Measurement of hadron production for T2K at CERN NA61 experiment (Nu_1_2)

B.Andrieu (LPNHE-Paris, IN2P3/CNRS)

(on behalf of T2K KEK and Paris groups)

Outline:

- Introduction
- T2K & J-PARC Neutrino facility
- Nu_1_2 project
- NA61 status and plans
- Summary and Outlook

Introduction

In neutrino sector, flavor states ≠ mass states
→ neutrino mixing described by a 3x3 matrix

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix}$$

3 mixing angles (θ_{12}, θ_{23}, θ_{13})
1 CPV phase (δ)
2 (indep.) mass differences ($\Delta m_{ij}^2 = m_i^2 - m_j^2$)

θ_{12}, Δm_{12}^2 : measured with good precision (Solar + KamLAND)
θ_{23}, Δm_{32}^2 : known with less precision (Minos + K2K/SK)
θ_{13} : only upper limit
δ : no information

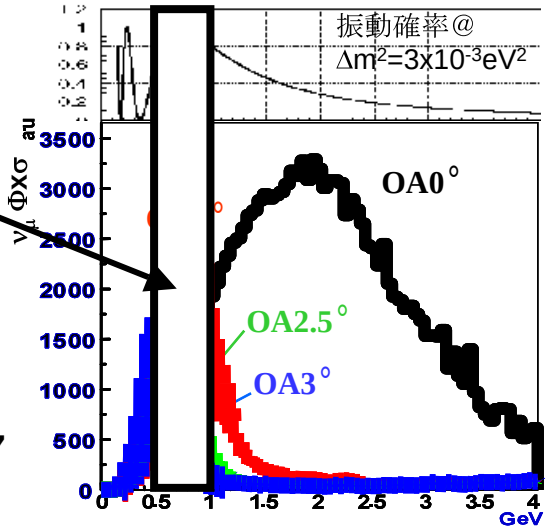
With conventional neutrino beam (ν_μ with 0.4% ν_e contamination), T2K goals are:
ν_μ disappearance: measure (2,3) mixing with sensitivity
- $\delta(\sin^2(2\,\theta_{23})) \sim 0.01$
- $\delta(\Delta m_{32}^2) \leq 3 \times 10^{-5}$ eV^2

$\nu_\mu \rightarrow \nu_e$ appearance: measure a non-zero value of (1,3) mixing or set upper limit
- $\sin^2(2\,\theta_{13}) \leq 8 \times 10^{-3}$ eV^2

T2K (Tokai to Kamioka) @ J-PARC

- T2K @ JPARC (Japan):
  - Long baseline (295km) neutrino oscillation experiment
  - Protons (30-50GeV) + carbon target (90cm) → intense off-axis ν_μ–beam
  - Neutrino spectra measured at the near and far detectors: ND280 and SK

(~100xK2K)



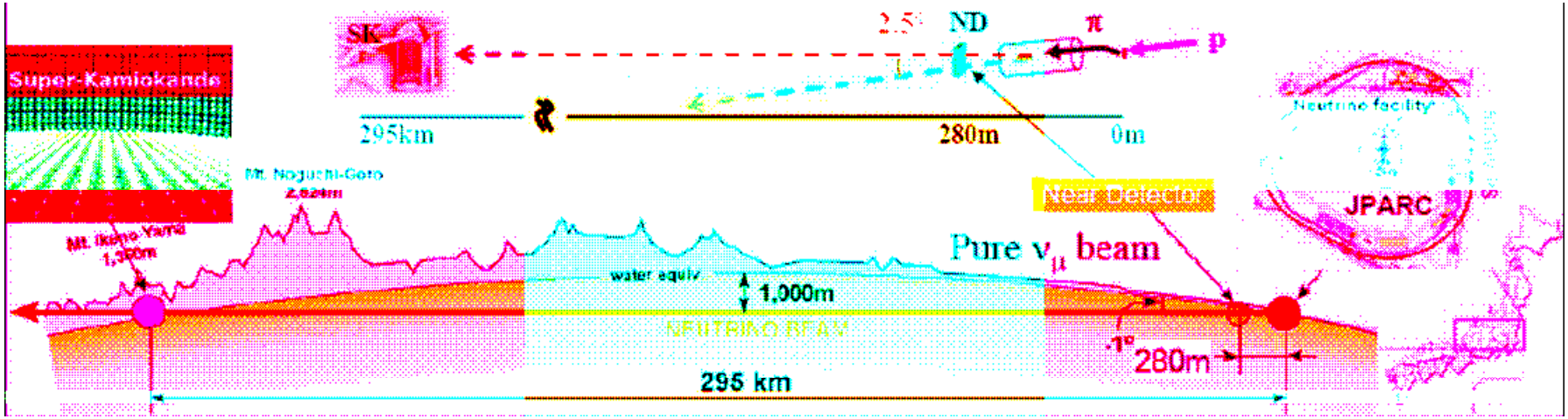
J-PARC (50 GeV/750kW PS)
- Construction: 2001~2007
- Operation: 2008~

T2K (Approved in Dec-03)
- Construction: 2004~2008
- Experiment: 2009.4 ~

1600ν_μCC/yr/22.5kt
ν_e ~ 0.4% at peak (2.5deg)

Phase 1 (0.75MW + SK)

Possible future extension
CPV w/ Multi-MW & HyperK



T2K & France-Japan collaboration

~350 members from 12 Countries

Japan(66), US(58), Canada(50), **France(38)**, UK(37) Switzerland(31), Poland(22), Korea(13), Russia(12), Spain(11), Itary(9), Germany(2)

France is one of major countries
Saclay,Lyon, Ecole Polytechnique, Paris

F-J collaboration (Nu_1) at T2K

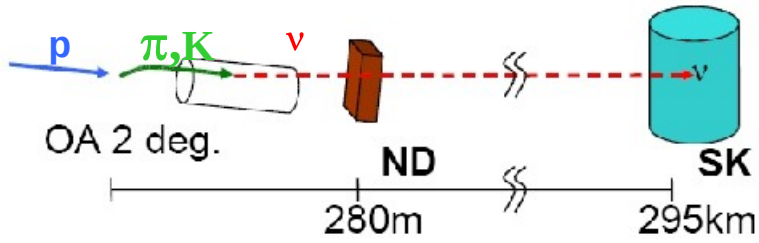
Goal of Nu_1 is to establish MW beam technology / methodology at T2K

- Nu_1 (2006~) : R&D on T2K beam line (previous talk)
- Nu_1_2 (2007~) : Hadron production measurement: Paris & KEK group (+ other T2K-european institutes) ➔ **This talk**

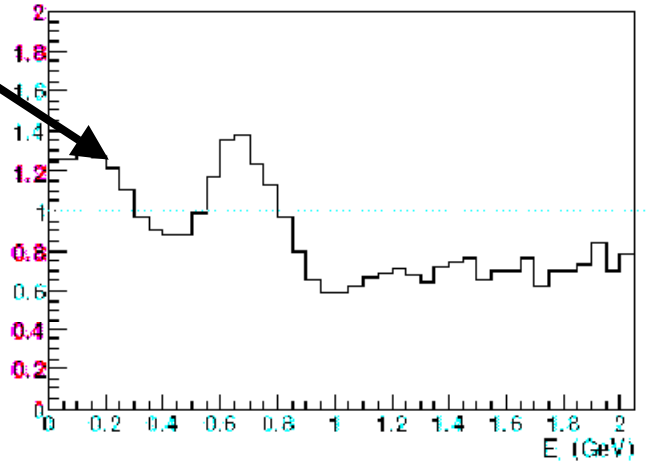
Measurement of hadron production at NA61 for T2K

Both $\nu_\mu \rightarrow \nu_e$ appearance and ν_μ disappearance analyses rely on the comparison between the neutrino spectra measured at SK (far detector) and extrapolated at SK from ND280 (near detector)

$$\text{Extrapolated at SK} \quad \Phi^{SK}_{\mu,e}(E_\upsilon) = R_{\mu,e}(E_\upsilon) \times \Phi^{ND}_{\mu,e}(E_\upsilon) \quad \text{Measured at ND}$$



Far/Near ratio



But spectrum at far site is different from near site even w/o oscillation → Effect of non-point-like source

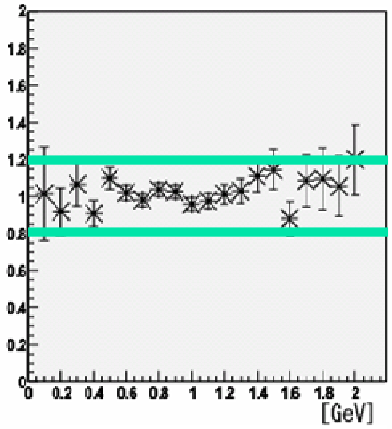
No measurement of particle production off carbon with 30 GeV protons available
→ **participation to NA61**

Expected systematic uncertainties w/ o NA61

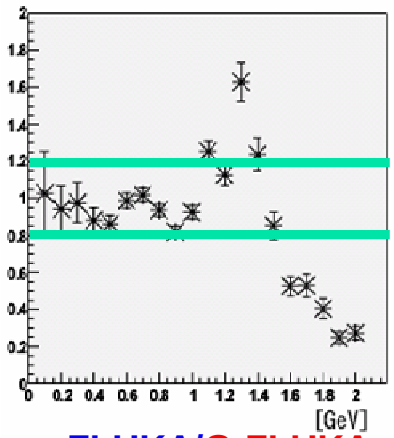
- No data for p+C interaction at 30 GeV exist → rely on MC simulation
- But validity of the hadron production model difficult to evaluate

→ uncertainty probably not less than the difference among several models

G-FLUKA vs. MARS vs. FLUKA



MARS/G-FLUKA



FLUKA/G-FLUKA

Ratios of F/N ratios

up to ~20% difference!

F/N ratio difference among hadron production models:
~ 20% @Eν≤1GeV

Syst. error due to F/N

ν_e *appearance*

$\delta(N_{bg}) \sim 15\%$

ν_μ *disappearance*

$\delta(\sin^2 2\theta_{23}) \sim \pm 0.015$ -0.03,
$\delta(\Delta m_{23}^2) <\sim \pm$ 5-10 10^{-5}eV^2

>>

Goal of T2K

ν_e *appearance*

$\delta(N_{bg}) \leq 10\%$

ν_μ *disappearance*

$\delta(\sin^2 2\theta_{23}) \sim \pm 0.01$,
$\delta(\Delta m_{23}^2) <\sim \pm$ 3 10^{-5}eV^2

Impossible to achieve T2K GOAL without NA61 measurements!

Goal of NA61 measurement for T2K

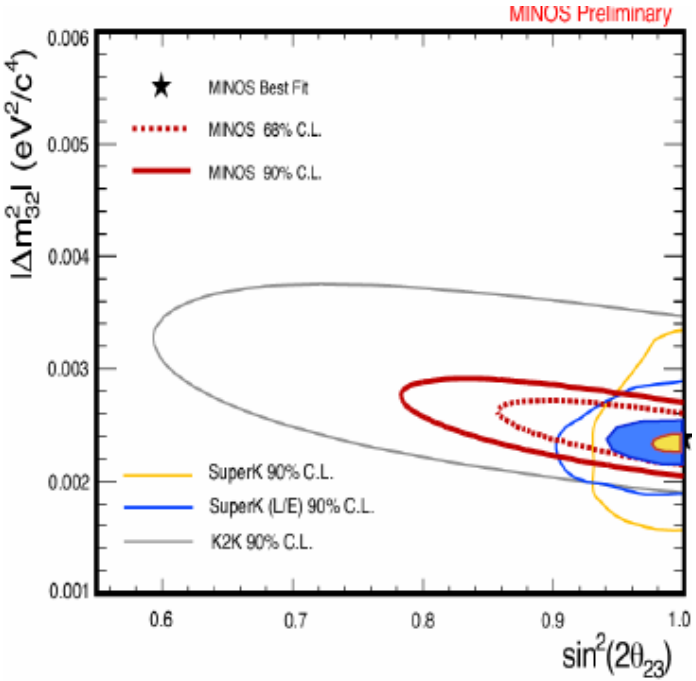
- ν_μ Far/Near ratio shape ~< 2~3%
- ν_e Far/Near ratio R(<1GeV), R(>1GeV) ~2~3%

K. Sakashita

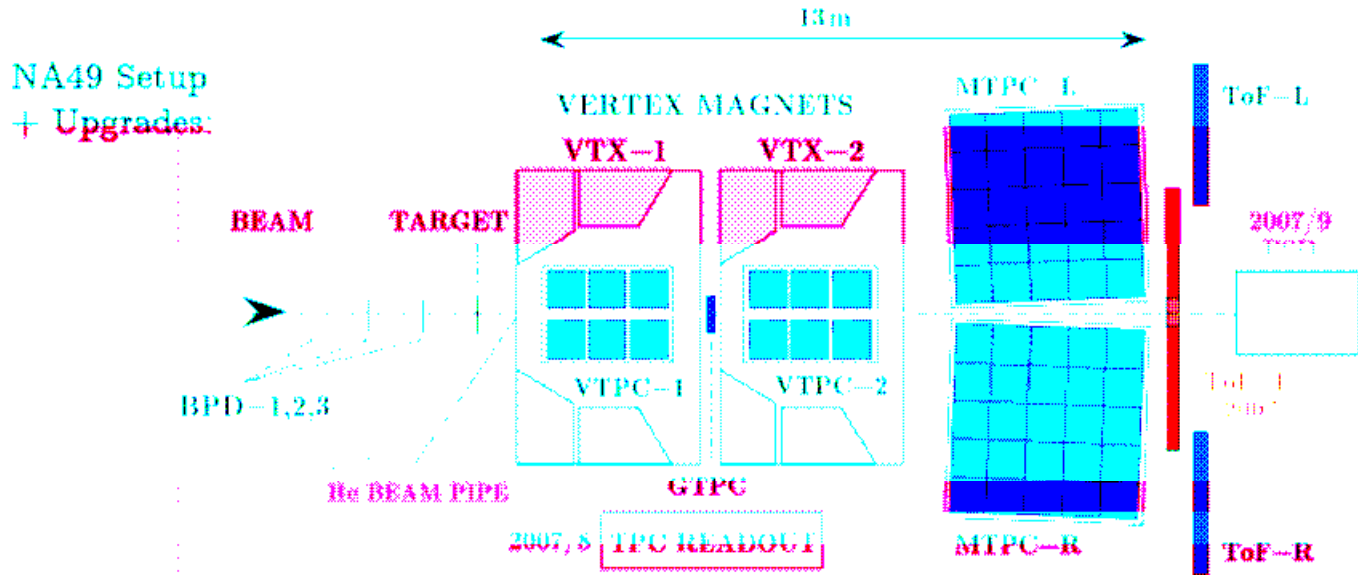
	T2K goal	Error from F/N ratio	
		w/o NA61	w/ NA61
$\delta(N_{bg})$ for ν_e app.	10%	15%	<<4%
$\delta(\sin^2 2\theta_{23})$	1%	1.5~3%	0.5%
$\delta(\Delta m_{23}^2)[10^{-4}eV^2]$	1	0.5~1	0.15

- ~200k good reconstructed pion tracks give sufficient precision

Impact of NA61 on T2K result



CERN SPS NA61 experiment



- 2 dipole magnets (1.2 Tm over 7 m)
- 2 VTX-TPC inside magnet (p)
- 2 main-TPC (dE/dx)
- 3 ToF, one (ToF-F) especially built for T2K
  (mass measurement to be combined to dE/dx for particle ID)

NA61 Collaboration

110 physicists from
25 institutes and
15 countries

University of Athens, Athens, Greece
University of Bari and INFN, Bari, Italy
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Cape Town University, Cape Town, South Africa
Jagellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Swietokrzyska Academy, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universites de Paris VI et VII, Paris, France
Pusan National University, Pusan, Republic of Korea
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland

NA61 2007 pilot run

- Aims of 2007 Pilot Run were:
  - set up and test the NA61 apparatus and the detector prototypes
  - to take pilot physics data for T2K with 30.9 GeV/c protons:
    - o Thin target: 660k events
      - 480k events with trigger on target interactions (Beam• $\overline{S4}$)
      - several k runs taken with special trigger settings to study efficiencies of the beam counters, an unbiased beam profile and interaction-events with hit in S4
    - o T2K replica target: 220k events
      - all taken with trigger on beam particles only (Beam)
    - o Empty target: 80k events
      - 45k events with trigger on interactions (Beam• $\overline{S4}$) for σ-normalization studies
    - o Target support: 30k events
      - all taken with trigger on interactions (Beam• $\overline{S4}$) for σ-normalization studies

- **30 days of run in October 2007**
- **pilot run successful and instructive for 2008 run**
- **analysis on-going, results expected by summer 2008**

NA61 2007 pilot run

Data taken with

2 different carbon targets (isotropic graphite, $\rho = 1.84$ g/cm^3):

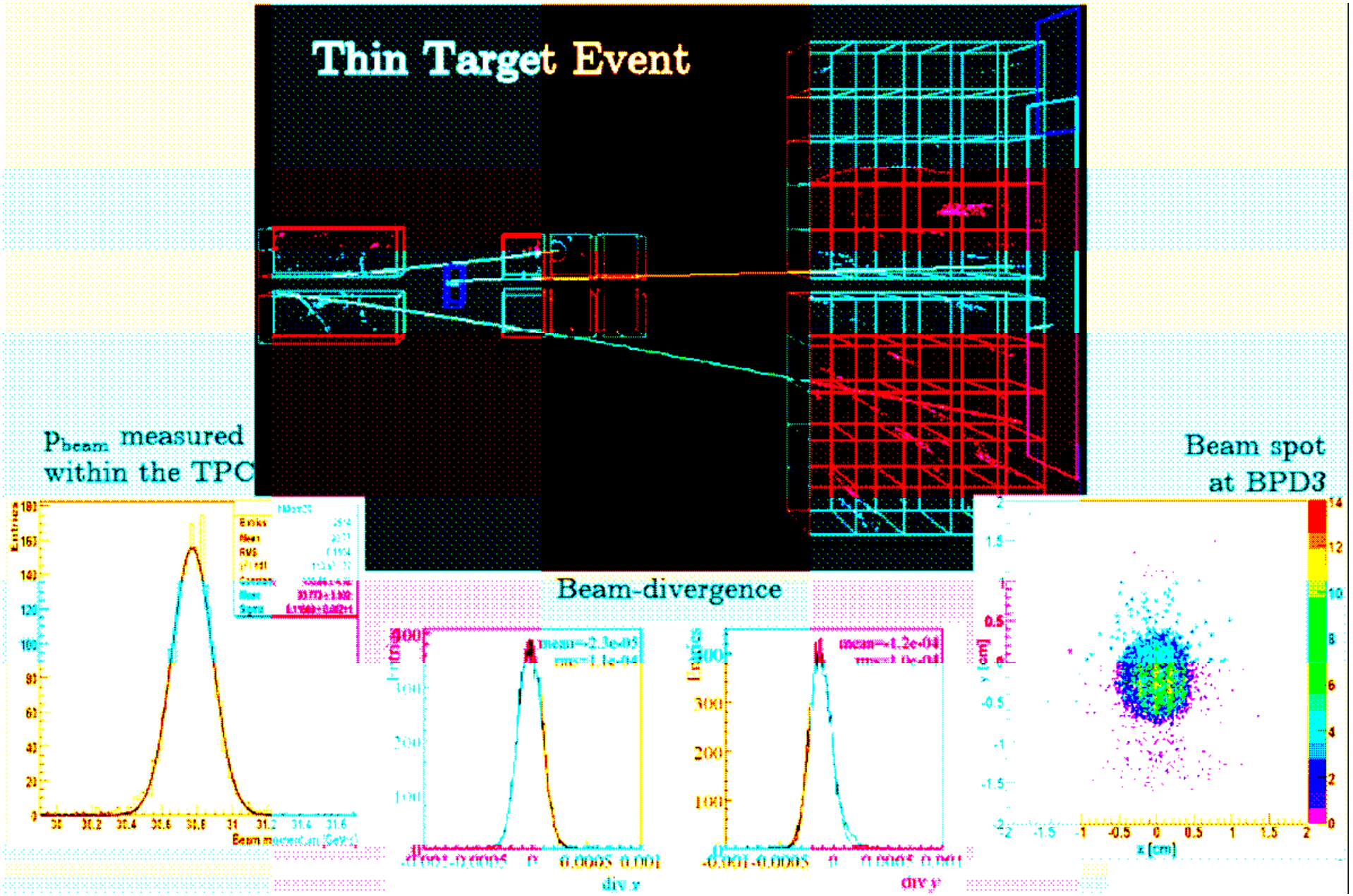
- Thin Carbon Target: 2.5 x 2.5 x 2cm^3, int. length ~0.04

- T2K Replica Target: Ø=2.6cm x 90cm, int. length ~1.9

Produced by KEK group, brought and installed at CERN with active Paris (J. Dumarchez) participation

NA61 2007 pilot run

First look at data



NA61 2007 pilot run

Preliminary results shown at SPSC

→ see CERN-OPEN-2008-012 document

http://cdsweb.cern.ch/record/1102699/files/CERN-OPEN-2008-012.pdf?version=1

prepared with significant contributions from KEK and Paris groups

FTOF performance

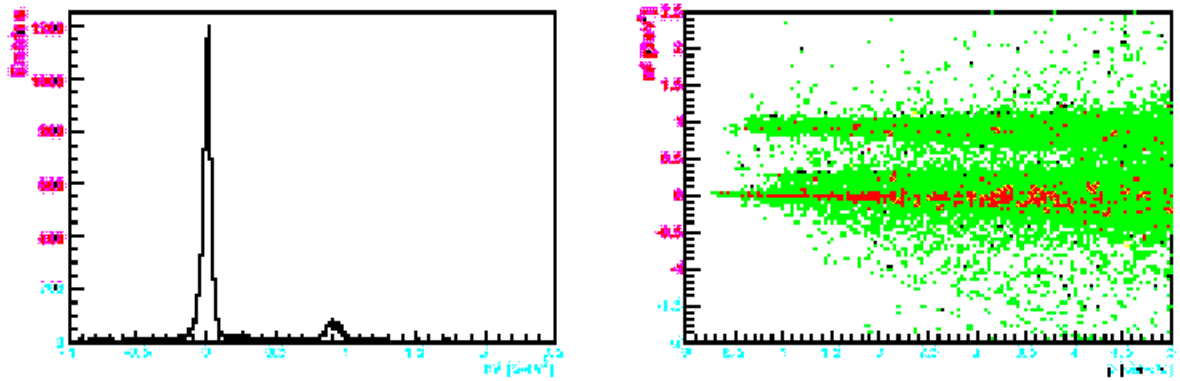


Figure 18: The mass squared calculated from the time measured in the ToF-F after a preliminary calibration (left). The mass squared as a function of momentum (right). Contributions from pions, kaons and protons are clearly visible.

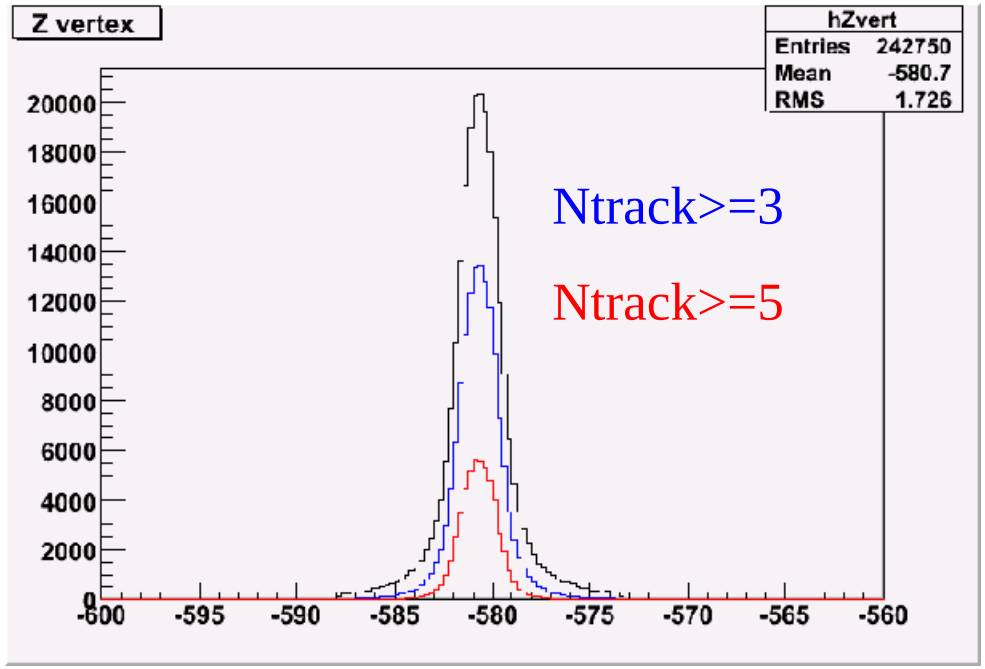
Conclusion :

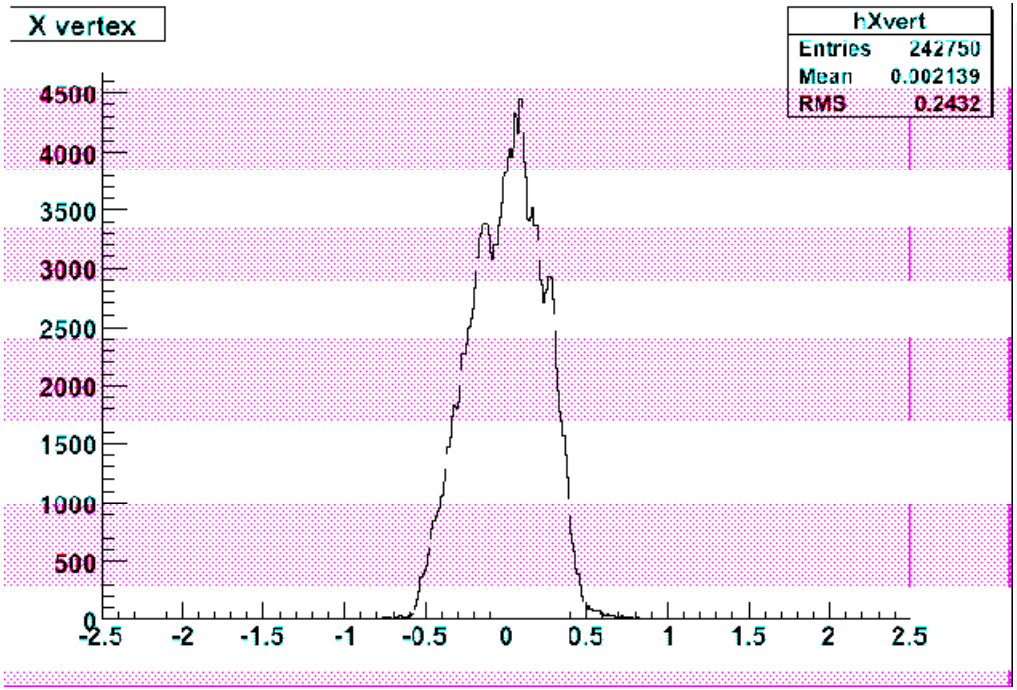
- the NA61/SHINE apparatus (including the new ToF-F system) was run successfully and detector prototypes were installed and tested
- pilot physics data on interactions of 31 GeV/c protons on thin and T2K replica carbon targets were registered

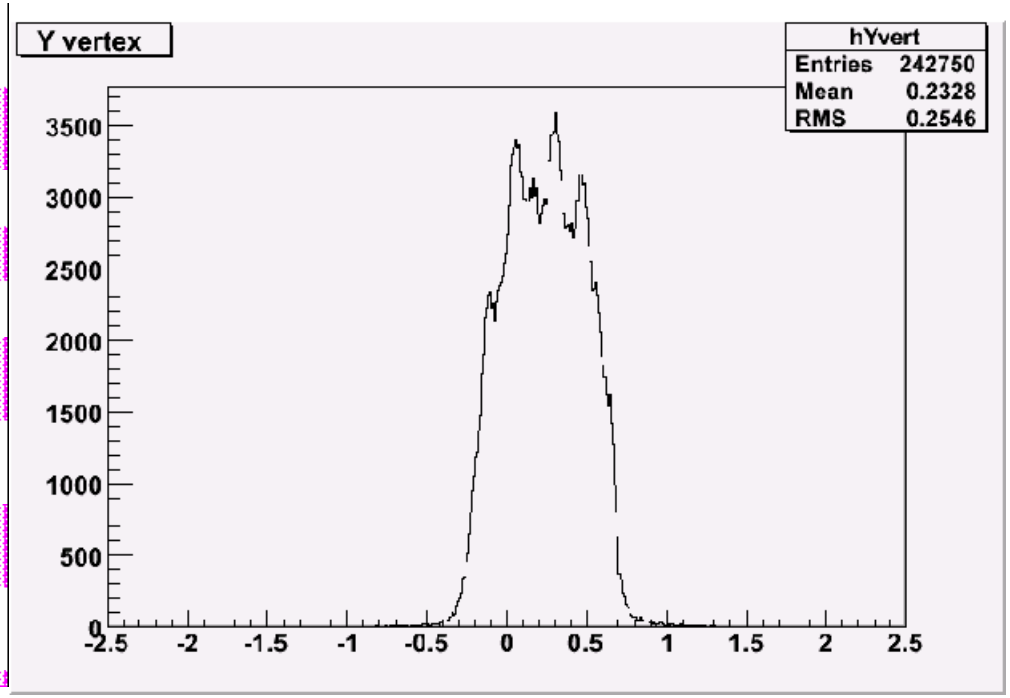
NA61 2007 pilot run

On-going analysis (B. Popov)

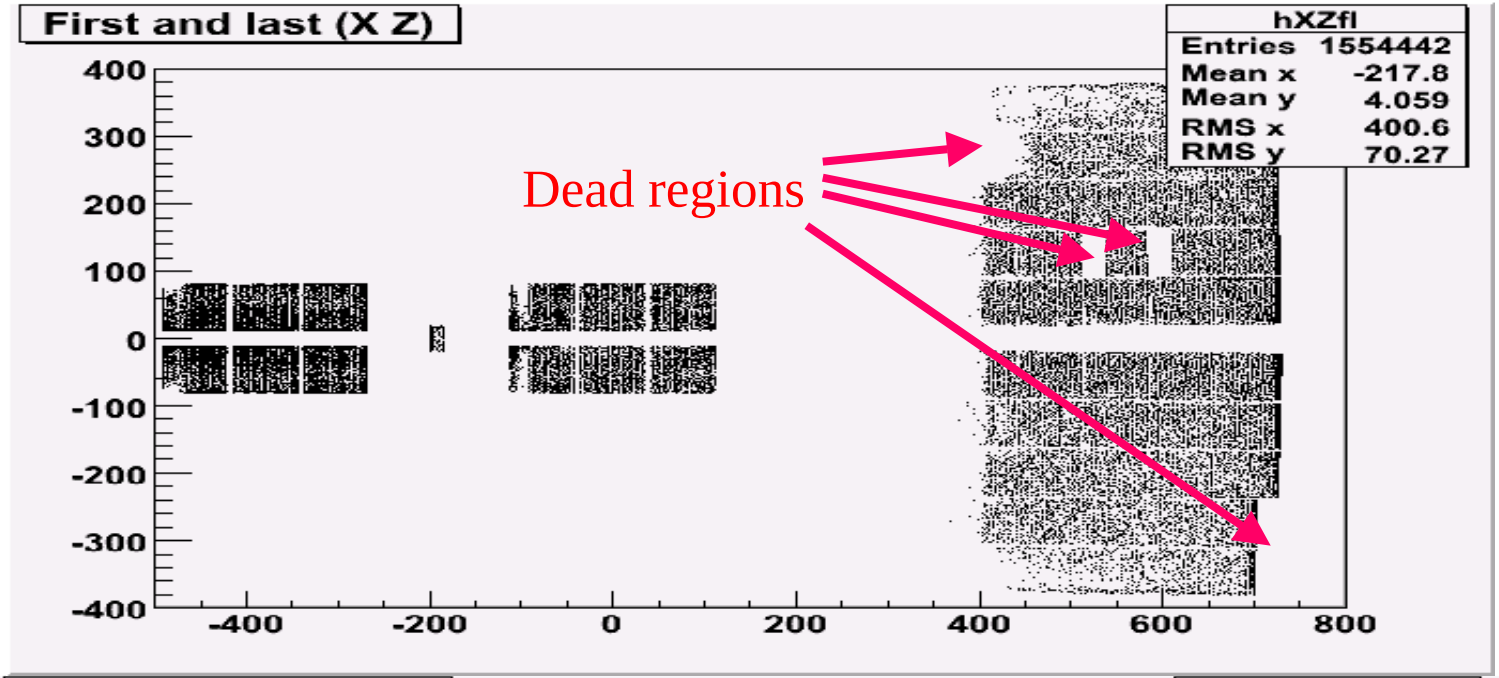
250K events from preproduction after selection

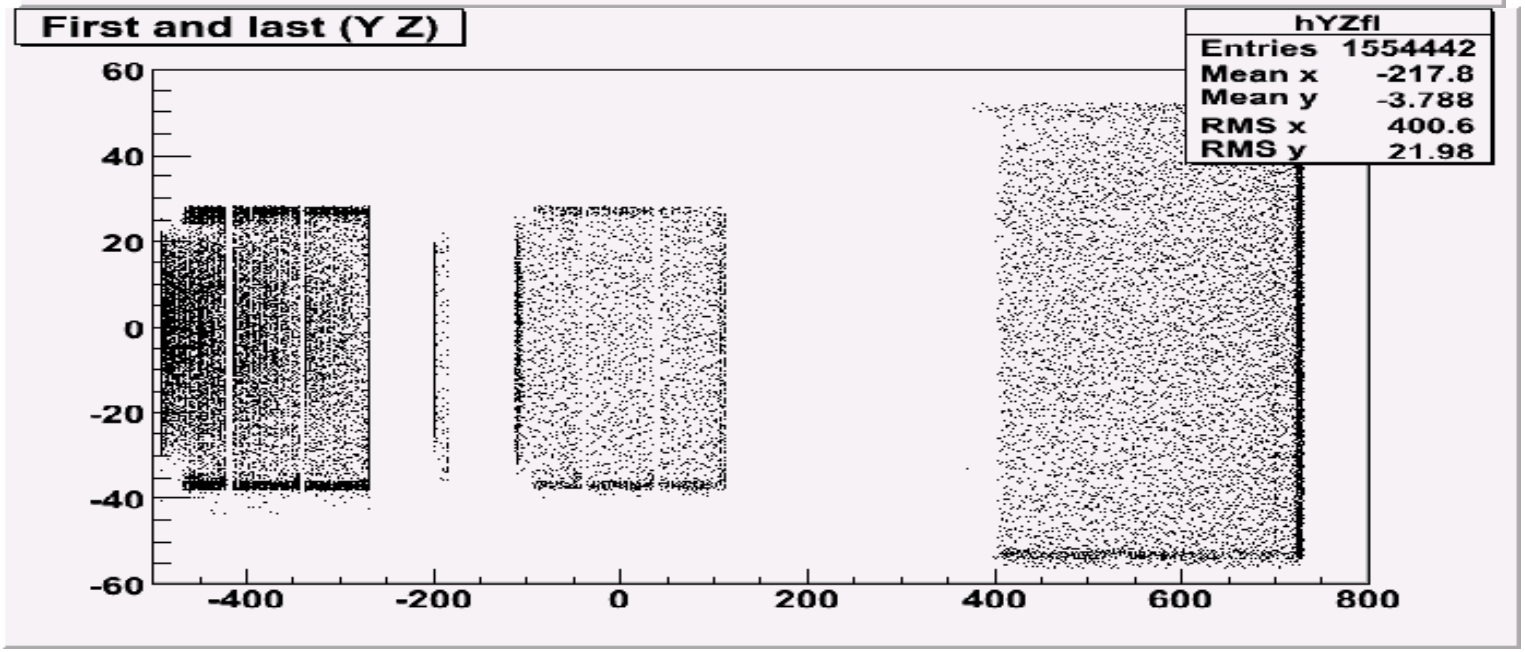






On-going analysis (B. Popov)





NA61 plans for 2008 run

- TPC electronics and DAQ upgrades foreseen (not sure yet, decision to be taken soon) with an expected event rate of about 100 Hz (factor ~10 improvement)
- If upgrades happen in 2008, NA61 2008 run statistics sufficient for T2K if not, other run(s) will be needed to reach expected precision
- Beam request:

Beam	Energy (A GeV)	Year	Days	Physics	Status
p	30	2007	30	T2K, C-R, RA-D	*performed*
p	30, 40, 50	2008	14	T2K, C-R	*approved*
π^-	158, 350	2008	3	C-R	*approved*
p	**158**	**2008**	**28**	**High p_T**	***approved***
S	10, 20, 30, 40, 80, 158	2009	30	CP&OD	*recommended*
p	**10, 20, 30, 40, 80, 158**	**2009**	**30**	**CP&OD**	***recommended***
In	**10, 20, 30, 40, 80, 158**	**2010**	**30**	**CP&OD**	***to be discussed***
p	**158**	**2010**	**30**	**High p_T**	***to be discussed***
C	10, 20, 30, 40, 80, 158	2011	30	CP&OD	*to be discussed*
p	**10, 20, 30, 40, 80, 158**	**2011**	**30**	**CP&OD**	***to be discussed***

Description and requests for 2008

- Members
  - KEK: T.Kobayashi, T.Nakadaira, K.Sakashita, T.Sekiguchi, T. Hasegawa
  - Paris: J.Dumarchez, B.Andrieu, B. Popov

- Research Items
  - Main goal : Measurement of hadron production for T2K at NA61
  - KEK: Physics studies/Target production/data taking/T2K beam MC
  - Paris: TOF calibration/Data taking/Global Software/Analysis

- Requests for support for FY2008
  (Travel budget to CERN, Preparation/Shifts, Meetings, Analysis)
  - Paris: 5.400 Euros
    (Reminder FY 2007: 4.200 requested, 2.020 attributed and spent for travel and per diem for NA61 october 2007 run at CERN)
  - KEK: 600 Kyen
  - Common fund contribution from KEK to NA61 (CERN): 500 Kyen

Summary and Outlook

- To meet T2K physics goals, F/N ratio must be known with 2-3% precision
- Hadro-production from p^+C interaction at 30 Gev not known precisely enough → new measurements needed at CERN SPS with NA61 hadron spectrometer for the interaction of 30 GeV protons with different Carbon targets
  - T2K replica target (prediction of T2K ν flux)
  - Thin target (determination of invariant inclusive cross sections)
- NA61 2007 pilot run successful, results expected for this summer
- In 2008 run, enough events should be recorded to achieve required (2-3 %) precision on F/N ratio in T2K (provided foreseen NA61 upgrades come in time)

Thanks to T. Kobayashi, J. Dumarchez and B. Popov for their help in preparing this talk
Credits : T. Kobayashi (KEK 2007), C. Strabel (CERN 2008), A. Meregaglia (Saclay 2008)