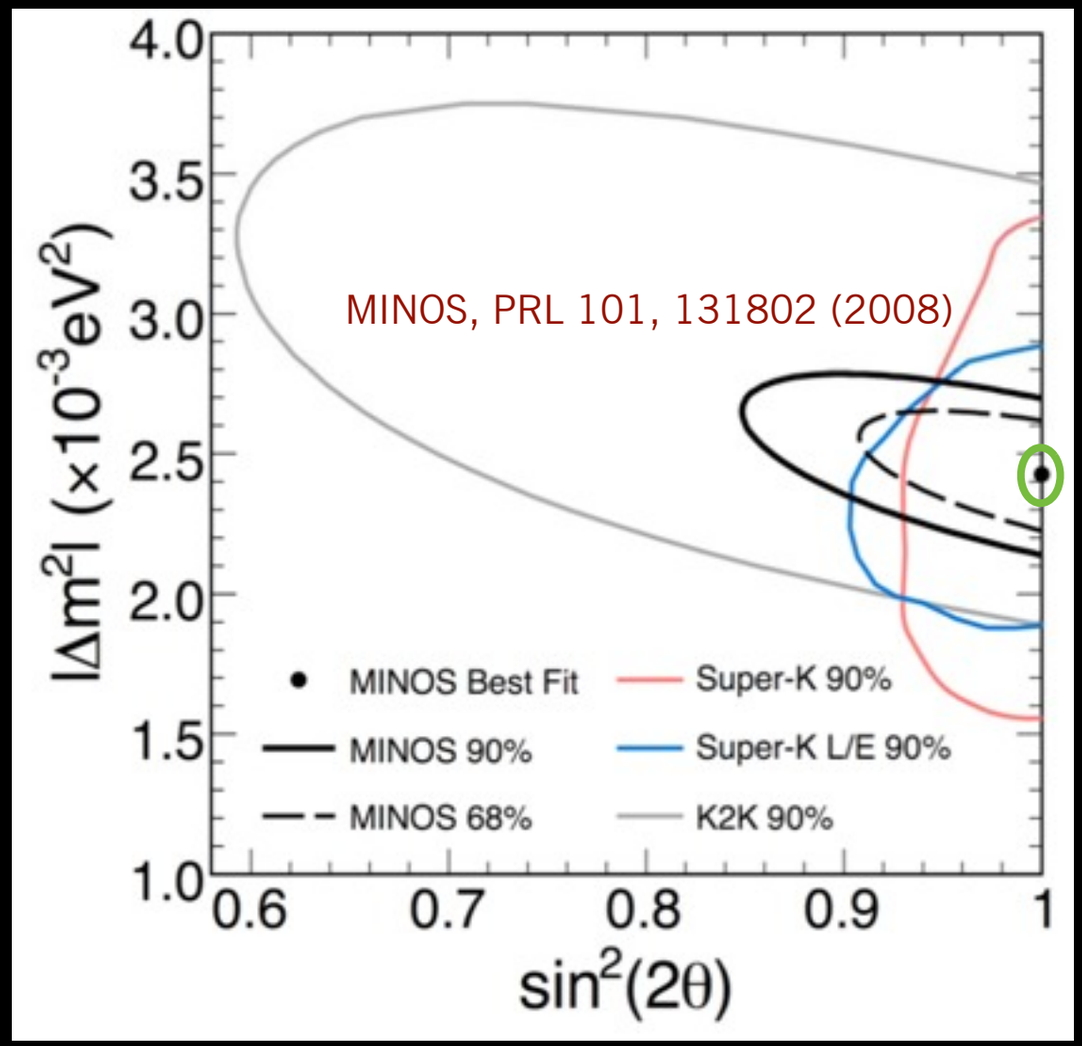
- Initially:
  - Discover ν_e appearance and determine θ_{13}
  - Precise measurement of ν_μ disappearance θ_{23}, Δm^2_{23}
- Future:
  - Possible search for CP violation in lepton sector

Expected Sensitivity of T2K

$\nu_\mu \rightarrow \nu_e$ appearance



ν_μ disappearance



Full T2K statistics goal: 3.75MWx10^{7}s

$\delta(\sin^2 2\theta_{23}) \sim 0.01$, $\delta(\Delta m^2_{atm}) < 1\times10^{-4}$ eV^2

The T2K Collaboration

~500 members, 61 Institutions, 12 countries

Canada
TRIUMF
Univ. Alberta
Univ. Brit. Columbia
Univ. Regina
Univ. Toronto
Univ. Victoria
York Univ.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany
Univ. Aachen

Italy
INFN, Univ. Rome
INFN, Univ. Naples
INFN, Univ. Padua
INFN, Univ. Bari

Japan
ICRR Kamioka
ICRR RCCN
KEK
Kobe Univ.
Kyoto Univ.
Miyagi Univ. of Educ.
Osaka City Univ.
Univ. Tokyo

Poland
Soltan Inst., Warsaw
Niewodniczanski Inst., Cracow
Technical Univ. Warsaw
Univ. Silesia, Katowice
Univ. Warsaw
Univ. Wrocław

Russia
INR

S. Korea
N. Univ. Chonnam
Univ. Dongshin
Univ. Sejong
N. Univ. Seoul
Univ. Sungkyunkwan

Spain
IFIC, Valencia
Univ. A. Barcelona

Switzerland
Univ. Bern
Univ. Geneva
ETH Zurich

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

USA
Boston Univ.
BNL
Colorado St. Univ.
Duke Univ.
Louisiana St. Univ.
SUNY-Stony Brook
U. C. Irvine
Univ. Colorado
Univ. Pittsburgh
Univ. Rochester
Univ. Washington

T2K design

- High-intensity 30 GeV proton beam from J-PARC sychrotron
- First use of off-axis technique to produce intense ~600 MeV narrow-band ν_μ beam from pion decays in flight
- Beam monitors to measure primary and secondary beam each pulse
- Neutrino monitors at 280 m baseline:
  - On-axis neutrino detector “INGRID” measures beam profile and direction
  - Off-axis near detector measures flux, cross-sections, and flavor composition of beam in the direction of the far detector
- Far detector is 22.5 kton Super-Kamiokande water Cherenkov, at 295 km baseline

Linac

3 GeV Synchrotron

Pacific Ocean

Near Detector

Neutrino Beam to Kamioka

1200-year-old temple

Design Intensity 750kW

30 GeV Main ring

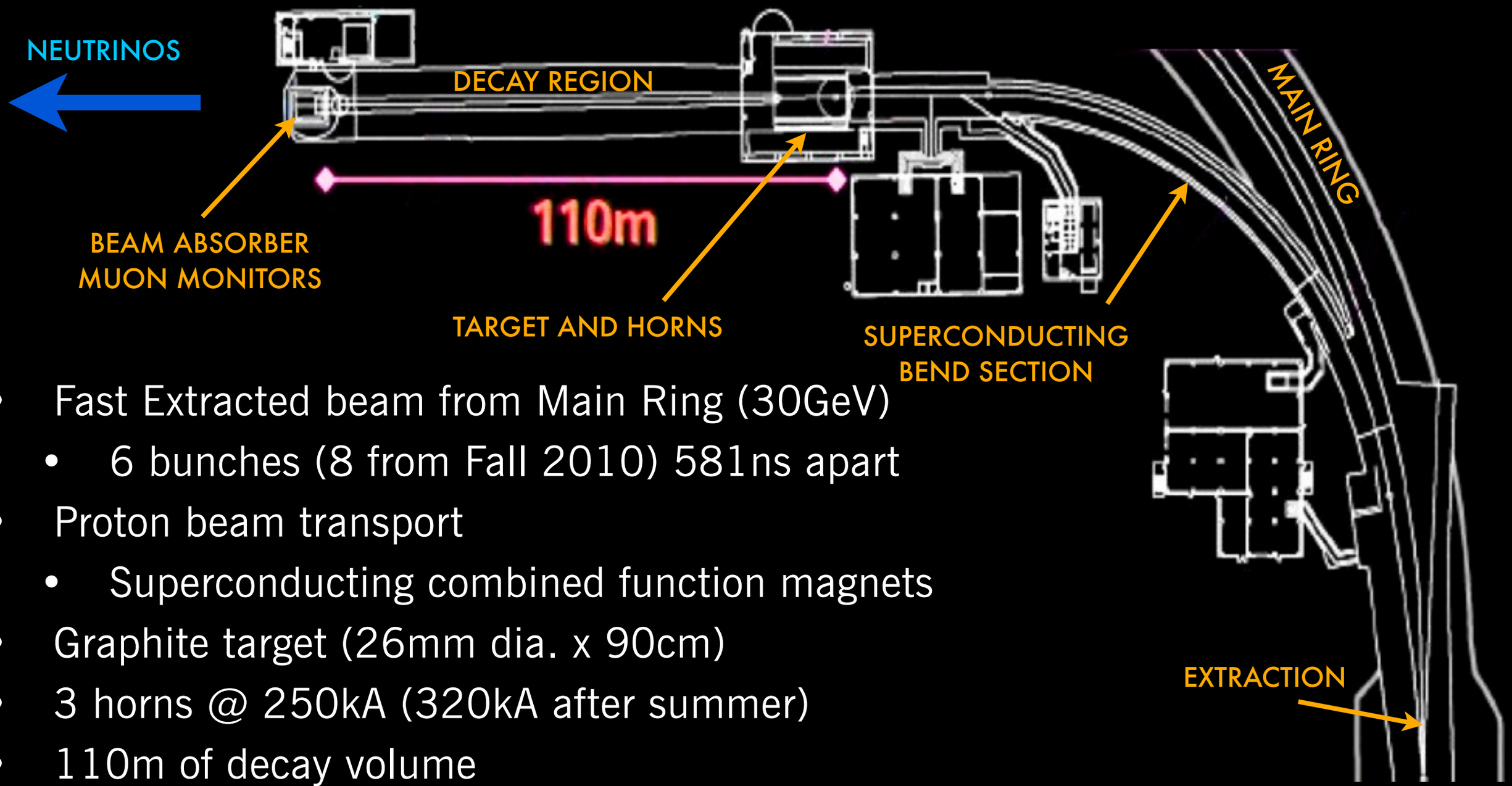
J-PARC Facility (KEK/JAEA)

View to North

Photo: January 2008

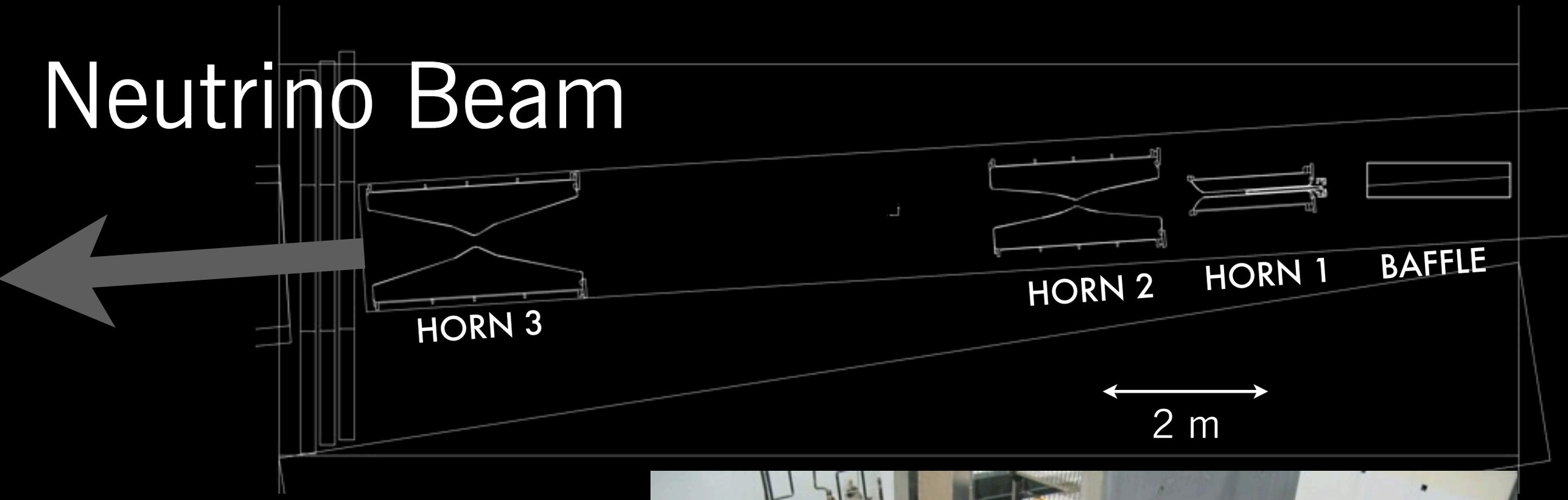
Construction 2001~2009

Neutrino Beam



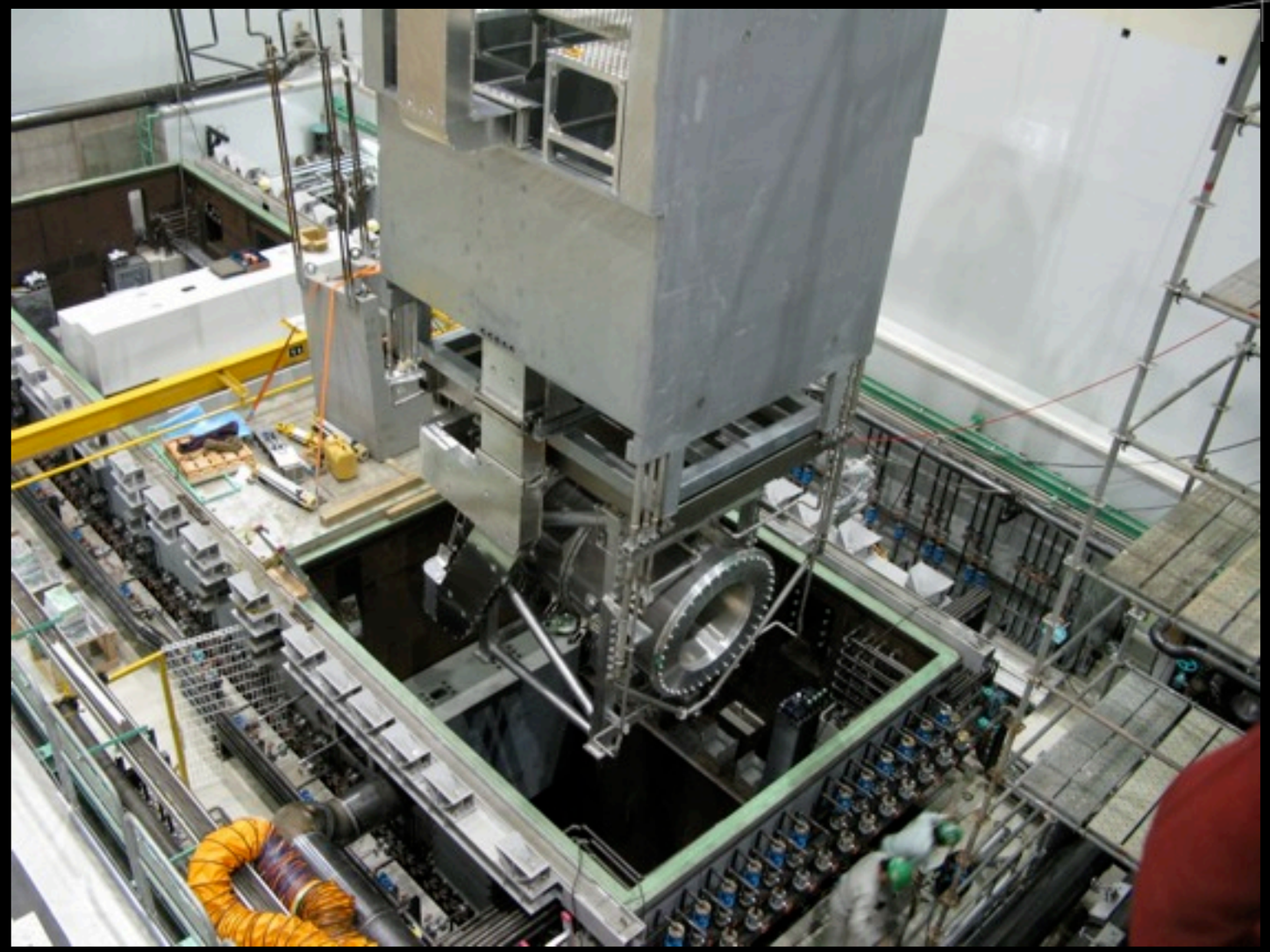
- Fast Extracted beam from Main Ring (30GeV)
  - 6 bunches (8 from Fall 2010) 581ns apart
- Proton beam transport
  - Superconducting combined function magnets
- Graphite target (26mm dia. x 90cm)
- 3 horns @ 250kA (320kA after summer)
- 110m of decay volume
- SK direction is given by GPS survey

Neutrino Beam



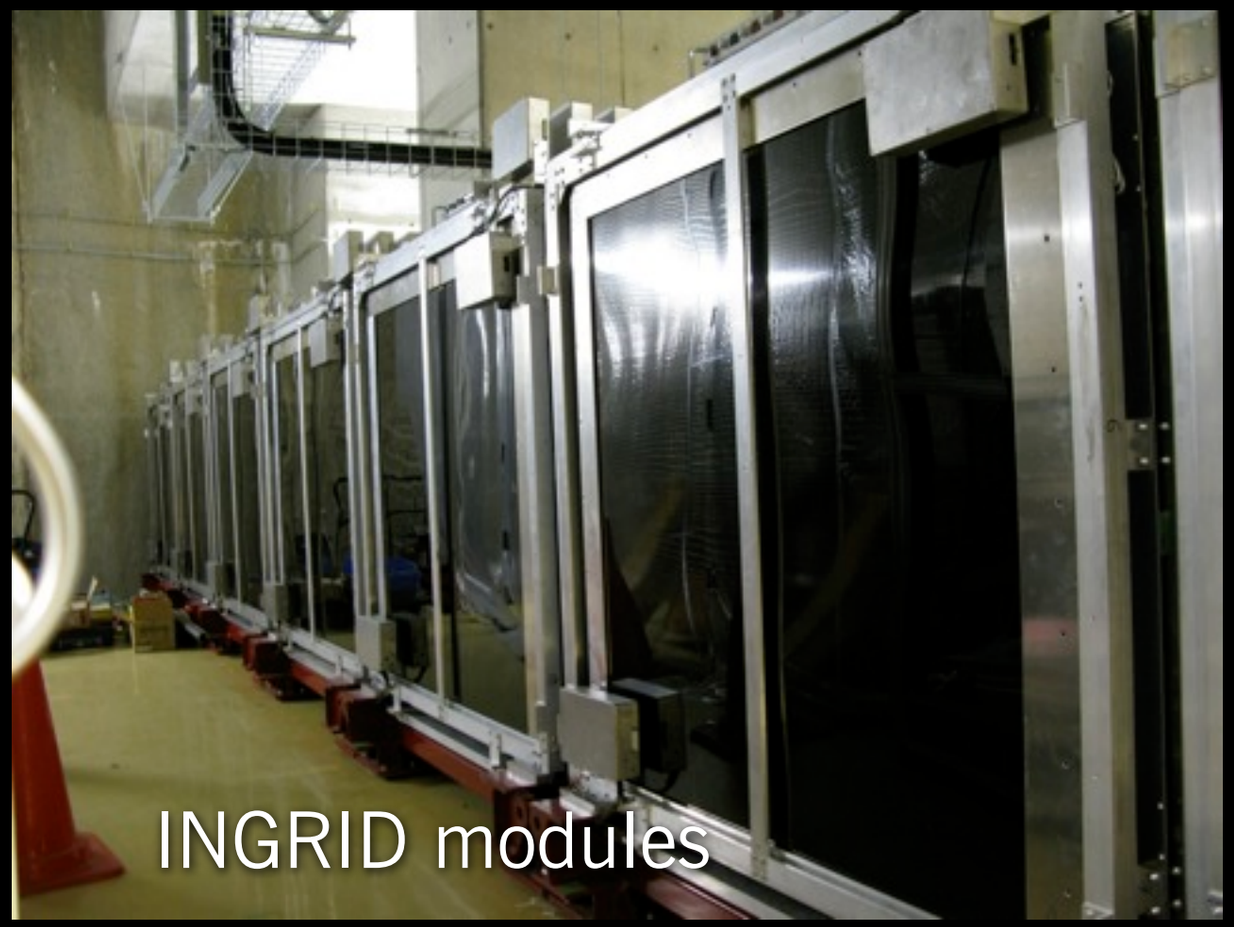
Target Station building: three horns in helium vessel

(Horn 3 shown during installation)



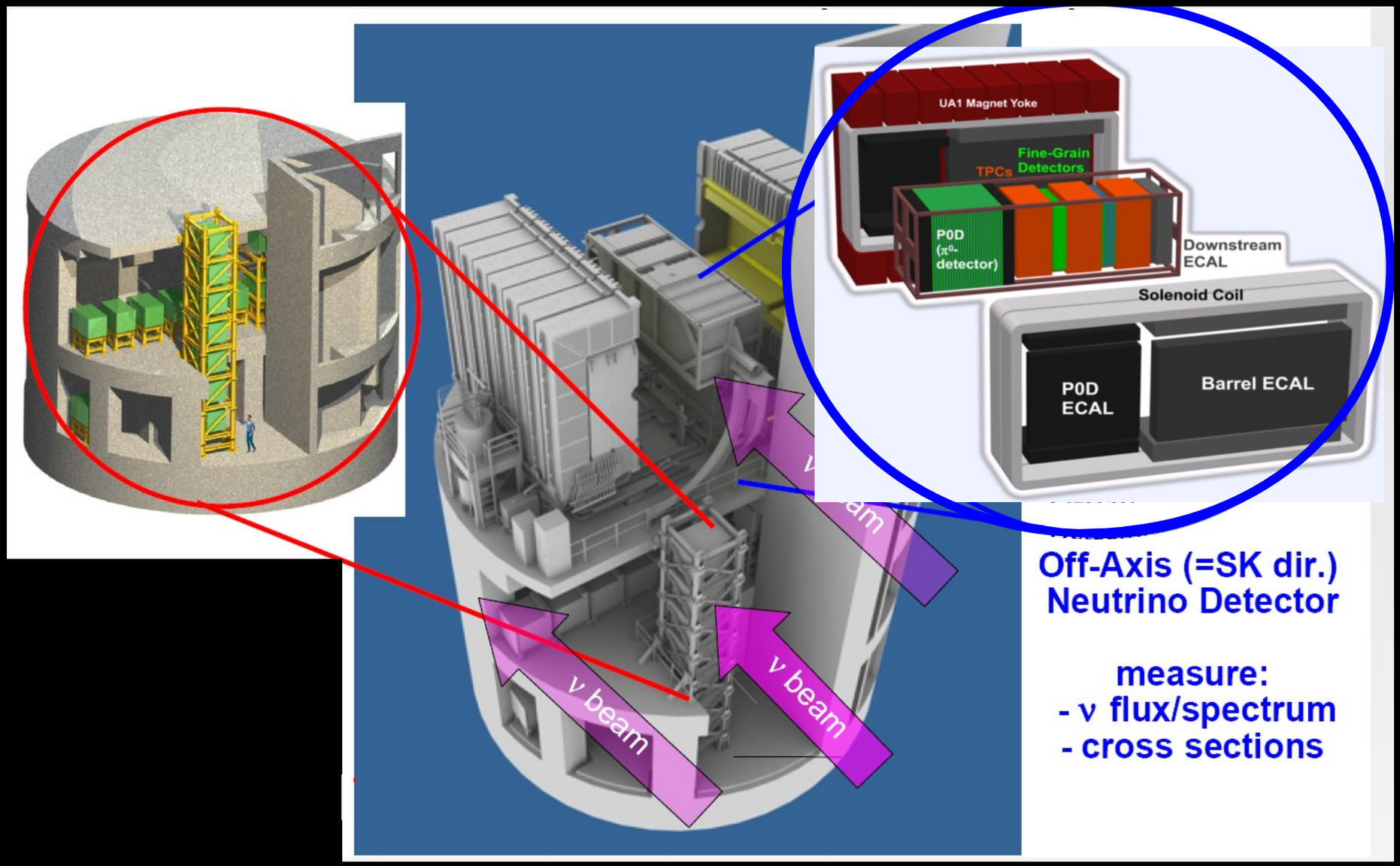
280m on-axis near detector: INGRID

- Array of 9-ton iron-scintillator neutrino detectors in cross shape centered on beam axis
- Designed to show neutrino beam profile, event rate, and precise measure of beam center/off-axis angle



INGRID modules

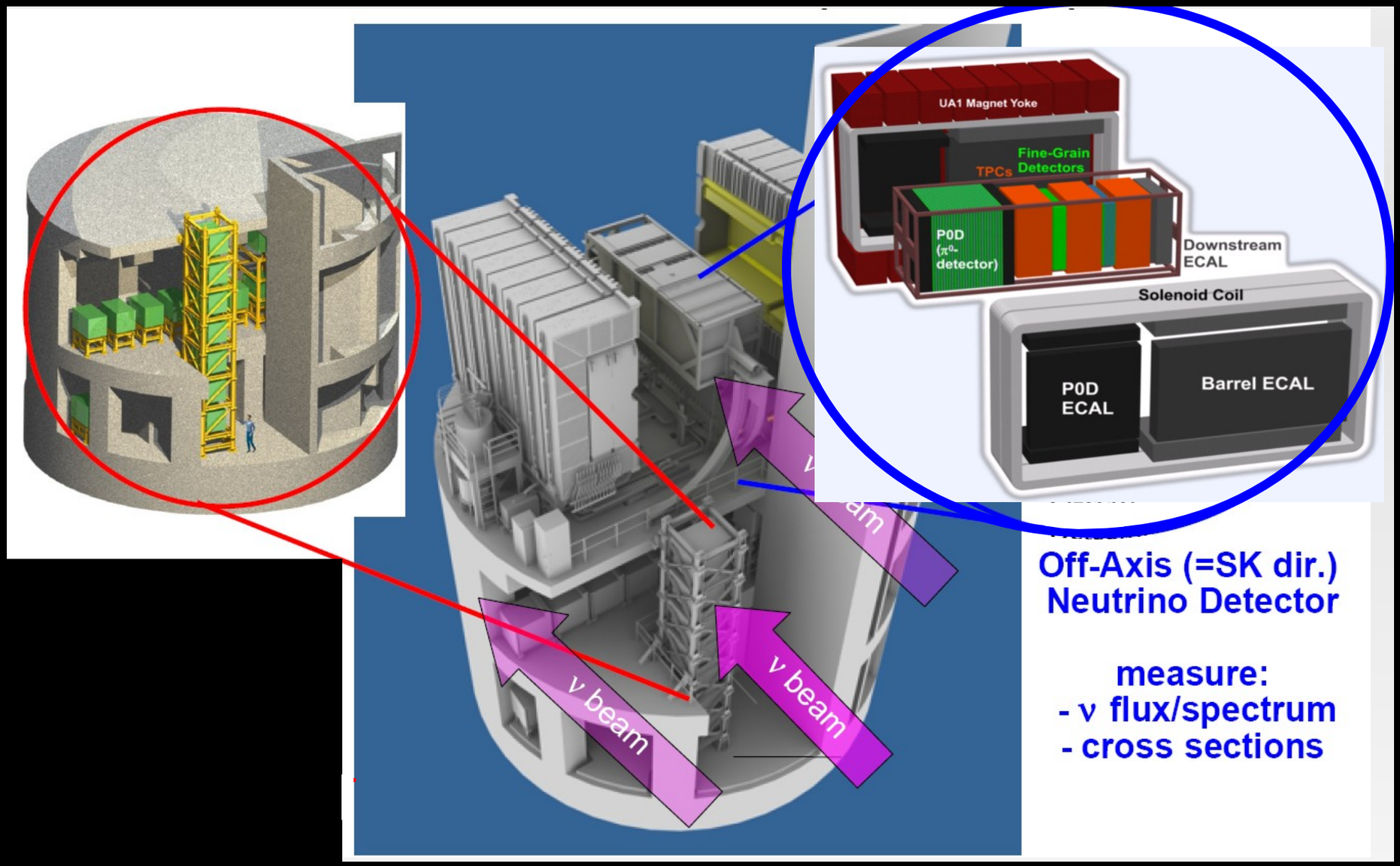
280m off-axis Near Detector



- PØD: optimized for π^0 detection, includes H_2O target
- Tracker (2 FGDs, 3 TPCs): measure fluxes before oscillation
- ECAL: surrounding POD and Tracker, measure EM activity
- SMRD: in the magnet yokes, identify muons

Installation completed in December 2009 (except Barrel ECAL, Summer 2010)
Commissioning completed at the beginning of 2010

280m off-axis Near Detector



See talk by Flor de Maria Blaszczyk in Session 13

- PØD: optimized for π^0 detection, includes H_2O target
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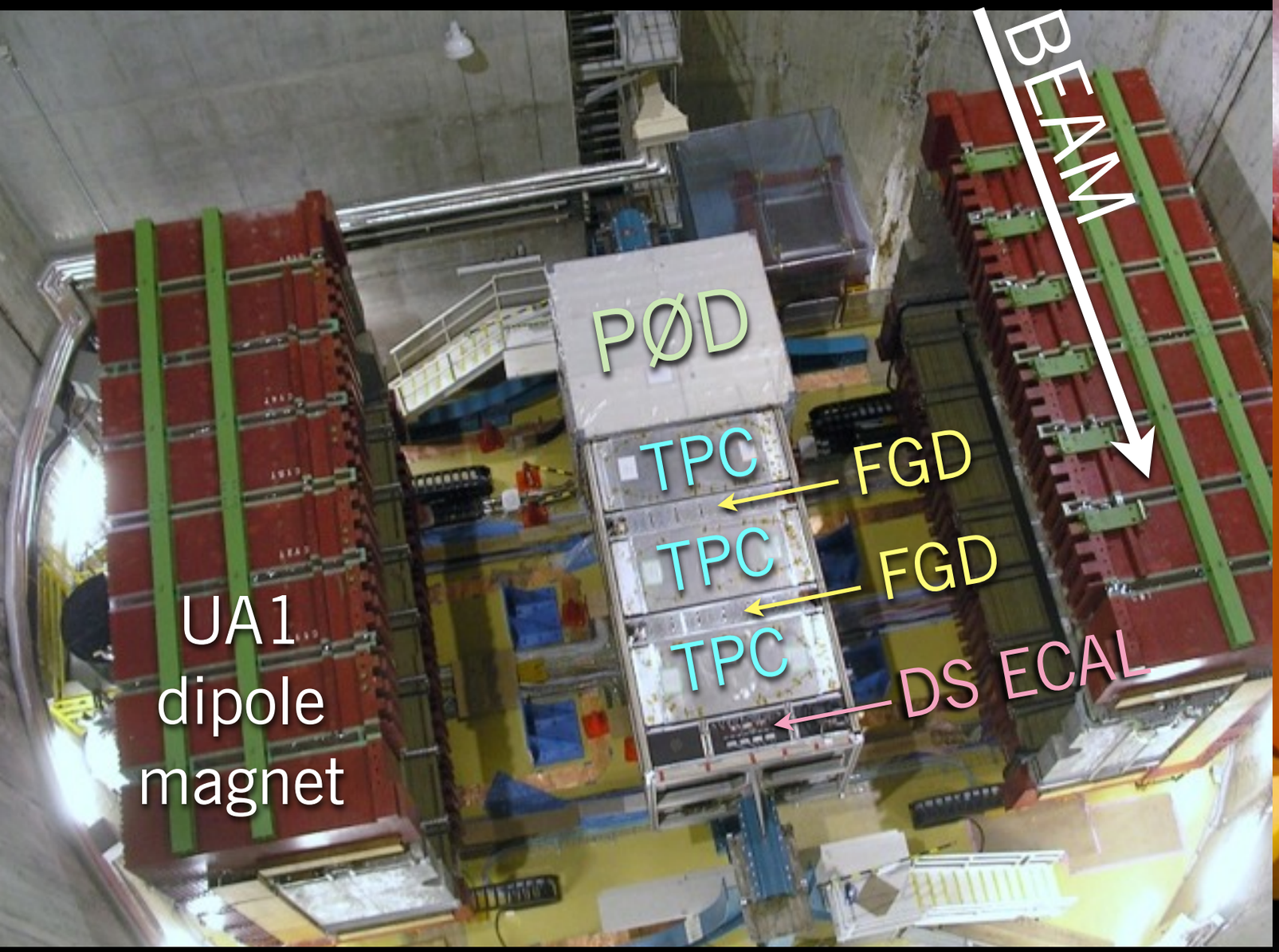
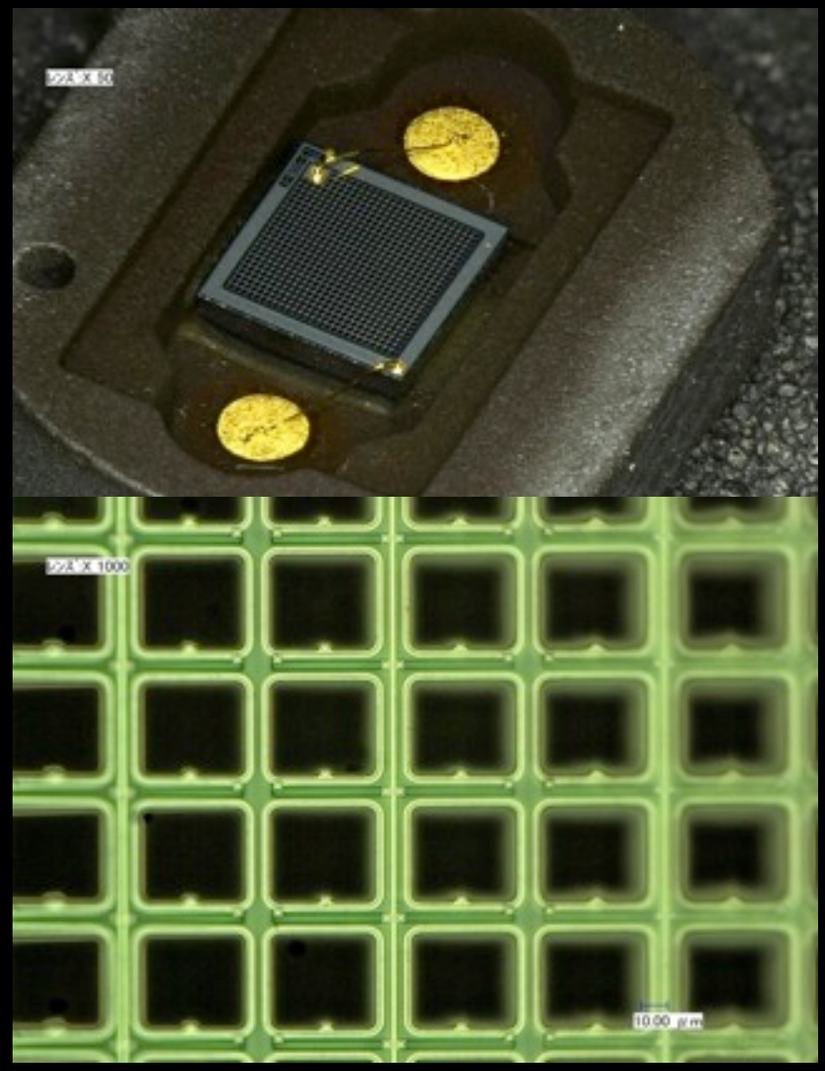
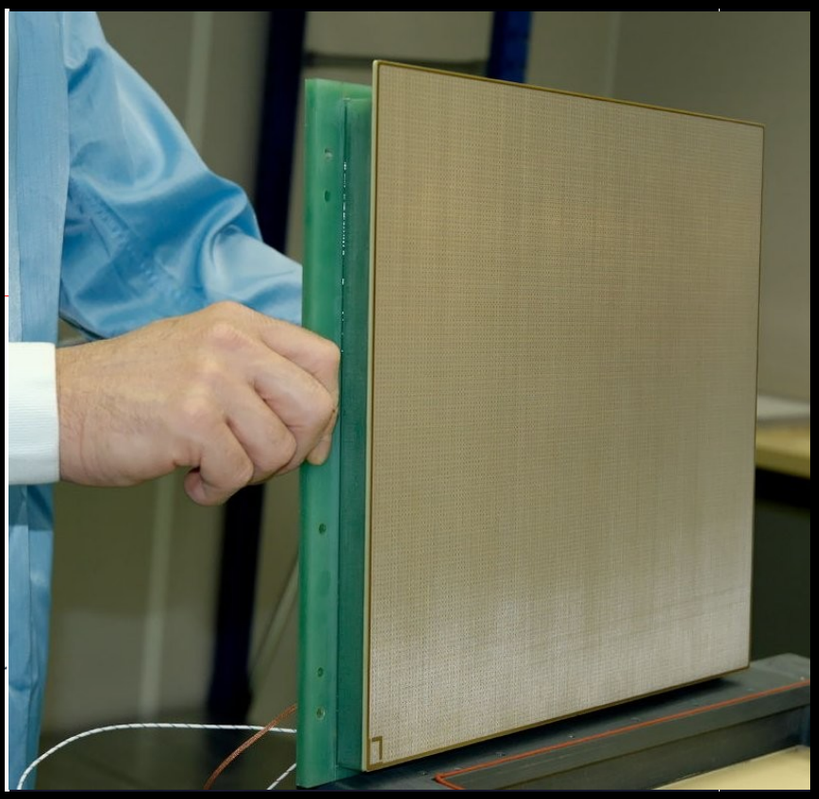
Off-axis Near Detector



Near Detector: novel features

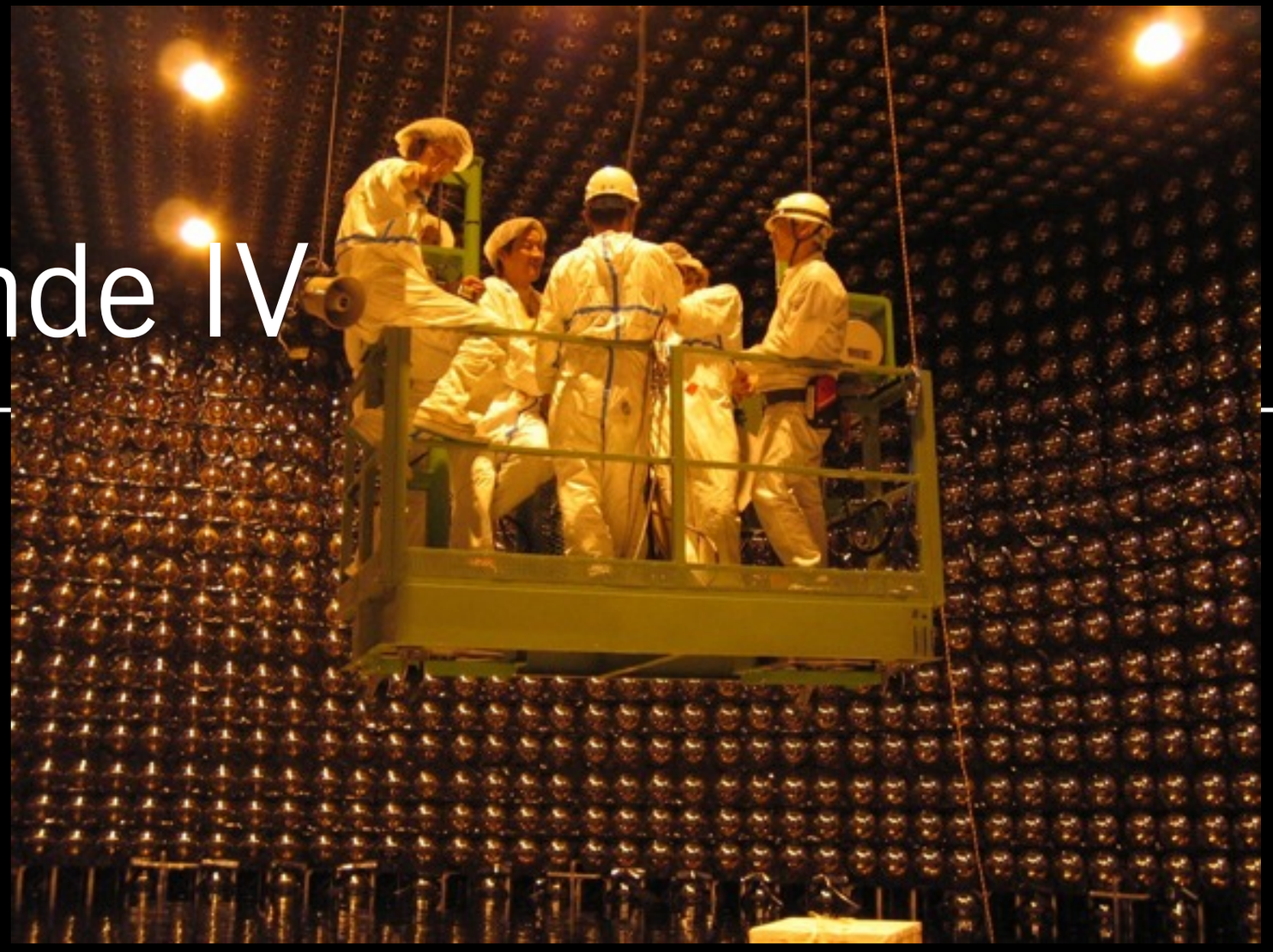
- Widespread use of solid-state multi-pixel photon counters (MPPC) in the near detector
  - Standard MPPC for all detector elements: 1.3×1.3 mm^2 module specifically designed for T2K fibers
  - 667 50 μm pixels



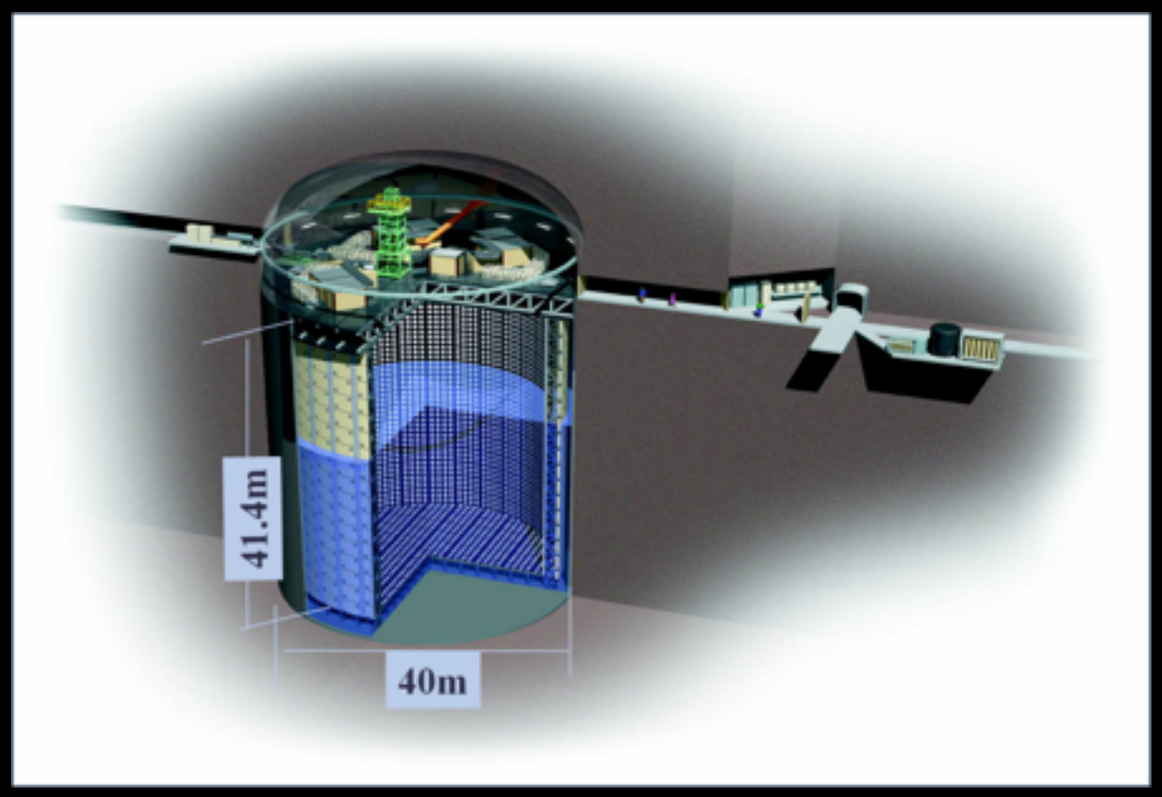


- “Wireless” TPC: Strong local field at the novel MicroMegas mesh creates avalanche of electrons read out on 7.0x9.8mm^2 pads

Far detector: Super Kamiokande IV



- 50 kt water Cherenkov (22.5 kt fiducial)
- 11129 20-inch PMTs in inner detector; 1885 8-inch PMTs in outer veto detector

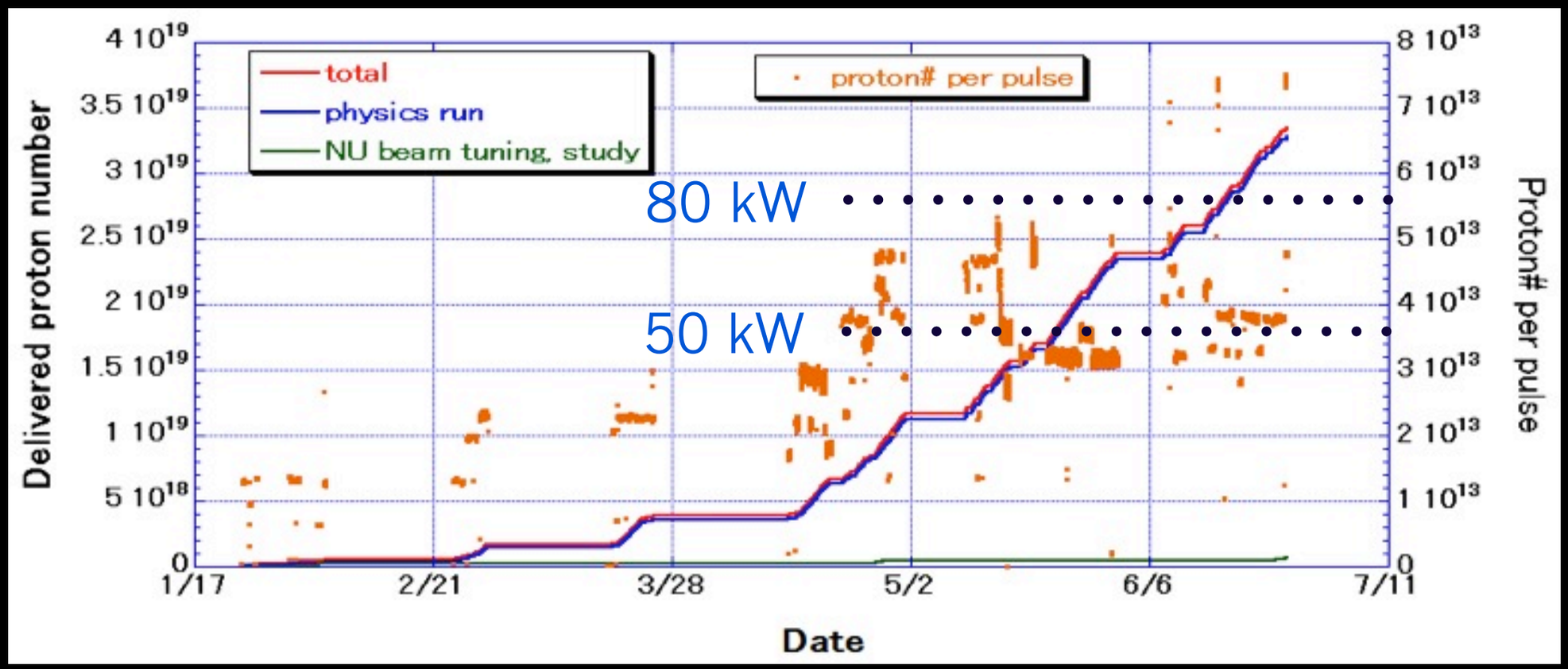


- New readout electronics commissioned in 2009: new system has no dead time
- GPS-based time stamp on beam is transmitted to SK, which records all activity within 500 μs of pulse
- See SK talk for more information

First proton beam on target
April 2009

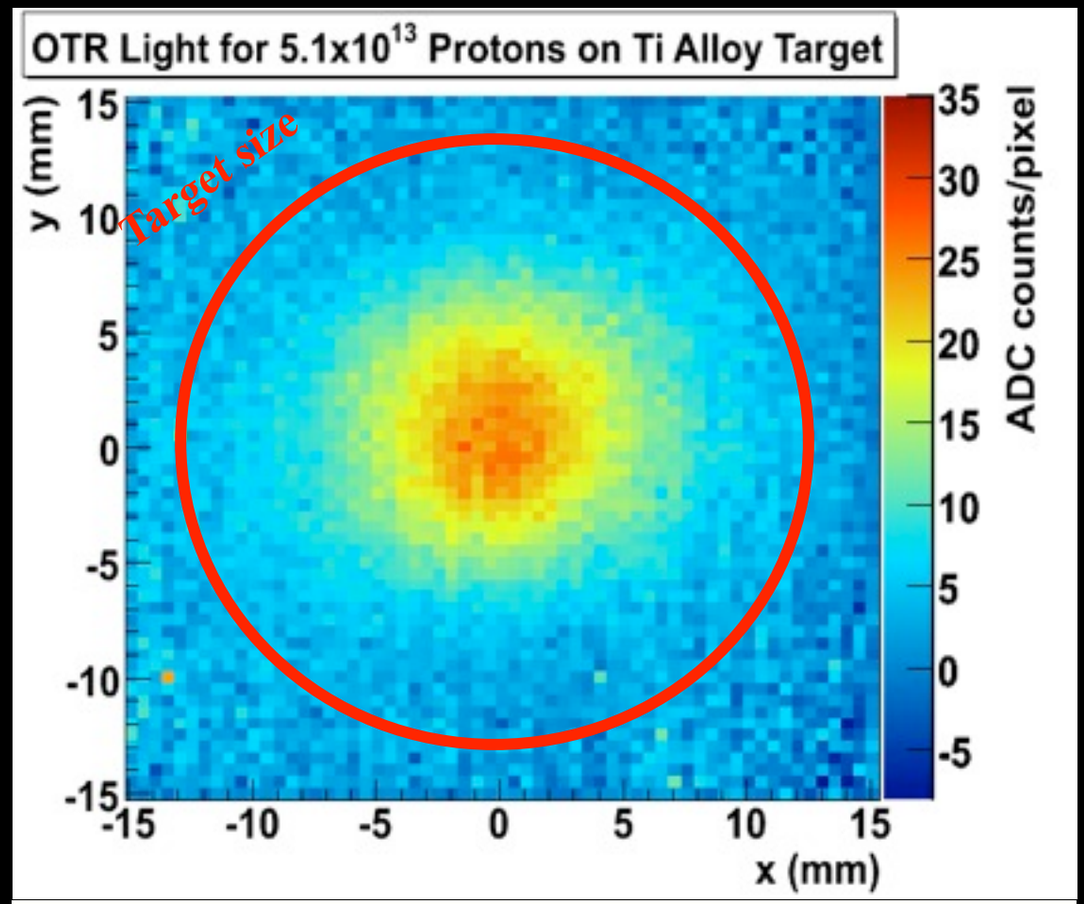
First neutrino physics run

- Operated January-June 2010
- Beam power up to 100 kW (most running around 50 kW)
- Accumulated $3.29 \cdot 10^{19}$ protons on target ($16\ \text{kW} \cdot 10^{7}$ s) in physics configuration with all detectors working



First neutrino physics run: Primary beam

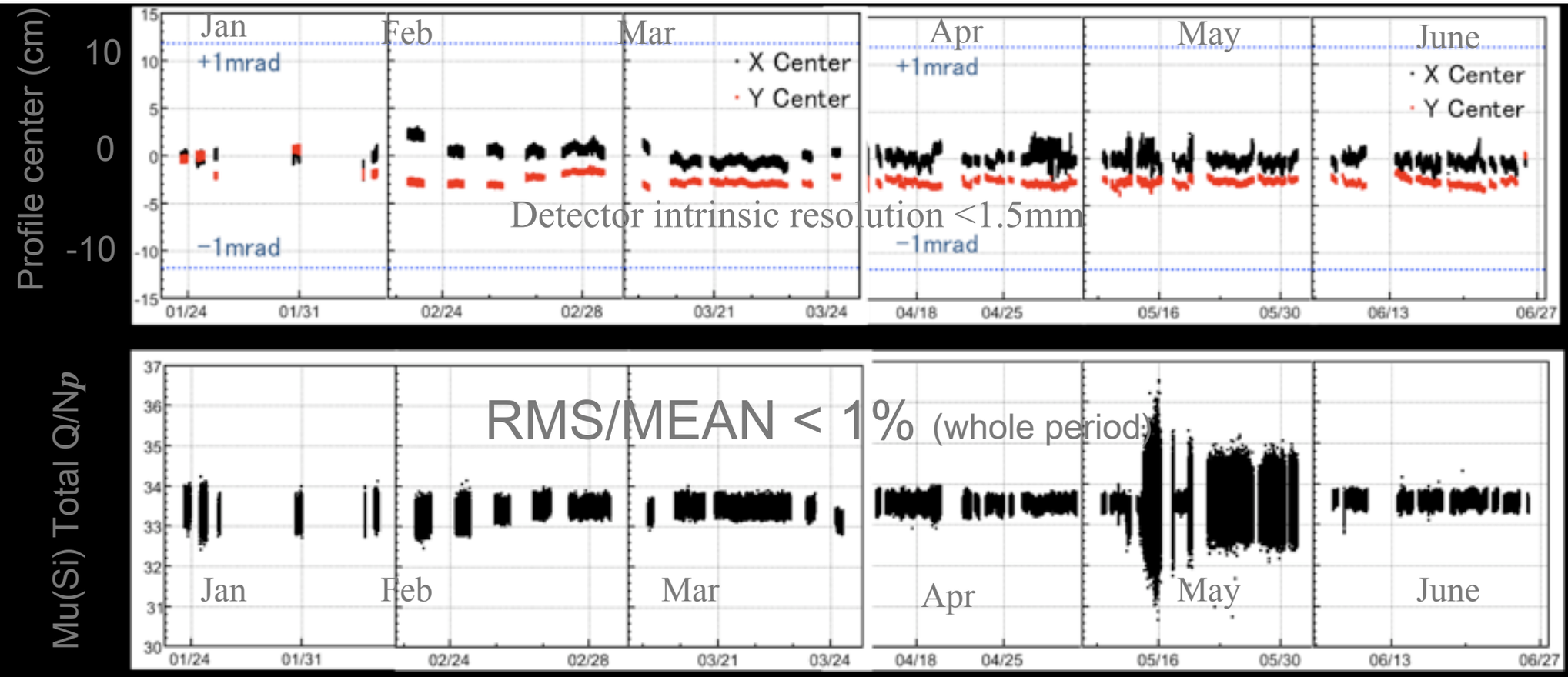
Beam orbit is tuned within 2mm from design orbit. (Critical for controlling beam loss)



Optical transition radiation detector (OTR) immediately upstream of target:

See poster by M. Hartz.

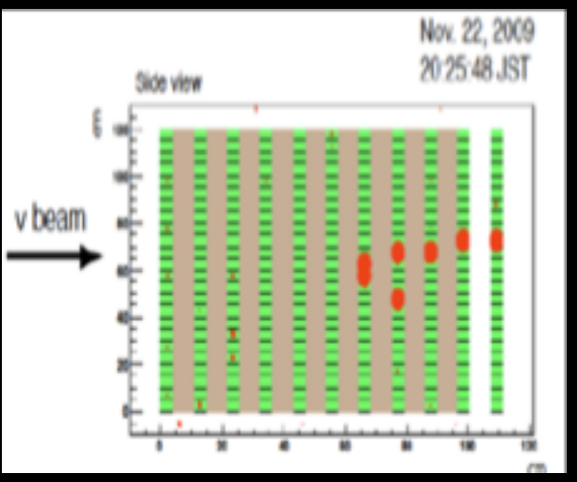
First neutrino physics run: muon monitor

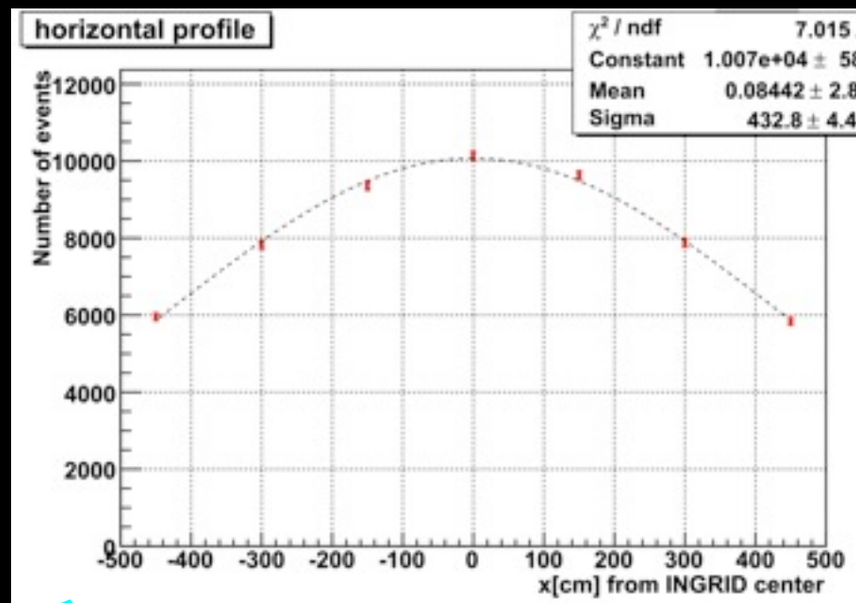


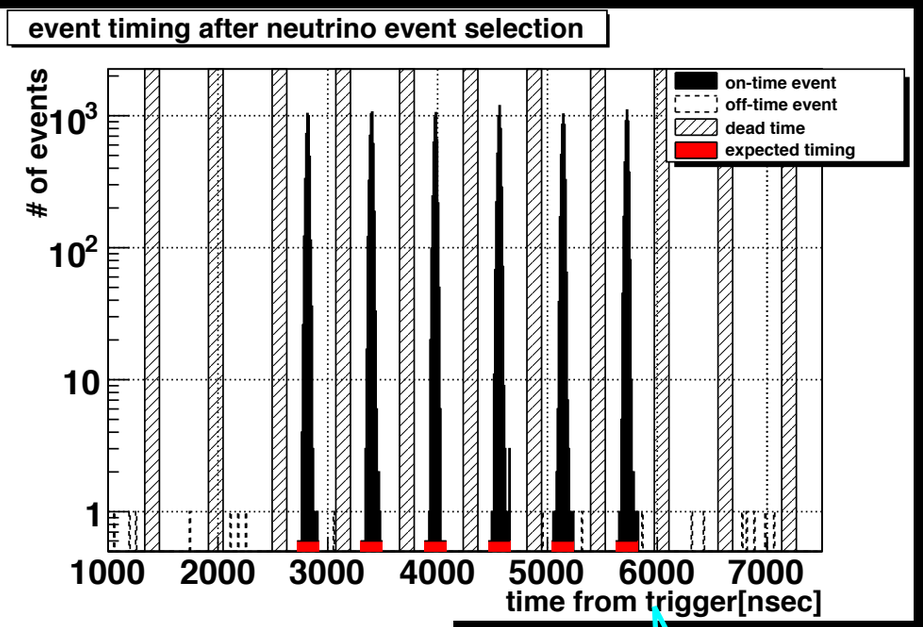
- Muon monitors:
  - Silicon detectors and ionization chambers downstream of hadron absorber
  - Additional emulsion detectors during commissioning runs
- Direction stable to <1 mr
- Secondary/primary beam intensity ratio stable to 1%

First neutrino physics run: On-axis neutrino monitor (INGRID)

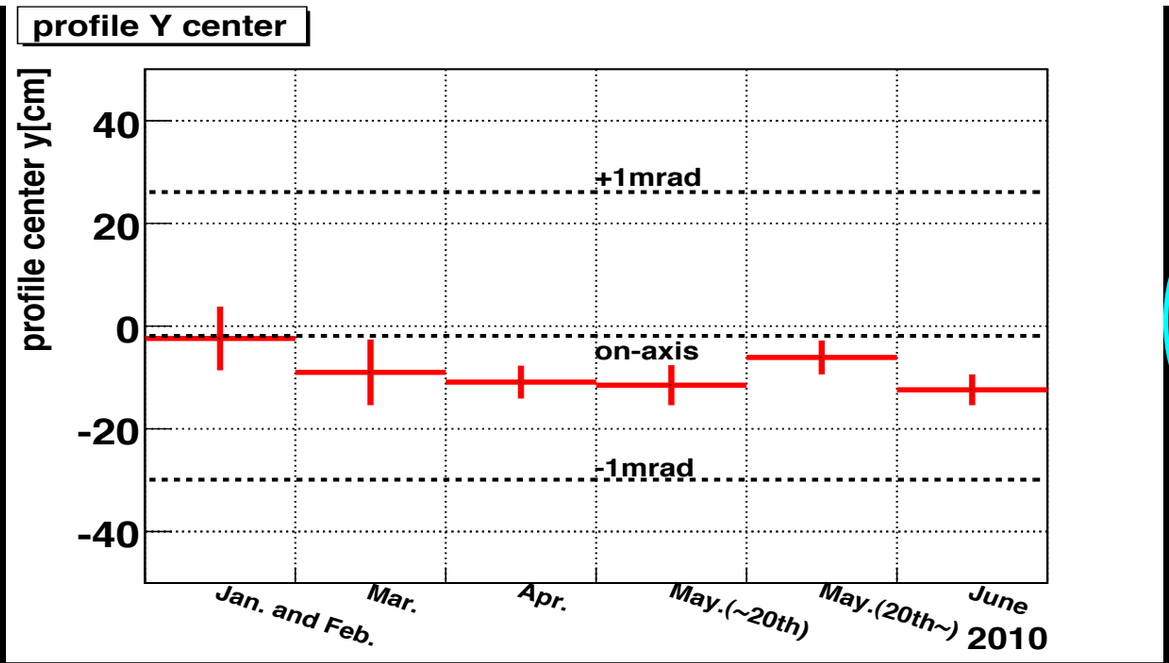
The first INGRID neutrino candidate







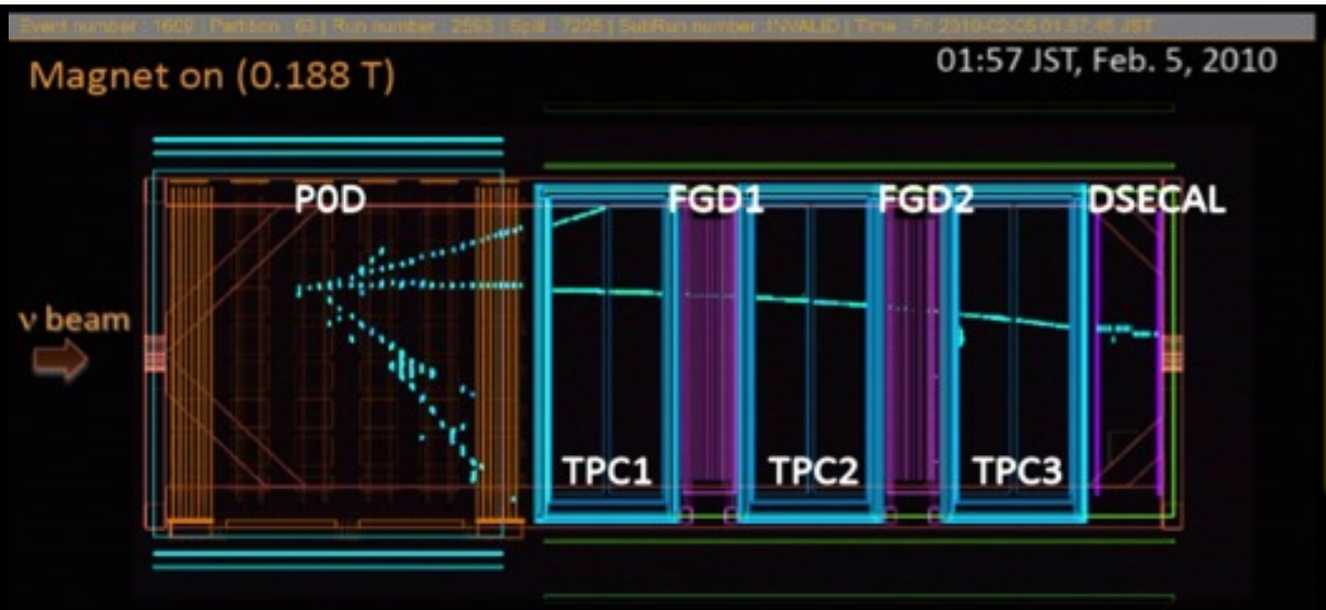
Neutrino event rate shows good symmetry: detectors and beam working well

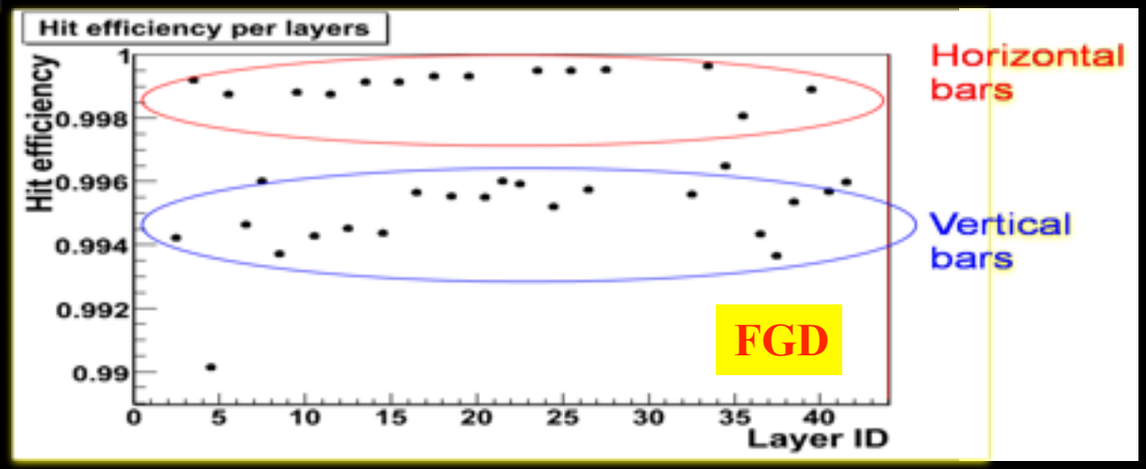


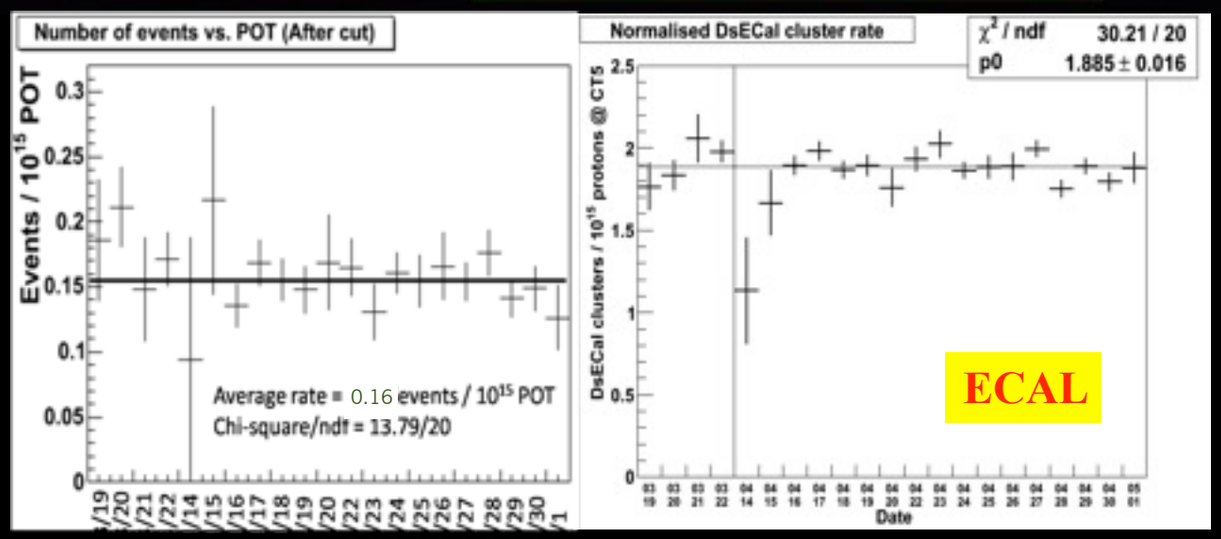
Neutrino timing distribution shows six-bunch structure of primary proton beam

Beam profile center is within 1 mrad requirement

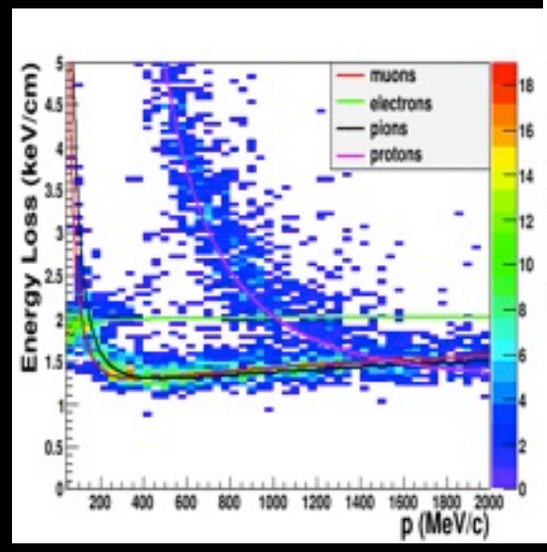
First neutrino physics run: Off-axis neutrino detector

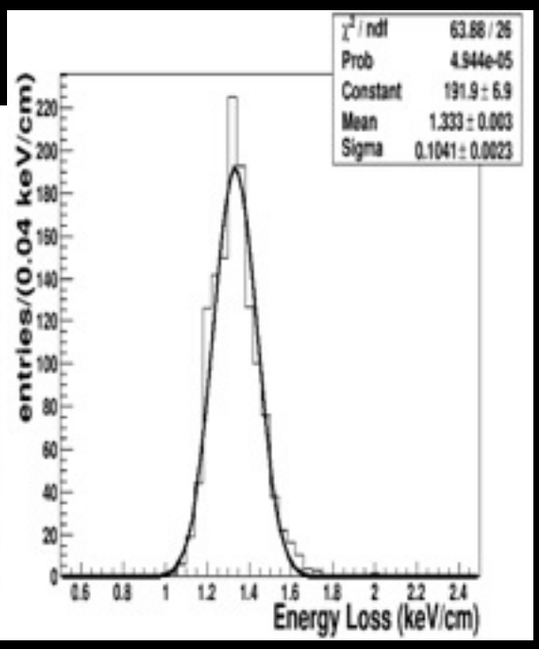






dE/dx from TPC





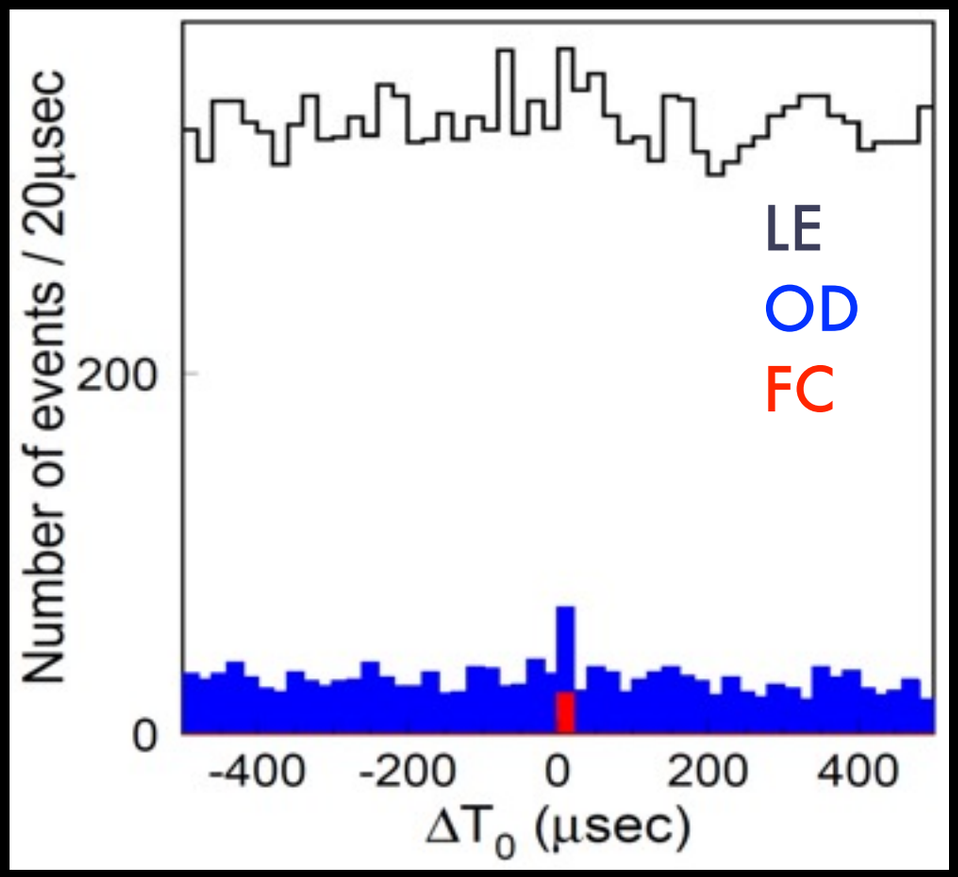
- Detectors are performing well

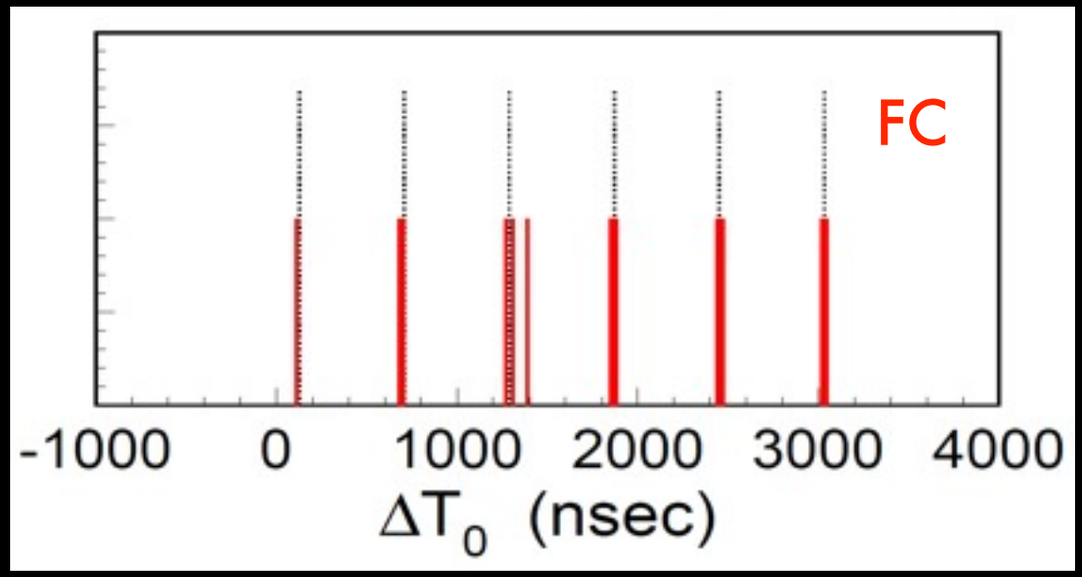
First neutrino physics run: Super-Kamiokande

- J-PARC neutrino events selected by event timing using GPS
- SK analysis is very well established
- Event selection & cut values fixed before data collection for this run

For ν_μ disappearance analysis	For ν_e appearance search
Timing coincidence w/ beam timing (+TOF)	
Fully contained (No OD activity)	
Vertex in fiducial volume (>2m from wall)	
Evis > 30MeV	Evis > 100MeV
Number of rings =1	
μ-like ring	e-like ring
	No decay electron
	Forced 2nd ring: $m_{\gamma\gamma}$<105 MeV
	E_ν^{rec} < 1250MeV

First neutrino physics run: Super-Kamiokande



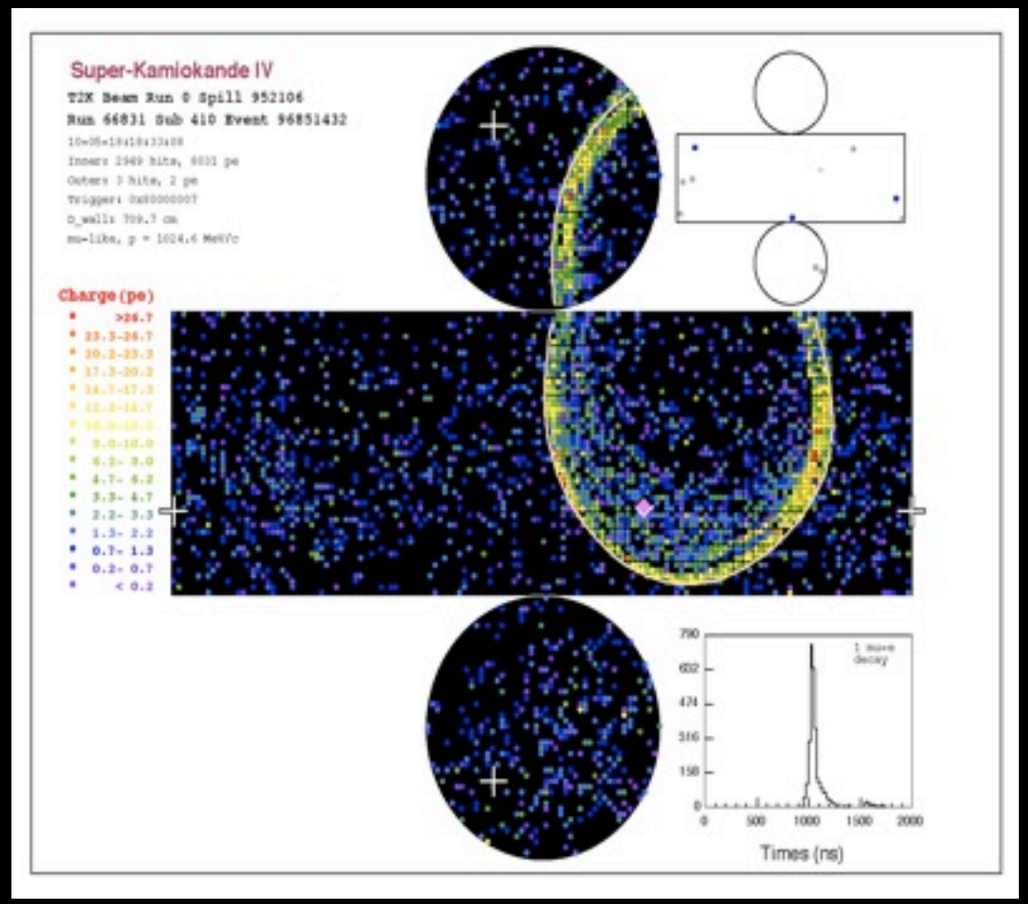


LE: Low energy triggered events
OD: Outer detector events
FC: Fully contained events

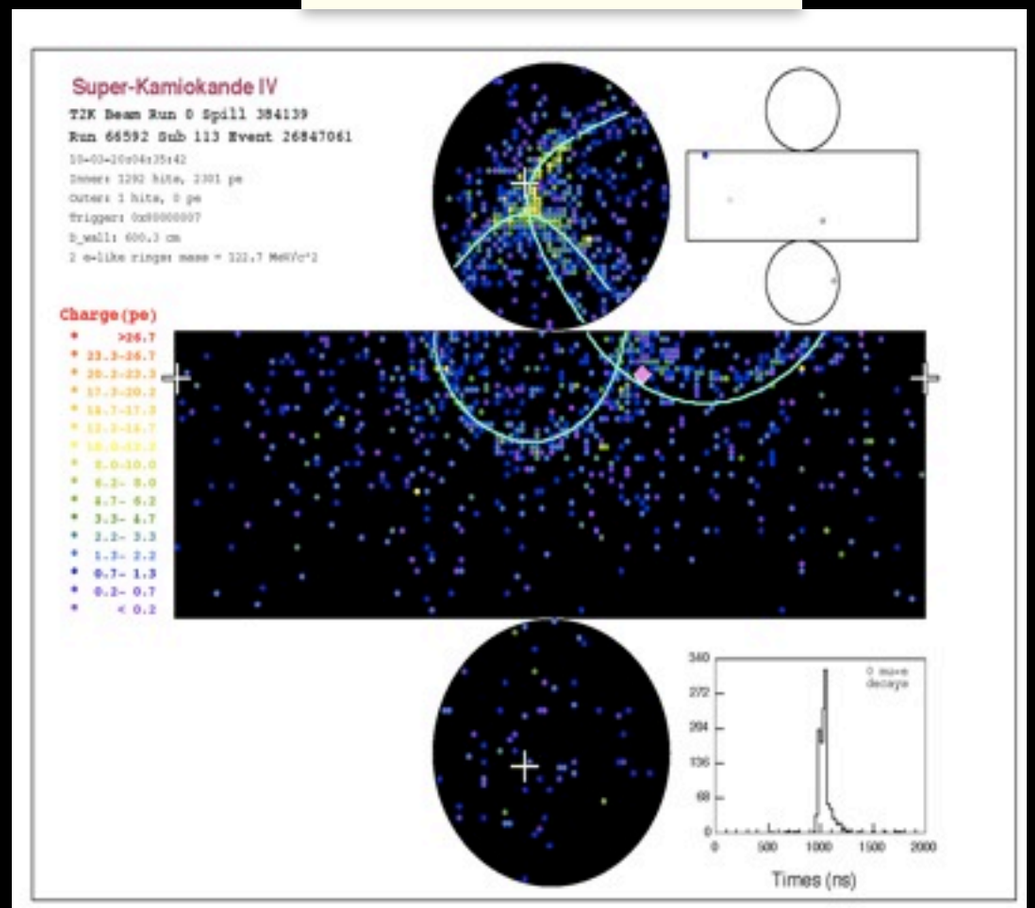
- Event time distribution clearly shows six-bunch beam structure
- Observed # of fully contained events: 22 (by mid-May)
- Expected non-beam background: $<10^{-3}$ events

T2K neutrino events

Single-ring μ-like event



Two-ring event



- Pink diamonds are placed on the wall in the beam direction starting from the reconstructed vertex.

Analysis strategy

- Predict neutrino fluxes using:
  - GEANT3-based beam MC
  - Hadron production measurements from NA61

See talk by
A. Bravar this session

- Near detector analysis:
  - GEANT4-based detector MC
  - Measure beam flux × cross section at near detector
  - Compare to prediction

- Propagate near detector constraint to far detector using data/MC ratio and near→far flux transfer matrix developed from beam MC:
  - Predict event rates and spectra at Super-Kamiokande

- Far detector analysis:
  - GEANT3-based Super-K detector MC
  - Measure event rates, spectra
  - Compare to unoscillated prediction→fit results to oscillation hypotheses

T2K's next steps

- Summer-fall 2010 shutdown underway
  - New kicker magnets and power supply (8 bunches)
  - New horn power supply (250 kA → 320 kA)
  - Barrel ECAL installation
- Resume data collection in November 2010
  - Plan 100 kW and higher
  - Increase steadily toward design intensity

T2K physics goals

- Accumulate 3.75 MW·10^7 s beam on target
- Discover ν_e appearance:
  - $\sin^2 2\theta_{13}$ down to ~0.018 (3σ), ~0.008 (90%CL)
    - Precise sensitivity depends on systematic errors and Δm_{23}^2
- Precise measurement of ν_μ disappearance:
  - $\delta(\Delta m_{23}^2) \sim 1 \times 10^{-4} \mathrm{eV}^2$, $\delta(\sin^2 2\theta_{23}) \sim 1\%$