Status report from T2K

- **First T2K results**
- **Swiss contribution**

F. Juget

Albert Einstein Center for Fundamental Physics

Laboratory for High Energy Physics

Bern University

2010 CHIPP Annual Plenary Meeting

23/24 August 2010 – Gersau

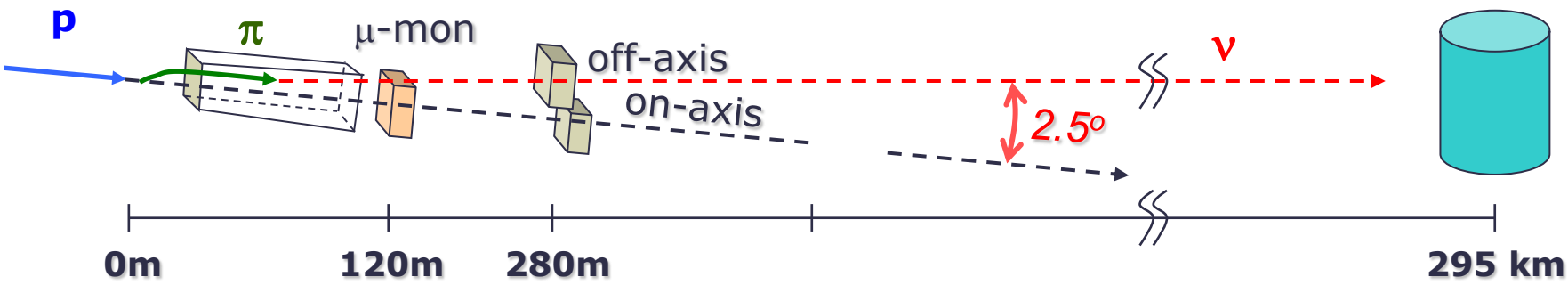
T2K (Tokai to Kamioka) experiment

- High intensity ν_μ beam from J-PARC MR to Super-Kamiokande @ 295km
- **Discovery of ν_e appearance → Determine θ_{13}** $\sin^2 2\theta_{13} \sim 0.008$ (90%CL)
  - **Last unknown mixing angle**
  - **Open possibility to explore CP violation in lepton sector**
- **Precise meas. of ν_μ disappearance → θ_{23}, Δm^2_{23}**

$\delta(\sin^2 2\theta_{23}) \sim 0.01$

$\delta(\Delta m^2_{23}) < 1\times10^{-4}$ [eV^2]

Experimental setup



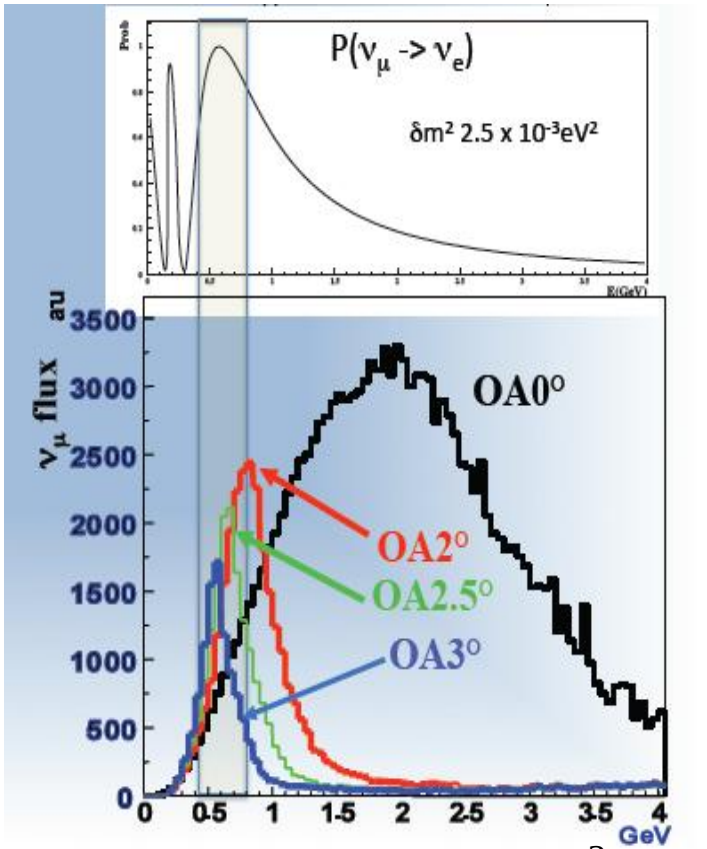
- **2.5 degrees off-axis beam**
  - Low energy, narrow band beam tuned at oscillation maximum
  - Neutrino peak 600 MeV/c
- **MUMON** @ 120 m from target

⇒ measures the beam direction (precision better 1 mrad)

  - Monitor spill by spill the beam direction looking at high energy muons
- **Near detector @ 280 m from target**

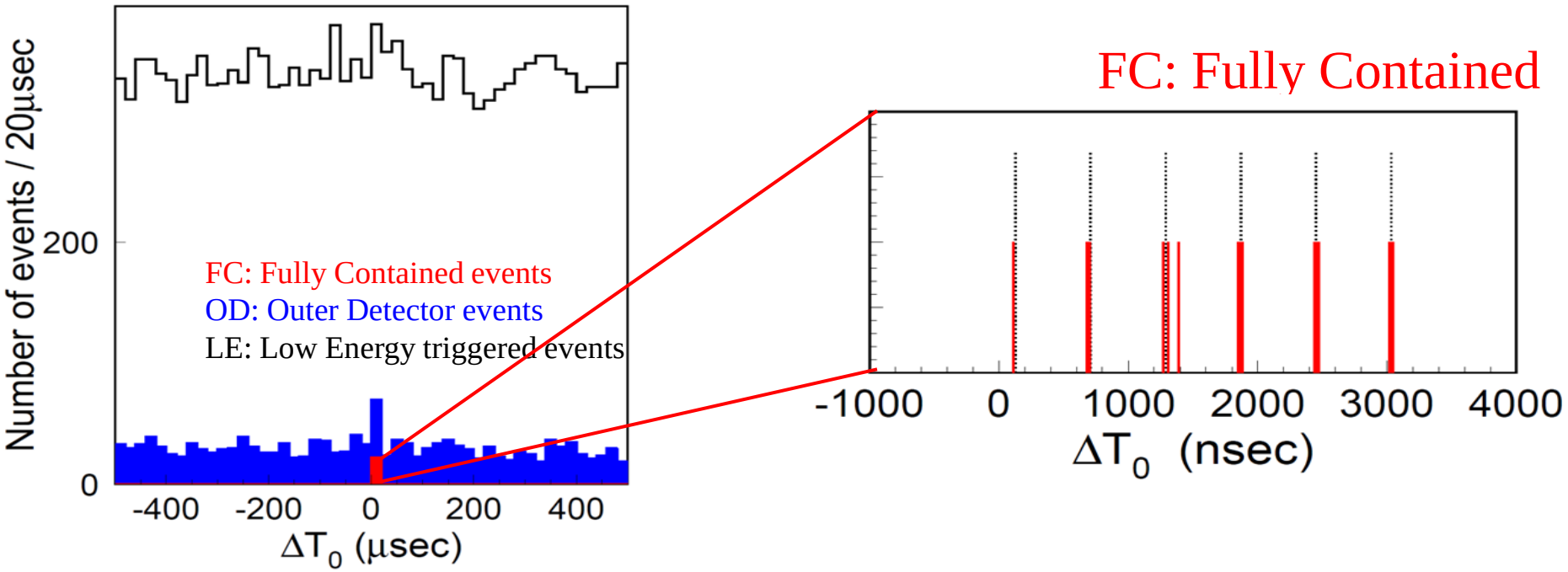
⇒ extrapolate the ν energy spectrum and flux to SK

  - **INGRID:** on axis to monitor beam direction
  - **ND280:** off axis to measure ν_μ and ν_e interaction rates and kinematics
- **Far detector SuperKamiokande @ 295 km**
  - Very large water Cerenkov detector
  - Very good μ/e separation capability



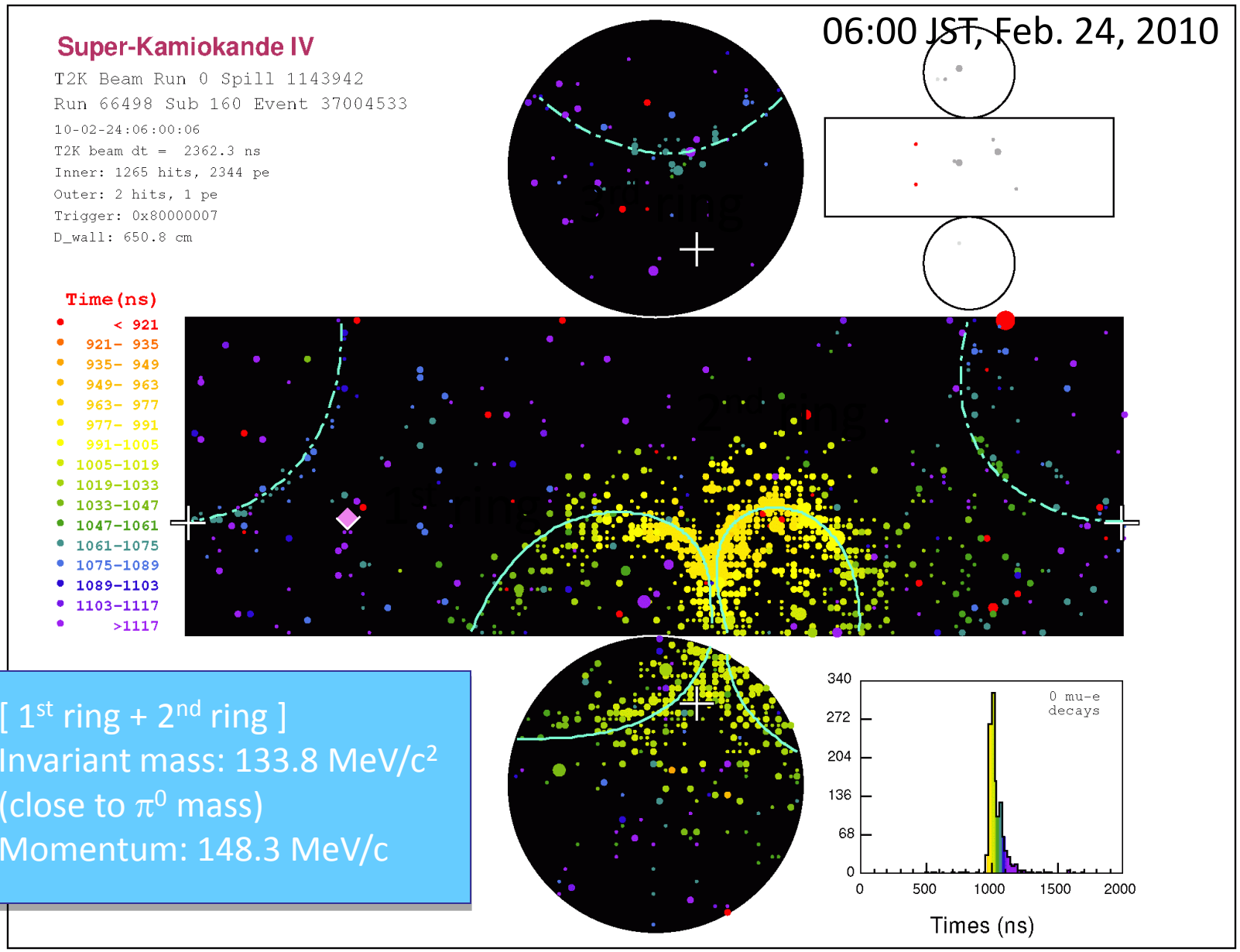
First neutrino physics run

- 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



- Event time distribution clearly shows 6-bunch beam structure
- Observed # events: 23 (FCFV: Fully Contained + Fid.Vol. + E_{vis} >30MeV)
- Expected non-beam BG: $<10^{-3}$evts

T2K 1st neutrino event in Super-K



[1st ring + 2nd ring]
Invariant mass: 133.8 MeV/c^2
(close to π^0 mass)
Momentum: 148.3 MeV/c

Summary and next steps

- Construction completed March 2009 (on schedule)
- First beam on 23 April, 2009

- **Data recording for oscillation studies started in Jan. 2010**
  - Stable operation at ~50kW power intensity
  - 3.294E19 protons delivered (16 kW·10^7 s)
  - 23 FCFV events observed in SK (far detector)

- **Summer-Fall 2010 beam shutdown**
  - New kicker magnet and power supply (8 bunches)
  - New horn power supply (250 kA → 320 kA)
  - ⇒ from ~100 kW, increase steadily toward design intensity 0.75 MW

- **Resume data taking November 2010**

- **Physics goals:**
  - Accumulate 0.75 MW x 5x10^7sec (= 3.75 MWx10^7sec)
    - **$\sin^2 2\theta_{13}$** down to **0.018 (3σ), 0.008 (90%CL)**
    - **$\delta(\Delta m^2_{32})$~1x10^{-4}eV^2, $\delta(\sin^2 2\theta_{23})$~0.01**

Swiss contribution

ETH Zürich/Geneva/LHEP Bern

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

- A. Rubbia
- A. Badertscher
- A. Marchionni
- A. Curioni
- S. Di Luise
- L. Esposito
- S. Horikawa
- C. Strabel (PhD)
- A. Gendotti
- L. Knecht
- G. Natterer
- V. Pettinacci
- T. Viant

UNIVERSITÉ DE GENÈVE

- S. Bravar
- A. Blondel
- A. Ferrero
- G. Wikström
- J. Argyriades
- F. Dufour
- A. Korzenev
- N. Abgrall (PhD)
- S. Murphy(PhD)
- M. Ravonel (PhD)

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

- A. Ereditato
- A. Ariga
- T. Ariga
- F. Bay (PhD)
- E. Frank (PhD)
- F. Juget
- I. Kreslo
- M. Messina
- U. Moser
- C. Pistillo

Management

A. Rubbia, elected EC member since 2007
A. Marchionni, member of the speaker board
A. Blondel, global analysis coordinator until 2009
A. Ereditato member of the speaker board until 2008

Beam (Geneva/ETH)

- NA61@CERN: pion and Kaon production x-sections to characterize the T2K beam
- Beam Analysis (MC, flux predictions)

ND280 (Geneva/ETH/LHEP)

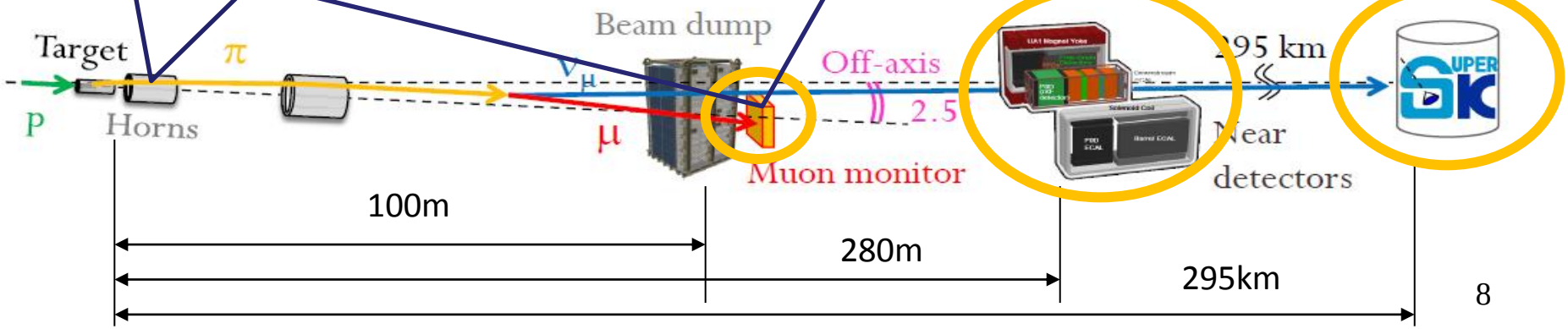
- Magnet project
- B-field measurement
- TPC construction and tests
- Analysis & MC studies

Emulsion tracker (LHEP)

- Absolute muon flux measurement
- Muon angular and momentum distribution
- Cross-check of the Beam MC

SuperK (Geneva)

- Neural network based electron-π^0 separation



Swiss involvement in T2K ν beam group analysis

S. Bravar (U. Geneva): NA61 deputy spokesperson, former convener of the NA61 analysis group

A. Marchionni (ETHZ): co-convener of the T2K beam group, co-convener of the NA61 T2K/CR analysis group

NA61 thin C target analysis: S. di Luise (ETHZ) , S. Murphy (U. Geneva), C. Strabel (ETHZ)

NA61 T2K replica target analysis: N. Abgrall (U. Geneva), L. Esposito (ETHZ)

NA61 reconstruction software: A. Korzenev (U. Geneva)

NA61 MC and T2K JNUBEAM: N. Abgrall (U. Geneva)

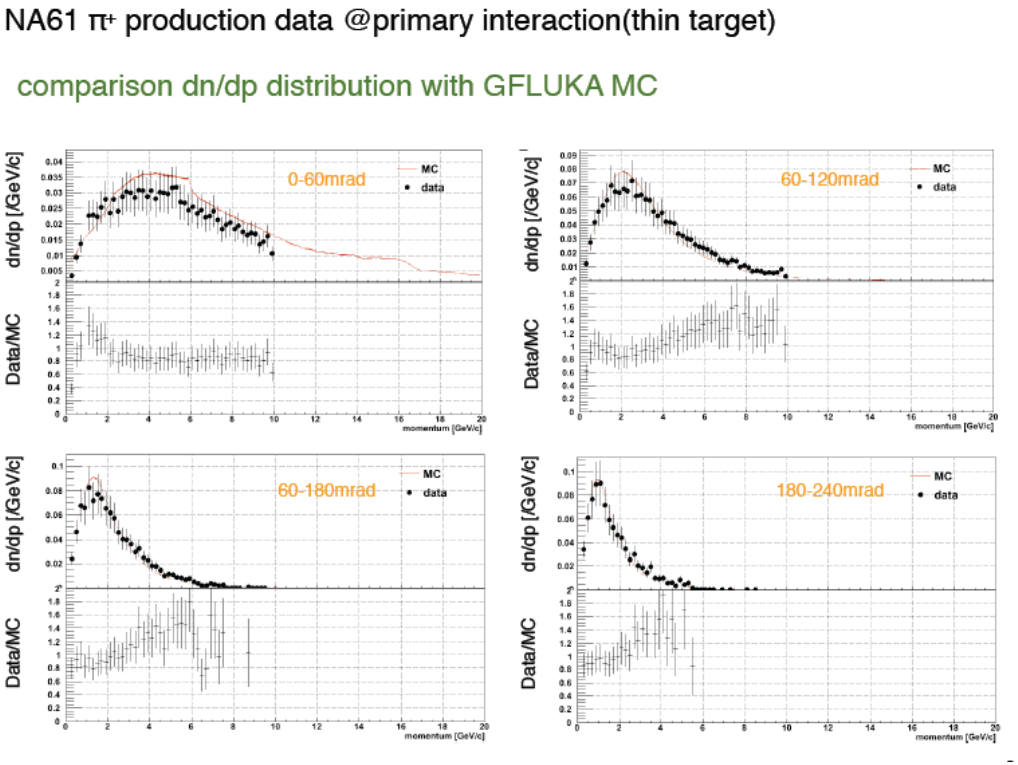
Measurement of muon flux using emulsion: A. Ariga, T. Ariga, F. Juget (U. Bern)

Hadroproduction measurements for T2K

Measurements of π and K production from 30 GeV protons on C

- thin C target 4% λ_I
- 90 cm long T2K replica target

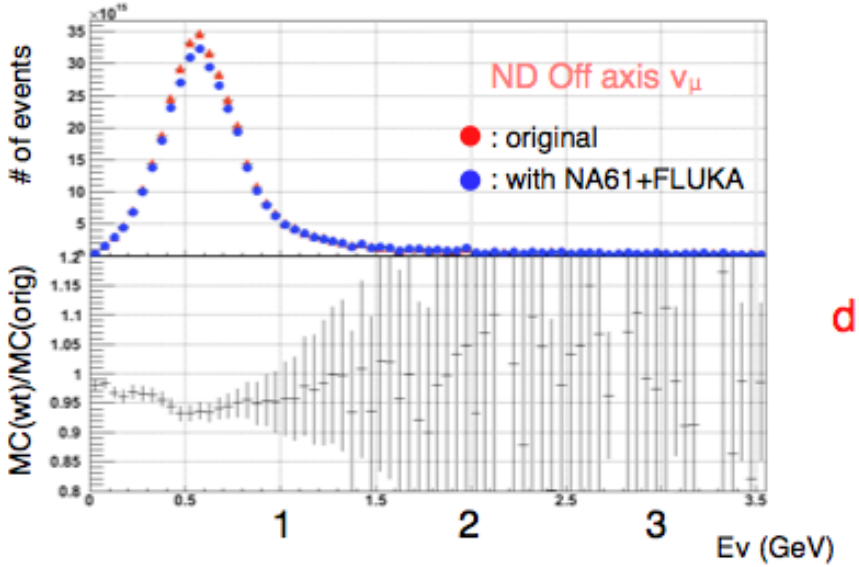
GFluka MC is presently used for the T2K JNUBEAM ν flux generator



- Formulation of T2K requirements for the NA61 data taking
- Use of the NA61 data for T2K ν flux prediction
- Use of additional experimental data (total absorption cross section,…) to constraint absorption of primary produced particles and production of secondary particles from re-interactions

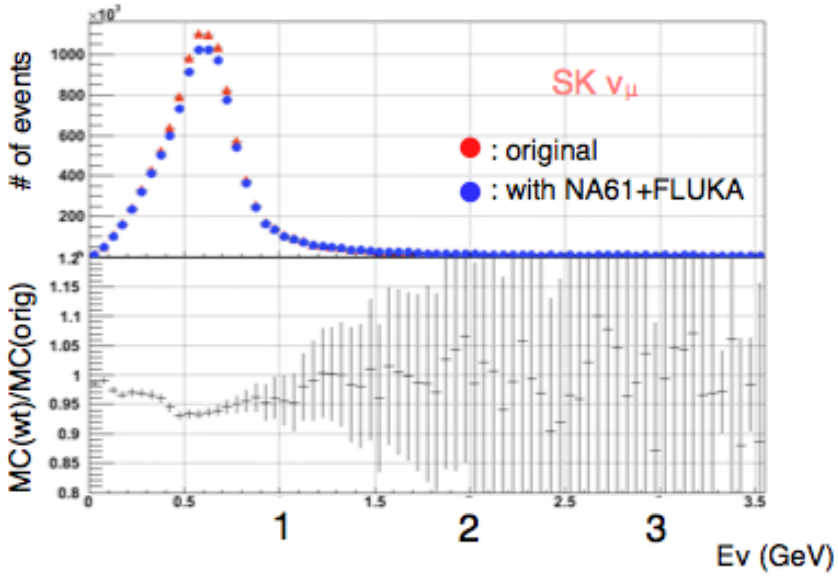
Use of NA61 data in T2K flux prediction

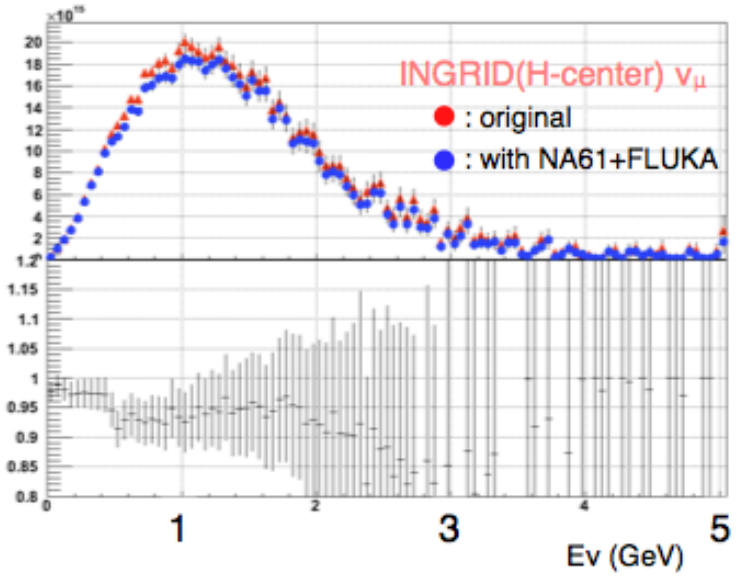
A. Marchionni (ETHZ), co-convener T2K beam group



with dn/dp re-weighting
no correction for $\sigma_{inel.}$

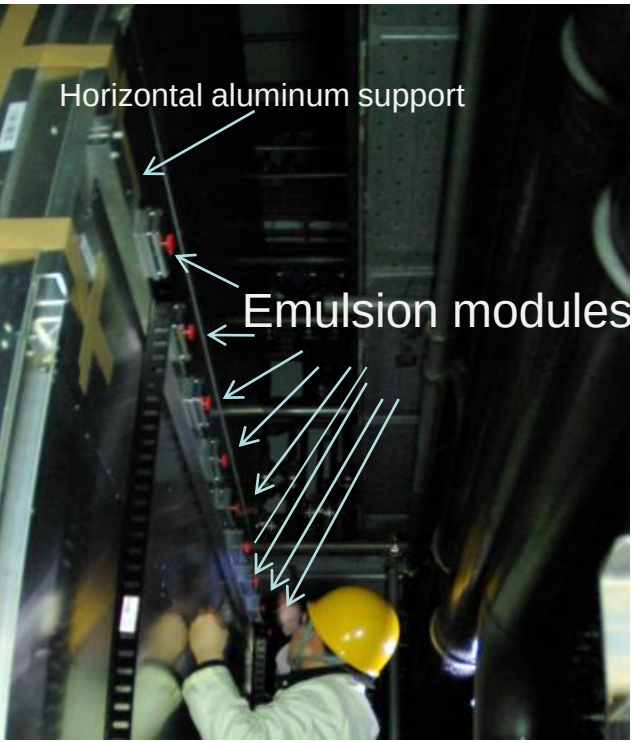
difference due to discrepancy between
NA61+FLUKA and GCALOR
is ~6%@0.5GeV
(both ND-off and SK)

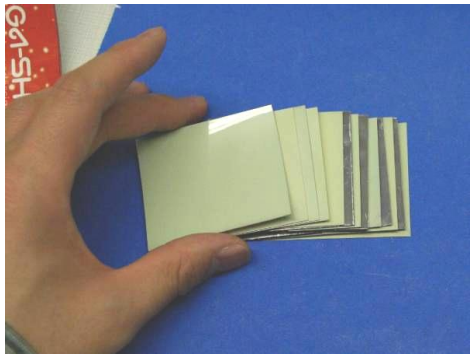




Emulsion tracker

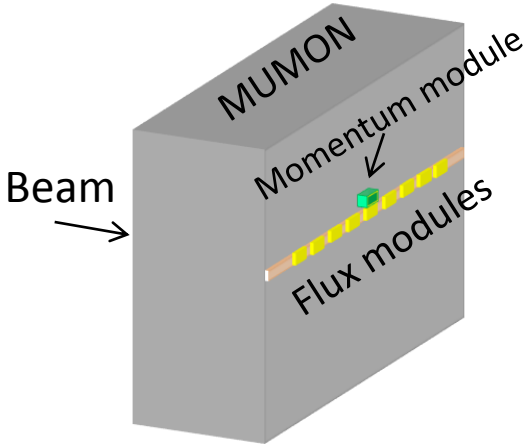
- Measure position, angle and momentum of muons.
  - Absolute flux, angular and momentum distribution.



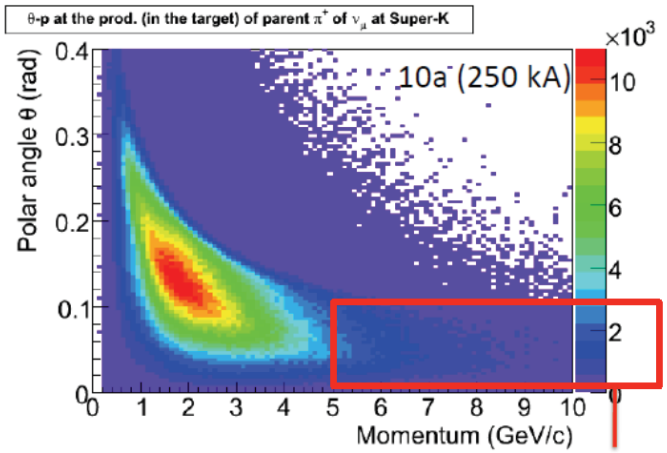


2nd emulsion exposure was done (run31, 18th Mar 2010)

- 9 flux modules + 1 momentum module for each shot.
  - Flux modules : 8 films
  - Momentum module : 25 films interleaved by 1mm lead plates.
- 2 shots for horn off (0kA) and 1 shot for horn on (250kA)



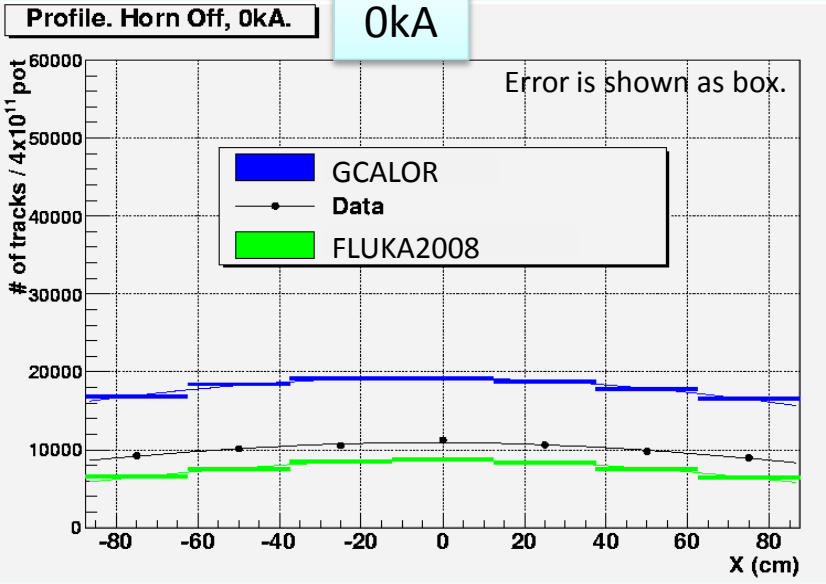
Phase space of pions whose daughter reach SK

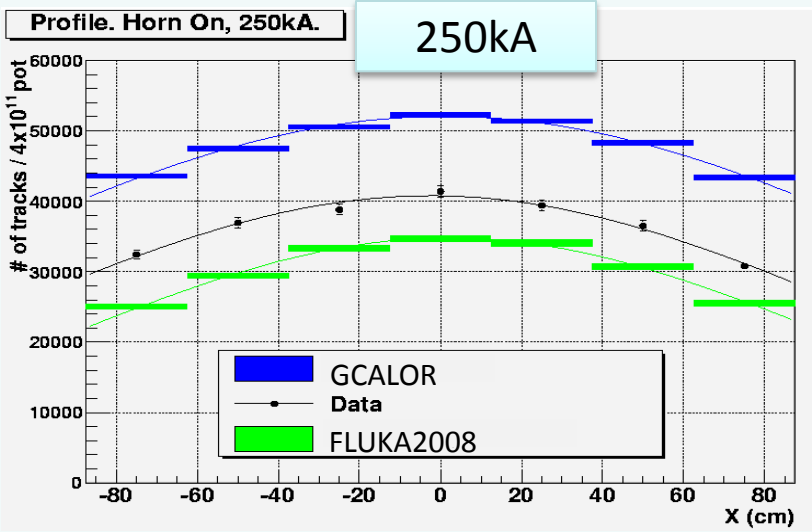


MUMON/Emulsion cover this region

Data from 2nd exposure and comparison with MC (GCALOR and FLUKA)

Absolute muon flux

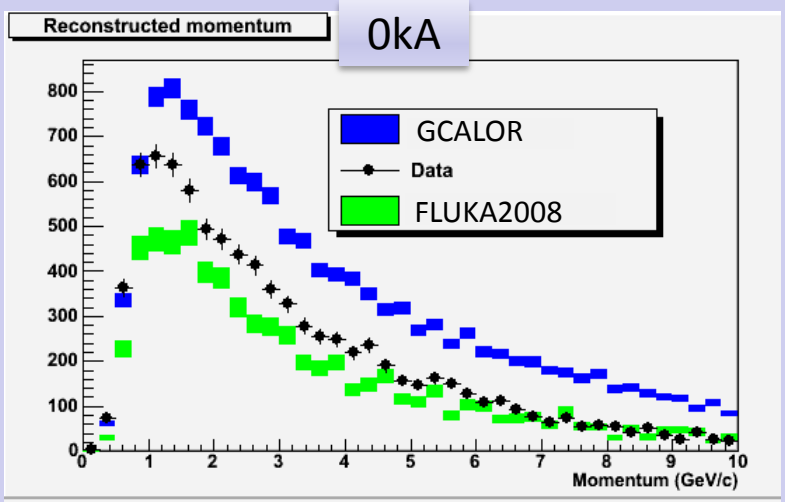




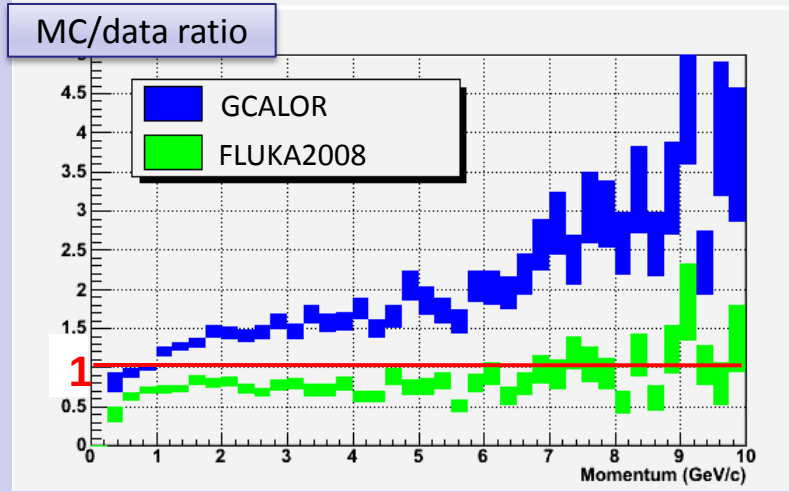
Data is between GCALOR and FLUKA2008.

Momentum distribution

Simulation in emulsion modules was done for MC samples.
Here we compare the reconstructed momentum for both MC and data.



MC/data ratio



- MC/data ratio is increasing by momentum for GCALOR.
- MC/data is fatter for FLUKA2008
  → reproducing similar momentum distribution.

ND280 magnet project

ETHZ group (A. Rubbia, ND280 magnet project leader)

- Refurbishing of UA1/NOMAD magnet and transport to J-PARC (ETHZ/CERN)
- Magnet installation at J-PARC (ETHZ/KEK)
- Magnet engineering + seismic analysis (ETHZ)
- Magnet 3000A power supply (ETHZ/IN2P3)
- Magnet and power supply water cooling system & government inspection (ETHZ/CERN)
- Magnet slow control and safety system (ETHZ/CERN/Barcelona)
- Magnet water & electricity services installation (ETHZ/KEK)

UA1/NOMAD magnet at J-PARC

Slow-control and safety system

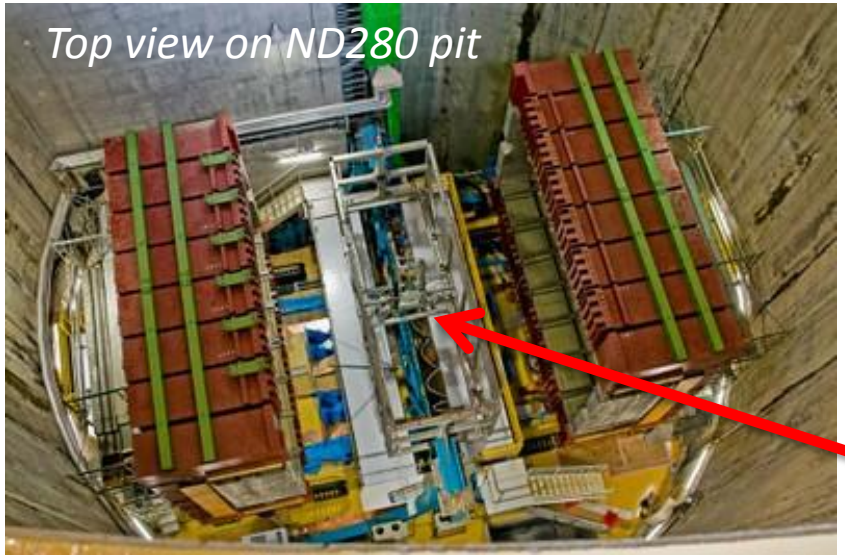
Cooling unit (750kW) built in CH/D

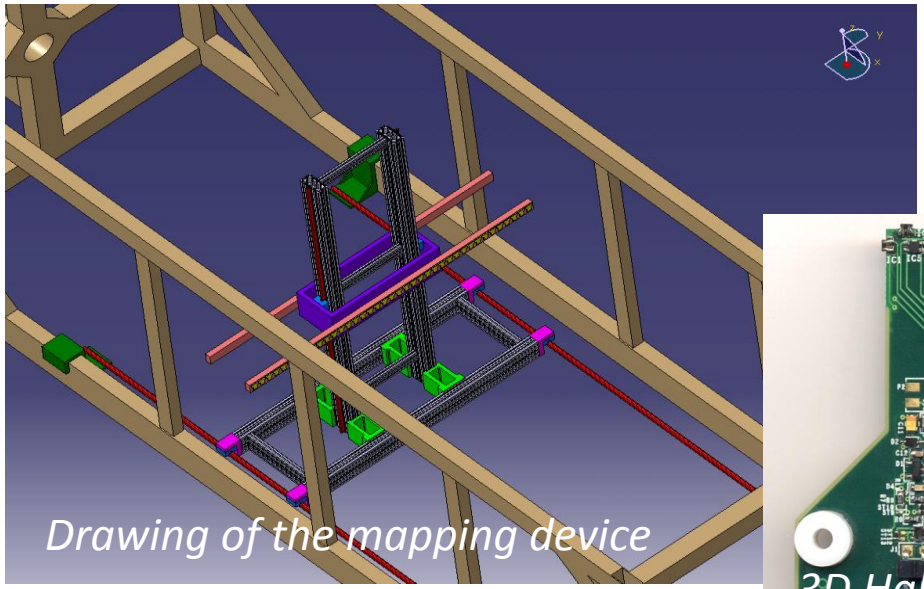
- From March-June 2010 the magnet was continuously operated 24/7 magnet during neutrino beam operation at B=0.18 T → On-call in-situ 24/7 magnet expert shifts (shared by Bern/ETHZ), next run foreseen from November 2010→July 2011
- Magnet data quality control → ND280 good runs list (ETHZ)

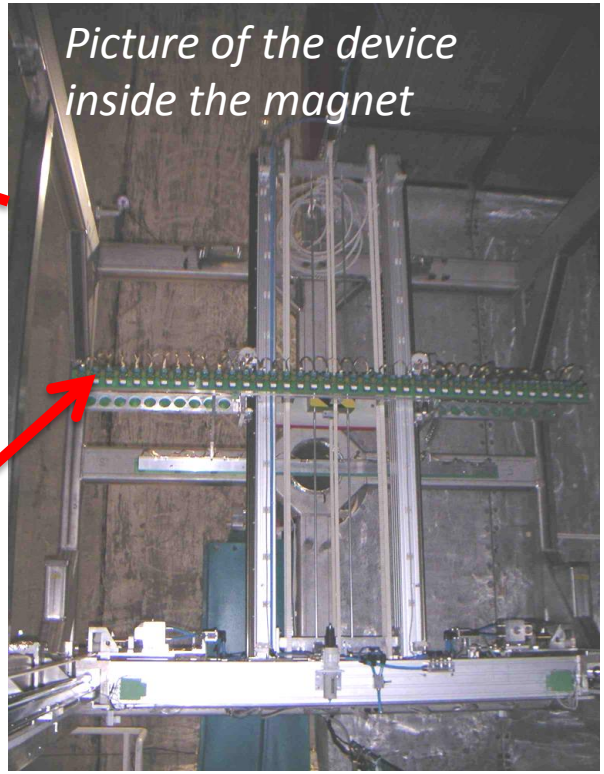
B-Field mapping device

Bern LHEP group (in collaboration with CERN)

- Device movable inside the magnet
- 89 3D Hall probes
- driven by pneumatic motors
- constructed in cooperation between CERN and LHEP Bern

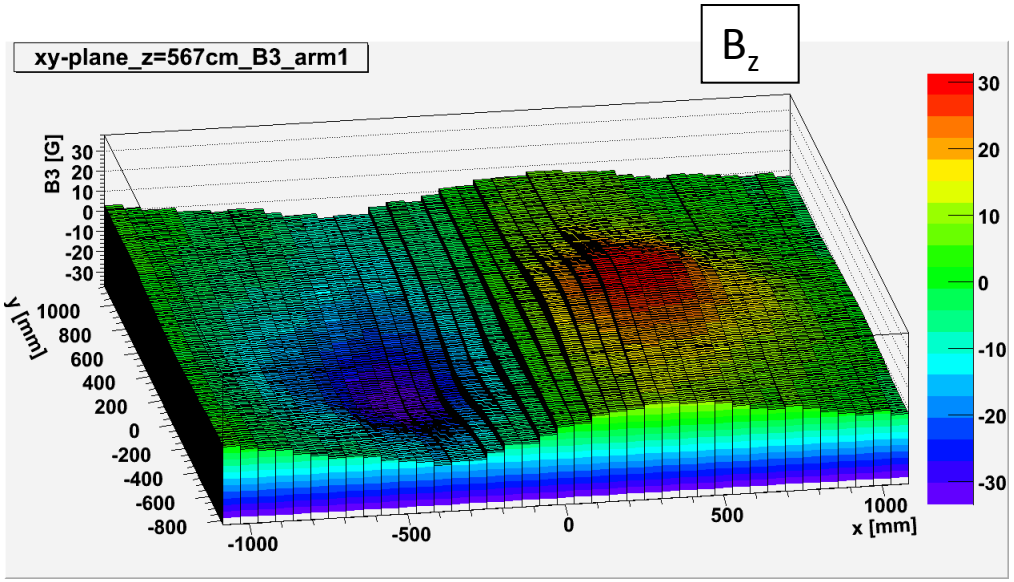




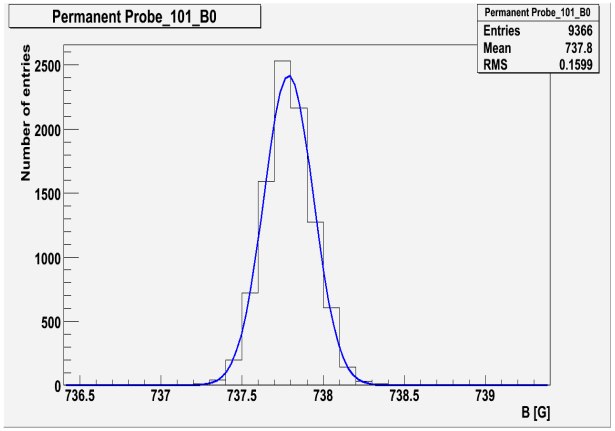


B-Field mapping performance

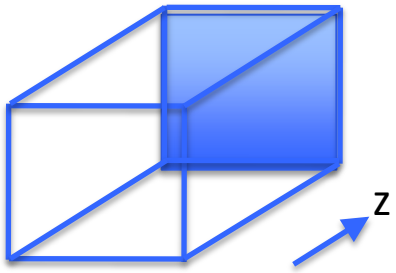
E. Frank, M. Messina, F. Bay (LHEP Bern)



Example xy-plane mapped in a region with strongly changing B-Field



Intrinsic uncertainty of probes at the level of ~0.2 G

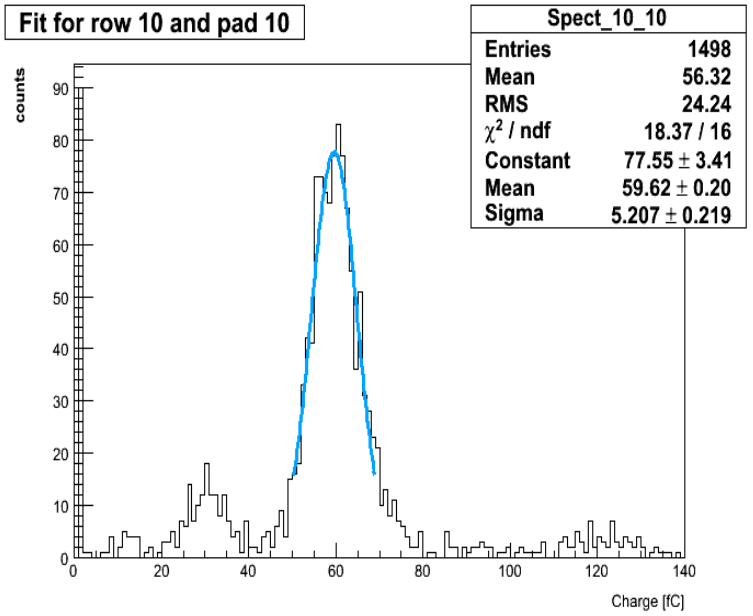


- 2 weeks measurement campaign in Sep 2009 at ~700 G
- Several scans in different regions with a total of more than 10^6 measurement points
- B-Field knowledge at the level of 1 Gauss for the nominal field at ~0.2 T

TPC in ND280

Geneva Group (N. Abgrall, A. Ferrero, D. Ferrere, N. Di Marco, R. Schroeter, G. Wikstroem, A. Blondel, F. Masciocchi, E. Perrin, F. Cadoux, P. Bene)

- Construction, tests and installation of the tracking detector (a TPC with MicroMegas readout)
  - mechanics and the precision mapping of the MicroMegas modules
    - Production and calibration of 84 MicroMegas completed, three TPCs operated routinely. First data recorded since December 2009.



Typical results of a production the Micromegas.

peak from ^{55}Fe : **2% uniformity**

The first TPC module while it is lowered into the ND280 in October 2009

Analysis and MC studies in ND280

- **Geneva group**

- Strong involvement in the data analysis
- CC-interactions workshop in Geneva in July 2010
- Responsible for the ND280 production data base

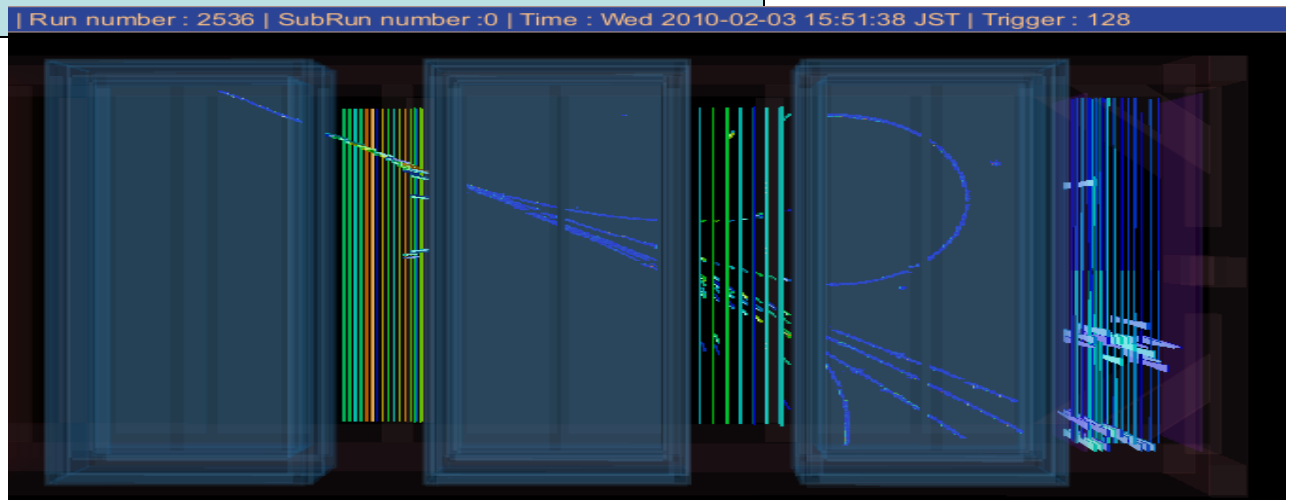
  - **Melody Ravonel**
    - CC interactions in the tracker on quasi-elastic interactions. Improvement of the track's charge reconstruction.
  - **Fanny Dufour**
    - event normalization for Super-K and simulation for event reconstruction
    - Also working on the π^0 bckg rejection in SK
  - **Gustav Wikstroem**
    - development of new code for the tracker, vertex reconstruction and CC interaction

- **Bern group**

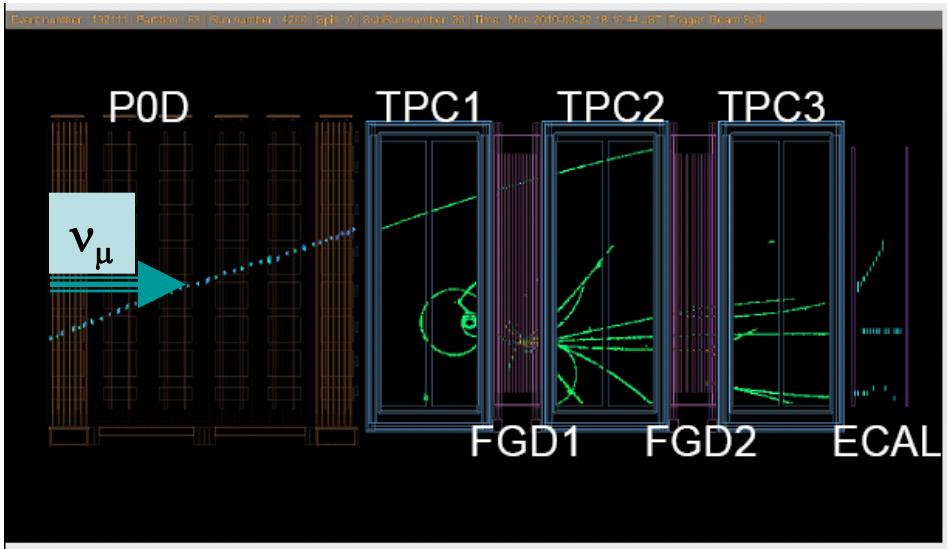
Started recently to work on software

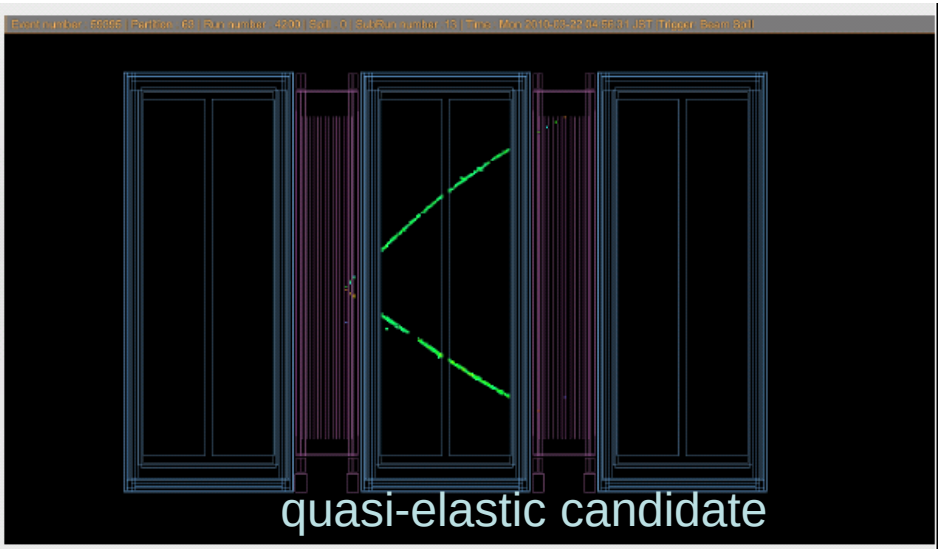
  - **Fatih Bay, Marcello Messina**
    - CC interactions focusing on resonance event (Δ^{++})

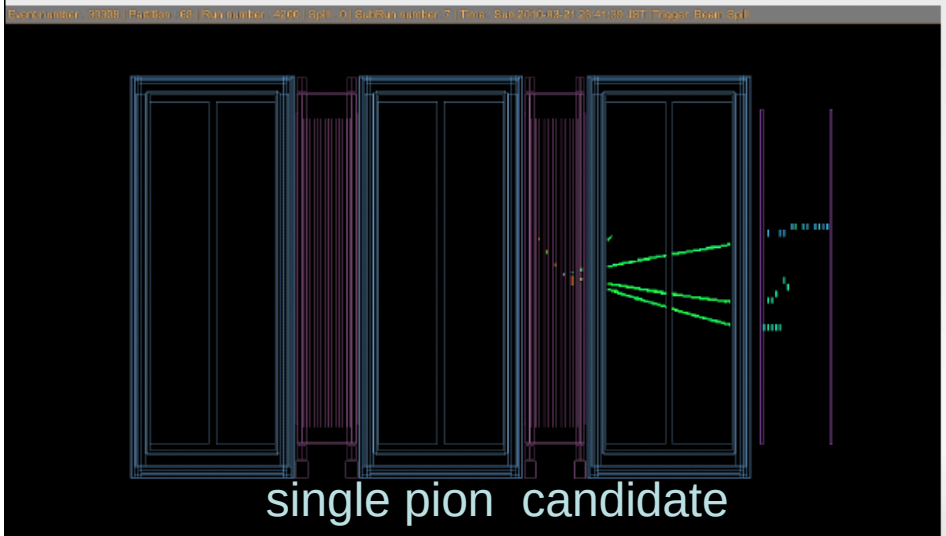
A cosmic ray event in ND280 with magnet at full field, showing tracks in the TPCs

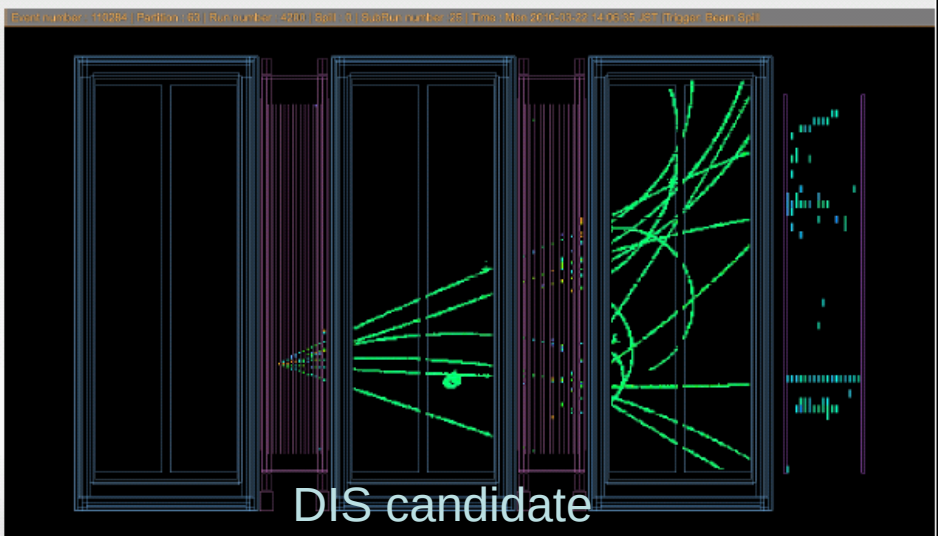


A few ND280 neutrino interaction candidates

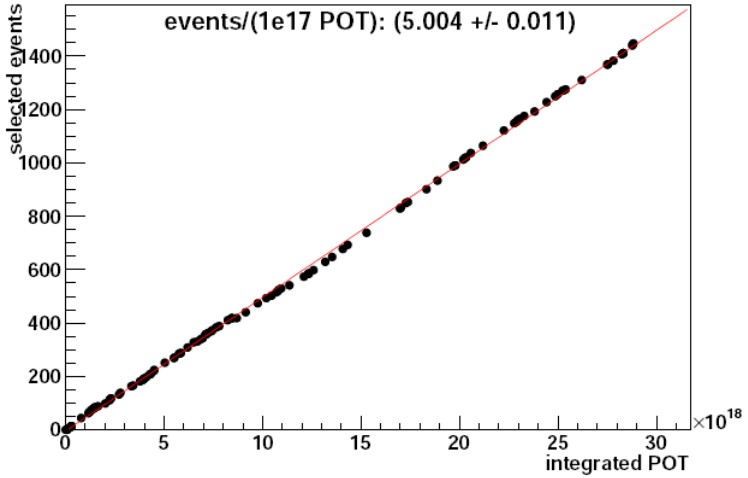



quasi-elastic candidate

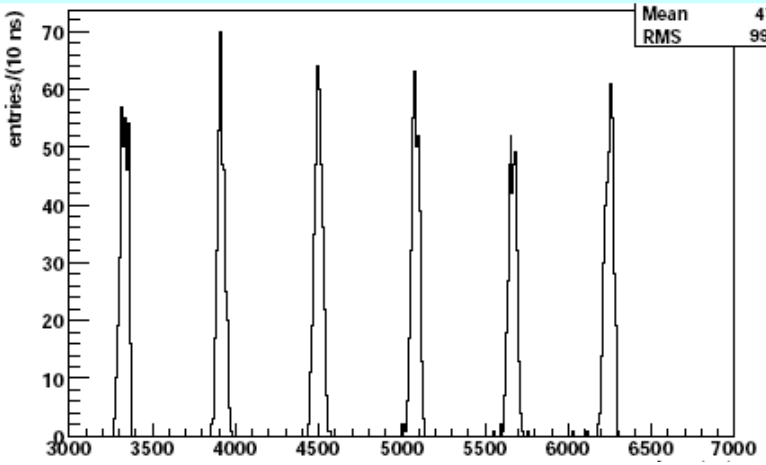

single pion candidate


DIS candidate

Interaction candidates vs p.o.t.



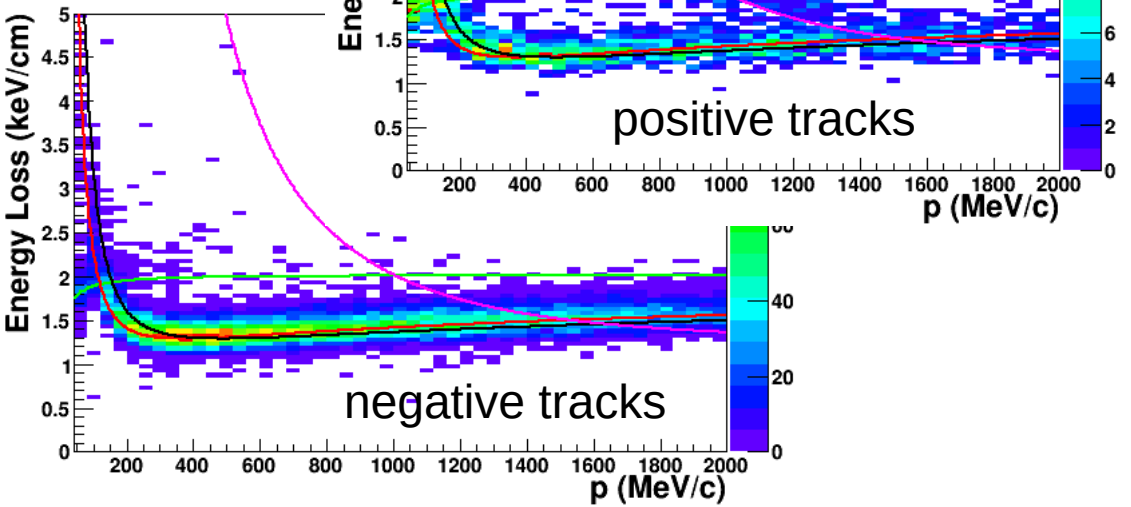
neutrino events time microstructure



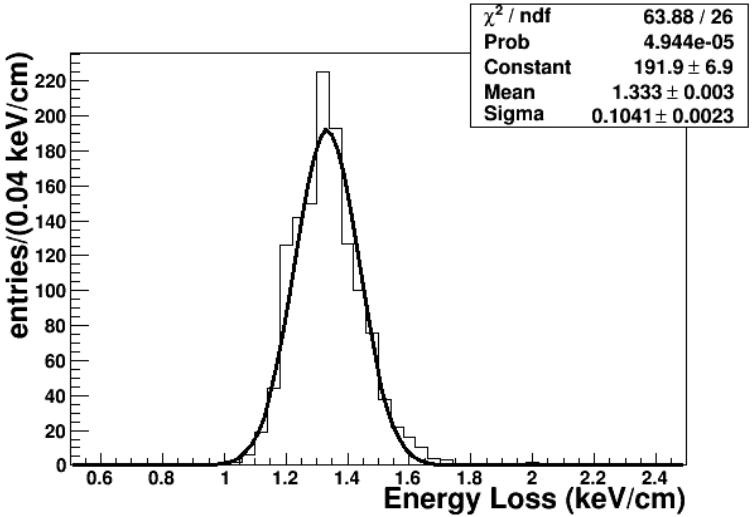
time (ns) in FGD

TPC performance:

dE/dx vs Momentum



MIP dE/dx resolution (now) 8%



Conclusion

- T2K, the first long baseline neutrino superbeam experiment has started taking data. Physics analysis on ν_e appearance (θ_{13}) and precision ν_μ disappearance on going.
- For the swiss groups T2K is the logic continuation of the successful CNGS program: The results of T2K will likely guide the future neutrino program worldwide.

- **Goal:**
  - **Accumulate 0.75MW x 5×10^7sec (=3.75MW$\times10^7$sec)**
  - **Discover ν_e appearance**
    - **$\sin^2 2\theta_{13}$ down to 0.018 (3σ), 0.008 (90%CL)**
  - **Precise measurement of ν_μ disappearance**
    - **$\delta(\Delta m_{23}^2)\sim1\times10^{-4}$eV^2, $\delta(\sin^2 2\theta_{23}) \sim 1\%$**

- **The Swiss groups (ETHZ/Geneva/LHEP Bern) are strongly involved in T2K with key role and scientific visibilty:**
  - **Management, beam study, ND280 detector, data analysis in ND280, SK data analysis**

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

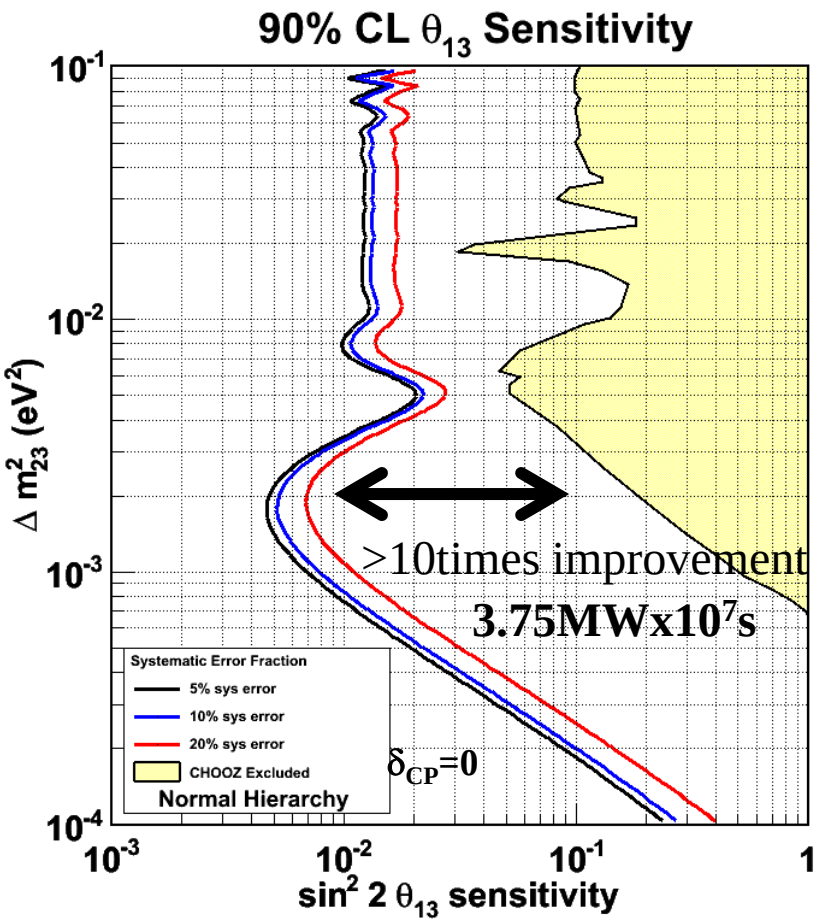
UNIVERSITÉ DE GENÈVE

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

backup

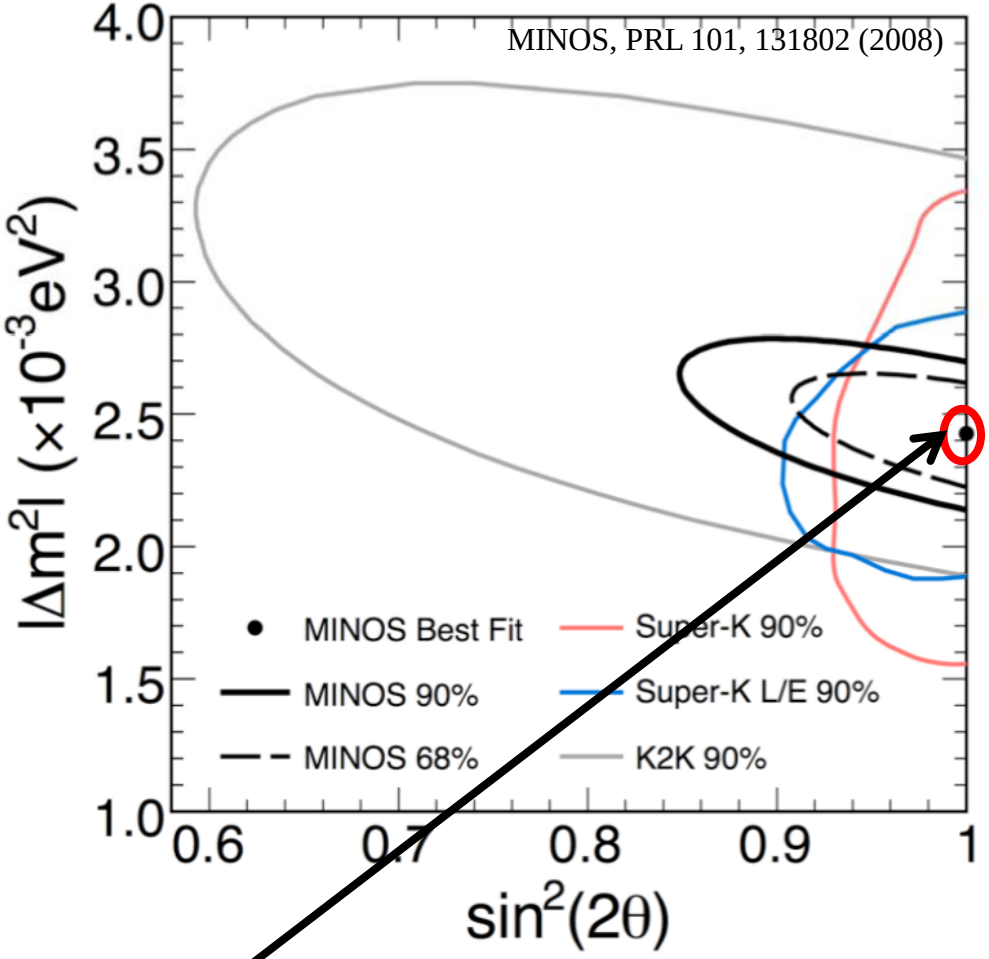
Expected Sensitivity of T2K

$\nu_\mu \rightarrow \nu_e$ appearance



$\sin^2 2\theta_{13}$ down to **0.018 (3σ)**
$\sin^2 2\theta_{13}$ down to **0.008 (90%CL)**

ν_μ disappearance



Goal @ 3.75MWx10⁷s:
$\delta(\sin^2 2\theta_{23}) \sim 0.01$,
$\delta(\Delta m^2_{23}) < 1\times10^{-4}$ [eV²]

Milestones

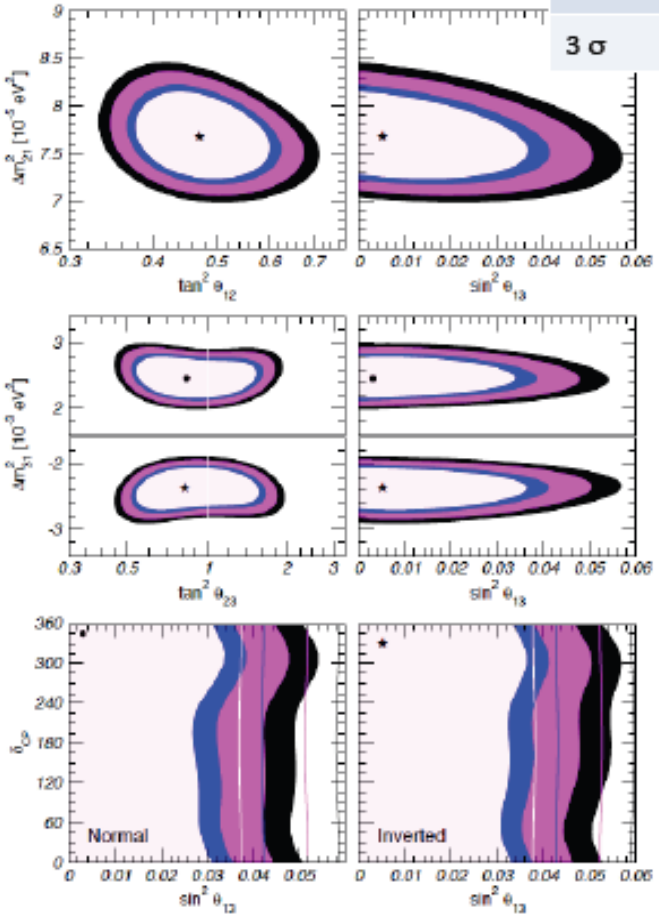
- 1999: Nishikawa&Totsuka proposed to measure ν_e appearance as a next critical step toward CP measurement
- 2001: “The JHF-Kamioka Neutrino Project” report (hep-ex/0106019)
- April 2004:
  - Officially approved by Japanese Government and 5yr Construction started
  - T2K international collaboration officially formed
- **March 2009: Construction completed as scheduled**
- April 23, 2009: First neutrino beam production and commissioning started
- **January 2010: Data accumulation for oscillation search started!**
- Feb. 24, 2010: First T2K Event in Super-Kamiokande!

State of art of the oscillation measurements

Parameters	$\Delta m^2/10^{-5}$ eV^2 solar	$\Delta m^2/10^{-3}$ eV^2 atmospheric	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
Best fit	7.67	2.39	0.321	0.016	0.466
1 σ	7.48-7.83	2.31-2.50	0.294-0.331	0.006-0.026	0.408-0.539
2 σ	7.31-8.01	2.19-2.66	0.278-0.352	<0.036	0.366-0.602
3 σ	7.14-8.19	2.06-2.81	0.263-0.375	<0.046	0.331-0.644

M.C. Gonzalez-Garcia and M. Maltoni, Phys.Rept.460:1-129,2008

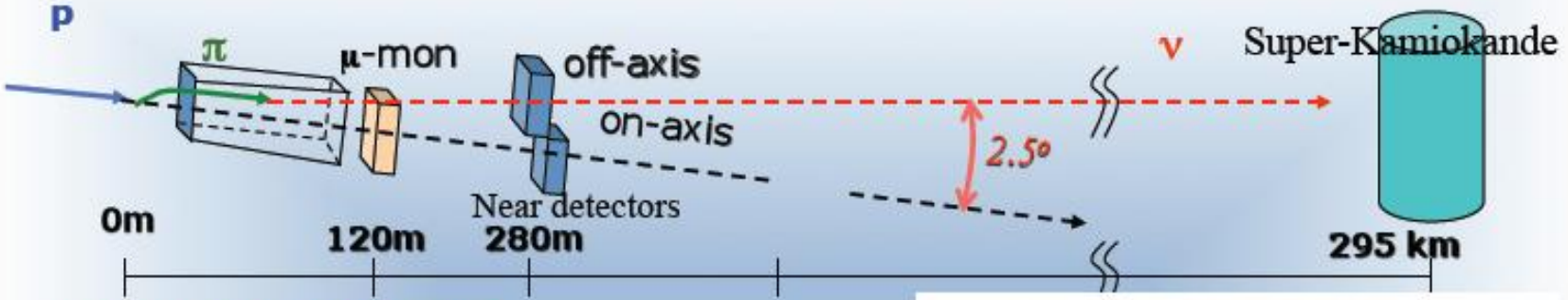
E. Lisi, Prog. in Part. and Nucl. Phys. 64 (2010 171)



Open issues:

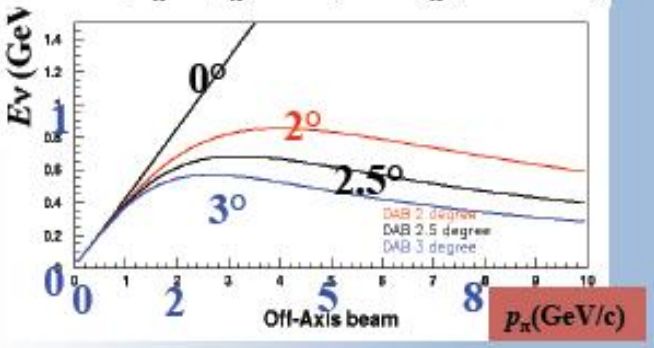
- θ_{13}
- CP violating phase
- mass hierarchy
- Is ν a Dirac or Majorana particle?

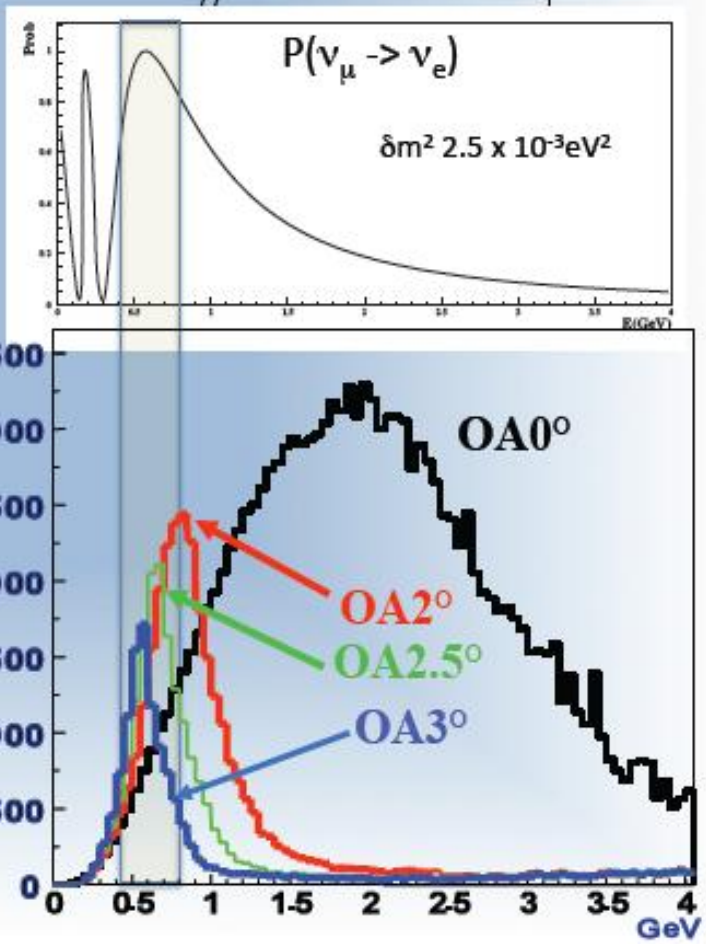
Off-axis beam: intense and narrow beam



Meson (π/K) decay Kinematics

$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\vartheta)} \approx \frac{m_\pi - m_\mu^2/m_\pi}{2\gamma_\pi(1-\cos\vartheta)}$$





- 2.5 deg "Off-axis beam" (cf. BNL-E899 proposal)
- Near detector @280m
- Far detector Super-Kamiokande
  - World largest detector (22.5kton)

Measurement of $\nu_\mu \rightarrow \nu_x$

$$1 - P(\nu_\mu \rightarrow \nu_x) = N_\nu^{obs} / N_\nu^{null}(E_\nu) \approx 1 - \sin^2 2\theta_{23} \sin^2\left(\Delta m^2_{32} L / 4E_\nu\right)$$

$N_\nu^{null} = R \times \Phi_\nu^{ND} \times \sigma_\nu^{water}$

Uncertainty is reduced by
- ND280 for Φ_ν^{ND} and σ_ν^{water}
- Beam monitoring for R

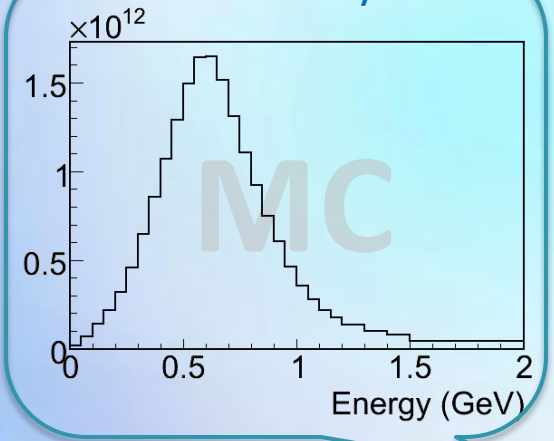
R(Far/Near)

Extrapolation by MC which is experimentally verified by NA61(*)

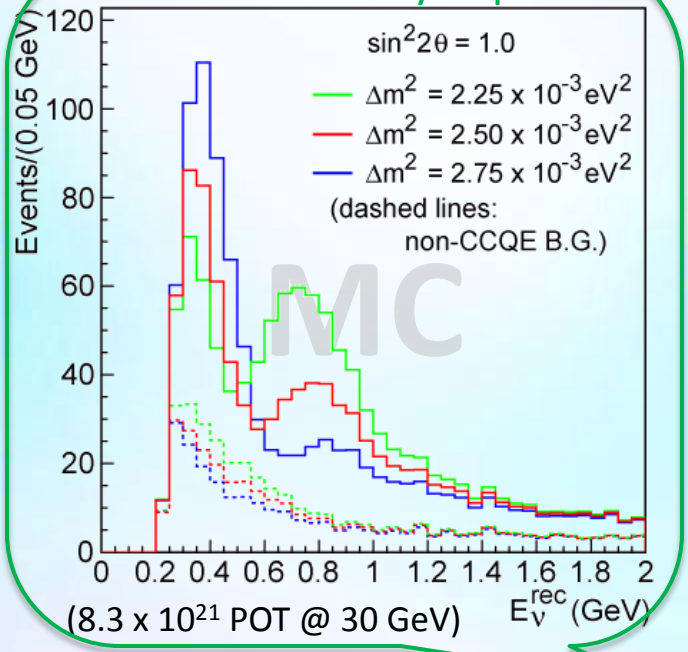
N_ν^{obs}

Φ_ν^{ND}

Measurement by ND280

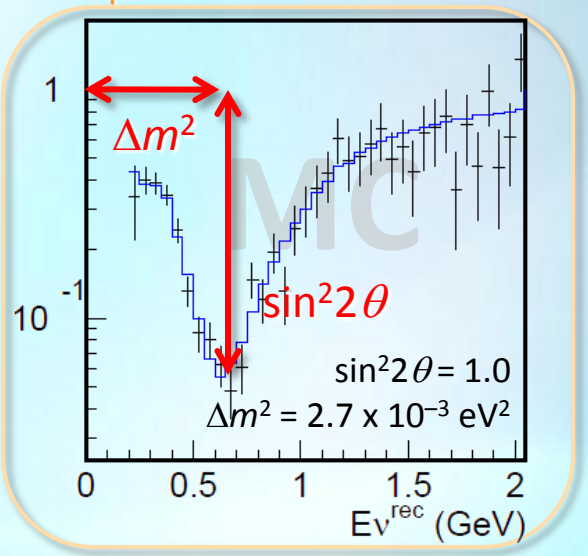


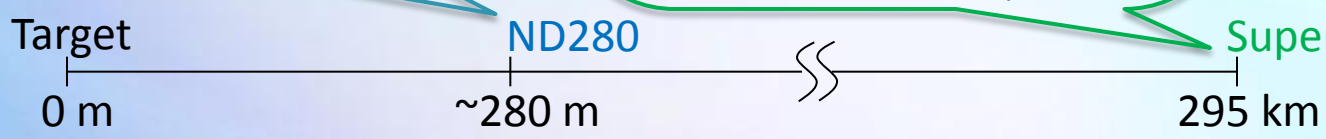
Measurement by Super-K



(8.3 x 10^{21} POT @ 30 GeV)

$P(\nu_\mu \rightarrow \nu_x)$





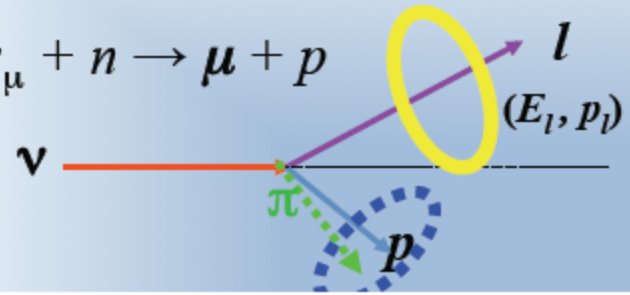
* See Nicolas' talk

Accurate prediction of N_ν^{null} is important to measure θ_{23} and Δm_{32}^2 precisely.

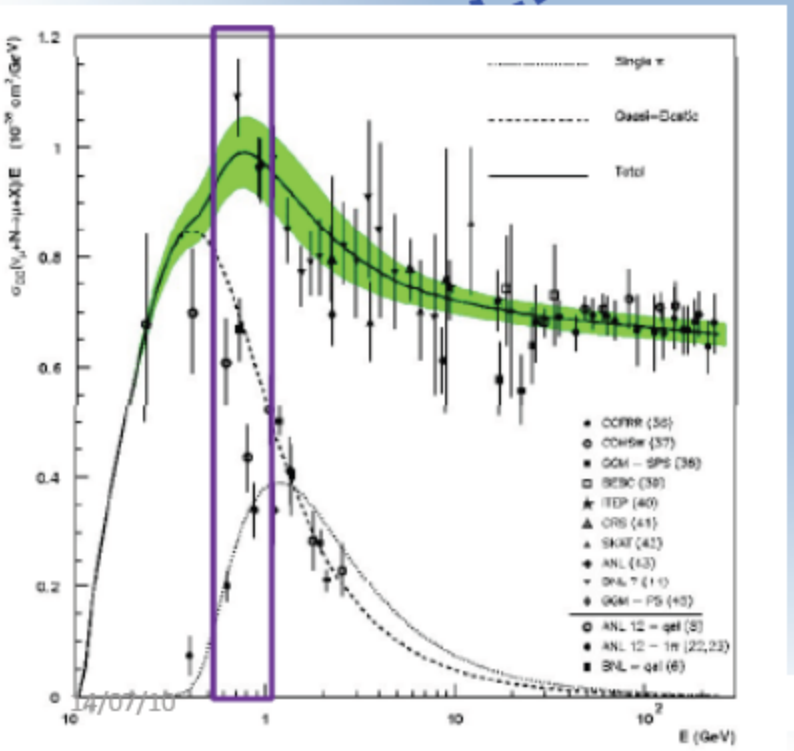
E_ν reconstruction in water Cherenkov

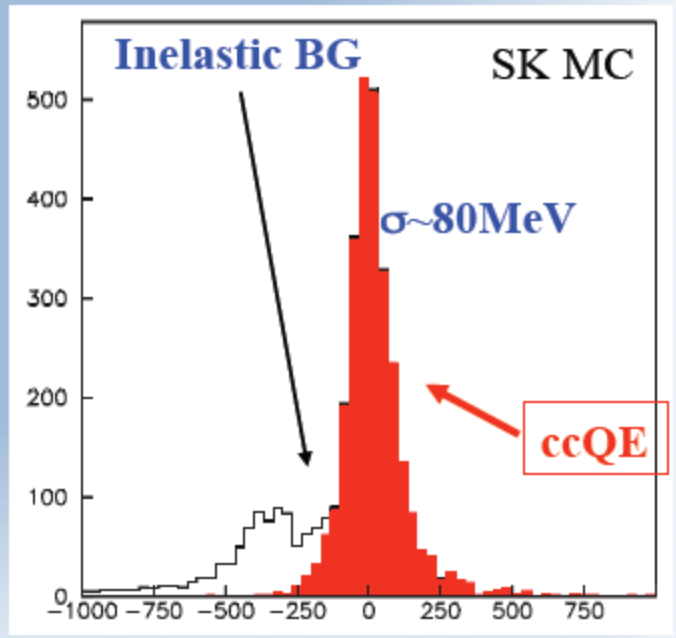
Assume CC Quasi Elastic (QE) reaction

$$\nu_\mu + n \rightarrow \mu + p$$



$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

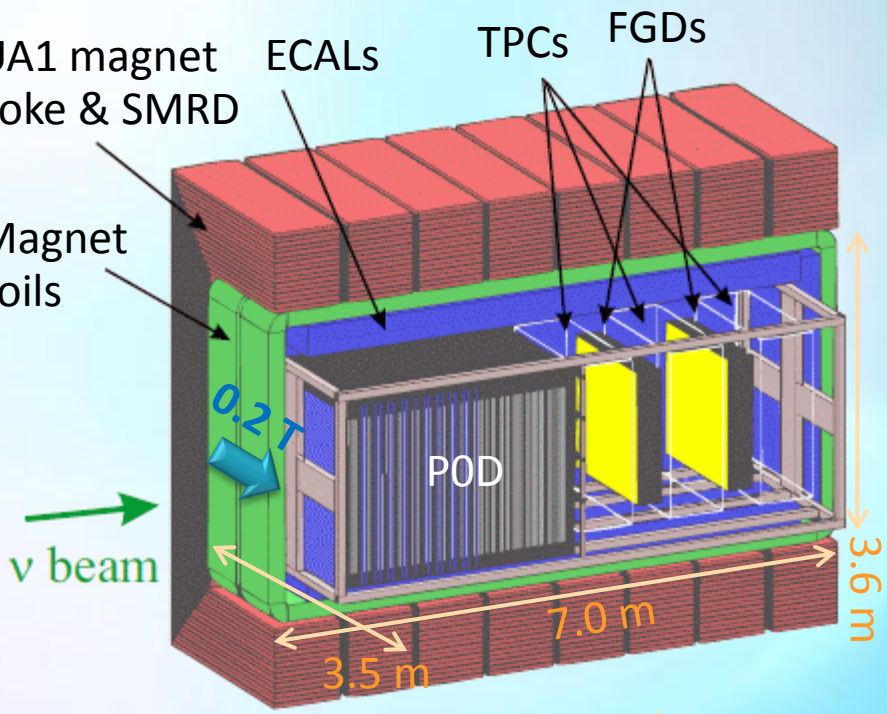




Ev(reconstruct) – Ev (True) (MeV)

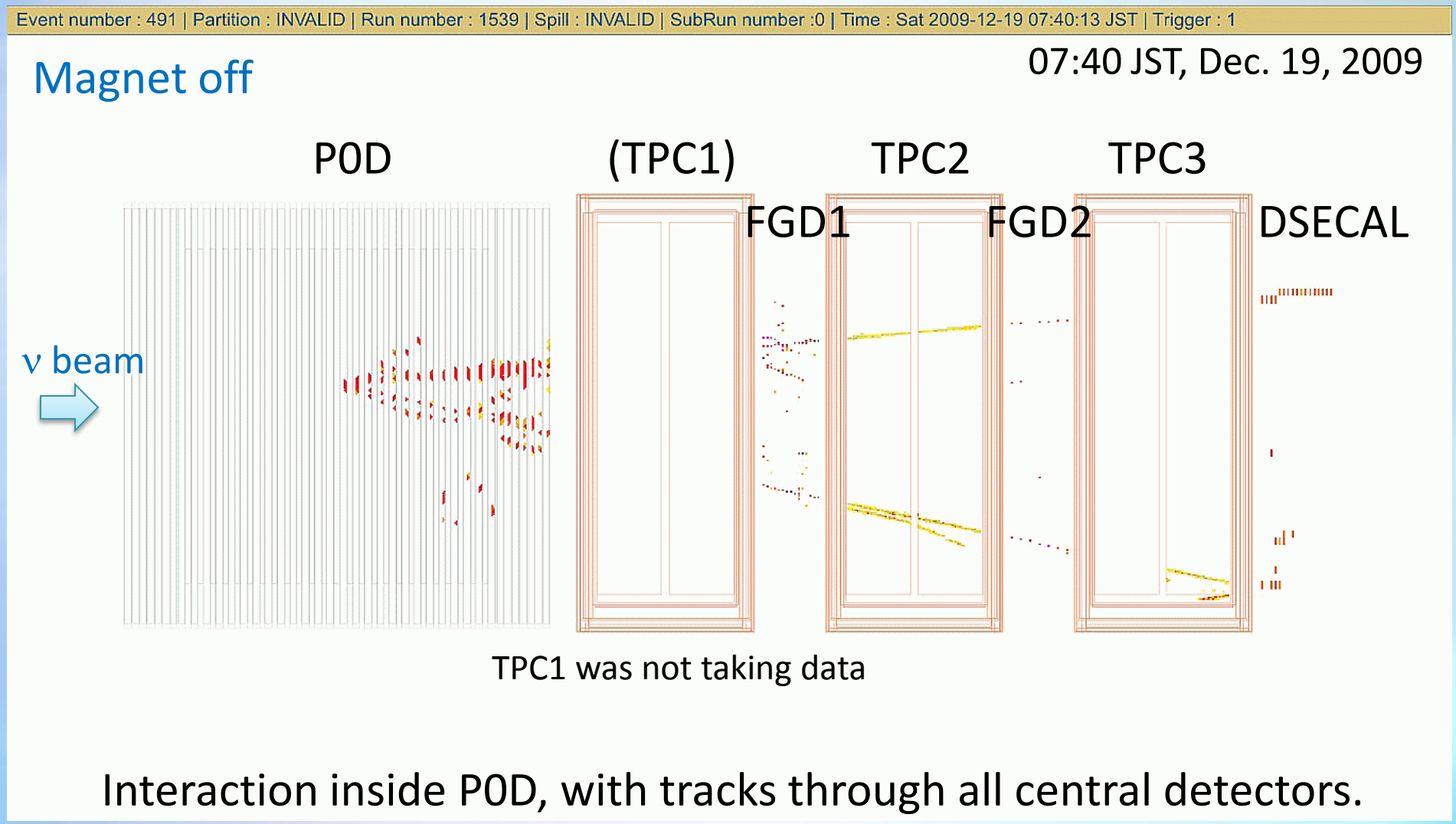
Near detectors (ND280)

- Measure ν beam energy spectrum, flux, flavor and interaction x-sec before the ν oscillation.
  - **Fine Grain Detectors (FGDs)** measure neutrino vertices.
    - Scintillator bars (FGD1), scintillator bars + water (FGD2)
  - **TPCs** measure p_μ to reconstruct E_ν spectrum and dE/dx for particle ID.
    - MicroMegas w/ Ar/iC$_4$H$_{10}$/CF$_4$ (95/2/3) gas mixture
  - **Side Muon Range Detector (SMRD)** measures the range of μ.
    - Scintillator planes btw the yokes
  - **π^0 detector (P0D)** measures the rate of NC-π^0 production.
    - Scintillator bars + lead foil/water
  - **ECALs** measure electrons from FGD and γ-rays from π^0.
    - Scintillator bars + lead foil



⇨ Extrapolate the ν energy spectrum and flux to Super-K.

1st neutrino event in ND280



TPC1 was not taking data

Interaction inside P0D, with tracks through all central detectors.

Super-Kamiokande Event Selection

- J-PARC neutrino events selected by event timing using GPS
- SK analysis is very well established
  - >20yrs of experiences w/ Water Cherenkov detector
- Event selection & cut values are fixed already

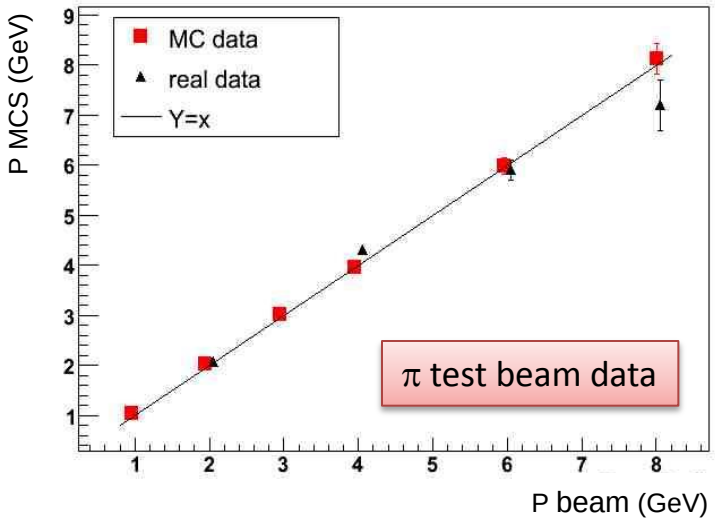
UNBIASED SELECTON

- Selection criteria

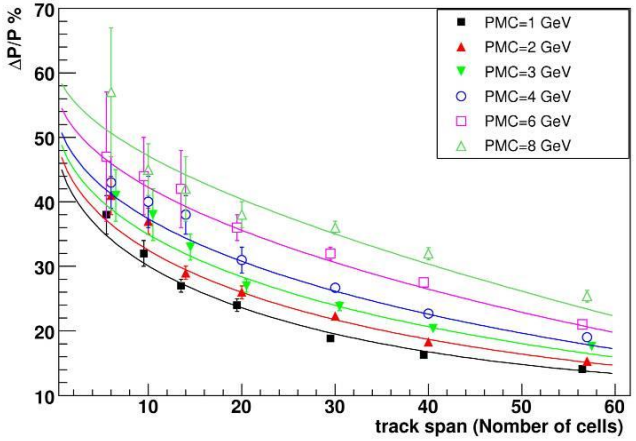
For ν_μ disappearance analysis	**For ν_e appearance search**
Timing coincidence w/ beam timing (+TOF)	
Fully contained (No OD activity)	
Vertex in fiducial volume (Vertex >2m from wall)	
Evis > 30MeV	Evis > 100MeV
# of ring =1	
μ-like ring	e-like ring
	No decay electron
	Inv. mass w/ forced-found 2nd ring < 105MeV
	E_ν^{rec} < 1250MeV

Performance of momentum measurement

Linearity of momentum center



Resolution



Track reconstruction + momentum estimation efficiency