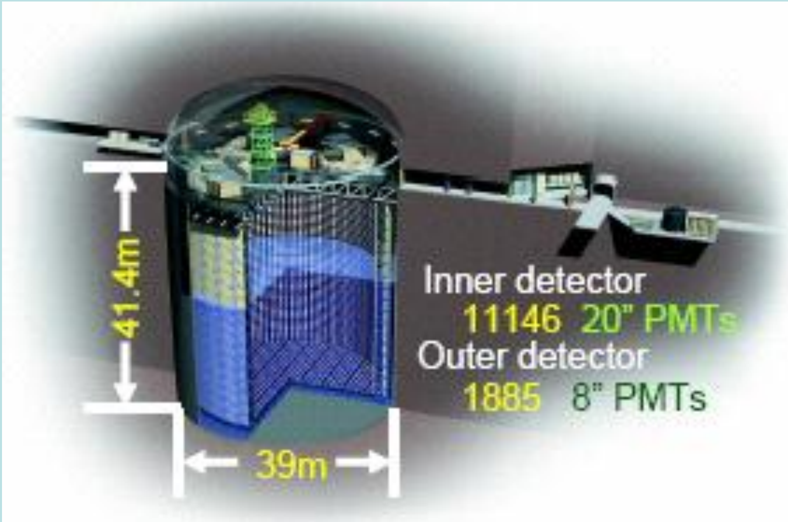
Proton-Carbon data from NA61/SHINE for neutrino experiments

Outline

- T2K – main physics goals
- The main sources of systematic errors due to the lack of knowledge about hadronic interactions
- T2K experiments: beam and target
- Na61 acceptance, particle identification
- Conclusions

T2K

Super Kamiokande



J-PARC

T2K-Main Goals

- $\nu_\mu \rightarrow \nu_x$ disappearance
  - Precise Δm^2, $\sin^2 2\theta$
- $\nu_\mu \rightarrow \nu_e$ appearance
  - Finite θ_{13} ?

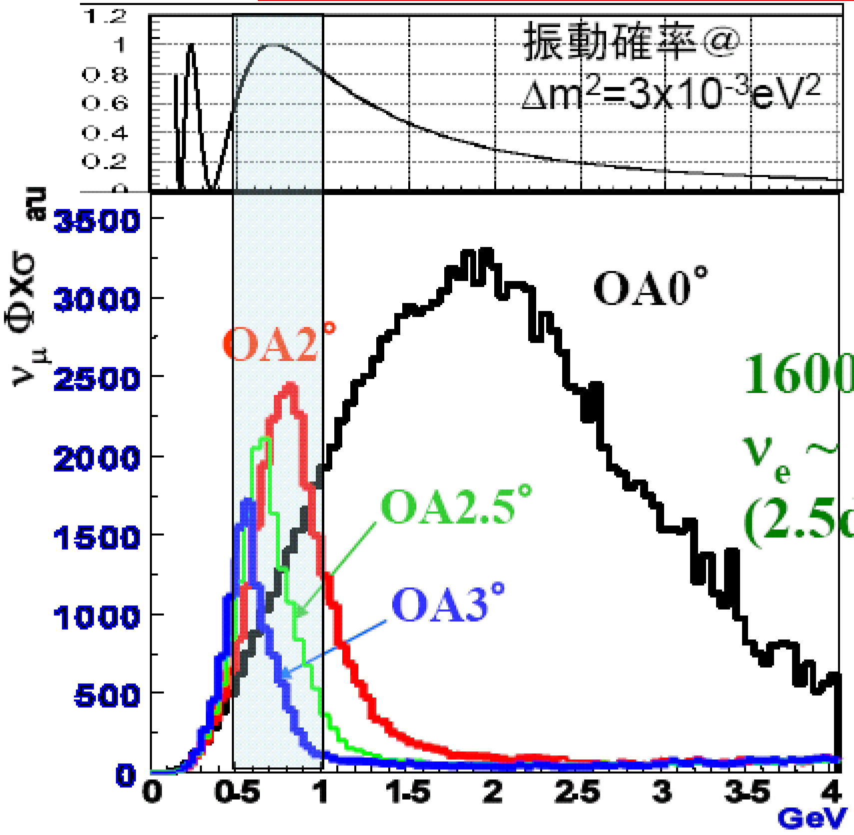
Appearance of ν_e in ν_μ beam is expected to be a small effect.

Discovery of oscillation will be possible for $\sin^2 2\theta_{13} > 0.006$.

Background to the ν_e from ν_e in the beam (0.4%)

T2K-beam

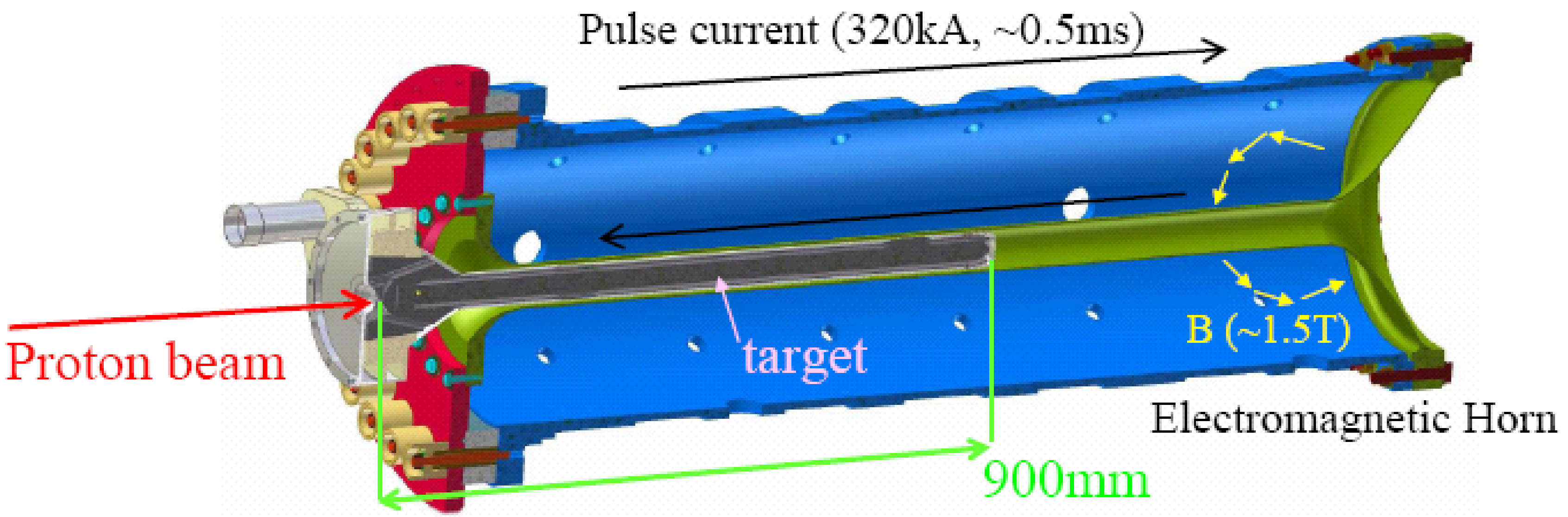
- 30 GeV (50 GeV) intense proton beam on Carbon target.
- Off axis ~2.5deg neutrino beam



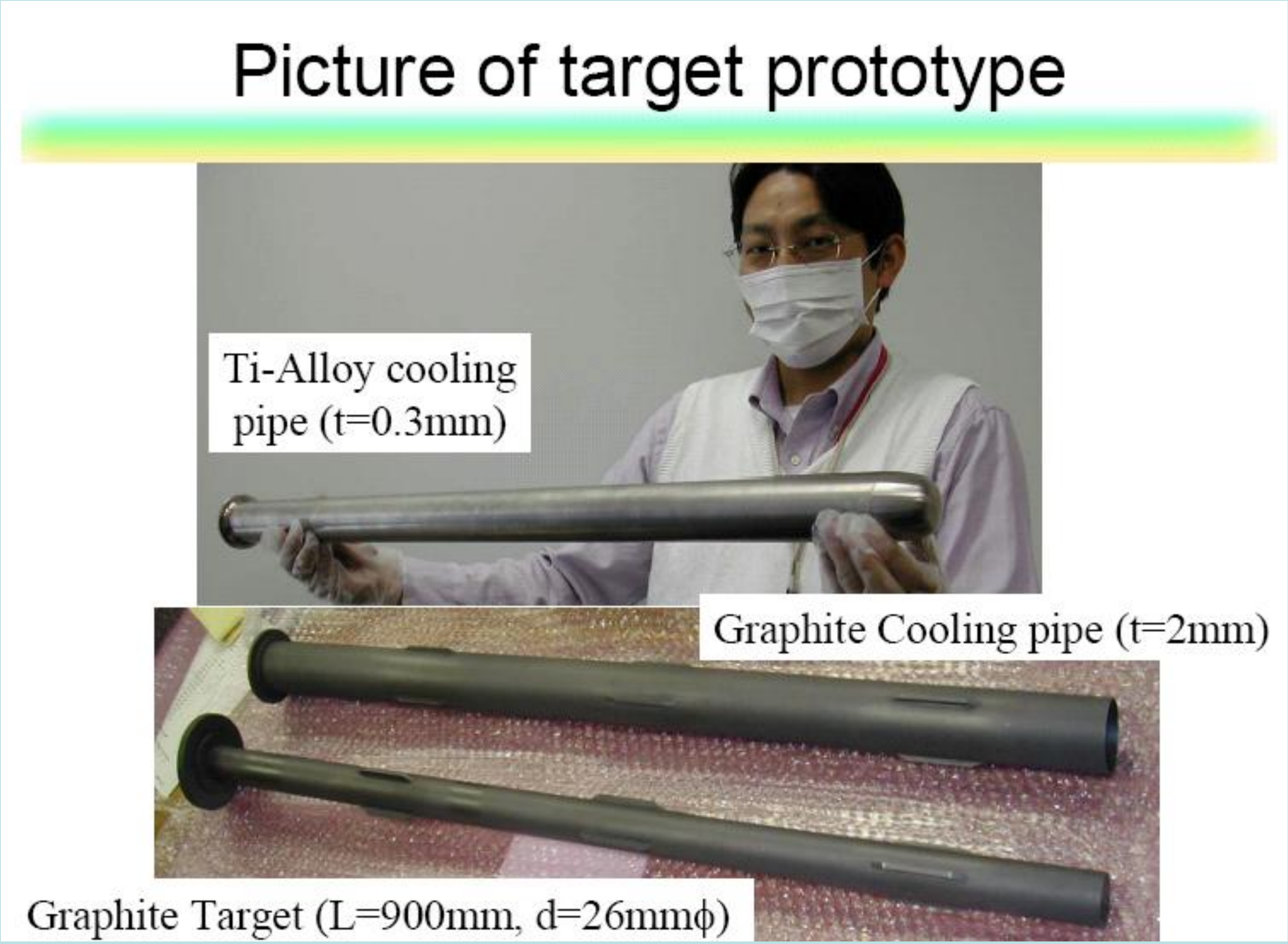
1600 ν_μ CC/yr/22.5kt
ν_e ~ 0.4% at peak
(2.5deg)

T2K target

- Material: Isotropic graphite (C) : ρ=1.82g/cm^3
- Length: 900mm = 1.9 $\times$ λ_{int} (85%)
- Diameter: ϕ26mm
  ←→ 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

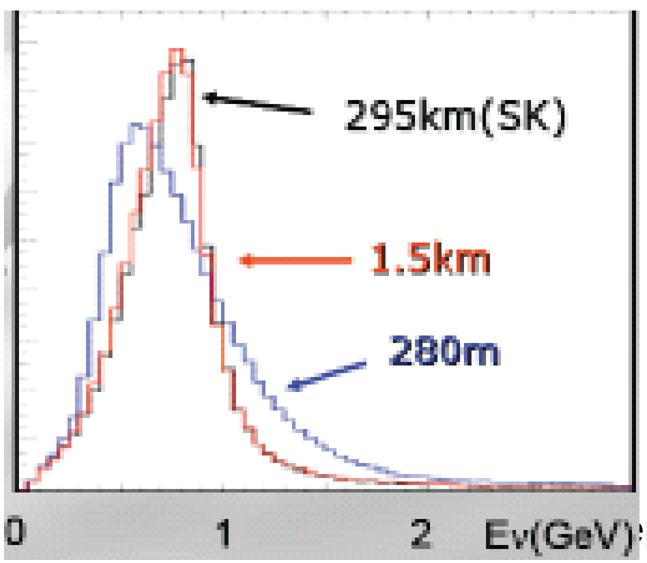

Picture of target prototype
Ti-Alloy cooling pipe (t=0.3mm)
Graphite Cooling pipe (t=2mm)
Graphite Target (L=900mm, d=26mmϕ)

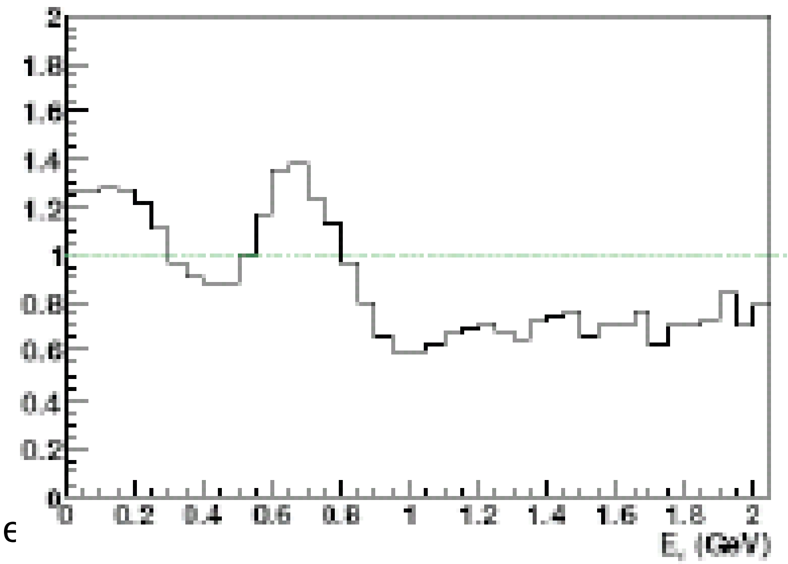
The standard strategy of the long baseline experiments is:

- Measure the neutrino interactions near the end of the decay pipe in „Near Detector".
- Compare to the observed in the „Far Detector"

But the source of neutrinos is not pointlike and isotropic. must know the flux as a function of the emission angle, energy and the neutrino flavor structure to transport it to the far detector.

The ratio R(E)=Far/Near is a function of E_ν

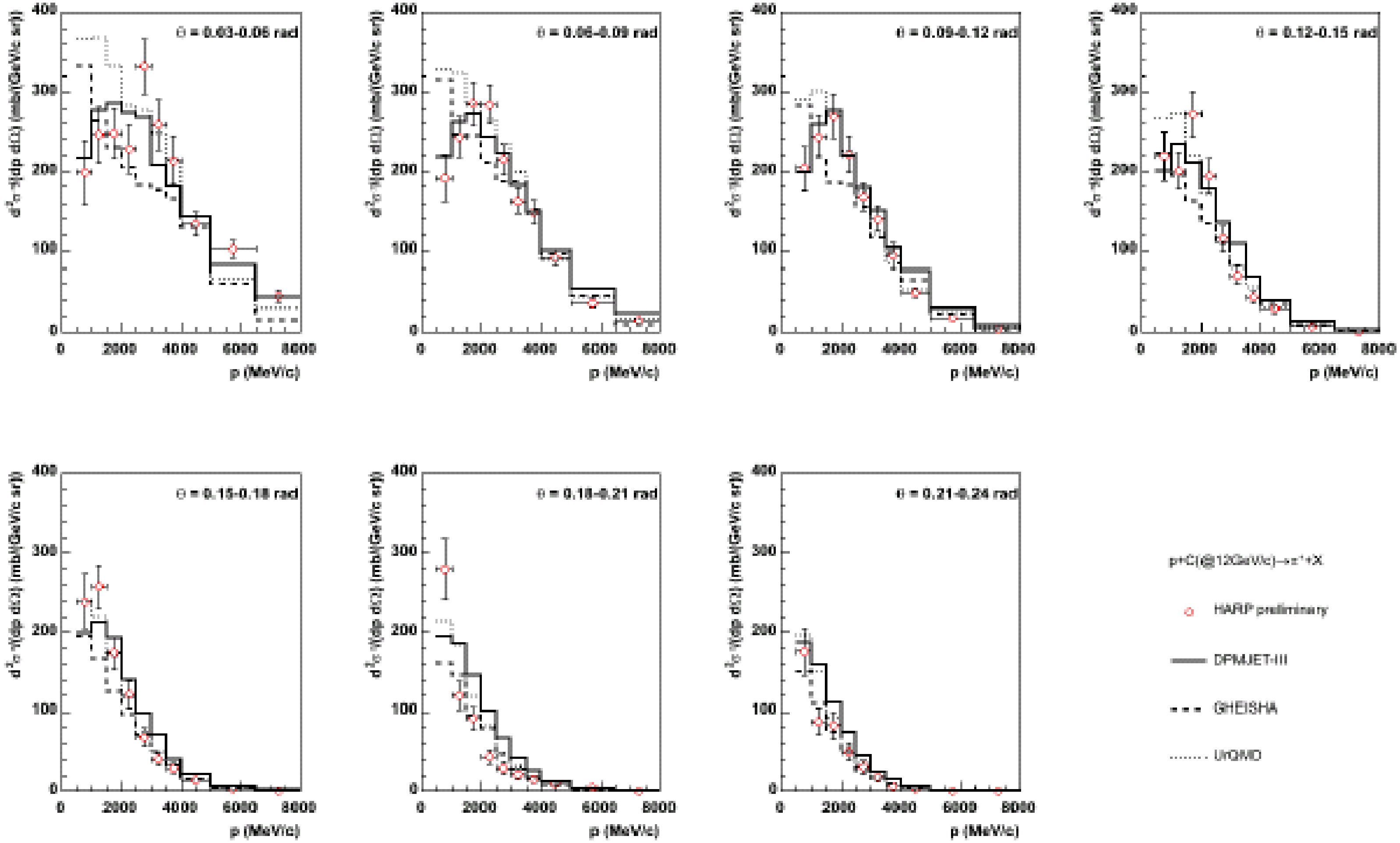




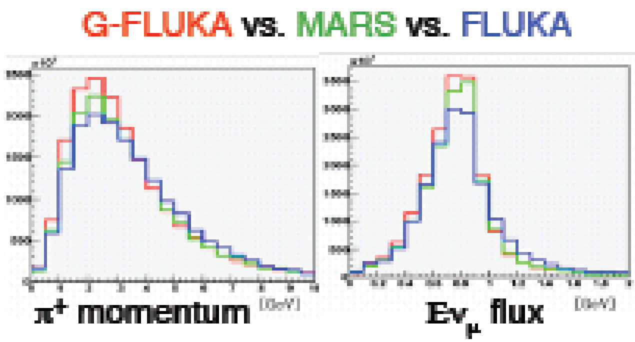
Model dependence of MC pion momentum distributions.

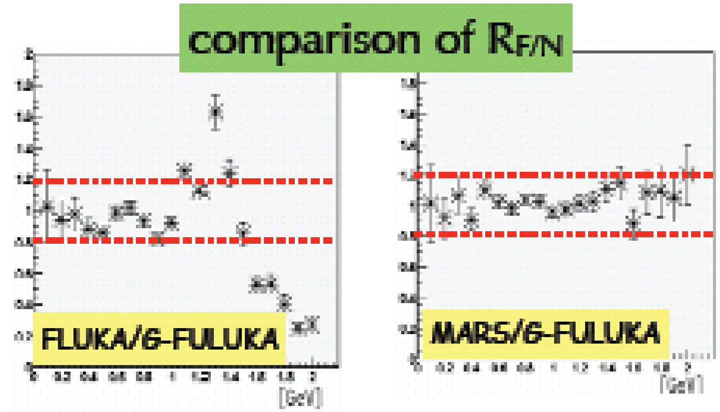
Different models comparison with HARP results for p+C -> π^+ + X 12 GeV/c

Pion momentum distributions in θ bins



- No data for 30GeV p+C → if we evaluate $R_{F/N}$ using MC...





~20% difference @ E_ν < 1GeV

systematic error from $\delta(R_{F/N})$

ν_e appearance

$\delta(N_{bkg})$ ~15%

ν_μ disappearance

$\delta(\sin^2 2\theta_{23})$ ~ ±(1.5~3)%

$\delta(\Delta m^2_{23})$ ~ ±(5~10) x 10^{-5} eV^2

⇔

T2K-I goal

ν_e appearance

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

ν_μ disappearance

$\delta(\sin^2 2\theta_{23})$ ~ 1%

$\delta(\Delta m^2_{23})$ < 1 x 10^{-4} eV^2

measurement of the hadron production is necessary !!

Ken Sakashita (KEK)
2007/Mar/22, NA49-future collaboration meeting

- without NA49 measurements, the systematic errors on T2K final results is larger than T2K goals
- If we can evaluate $R_{F/N}(E_\nu; _{0\text{-}1.5GeV,\ 100MeV/bin})$ and $R_{F/N}(E_\nu; _{1\text{-}10GeV})$ with 2-3% uncertainty, we can achieve the T2K goals
- We need to measure
  - (P_π, θ_π) distribution less than 10% statistical error of each P_π bin and θ_π bin
    - 200k π^+ tracks in the region: 0-10 GeV, 0-400 mrad
  - K/π ratio with less than 10% accuracy
    - K^+ in 1-20 GeV, 0-300 mrad

Flavour structure of the neutrino beam

P+C interactions + positively charged particle selection in magnetic horns
yield high flux o muon neutrinos

$$\pi^+ \rightarrow \mu^+ \nu_\mu$$

$$K^+ \rightarrow \mu^+ \nu_\mu \;,\; K^0_L \rightarrow \pi^- \mu^+ \nu_\mu$$

With a small but not negligible background of electron neutrinos

$$\mu^+ \rightarrow e^+ \; \nu_e \; \nu_\mu$$

$$K^+ \rightarrow \pi^0 e^+ \nu_e \;,\; K^0_L \rightarrow \pi^- e^+ \nu_e$$

Good knowledge of Kaon/pion ratio is important!

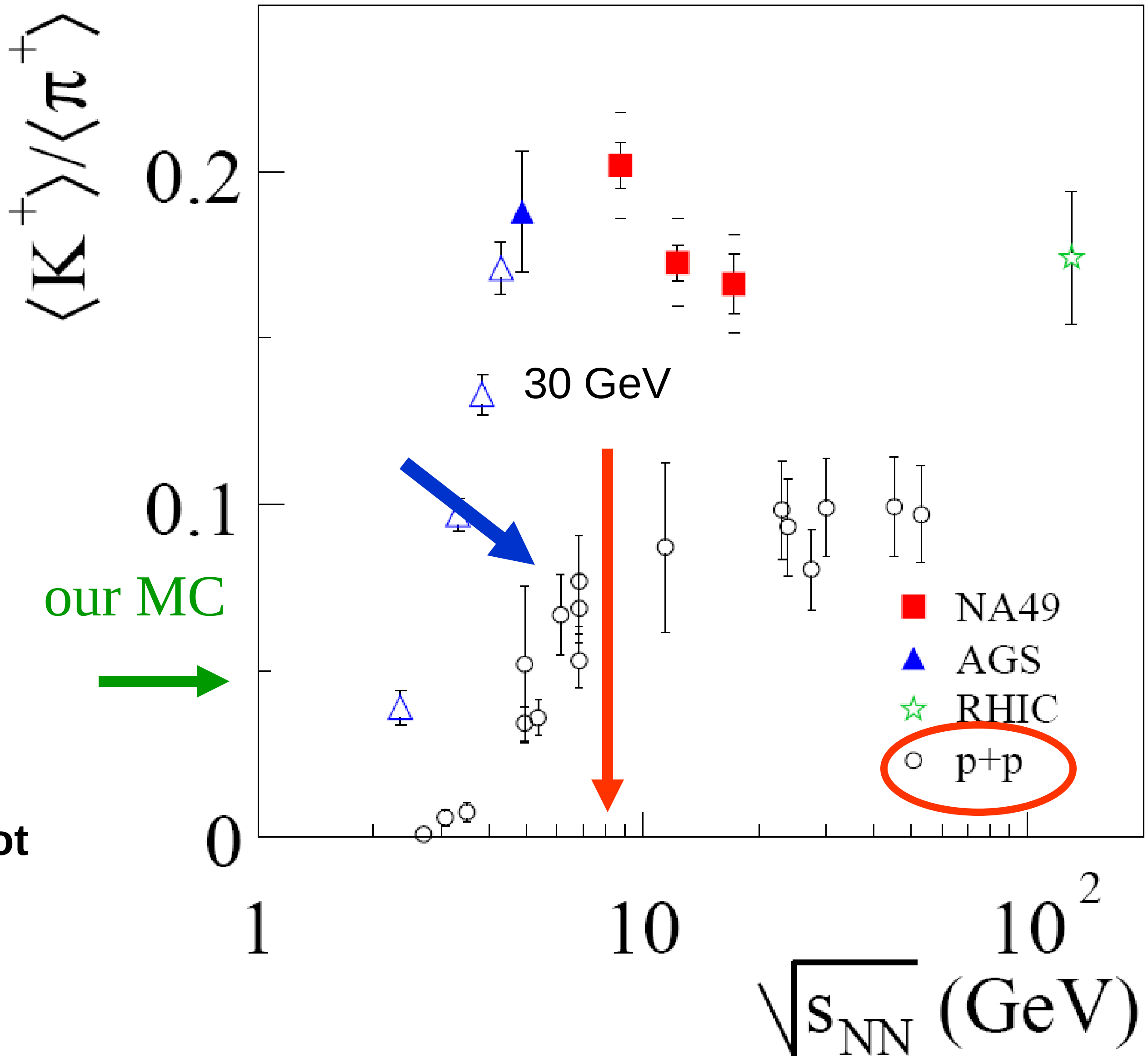
Present knowledge about K^+/π^+ ratio

NA49
C.Alt et al..Phys.Rev. C77:024903,2008
nucl-ex/0205002

pp data compiled by
M. Gazdzicki, D.Rohrich
Z.Phys.C71(1966)55

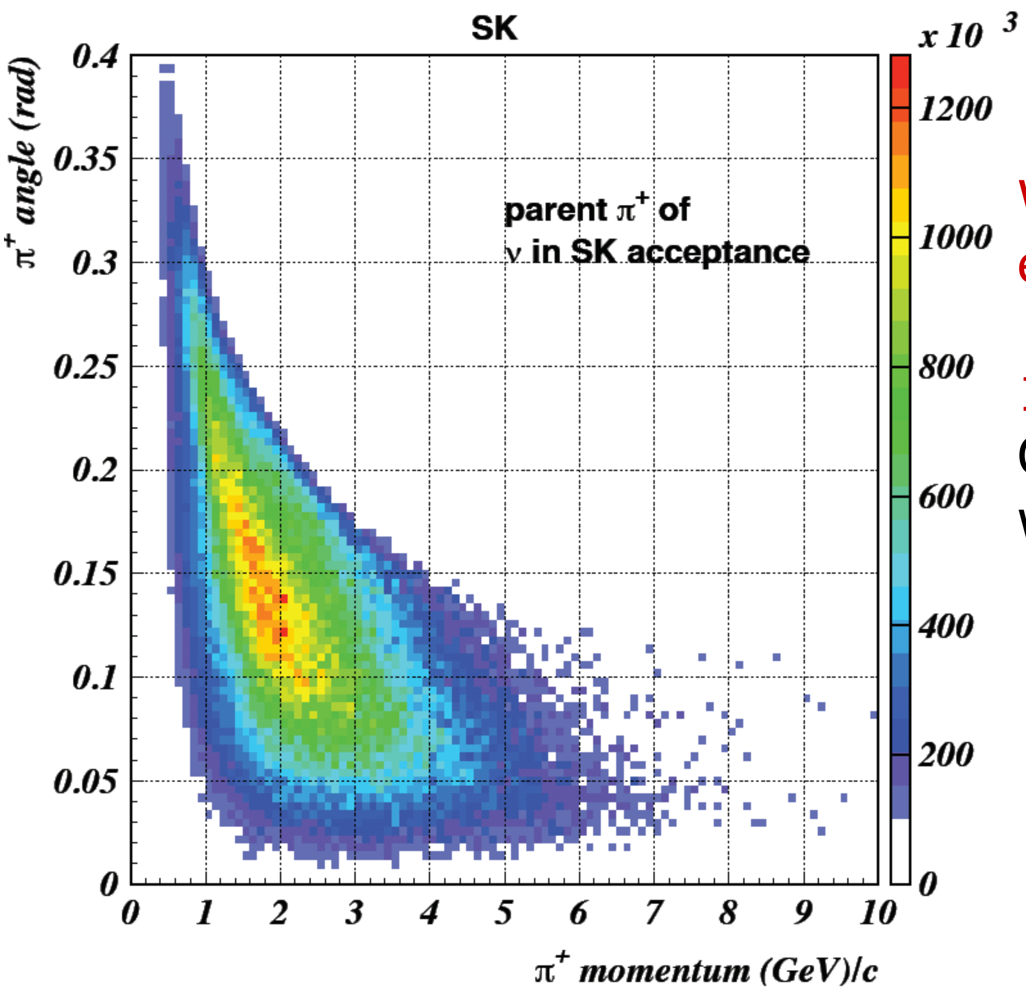
from this plot
$\langle K+\rangle / \langle \pi+\rangle \sim 0.06 – 0.08$
at 30 GeV

clearly the situation is not satisfactory at all



Parent π^+ of ν in SK acceptance

(Ken Sakashita 2007)

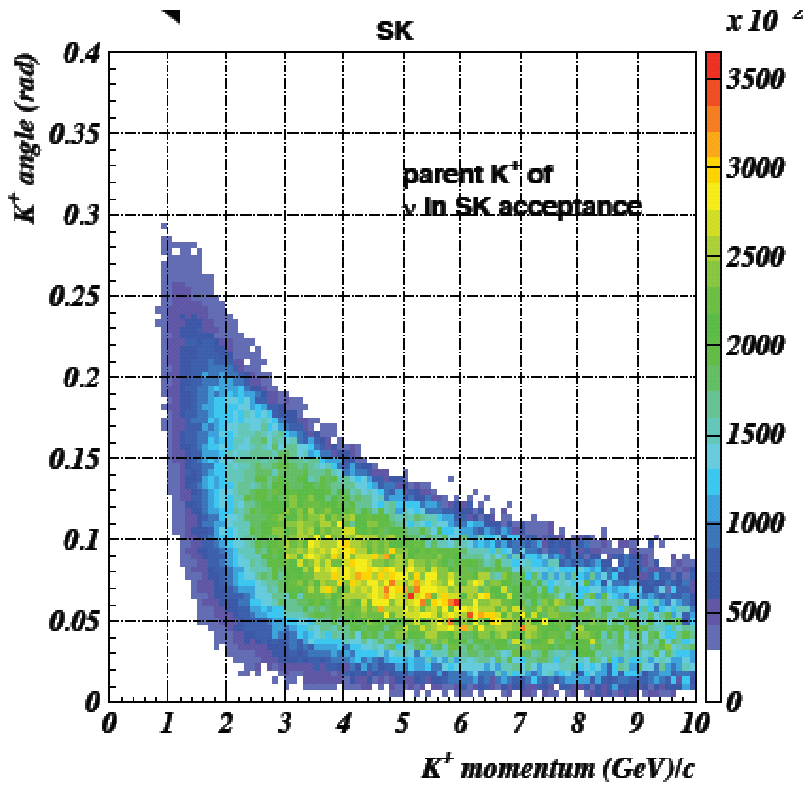


We need to measure pions emitted at the angle <400mrad with momentum smaller than 10 GeV/c.

Only neutrino from such pions will enter the SK.

Parent K^+ of ν in SK acceptance

(Ken Sakashita 2007)



- only K^+'s in $P_K > 1$ GeV and $\theta_K < 300$ mrad contribute to ν_μ which accepted by ND and/or SK

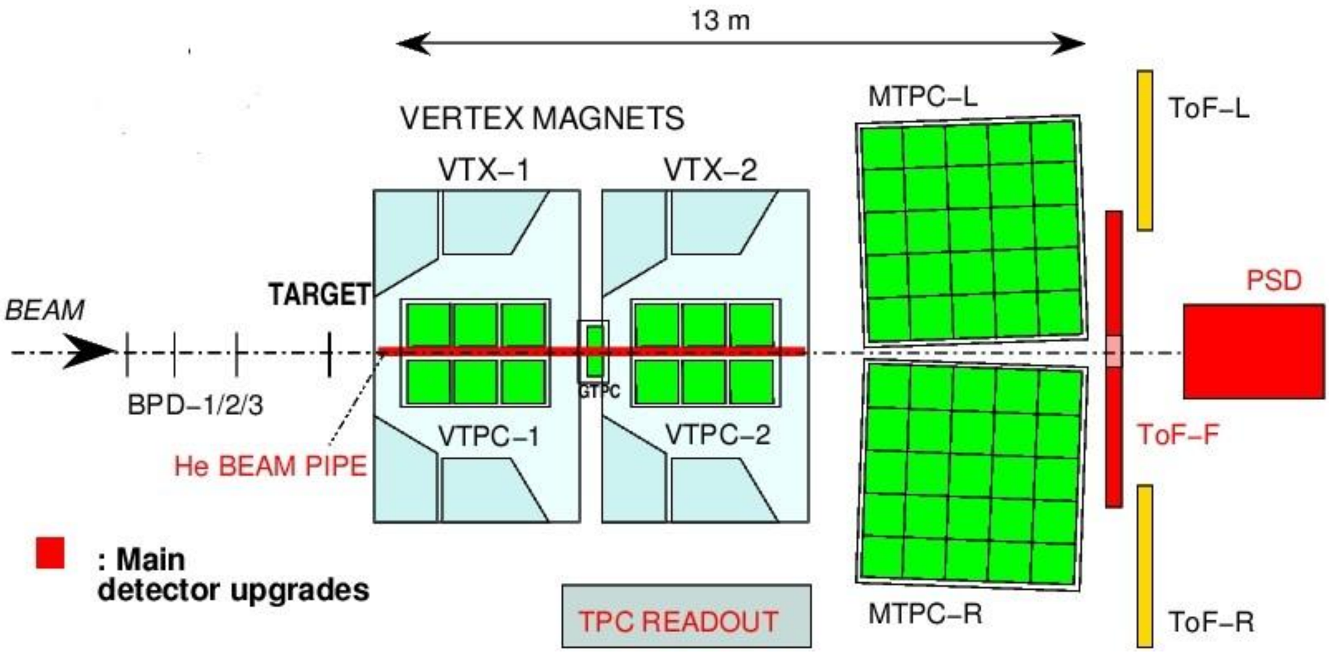
need to measure the number of K^+ in $1 < P_K < 20$ GeV and $0 < \theta_K < 300$ mrad

Why the results of NA61 are of importance for T2K and other future neutrino experiments

- There is no data on hadron production in the energy interval 30-50 GeV.
- The energy spectrum in the Near Detector is not the same as in the Far Detector.

  The uncertainties from simulations are high (up to 20%).
- There is no precise experimental information on the secondary interactions in the long target.
- The K^+ production cross section is crucial: it is source of ν_e.

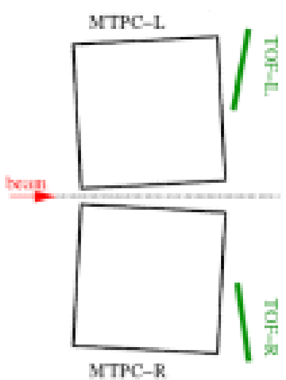
Schematic view of the NA61 set-up

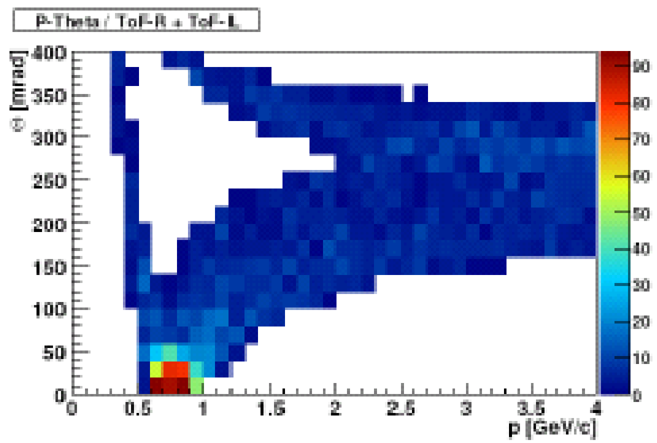


Time Projection Chambers (green) VTPCs and MTPCs are the main tracking devices.
The upgrade of the parent NA49 set-up is shown in red.
Time of Flight detector ToF-F was added to cover entirely the T2K acceptance.

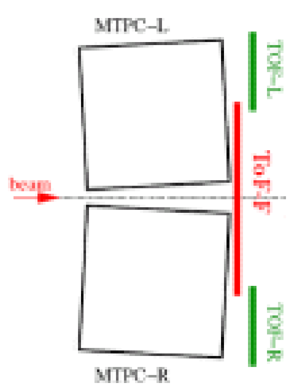
NA61 – new ToF detector

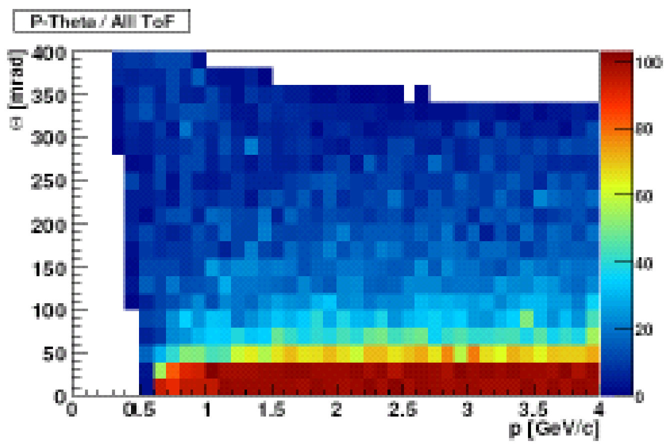
Without ToF-F



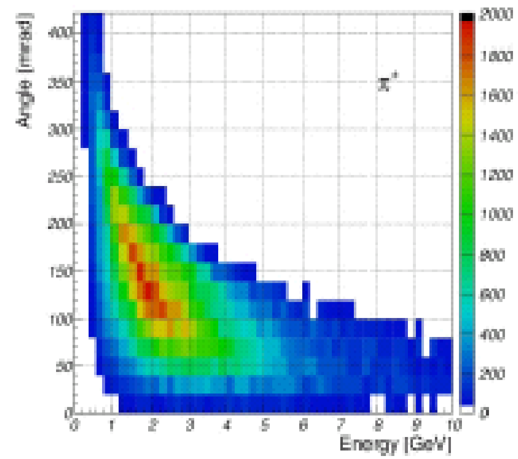


With ToF-F





π contributing to ν flux (SK)



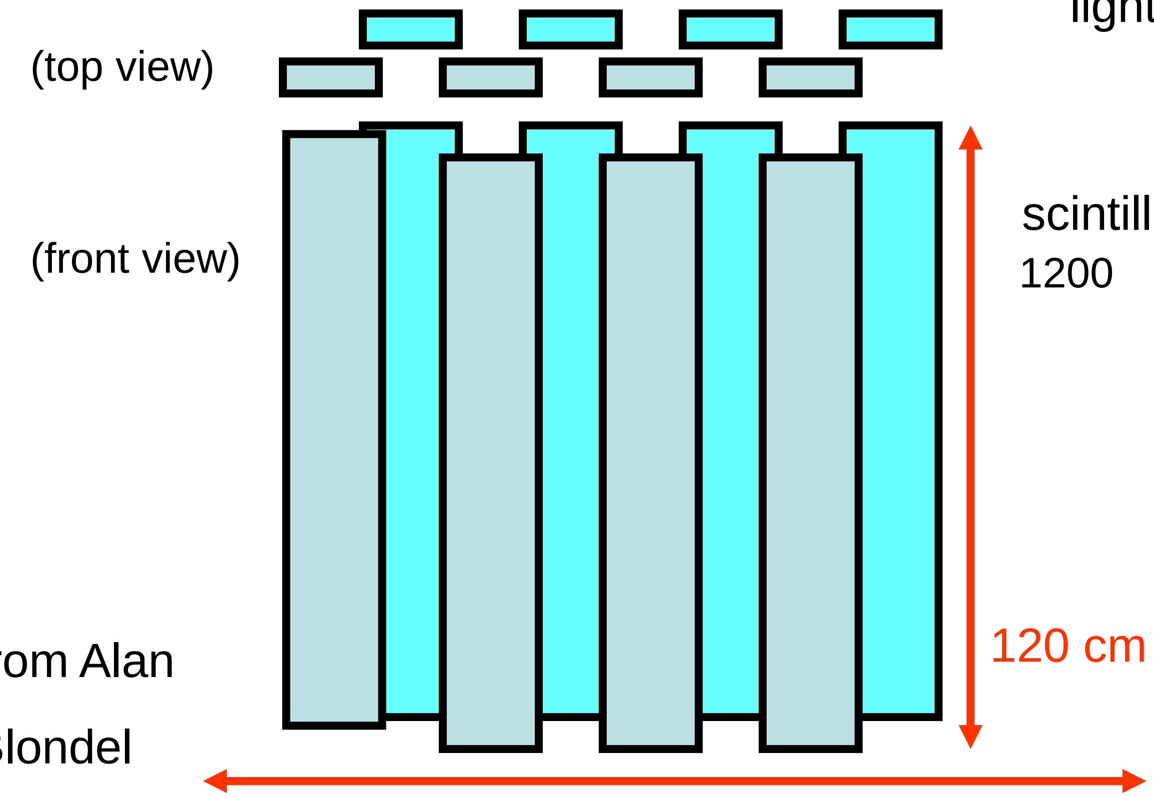
→ **Extended acceptance with new ToF wall**

→ **Full coverage of the T2K "phase space"**

New ToF Wall for NA61

total area 577 120 cm^2
σ_t = 120 ps (4σ K/pi @ 5 GeV)

64 scintillator bars read out on both sides
128 readout channels

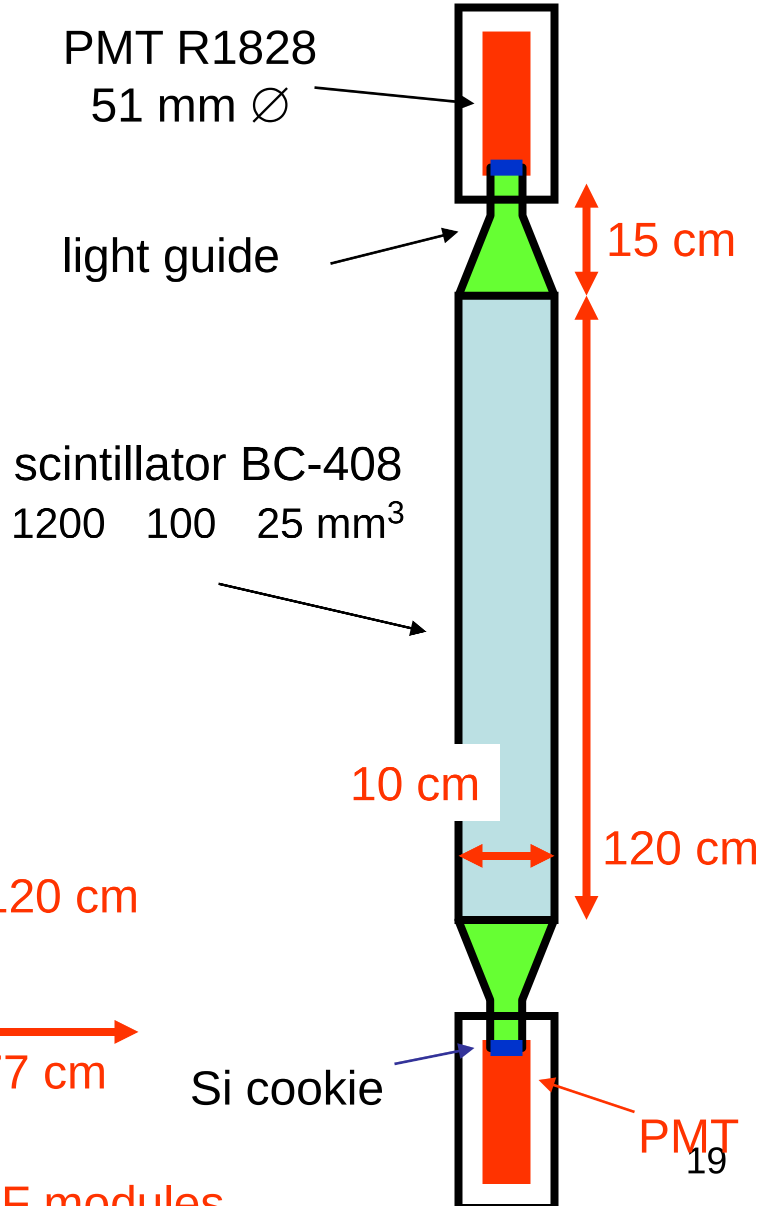


64 staggered scintillator bars
(10 mm overlap)

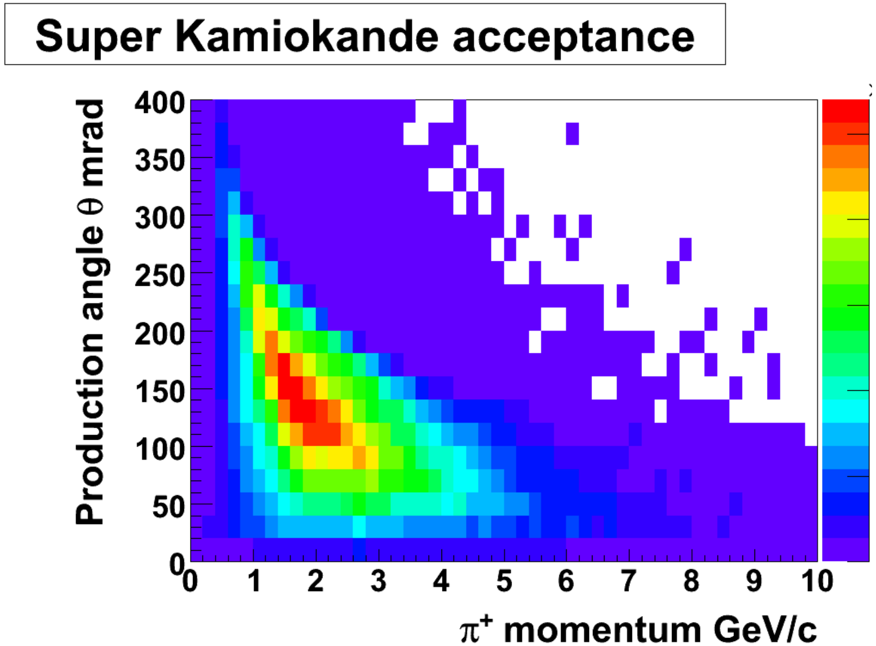
from Alan

Blondel

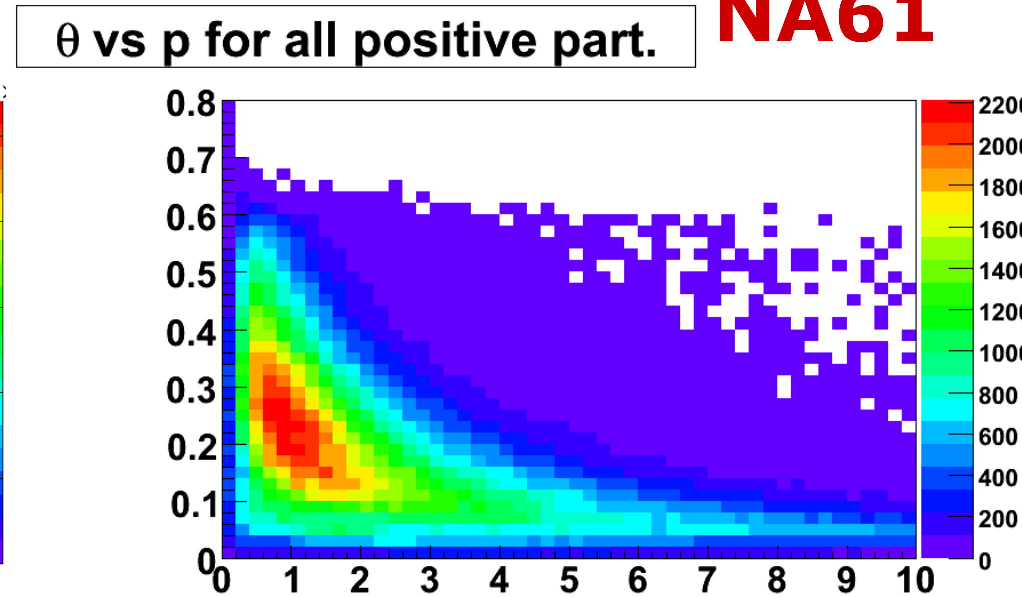
single element

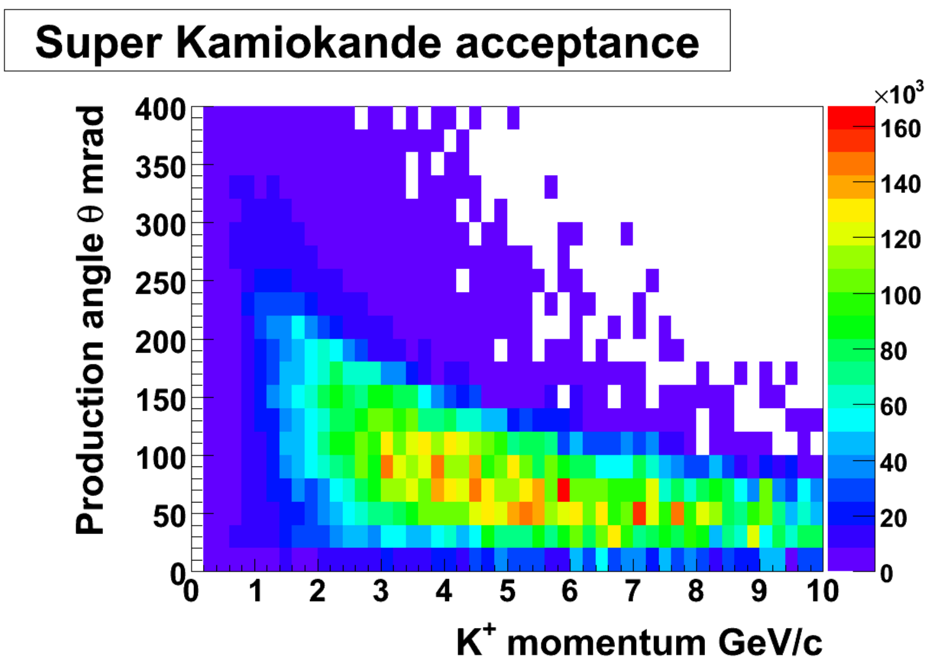


8 scintillators mounted on a single frame → 8 ToF modules



NA61

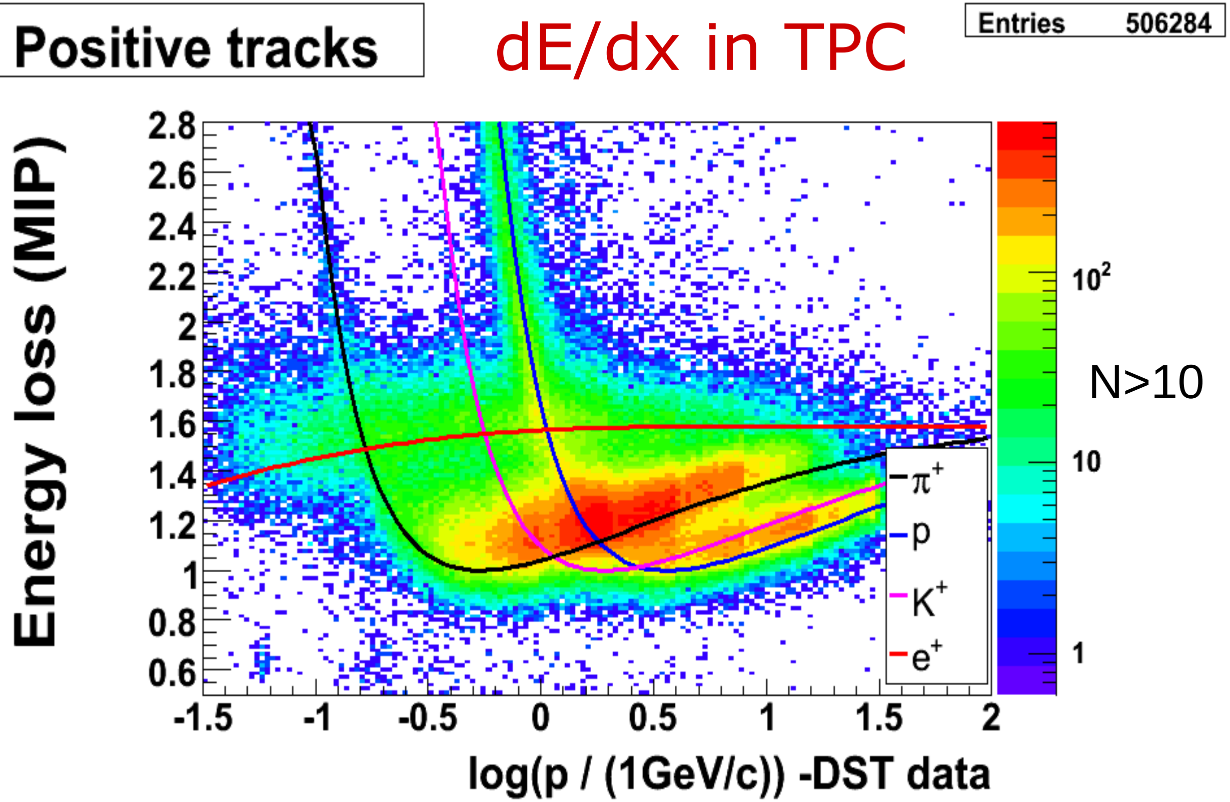




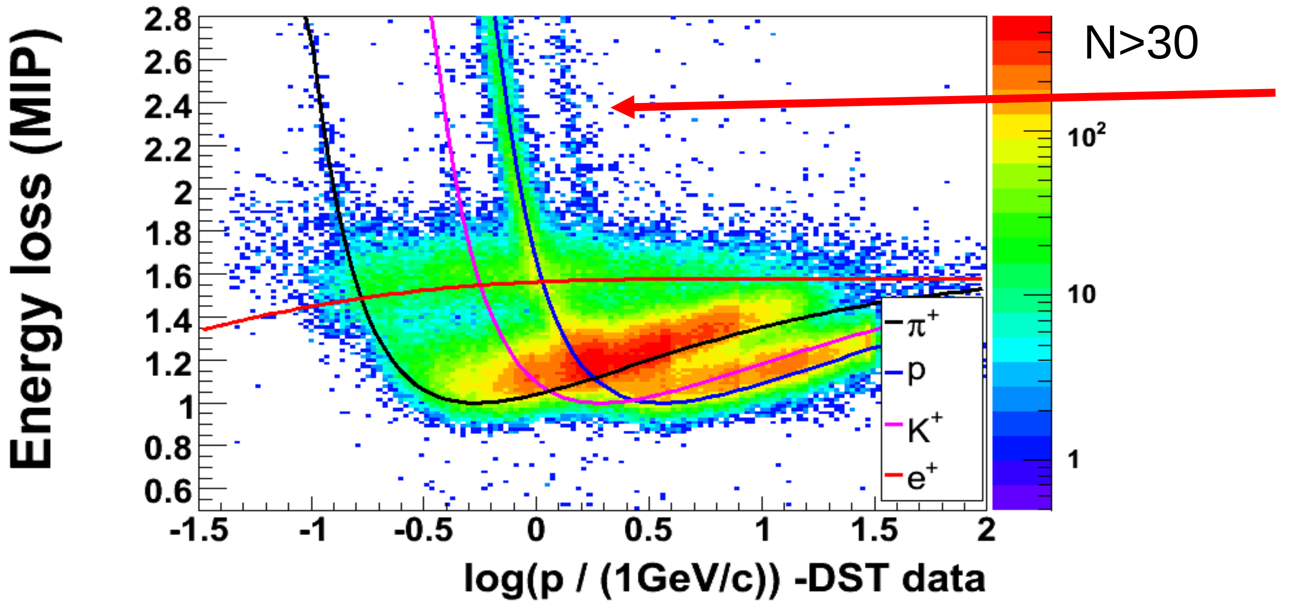
T2K acceptance region covered

Positive tracks

dE/dx in TPC



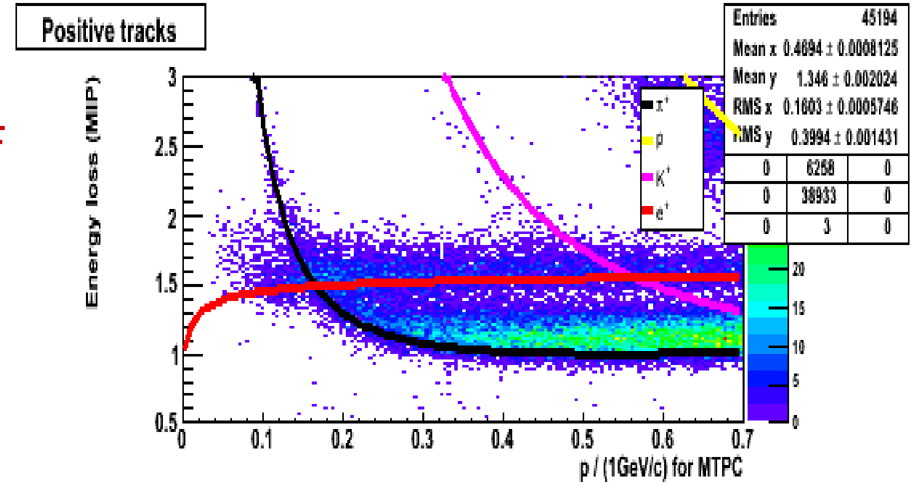
all positive
2C NA61
data

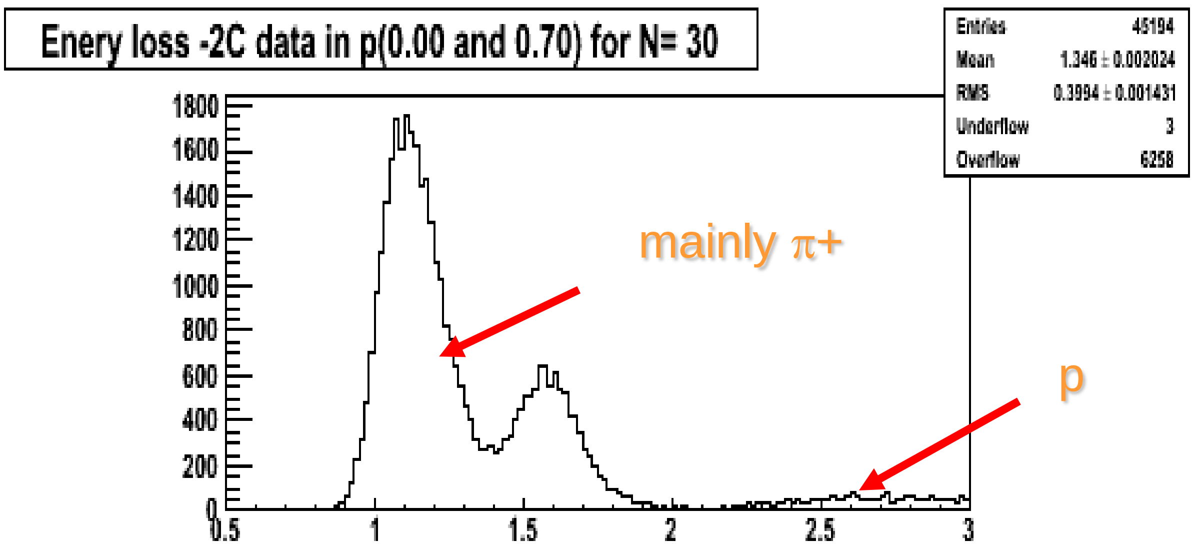


For N>30 deuterons are seen!

Particle identification

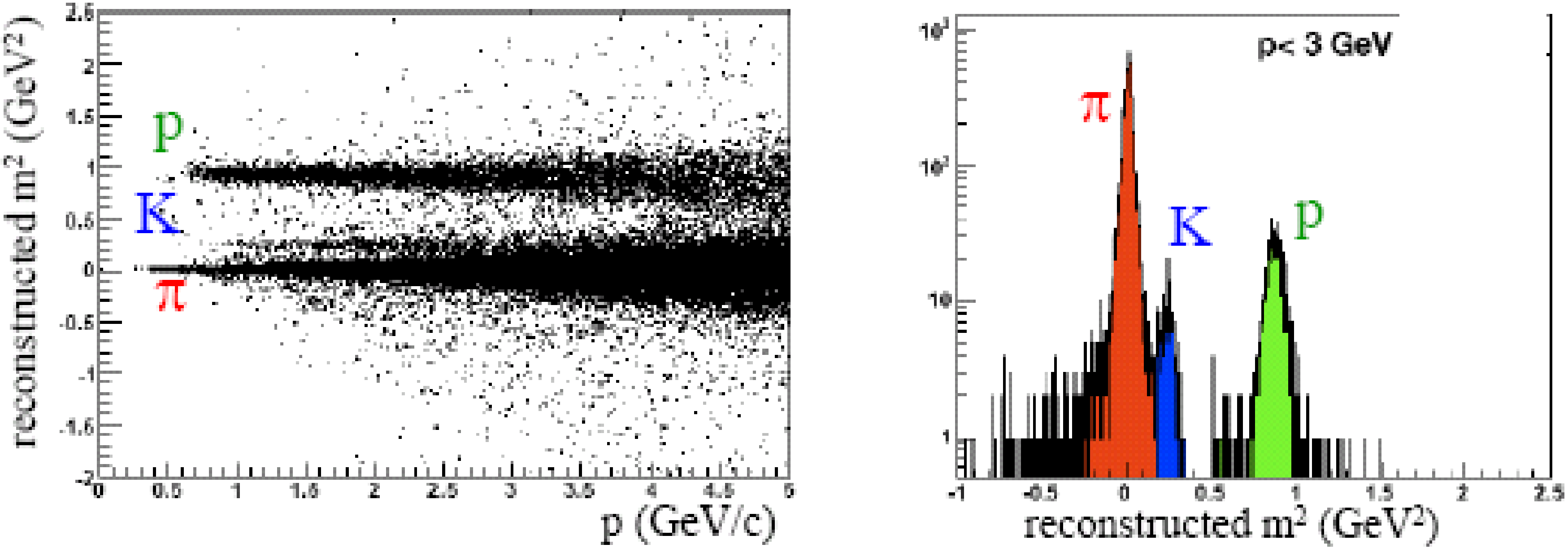
When a particle do not reach the TOF we must relay on dE/dx information from TPCs. Example for p<0.7 GeV





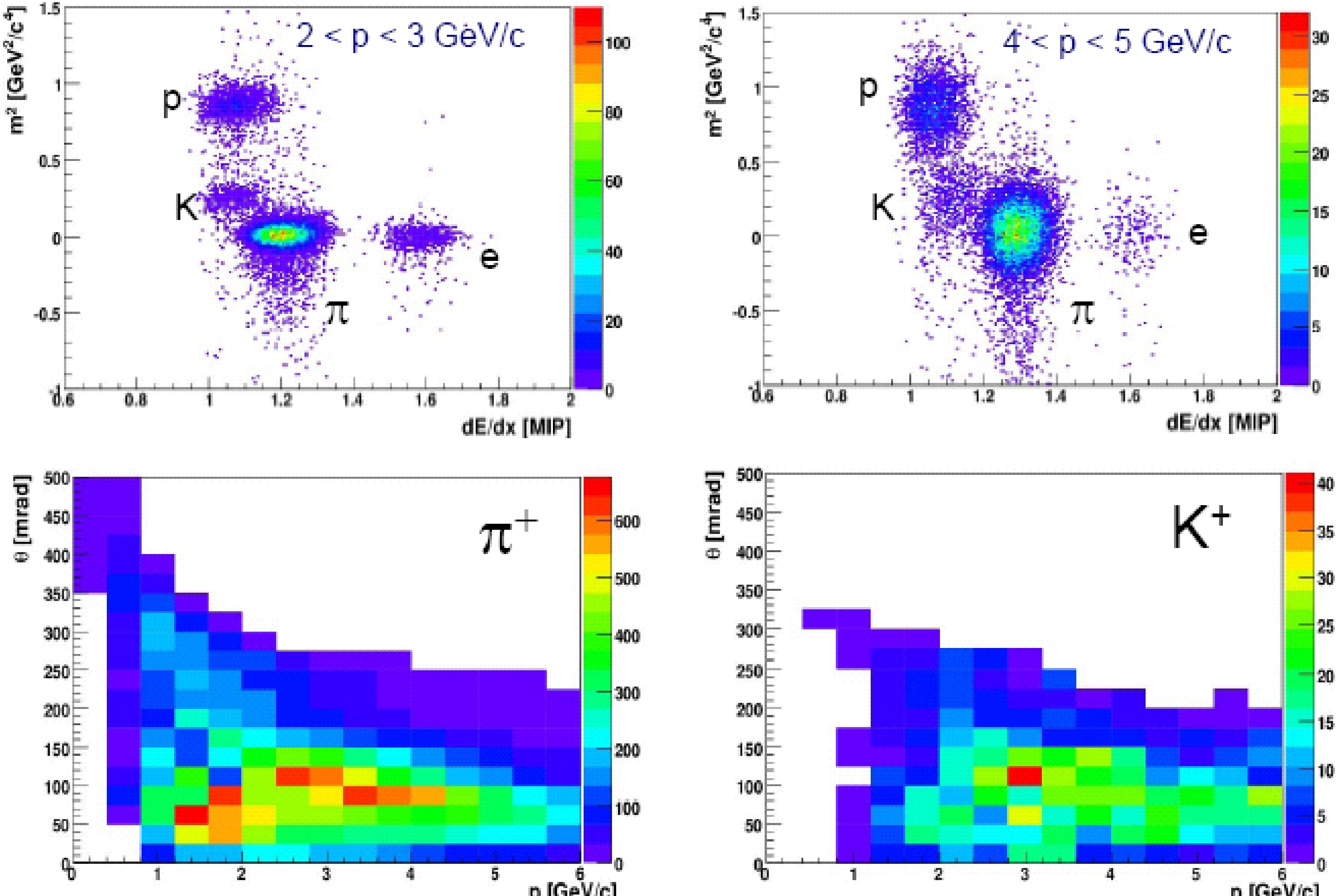
Separation possible between pions, electrons and protons.

Particle identification
based on Time of Flight Forward Detector



Particle identification

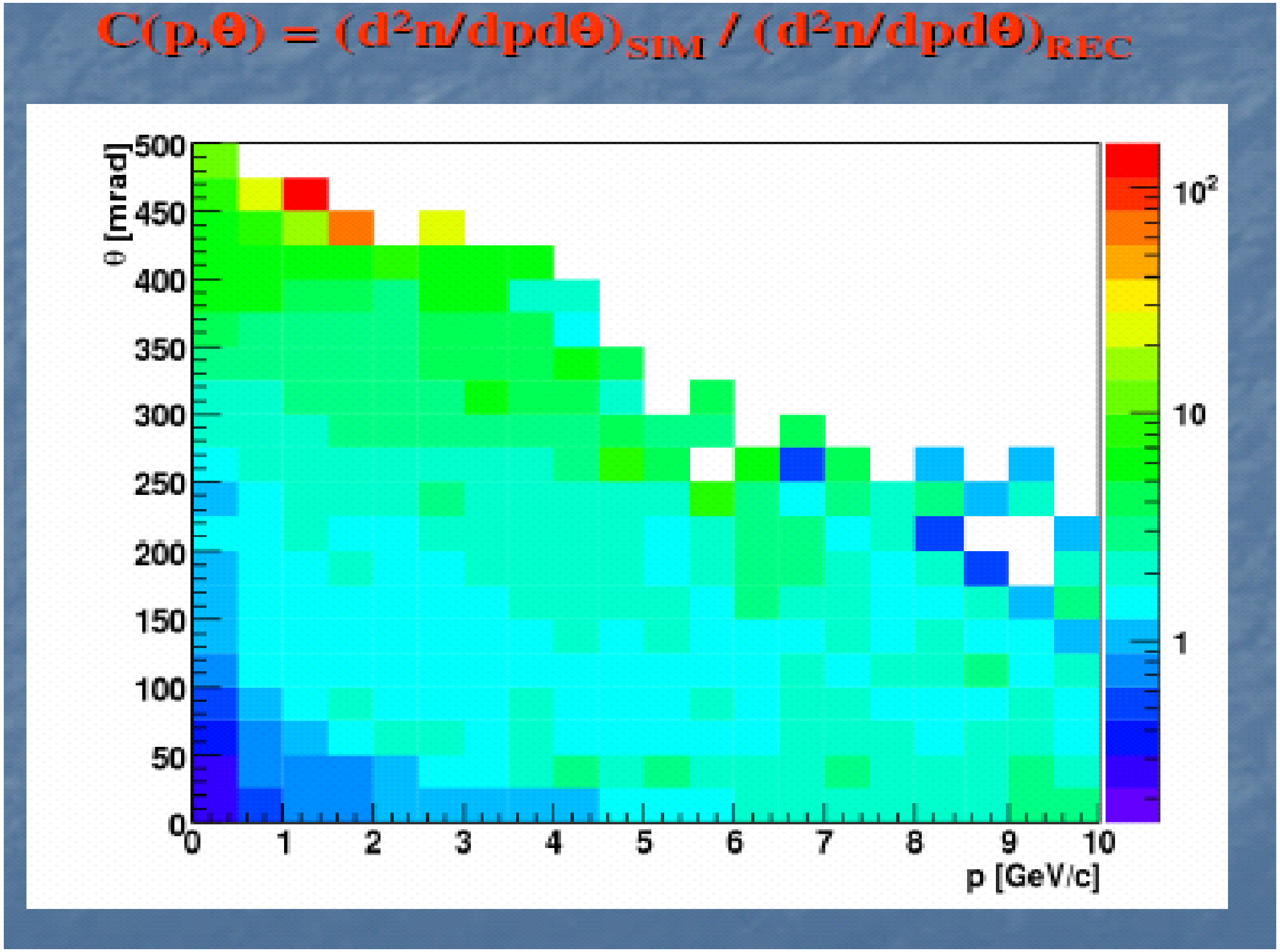
ToF-F and TPCs



CERN-SPS-2008-018 / SPSC-SR-033

T2K phase-space is well covered

NA61- Acceptance corrections from MC simulations for π's in p,θ bins



Statistics collected in the 2007 run

- **Thin (2cm) Carbon target**

Total number of events analyzed	672k
After cuts on vertex quality	277k

Total Nb of tracks after track quality cuts:

positively charged	574 k
negative charged	321 k

- **Thick (90cm long) T2K replica target**

Under study

Conclusions

- The analysis of the limited statistic thin target data from the 2007 run has shown, that NA61 acceptance, momentum resolution and capability of particle identification is sufficient to obtain the pions and kaons differential cross sections in the region of T2K phase space.
- Further effort is required to understand fully the data from T2K replica target. In particular the influence of the magnetic field in the target region should be taken into account.
- About 1M events should be collected to fulfill all the goals.