"Measurements of hadron production for neutrino physics within NA61 (SHINE) experiment at CERN SPS."

Cracow Epiphany Conference,
On Physics In Underground Laboratories and Its Connection with LHC
5-8 January 2010, Cracow, Poland

Magdalena Posiadała (University of Warsaw) for NA61 Collaboration

- **NA61 (SHINE) experiment**
  - **Physics program**
  - **NA61(SHINE) detector**
  - **Particle identification**
  - **Preliminary results from 2007 pilot run**
  - **Status and plans**

NA61 (SHINE) - Physics program

Physics of strongly interacting matter

Discovery potential:

- Search for the critical point of strongly interacting matter

Precision measurements:

- Study properties of the onset of deconfinement

Data for neutrino and cosmic ray experiments

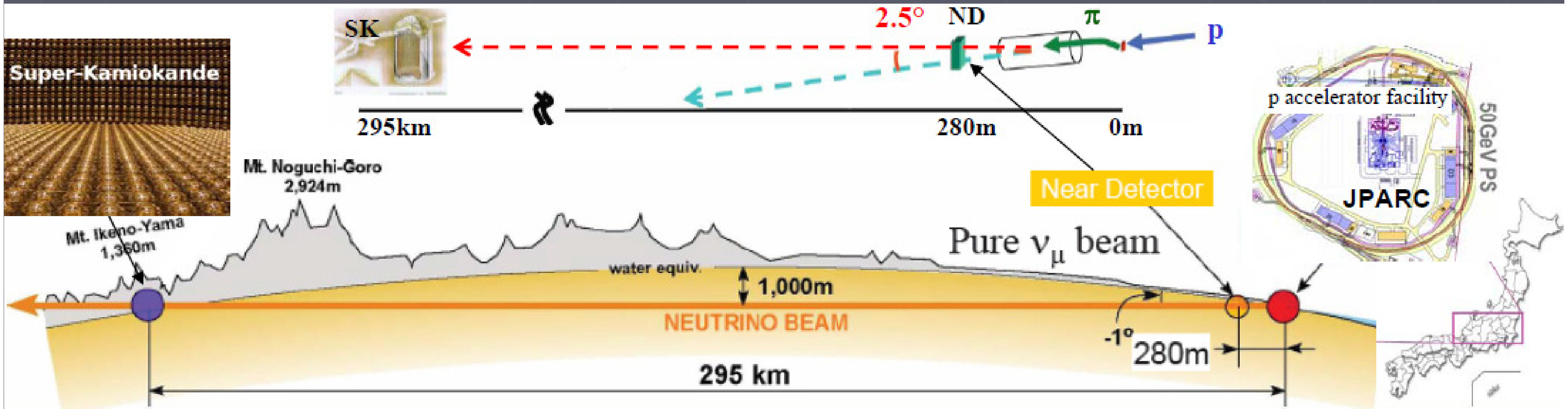
Precision measurements:

- **Measure hadron production in the T2K target needed for the T2K neutrino physics**
- Measure hadron production in p+C, (π+C) interactions needed for T2K and cosmic-ray Pierre Auger Observatory and Kascade, experiments

NA61 (SHINE)- Physics program - T2K (I)

Very important goal of the NA61 (SHINE) physics program is :

Precise measurements of hadron production for predictions of neutrino fluxes in T2K experiment



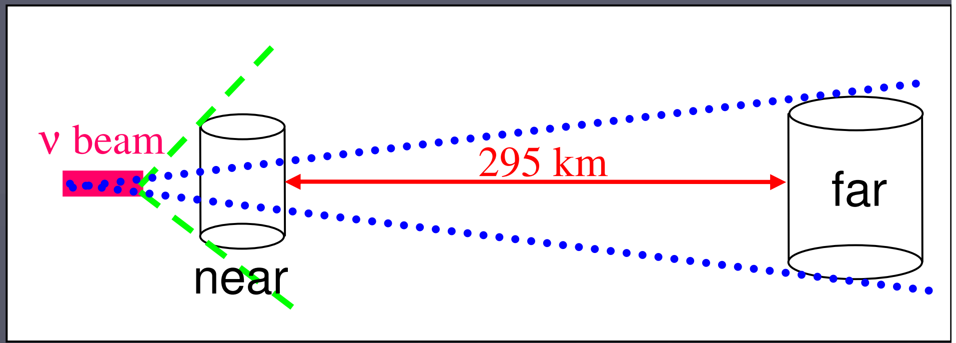
T2K (Tokai to Kamioka) at J-PARC (JAPAN):

- Long baseline neutrino oscillation experiment
- Measurements of **θ_{13} with $\nu_\mu \to \nu_e$ appearance** and **θ_{23}, Δm^2_{23} with $\nu_\mu \to \nu_\mu$ disappearance of ν_μ**
- Protons (30GeV) on carbon target (90 cm)->Intense off axis ν-beam
- Neutrino event rates measured at near (ND280) and far (Super-Kamiokande) detectors

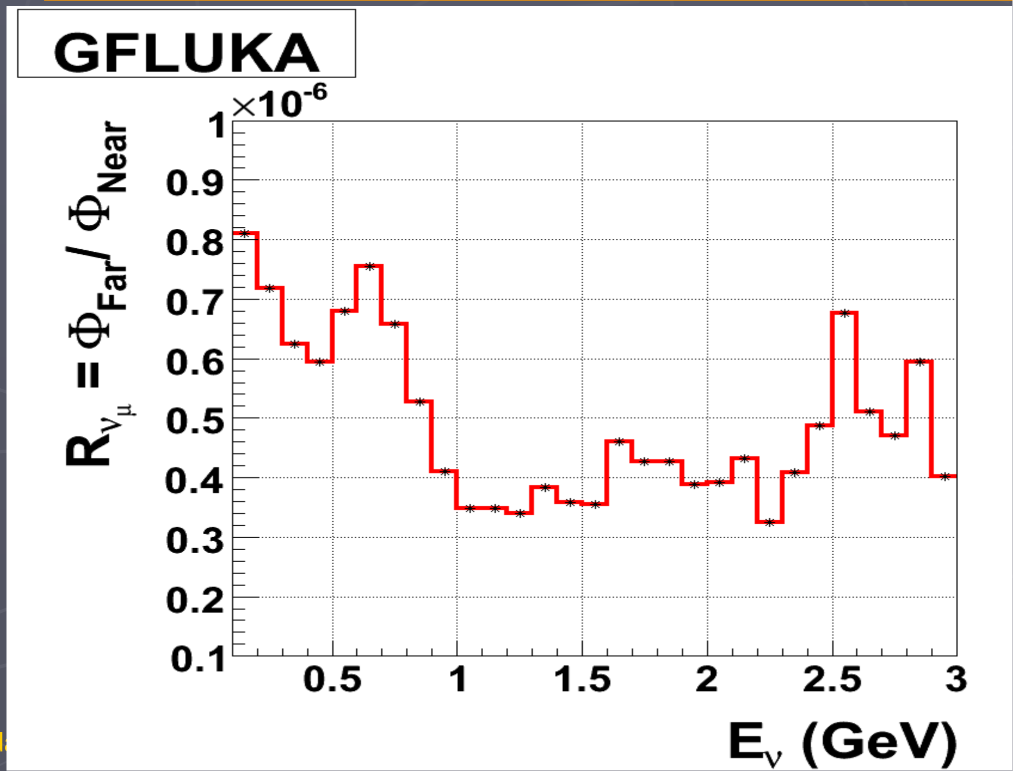
talk by Danuta Kiełczewska

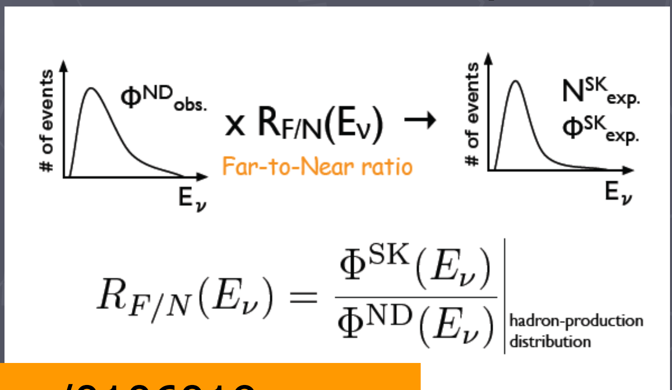
Far-to-Near Ratio ($R_{F/N}$)

- ν spectrum at far side is different even without oscillations; effect of non-point like source
- **Near and far** detectors see **different solid angles**:
  - far detector point like source at 2.5^0
  - near detector extended source from 1^0 to 3^0 (wide off-axis range)
- details of ν hadron production kinematics are needed in order to predict ν flux correctly



Complicated far-to-near ratio ($R_{F/N}$)

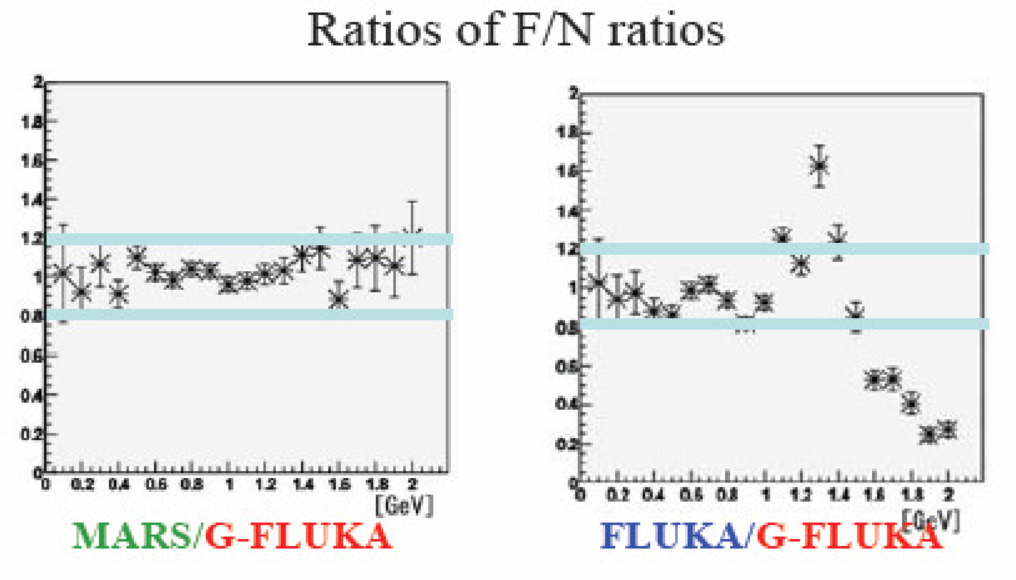




hep-ex/0106019

$R = \Phi^{MC}_{Far} / \Phi^{MC}_{Near}$
- dependence from hadron production models

Ken Sakashita – T2K, NA61 collaboration



Differences between hadron production models

$\delta R\nu_{\mu}$~20%

20% for E_{ν} <1 GeV

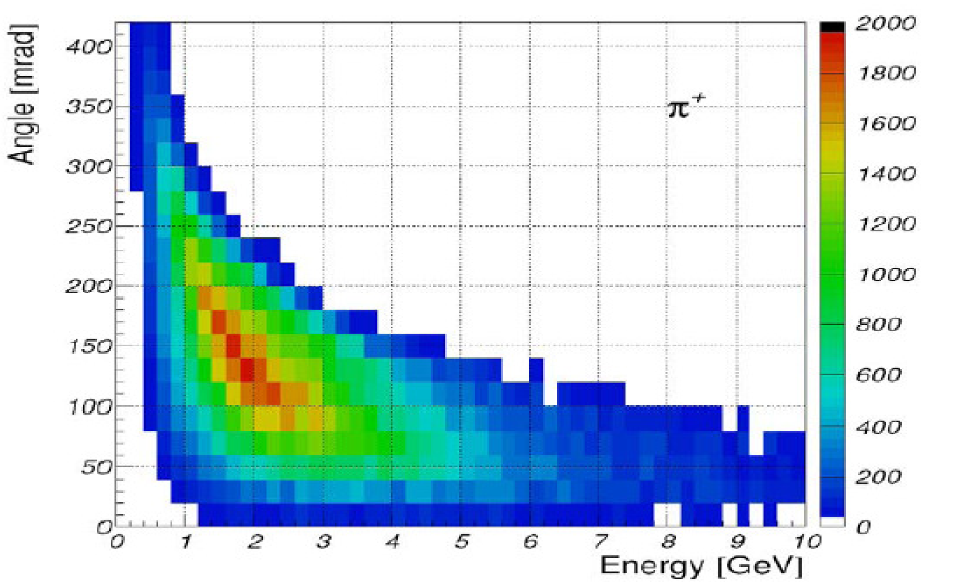
aim: $\boldsymbol{\delta R\nu_{\mu}<3\%}$

In order to reach this precision we need 200k reconstructed π^+ tracks. At the same time we will collect a similar number of π^- tracks since the NA61 acceptance is symmetric.

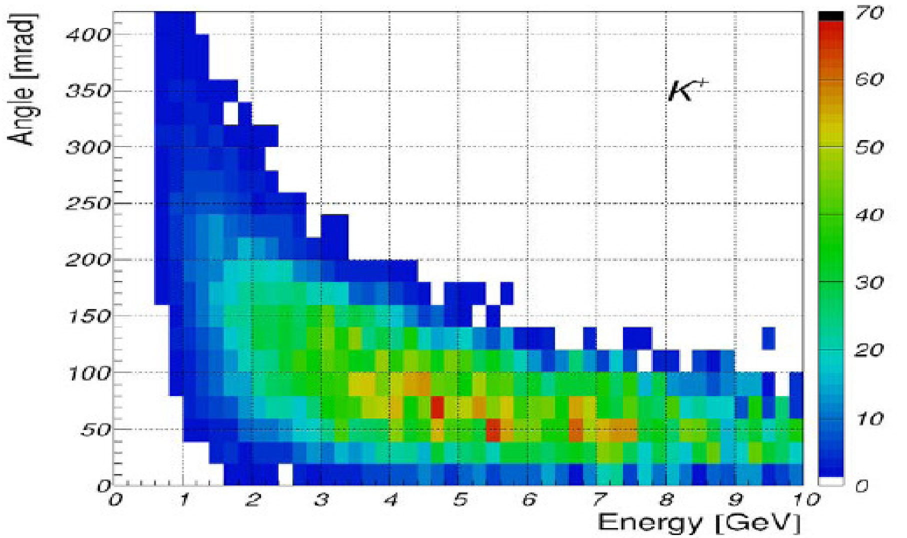
We also need to measure K/π ratio with uncertainty of $\delta(K/\pi)<10\%$

CERN-SPS-2007-019

NA61 (SHINE)- Physics program - T2K (II)

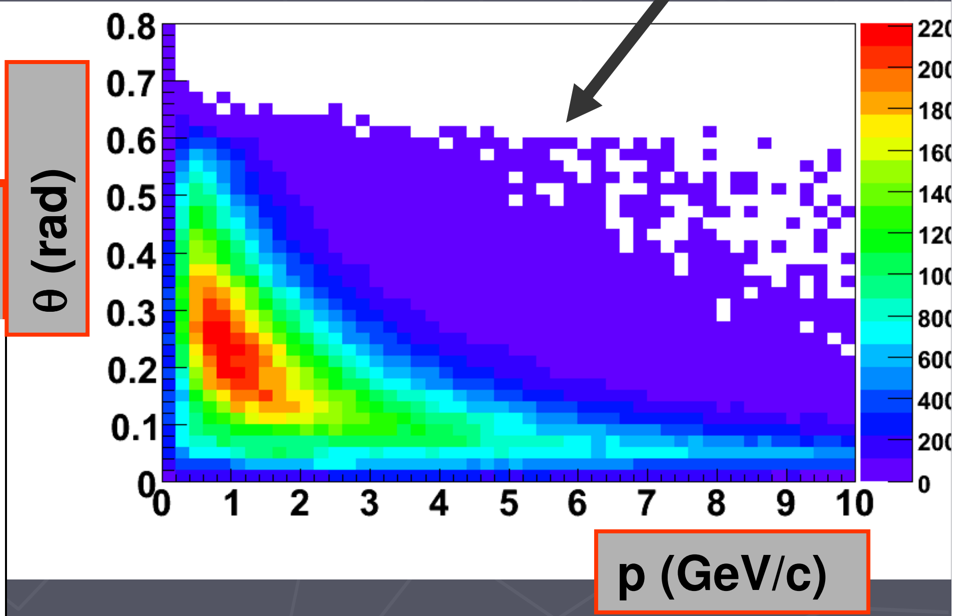


Pions and kaons producing neutrinos seen by T2K (JNUBEAM simulations)

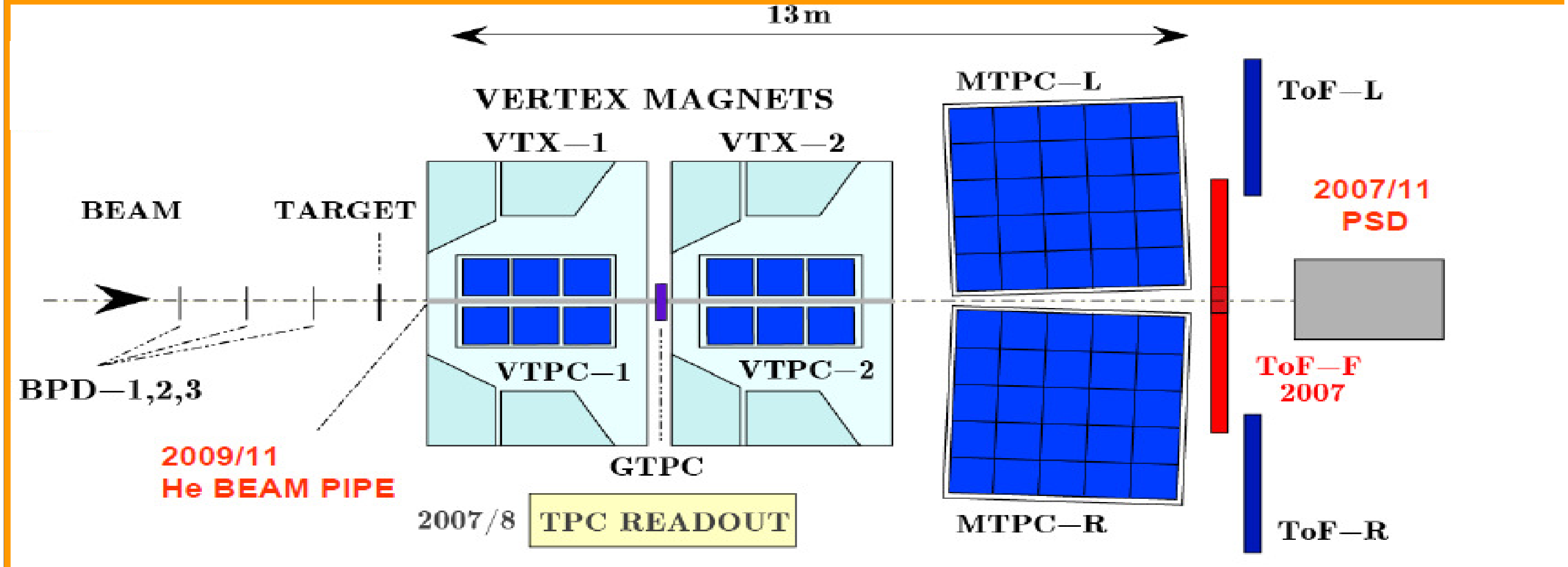


NA61 Acceptance versus T2K needs

Positive particles – NA61 data from 2007 pilot run

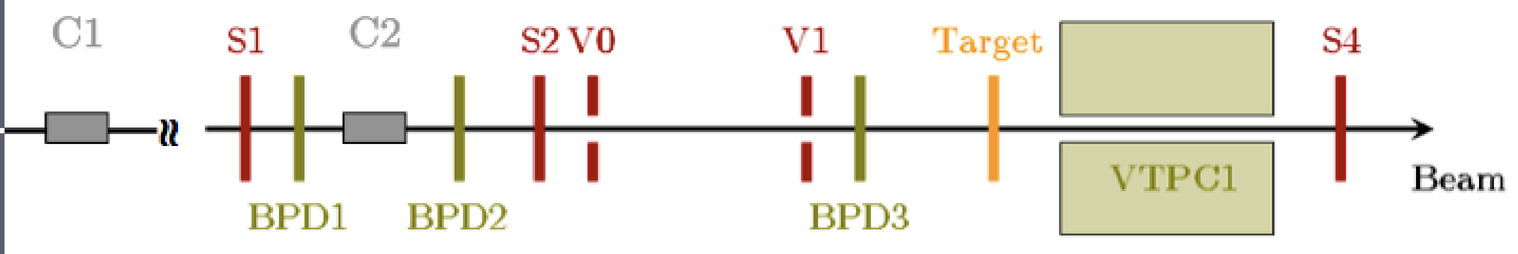


NA61 (SHINE)- detector performance



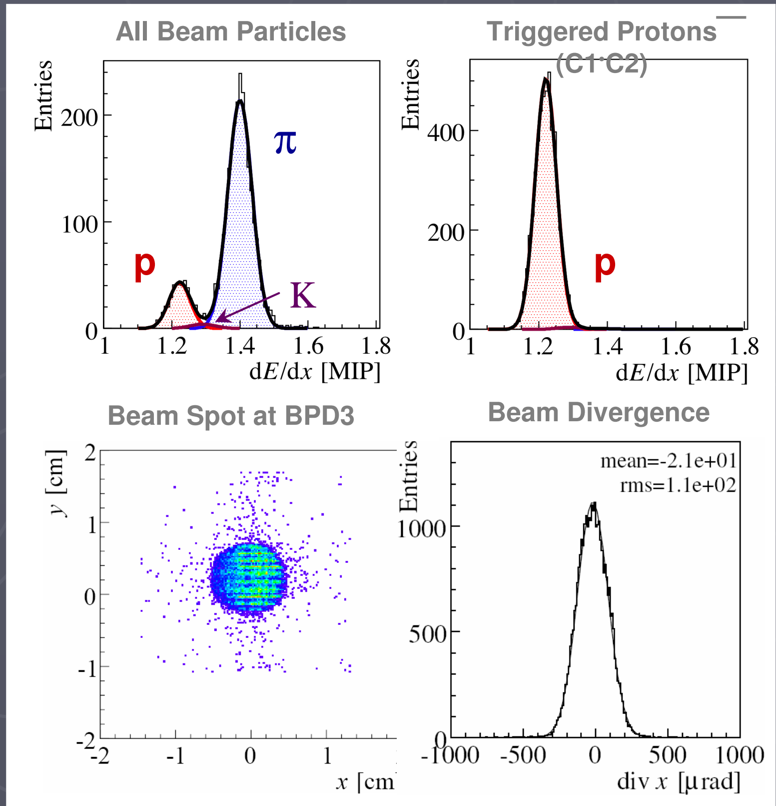
- Large Acceptance Spectrometer for charged particles
- TPCs as main tracking devices
- 2 dipole magnets with bending power of max 9 Tm over 7m length (2007 run:1.14Tm)
- New ToF-F to entirely cover T2K acceptance
- High momentum resolution $\sigma p/p^2 = 10^{-4}$ GeV/c
- Good particle identification (PID) : $\sigma(dE/dx)/\langle dE/dx\rangle=0.04$
- Good ToF resolution: σ(ToF-L/R)=60 ps, σ(ToF-F)<=120 ps

Setup of Beam Line

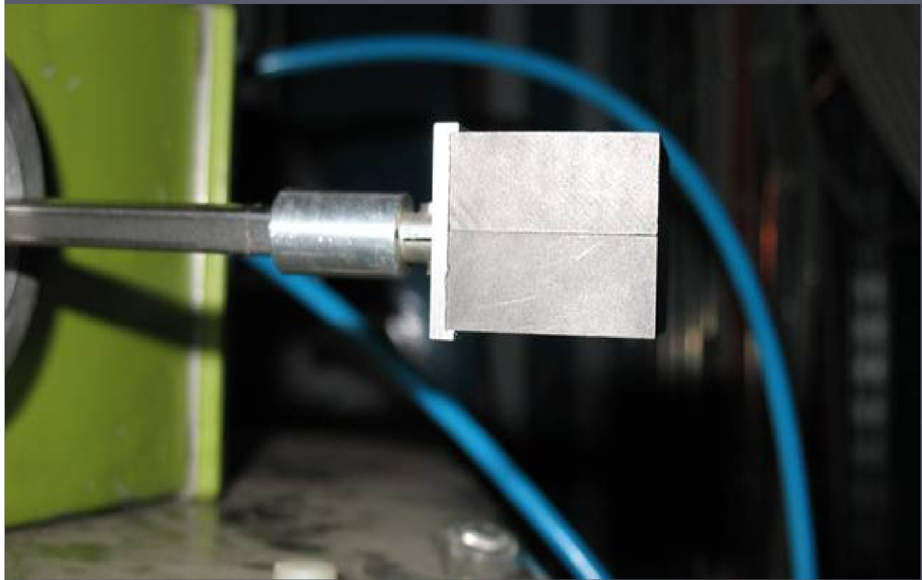


- **Secondary** hadron beam composed of 83.7% π^+, 14.7% p and 1.6% K^+
- Proton beam particles identified by CEDAR (C1) and threshold Cerenkov counters (C2)
- Incoming p then selected by several scintillator counters (S1, S2, V0, V1)

  → beam defined as B = S1•S2•$\overline{\text{V}}$•C1•$\overline{\text{C2}}$
- Trajectory of beam particles measured by the beam position detectors (BPD-1/-2/-3)
- Interactions in the target selected by anti-coincidence of the beam particle with a small scintillator S4 (B•$\overline{\text{S4}}$)



Targets used during 2007 pilot run



Thin carbon target

- 2cm length, size 2.5x2.5
- ρ=1.84 g/cm^3
- ~ 0.04 λ_{int}

T2K replica target

- length 90 cm, ϕ=2.6 cm
- ρ=1.83 g/cm^3
- ~ 1.9 λ_{int}

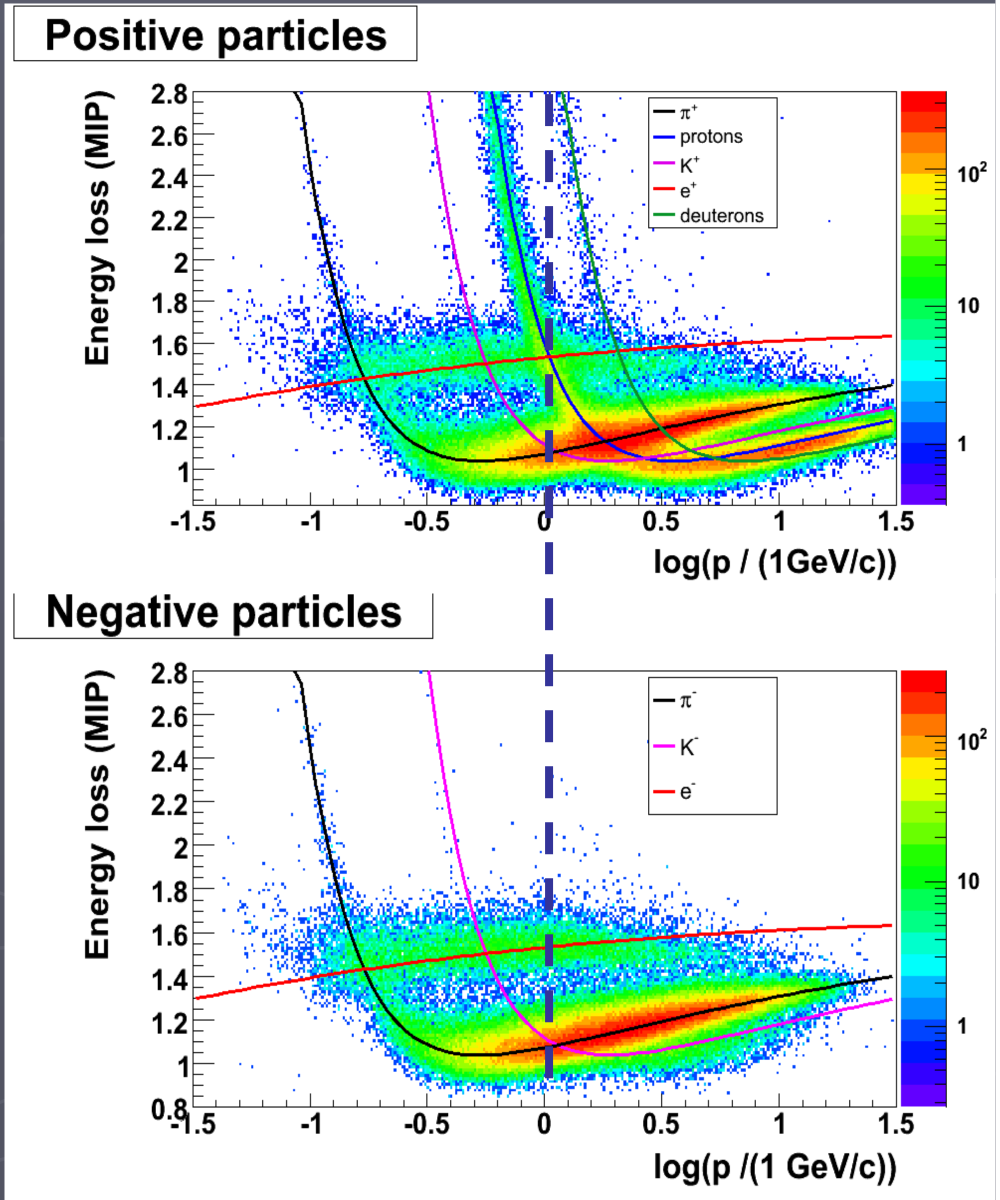
During October 2007 pilot run (30 days) taken pilot physics data for T2K 30.9 Gev/c protons (2 weeks)

Thin target: ~670k triggers   Replica target: ~230k triggers

Empty target: ~80k trig

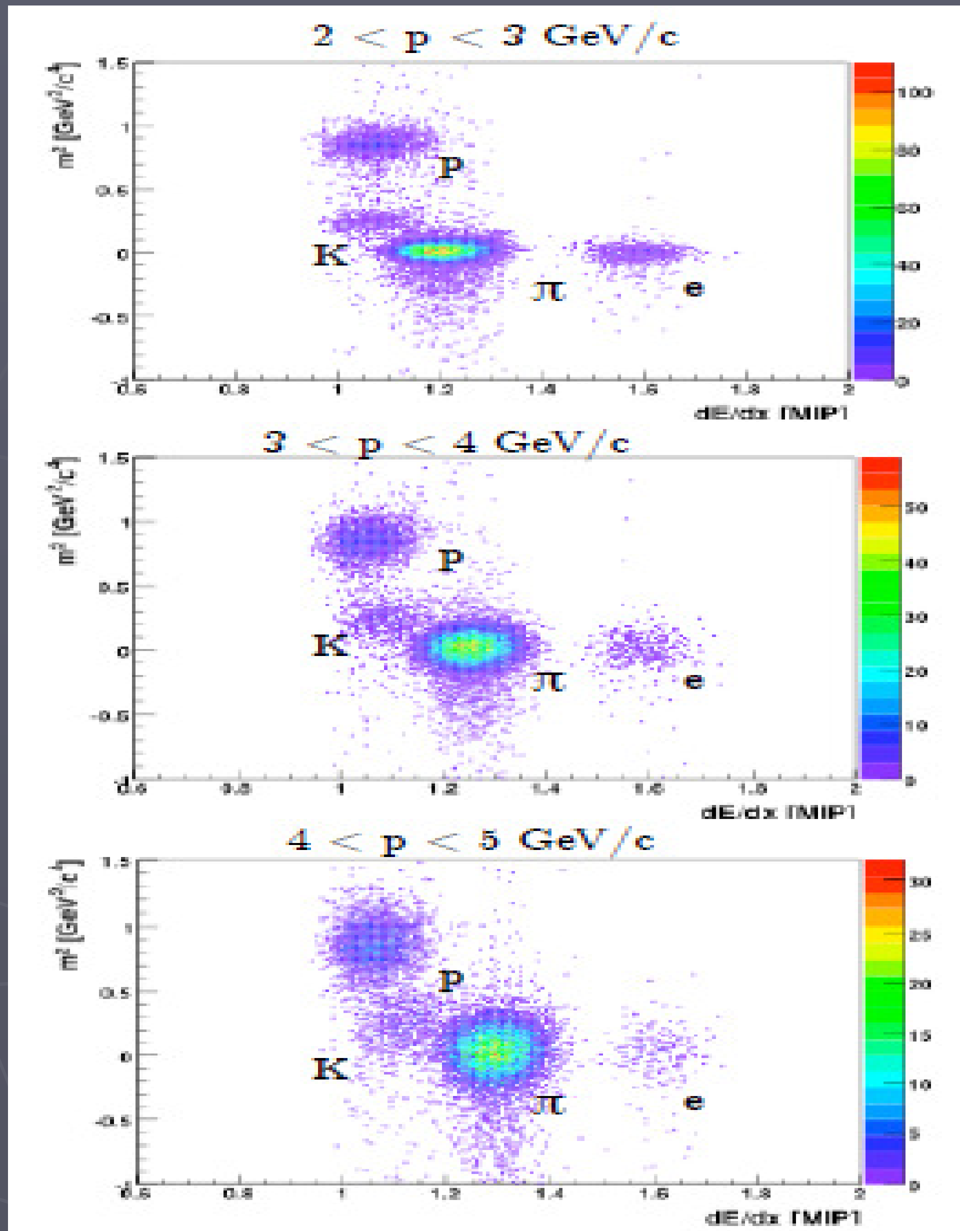
Particle identification strategy (I)

- **Energy loss measurements:**
  - below 1GeV/c dedicated dE/dx analysis to identify pions
  - for region p=[1,4]GeV/c Bethe Bloch curves cross each other making particle separation not reliable ->additional information from ToF is required
  - above 4 GeV/c dE/dx analysis



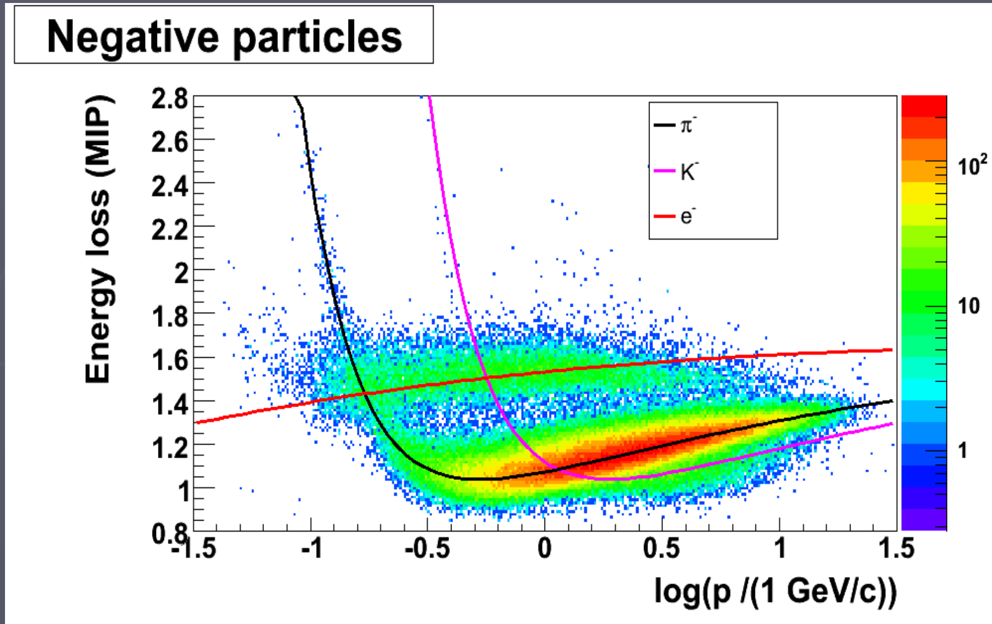
Particle identification strategy (II)

- **Combined energy loss and Time of Flight measurements :**
  - p~[1-6] GeV/c Time of Flight (ToF) measurements
  - combined dE/dx + ToF analysis



Particle identification strategy (III)

- **Analysis of negatively charged particles:**

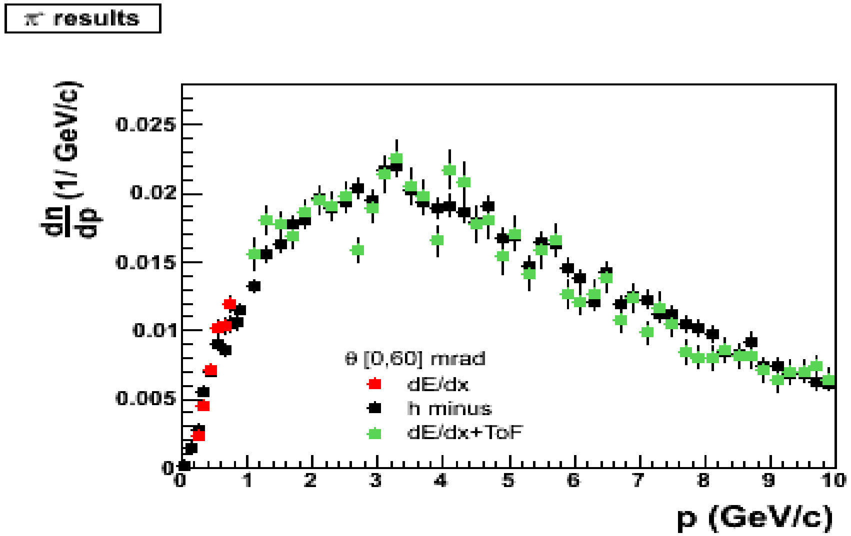


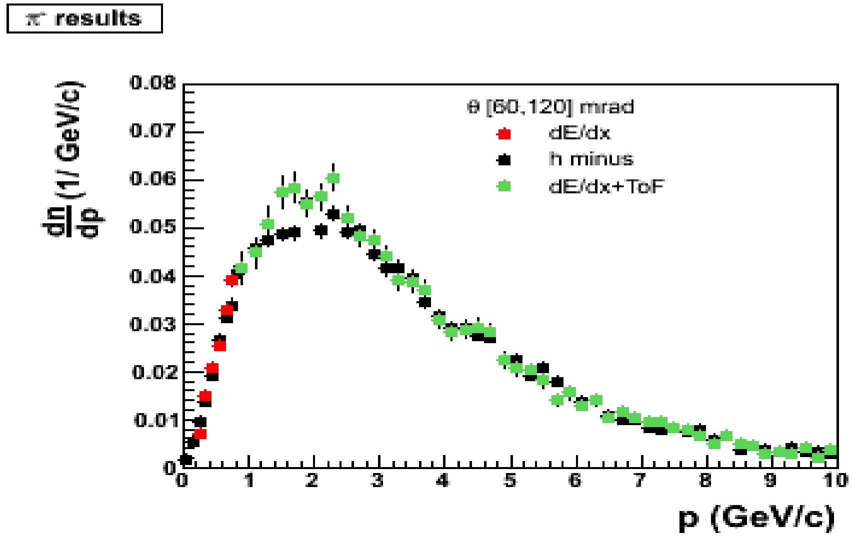
  - The analysis of negatively charged particles (h- analysis) from the primary vertex assumes that most of produced negatively charged particles at 31 GeV/c proton carbon interactions are **π^- mesons**.
  - The remaining fraction includes K^-, e^- and negligible number of anti-protons.
  - Venus-GHEISHA and Geant Monte Carlo simulation chain is used to calculate corrections for geometrical acceptance, reconstruction efficiency, weak decays vertex association.
  - Finally corrected spectra of π^- **mesons in broad momentum range** are obtained.

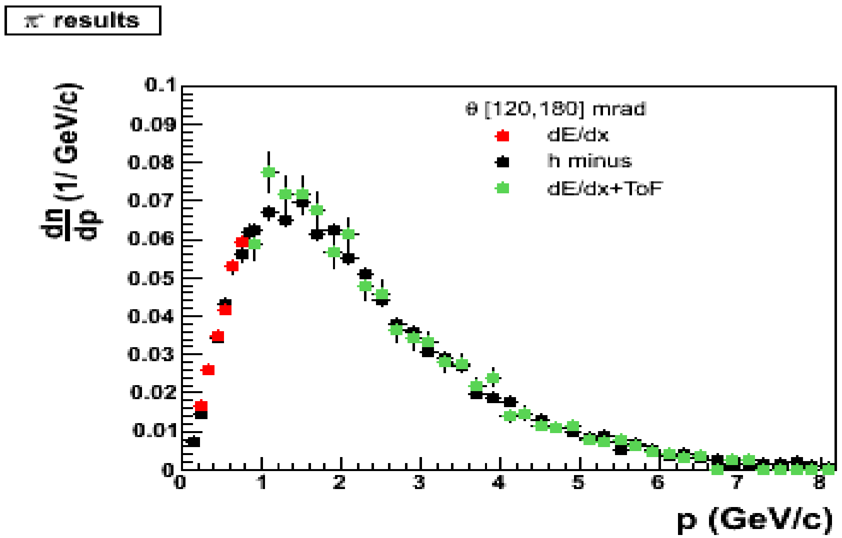
Preliminary spectra from p+C interactions at 31 GeV/c beam momentum

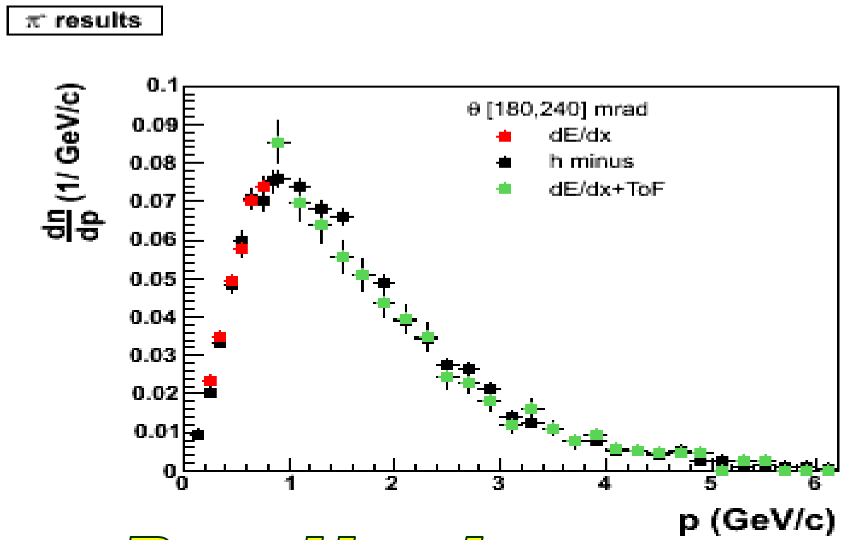
2007 pilot run

π^- - results from three analyses





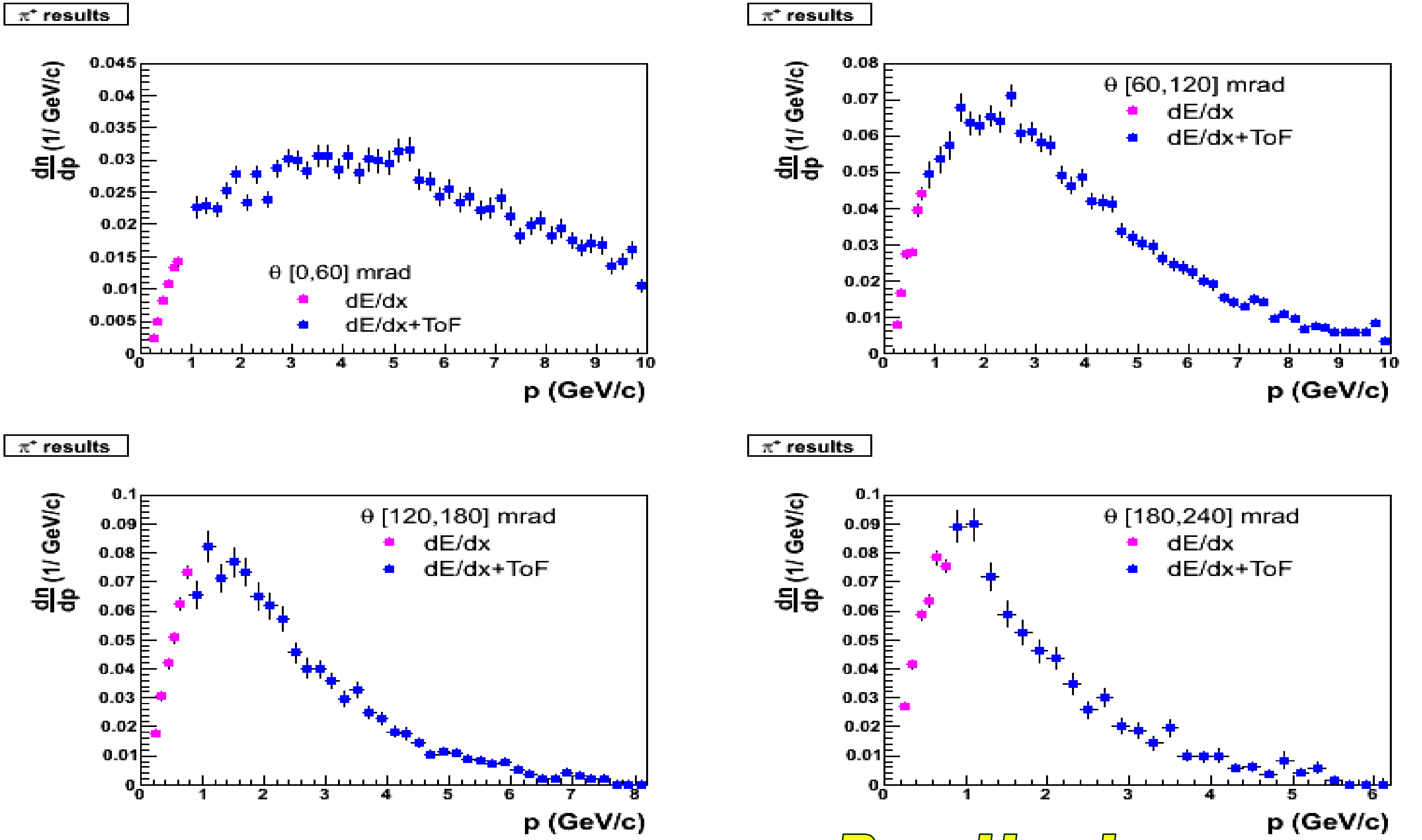




systematic errors below 20%

Preliminary

π⁺ - results from dE/dx and dE/dx + TOF analyses



systematic errors below 20%

Preliminary

Summary I

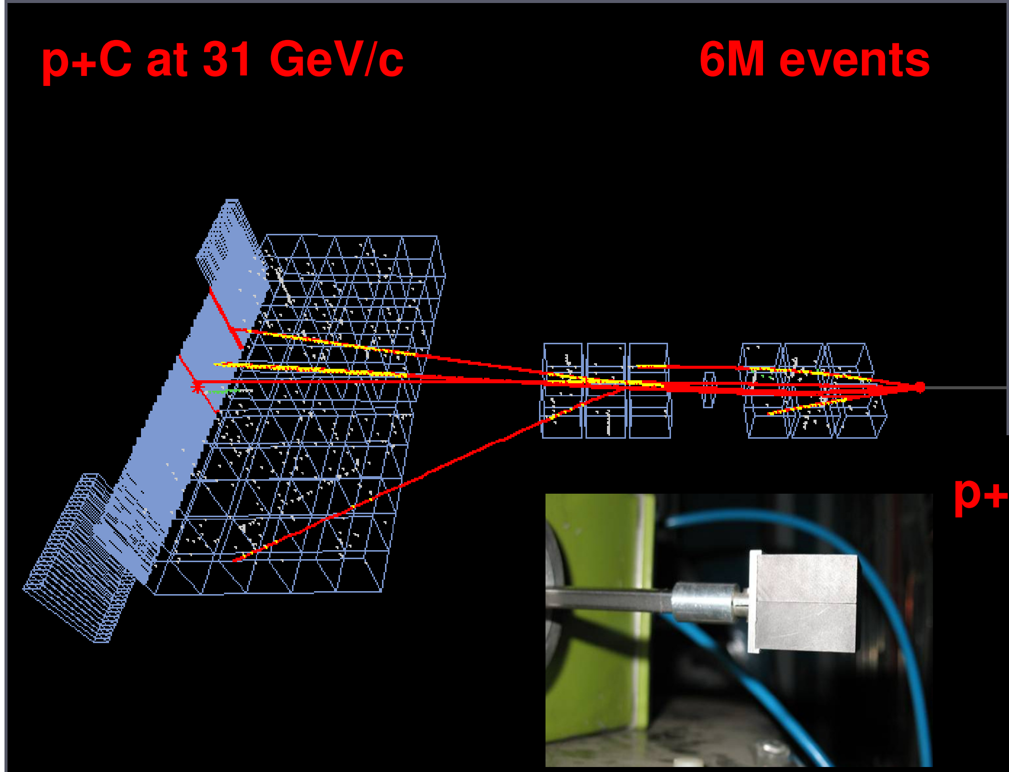
- NA61/SHINE is a large acceptance hadron spectrometer at the CERN SPS which precisely measures the particle production from the interaction of a 30 GeV proton beam on different Carbon targets
  - Thin target: for the determination of inclusive cross sections
  - T2K replica target: for the study of secondary interactions in the T2K target

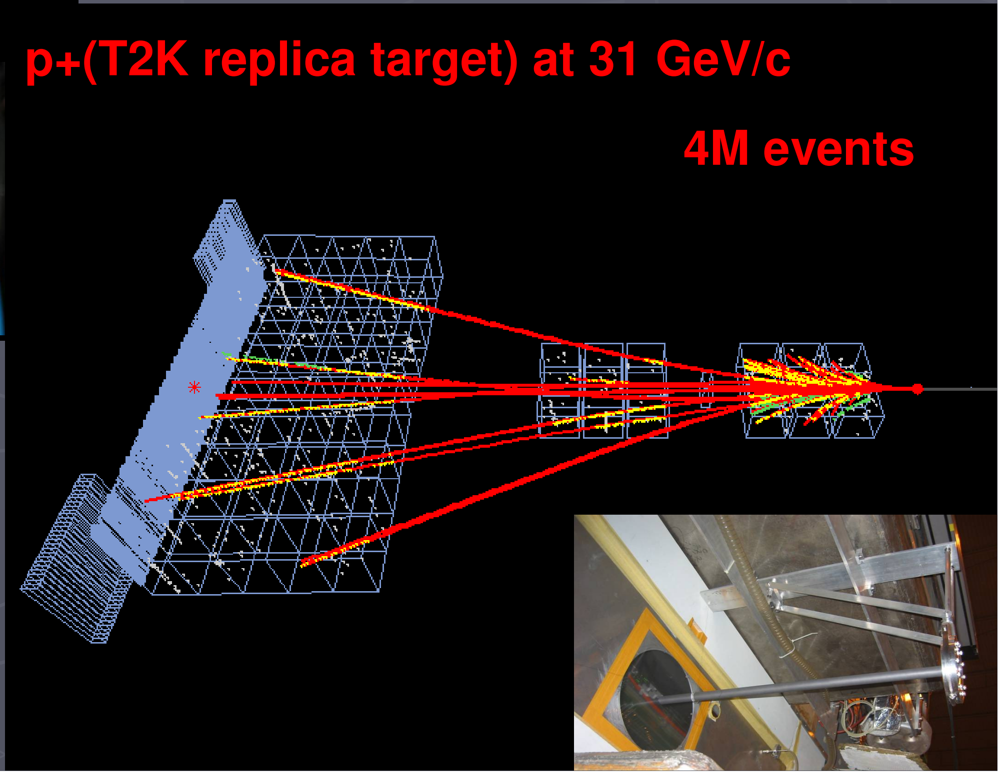
- During the 2007 pilot run data on proton-Carbon interactions were registered
  - good quality of data, though limited in statistics
  - high quality of track reconstruction and particle identification has been achieved
  - the data and detailed simulations confirm that phase space needed for T2K measurements is covered
  - first preliminary hadron spectra for T2K have been obtained
  - work on T2K replica target data is in progress

Summary II

- Successful 2009 run (July 26th – November 16th)
- Detector upgrades performed for this run:
  - TPC read-out and DAQ → increase of event rate by factor 10 (~70Hz)
  - new trigger system
  - increased ToF-acceptance (p_{min} ~ 1 GeV/c → 0.6 GeV/c)
  - new Beam Position Detectors of 5 x 5 cm2 to fully cover x- section of the T2K replica target
  - ~3 weeks were dedicated to T2K measurements (p+C at 31 GeV/c)
  - 6M interaction triggers collected for thin Carbon target and 4M triggers for the T2K replica target

Data taking in 2009- neutrino program

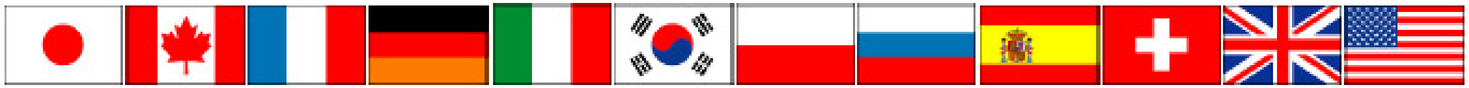




BACK UP SLIDES

Location:

T2K collaboration



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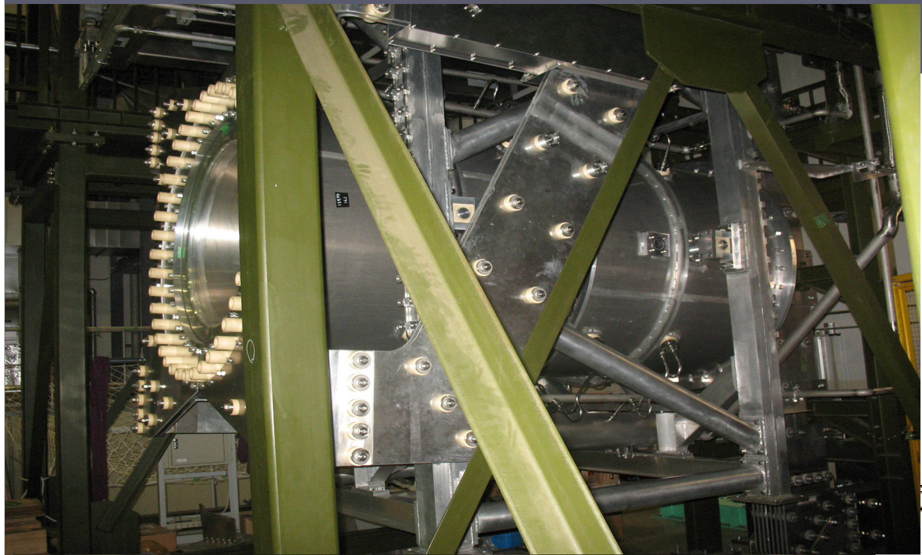
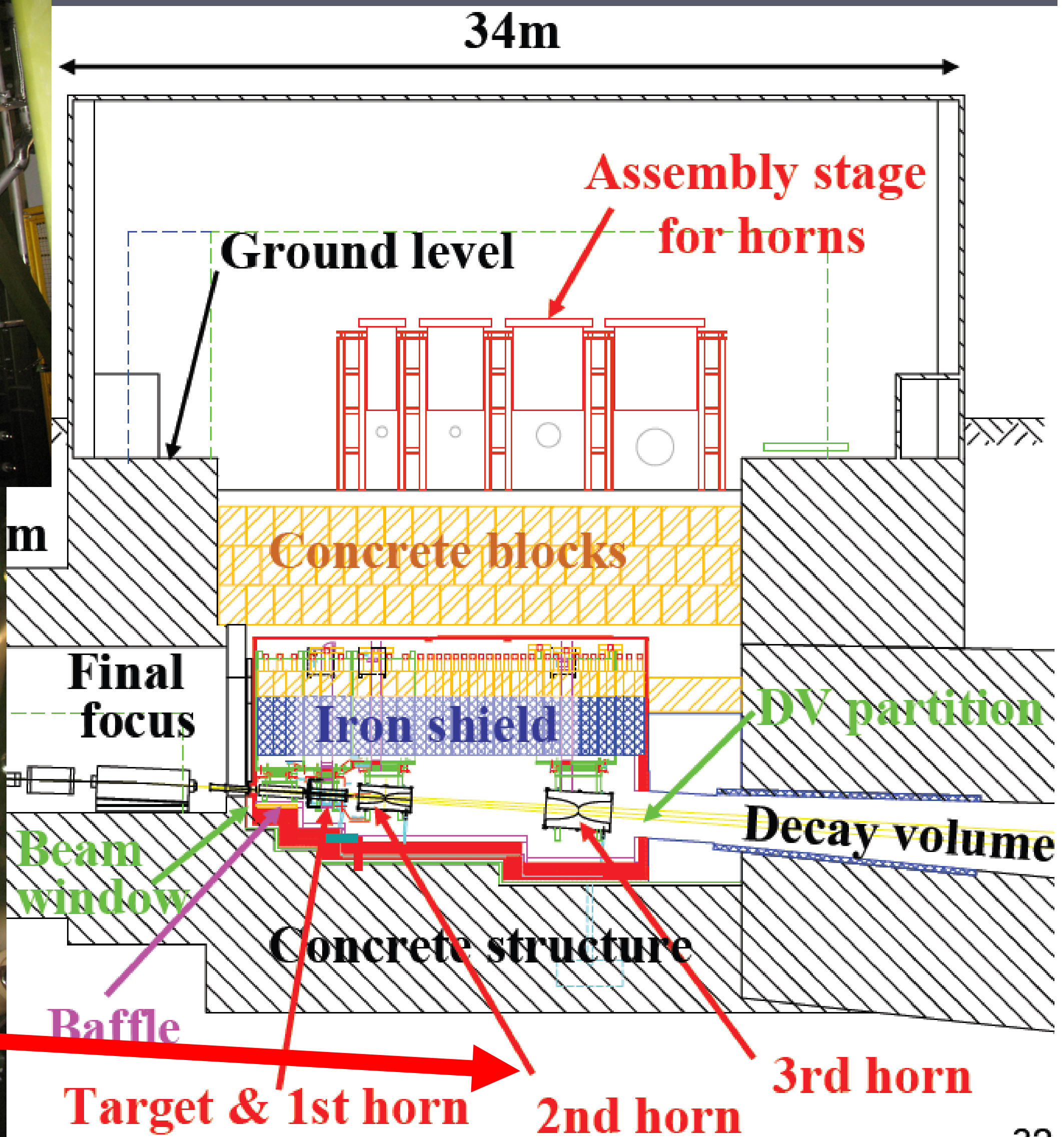
U. of Washington

- **477 members, 62 Institutes, 12 countries**

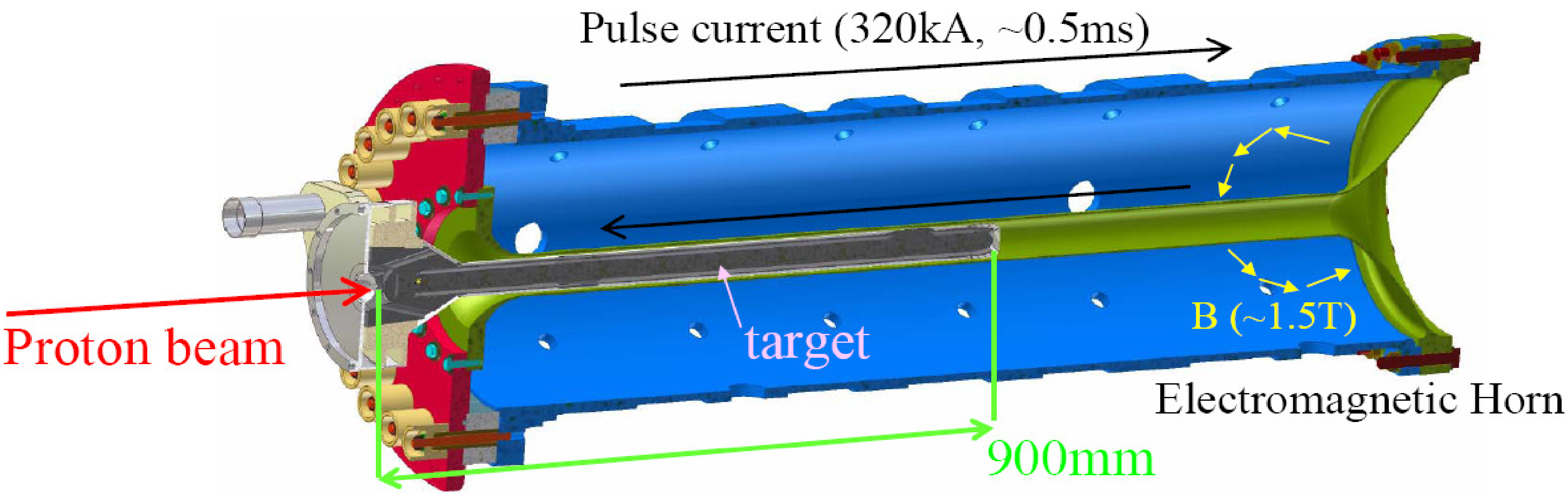
Target Station Design





T2K target

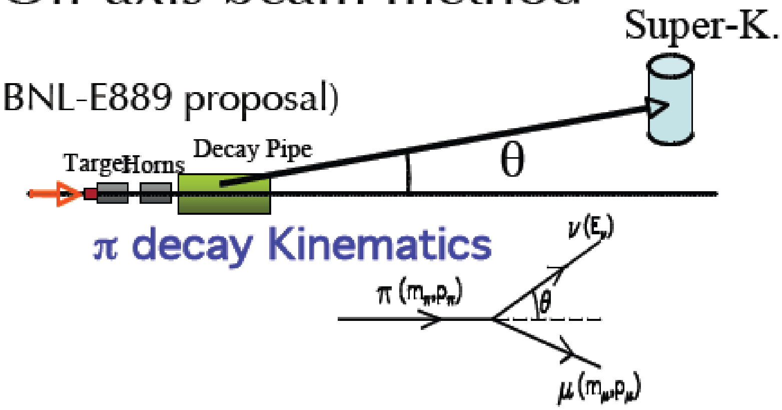
- Material: Isotropic graphite (C) : ρ=1.82g/cm^3
- Length: 900mm = 1.9 $\times$ λ_{int} (85%)
- Diameter: ϕ26mm
  $\leftrightarrow$ Beam size: σ_x=σ_y=4.2mm
- Target is installed inside the Electromagnetic horn
  - EM horn generate the toroidal magnetic field to correct pions.
  - Materials between target and the magnetic field:
    - Cooling tube: t=2mm graphite (C) + 0.3mm Ti-Alloy + 0.5mm ceramic

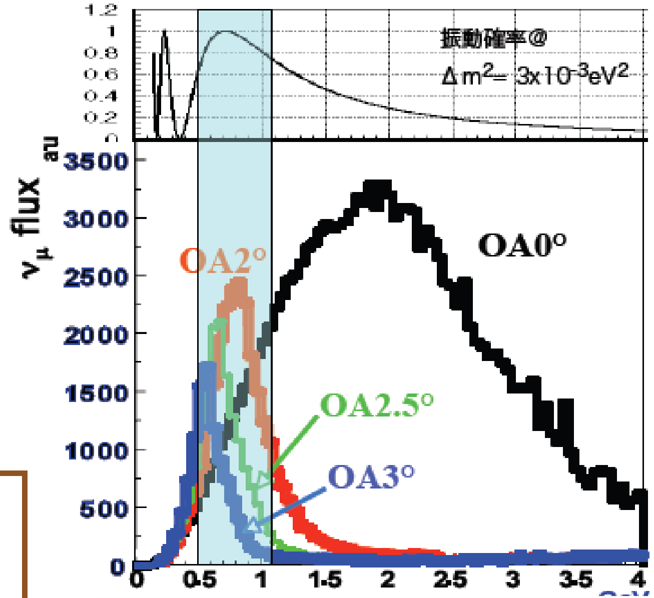


T2K off axis neutrino beam

- Off-axis beam method

(ref. BNL-E889 proposal)





L = 295 km

Δm^2_{23} = (2.2~3.0) x 10^{-3} eV^2

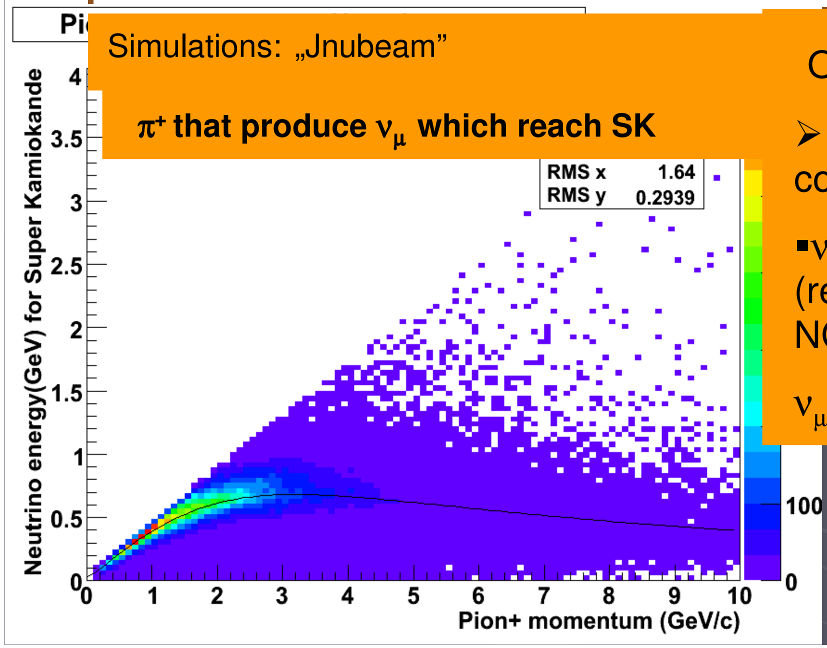
➡

Oscillation max.

E_ν = 0.5~0.7 GeV

Simulations: „Jnubeam"

π^+ that produce ν_μ which reach SK

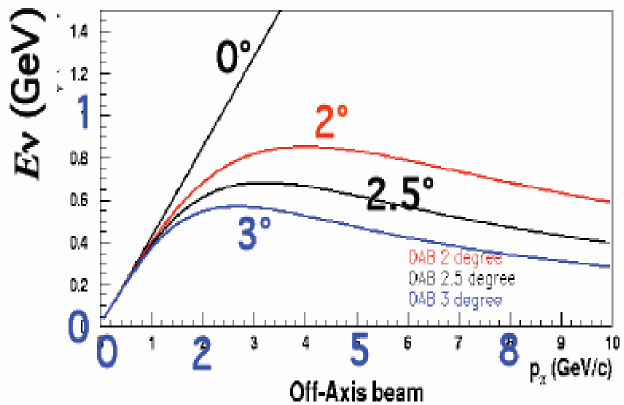


Off axis beam features:

- narrow band beam comparing to 0A0[0]

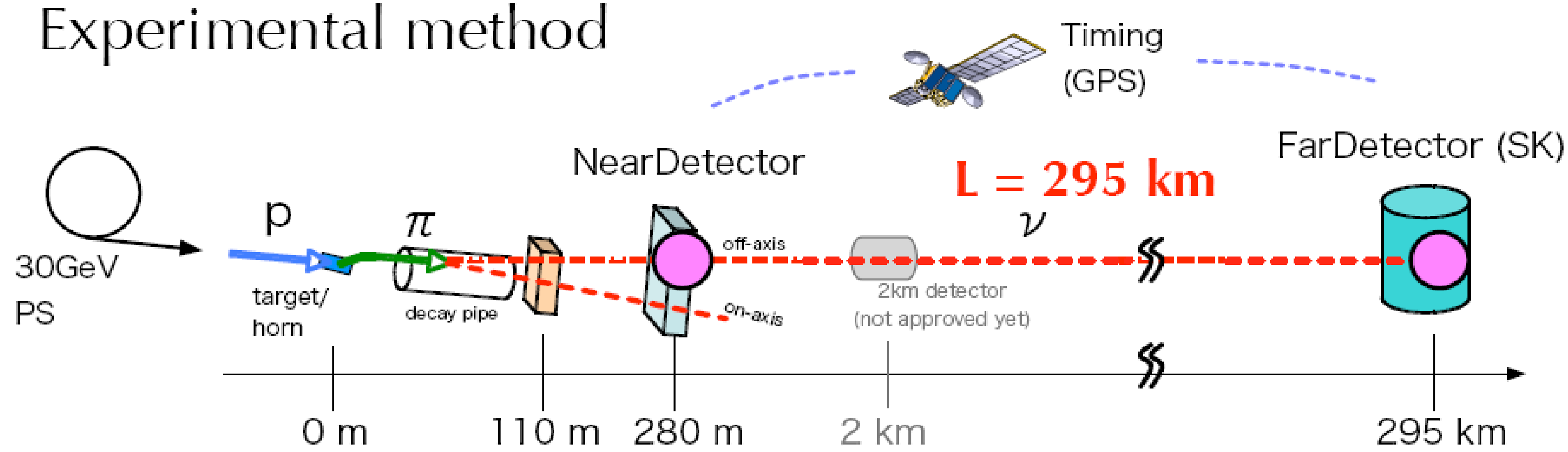
- ν_μ lower mean energy (reduced background from NC)

$\nu_\mu + N = \nu_\mu + N + \pi^0$

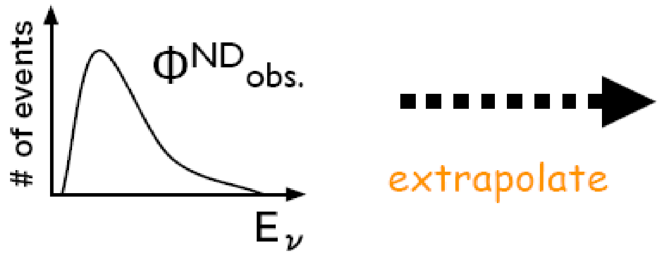


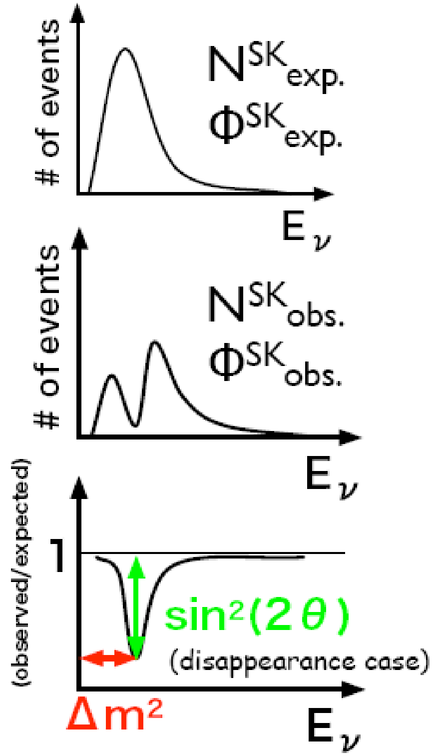
$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\theta)}$$

- Experimental method



(1) make ν_μ
narrow-band intense ν beam





(2) detect neutrino
- **CCQE interaction**
- reconstruct E_ν
- observable = $\Phi \times \sigma$(cross section)

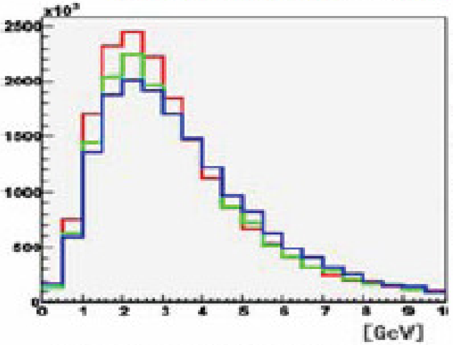
(3) expect ν spectrum in SK
for example, $\Phi^{SK}_{exp} = \Phi^{ND}_{obs} \times R_{F/N}(E_\nu)$

(4) evaluate ($\sin^2(2\theta)$, Δm^2) by
comparing the number ($N^{SK}_{exp.}$, $N^{SK}_{obs.}$)
and the spectrum ($\Phi^{SK}_{exp.}$, $\Phi^{SK}_{obs.}$)

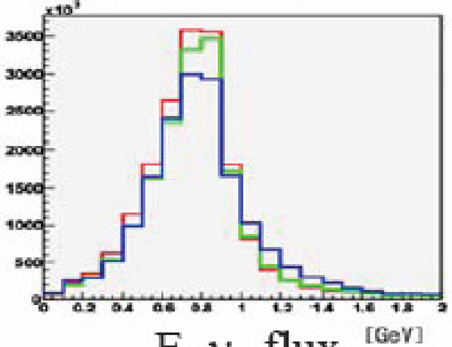
F/N uncertainties due to “models”

It is difficult to evaluate the validity of the hadron production model !!
The uncertainty is probably not less than the difference among several models inspired by similar data sets

G-FLUKA vs. MARS vs. FLUKA



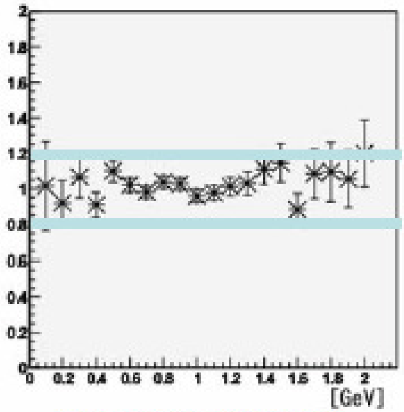
π^+ momentum



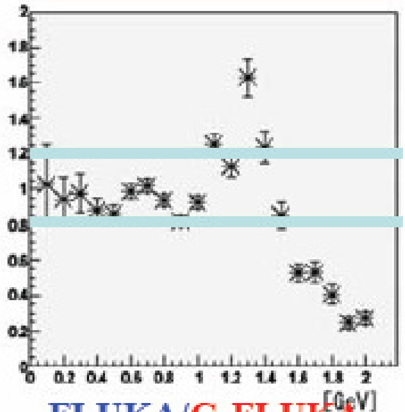
E_ν_μ flux

up to ~20% difference!

Ratios of F/N ratios



MARS/G-FLUKA



FLUKA/G-FLUKA

Systematical error due to F/N

F/N ratio difference among hadron production models:
~ 20% @ $E_\nu \leq 1$GeV

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*

$\delta(N_{BG}) < 10\%$

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

Normalization of π⁻ spectra

- The inclusive inelastic cross section of a given particle type a

$$\boxed{\frac{\Delta\sigma^{meas}_{inel,\alpha}}{\Delta p\Delta\theta} = \frac{1}{a}\frac{1}{N_{beam}}\frac{\Delta n_{\alpha}}{\Delta p\Delta\theta} = \frac{1}{a}\frac{N_{trig}}{N_{beam}}\frac{1}{N_{trig}}\frac{\Delta n_{\alpha}}{\Delta p\Delta\theta} = \frac{\sigma_{trig}}{N_{trig}}\frac{\Delta n_{\alpha}}{\Delta p\Delta\theta}}$$

a: target properties, N_{beam}: # of incoming beam particles,

N_{trig}: # of triggers, σ_{trig}: trigger cross section, Dn: # of identified particles in a given p-θ bin

- The evaluated total inelastic cross section is in good agreement with previous measurements

$$\boxed{\sigma_{inel} = \sigma_{trig}\frac{N_{\text{int}}}{N_{trig}}}$$

→ provides a good x-check of the measured s_{trig} used to the determine the inclusive x-section

Normalization to inclusive inelastic cross section

$$\boxed{\frac{\Delta\sigma^{meas}_{inel,\alpha}}{\Delta p\Delta\theta} = \frac{\sigma_{trig}}{N_{trig}}\frac{\Delta n_{\alpha}}{\Delta p\Delta\theta}}$$

$$\left[mb \,/\, {GeV}\!/\!{c} \,/\, mrad\right]$$

Normalization to mean multiplicity in inelastic collisions

$$\boxed{\frac{\Delta n^{meas}_{inel,\alpha}}{\Delta p\Delta\theta} = \frac{1}{N_{trig}}\frac{\sigma_{trig}}{\sigma_{inel}}\frac{\Delta n_{\alpha}}{\Delta p\Delta\theta}}$$

$$\left[1 \,/\, {GeV}\!/\!{c} \,/\, mrad\right]$$

The NA61/SHINE Collaboration

122 physicists from 24 institutes and 13 countries:

University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Cape Town University, Cape Town, South Africa
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
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Institute of Physics, University of Silesia, Katowice, Poland
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Institute for Nuclear Research, Moscow, Russia
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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
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