Hadro-Production Measurements for Neutrino Experiments by the NA61/SHINE Experiment at CERN

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for
the NA61 Collaboration

ICHEP 2010
Paris, 24 Juillet 2010

Why hadro-production measurements

neutrino cross sections → absolute neutrino flux
neutrino interaction physics

neutrino oscillations → compare measured neutrino spectrum "far" from the source
with the predicted one (flux shape and Far / Near flux ratio)
background ν_e flux in ν_μ beam
deviations from expectations ⇒ evidence for neutrino oscillations

solar neutrinos
ν flux predictions based on the solar model

reactor based neutrino sources
ν flux predictions based on fission models and reactor power

accelerator based neutrino sources
ν flux predictions based on π, K (→ ν + X) hadro-production models
ν flux at far detector predicted on the base of ν flux measured in near detector

Goals of NA61-T2K

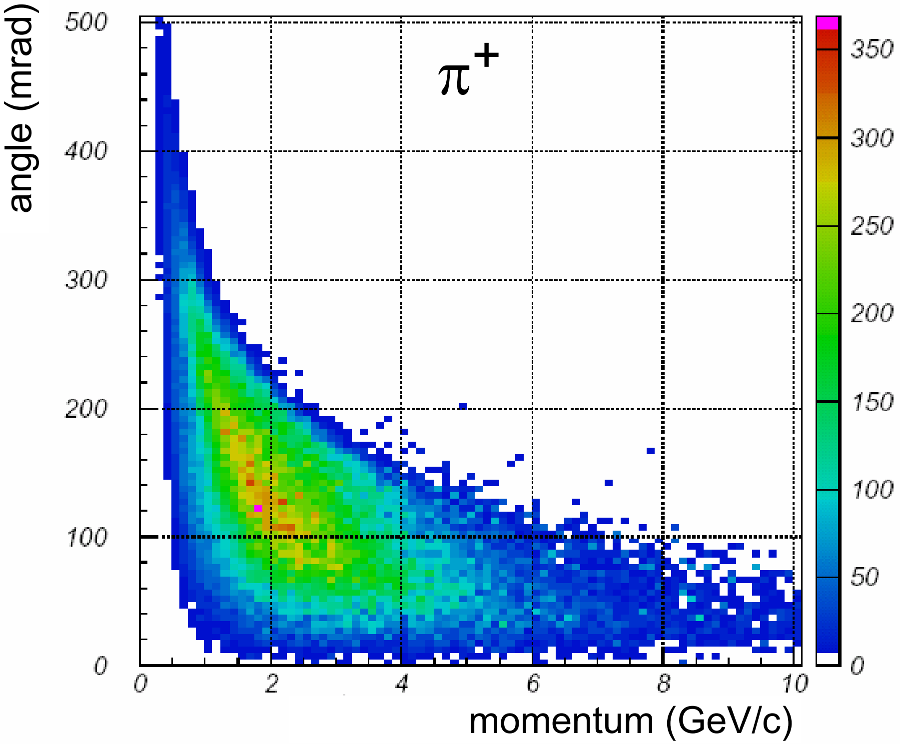
Predict Far / Near neutrino flux ratio to 3%
Predict the neutrino flux to 5%

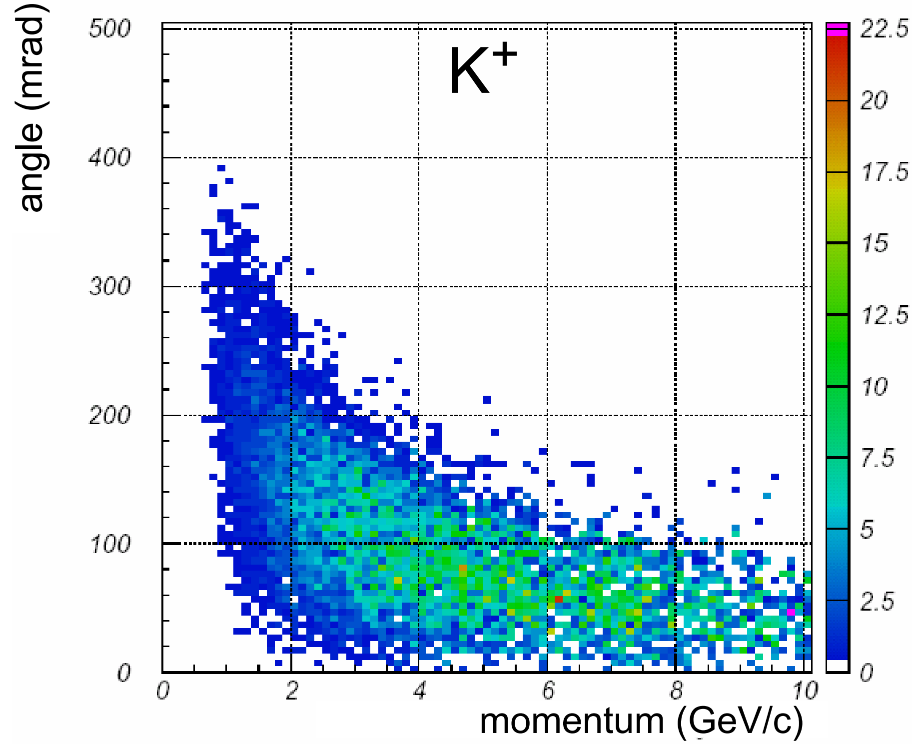
(see E. Zimmerman's T2K talk)

T2K ν parent hadron phase space

30 GeV proton beam on the 90 cm long T2K graphite target

no hadro-production data available at this energy





note: this is not a cross section

it shows the distributions of π and K contribution to the ν flux at SK

need to cover this kinematical region and identify the outgoing hadrons

K component important for ν_e appearance signal (it represents a *background*)

requires detector with large acceptance and particle ID

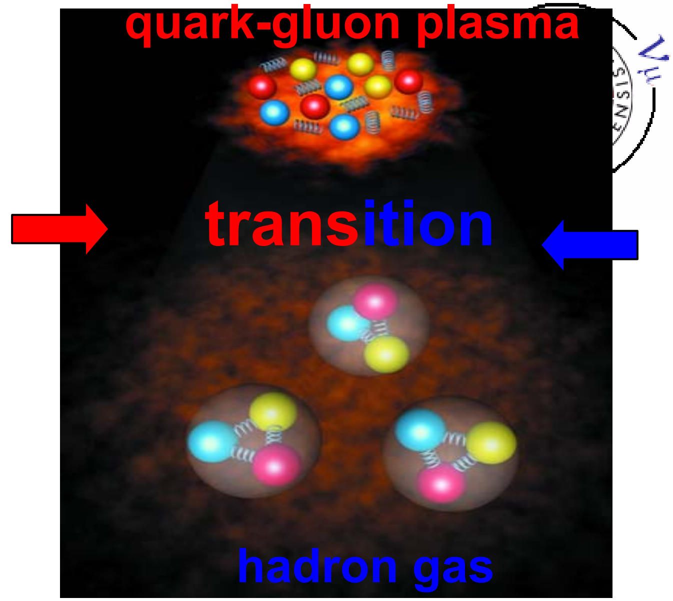
The NA61/SHINE Collaboration

an experiment at the CERN - SPS to measure
$\pi^{+/-}$ and $K^{+/-}$ hadro-production ×-sections to characterize the T2K ν beam

~ 130 physicists from
25 institutes and 14 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
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
University of Silesia, Katowice, Poland
Swietokrzyska Academy, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Université 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

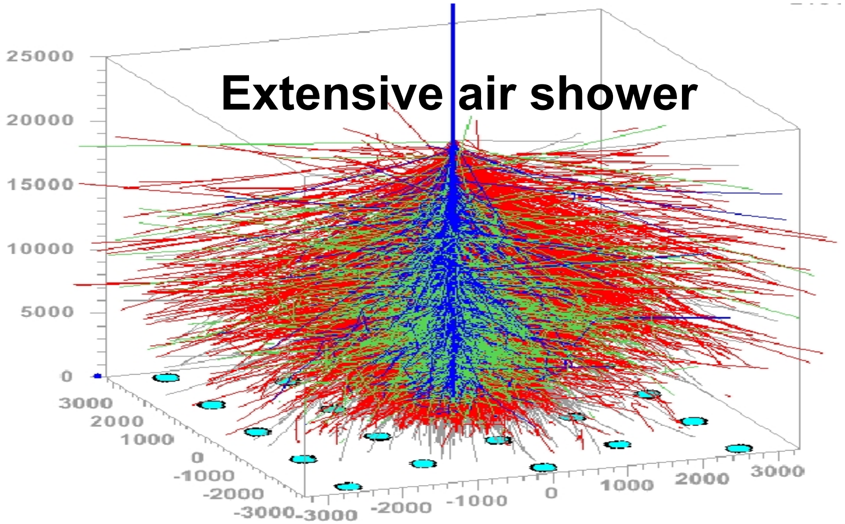
NA61 physics program



Physics of strongly interacting matter in heavy ion collisions
Search of the QCD critical point

(see P. Staszel's poster)

Measurement of hadron production off the T2K target (p+C) needed to characterize the T2K neutrino beam

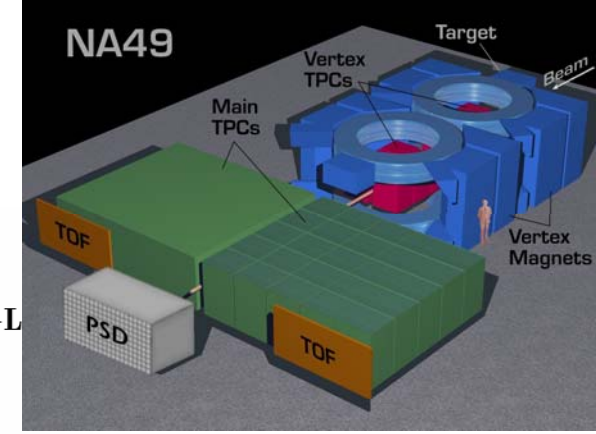


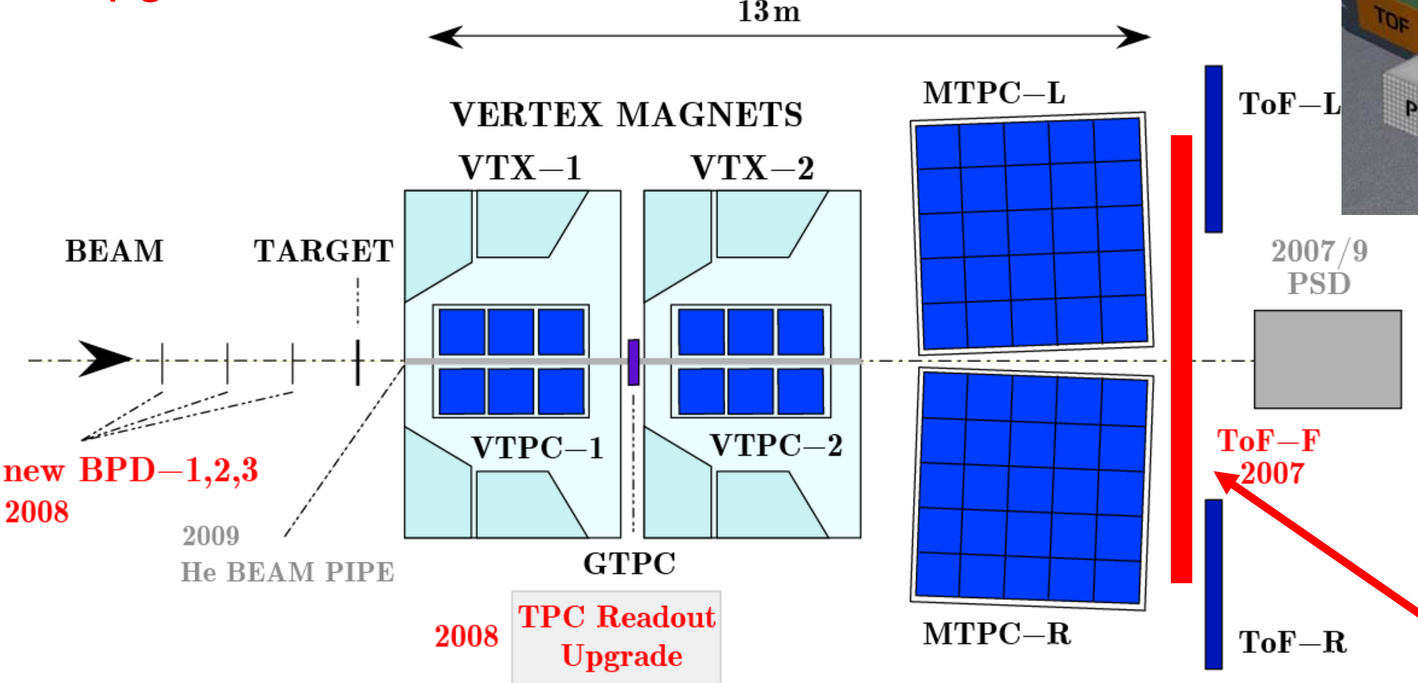
Measurement of hadron production in p+C interactions needed for the description of cosmic-ray air showers (Pierre Auger Observatory and KASCADE experiments)

(see M. Unger's talk)

The NA61 detector

upgraded NA49 detector

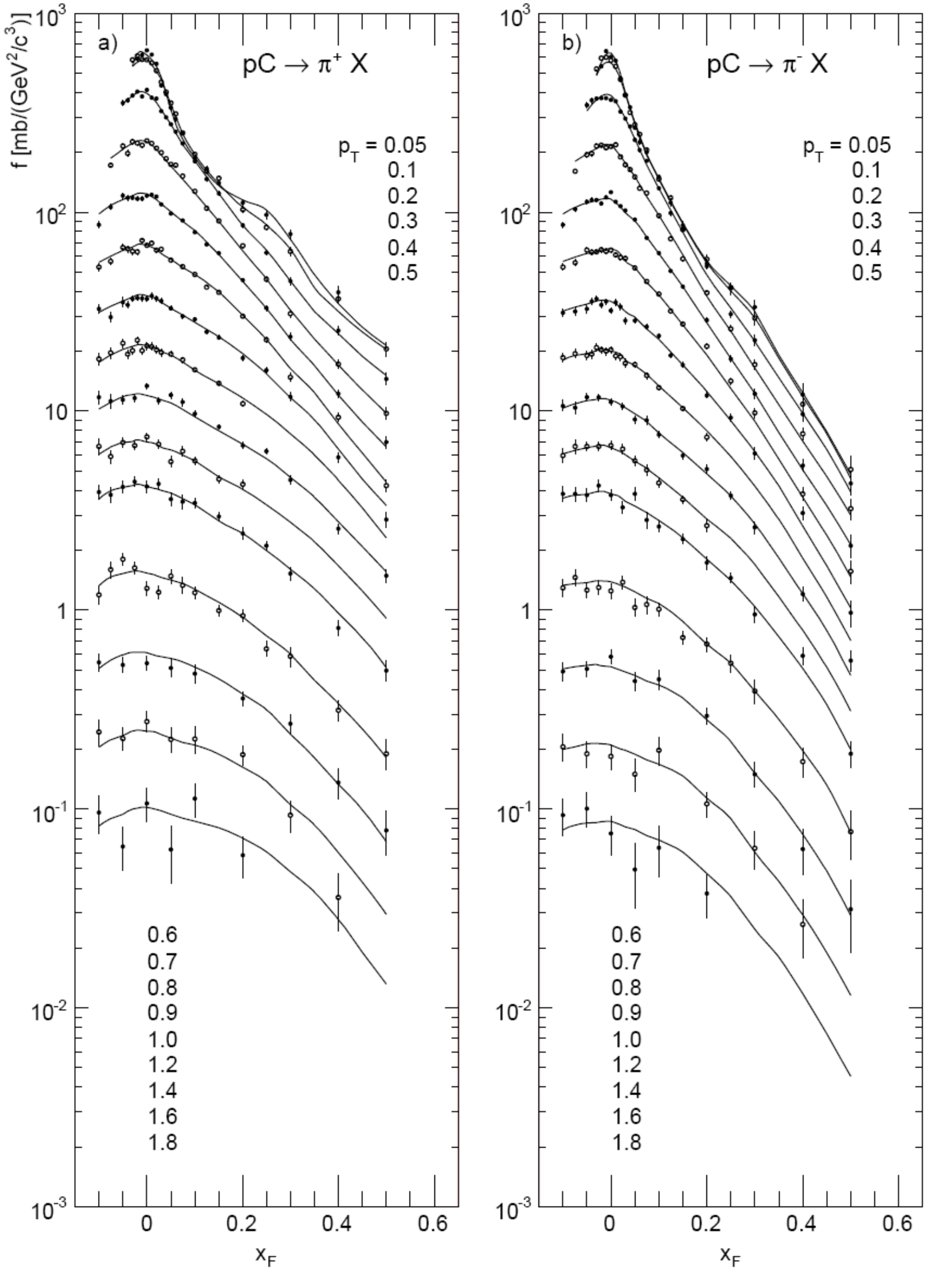




NB Forward-ToF wall used to identify low mom. particles produced at large angles and bent back into the detector acceptance by the vertex magnets

- **Large Acceptance Spectrometer for charged particles**
- **4 large volume TPCs as main tracking devices**
- **2 dipole magnets with bending power of max 9 Tm over 7 m length** (2007-Run: ∫Bdl ~ 1.14 Tm)
- **High momentum resolution**
- **Good particle identification:** σ(ToF-L/R) ≈ 100 ps, σ(dE/dx)/<dE/dx> ≈ 0.04, $\sigma(m_{inv}) \approx 5$ MeV
- **New ToF-F to entirely cover T2K acceptance** (σ(ToF-F) ≈ 120 ps, $1 < p < 4$ GeV/c, $\theta < 250$ mrad)

NA49 charged pion spectra



charged pion spectra in pC interactions at 158 GeV/c measured by NA49 over broad kinematical range

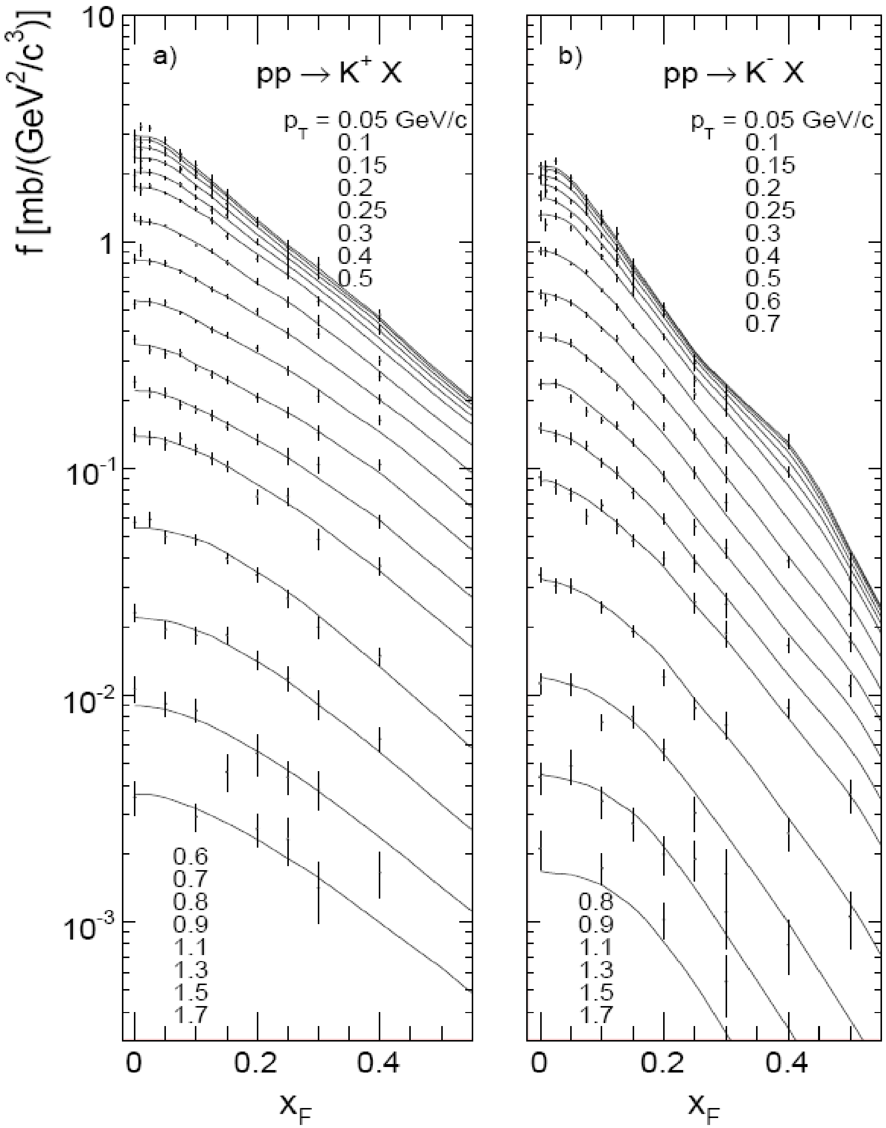
NA49 with empirical fits to the data

systematic error

Normalisation	2.5%
Tracking efficiency	0.5%
Trigger bias	1%
Feed-down	1–2.5%
Detector absorption	
Pion decay $\pi \to \mu + \nu_\mu$	0.5%
Re-interaction in the target	
Binning	0.5%
Total (upper limit)	7.5%
Total (quadratic sum)	3.8%

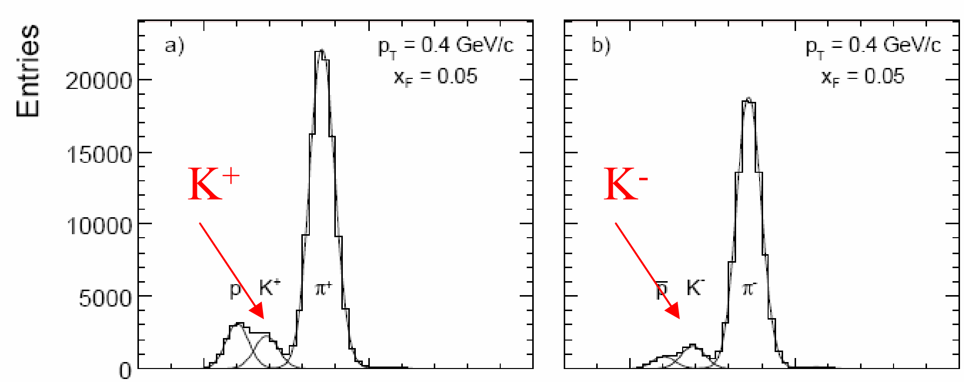
C. Al *et al.*, EPJ C49 (2007) 897

NA49 charged kaon spectra



T. Anticic *et al.*, arXiv:1004.1889
(see also T. Anticic's talk)

K identified using dE/dx in the TPCs



systematic error

	$x_F \leq 0.2$	$x_F \geq 0.25$	
	K^+, K^-	K^+	K^-
Normalization	1.5%	1.5%	1.5%
Tracking efficiency	0.5%	0.5%	0.5%
Particle identification	0.0%	4–12%	0–6%
Trigger bias	1.0%	1.0%	1.0%
Detector absorption, Kaon decay, Target re-interaction	1.0%	1.0%	1.0%
Binning	0.5%	0.5%	0.5%
Total(upper limit)	4.5%	8.5–16.5%	4.5–10.5%
Total(quadratic sum)	2.2%	4.6–12.2%	2.2–6.4%

The NA61 targets

2 different graphite (carbon) targets

Thin Carbon Target
- **length=2 cm, cross section 2.5x 2.5 cm^2**
- **ρ = 1.84 g/cm^3**
- **~0.04 λ_{int}**

T2K replica Target
- **length = 90 cm, Ø=2.6 cm**
- **ρ = 1.83 g/cm^3**
- **~1.9 λ_{int}**

Important to study hadro-production with the T2K replica target since ~ 30 – 50% of π, K from secondary interactions, which in general are very difficult to model. Both targets required to model reliably the ν flux.

2007 pilot run

Thin target: ~ 660k triggers

Replica target: ~ 230k triggers

2009 run

~ 6 M triggers

~ 2 M triggers

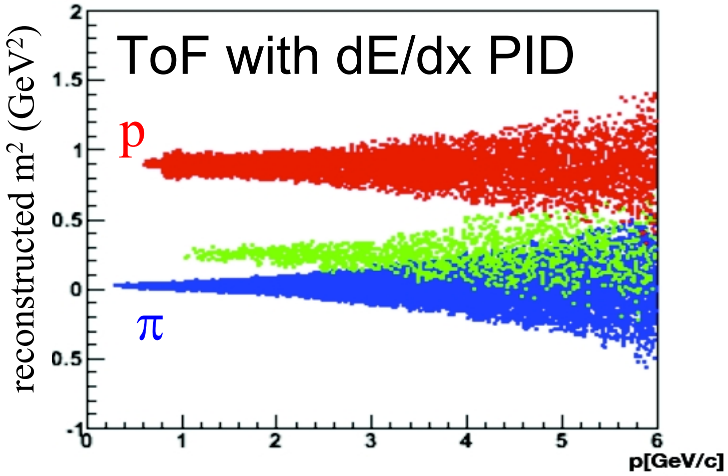
$\Rightarrow$ 200 k π^+ tracks in T2K *phase space*

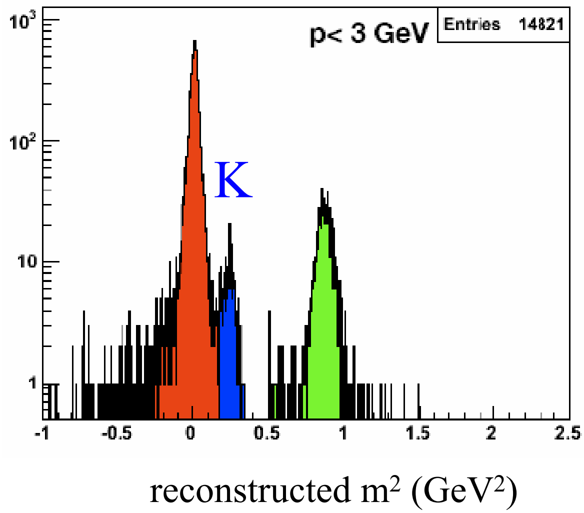
2010 run

complete measurements with long target (expect ~10 M triggers)

Particle identification

Time of Flight measurements

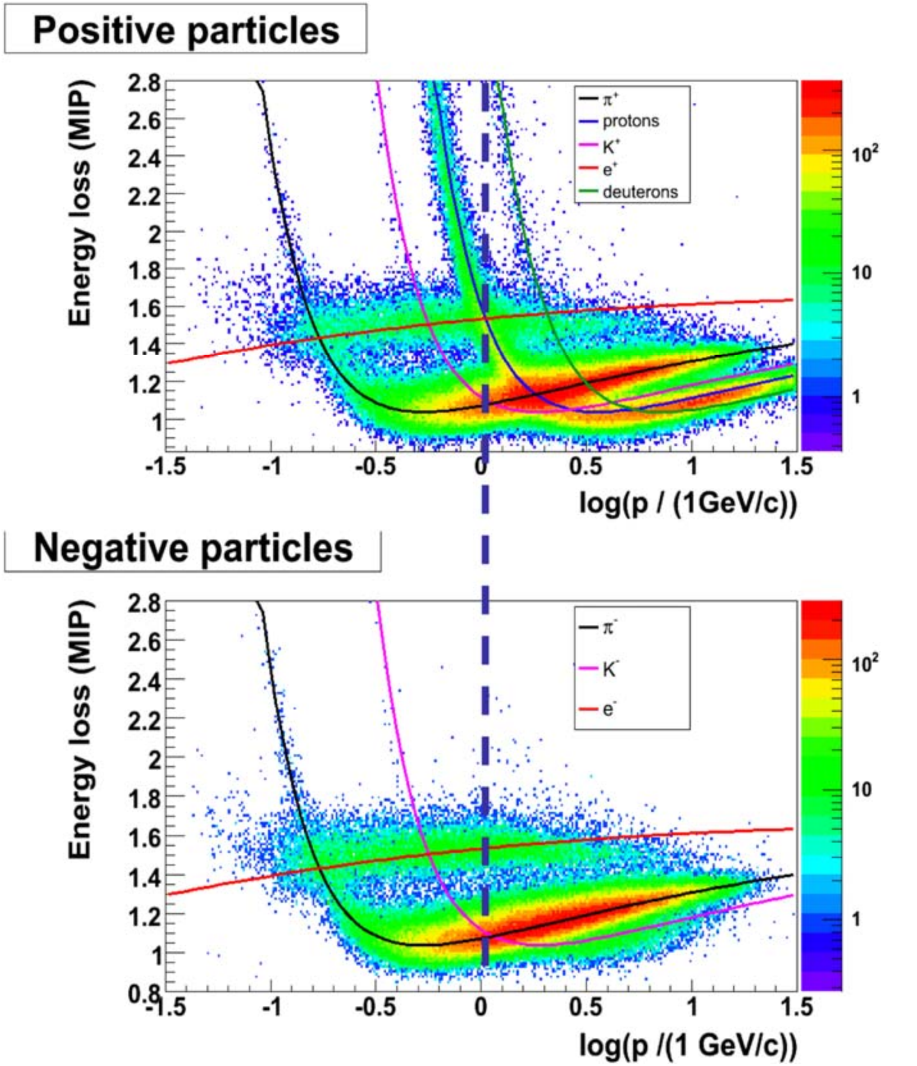




5 σ π/K separation up to 4 GeV/c

Energy loss in TPCs

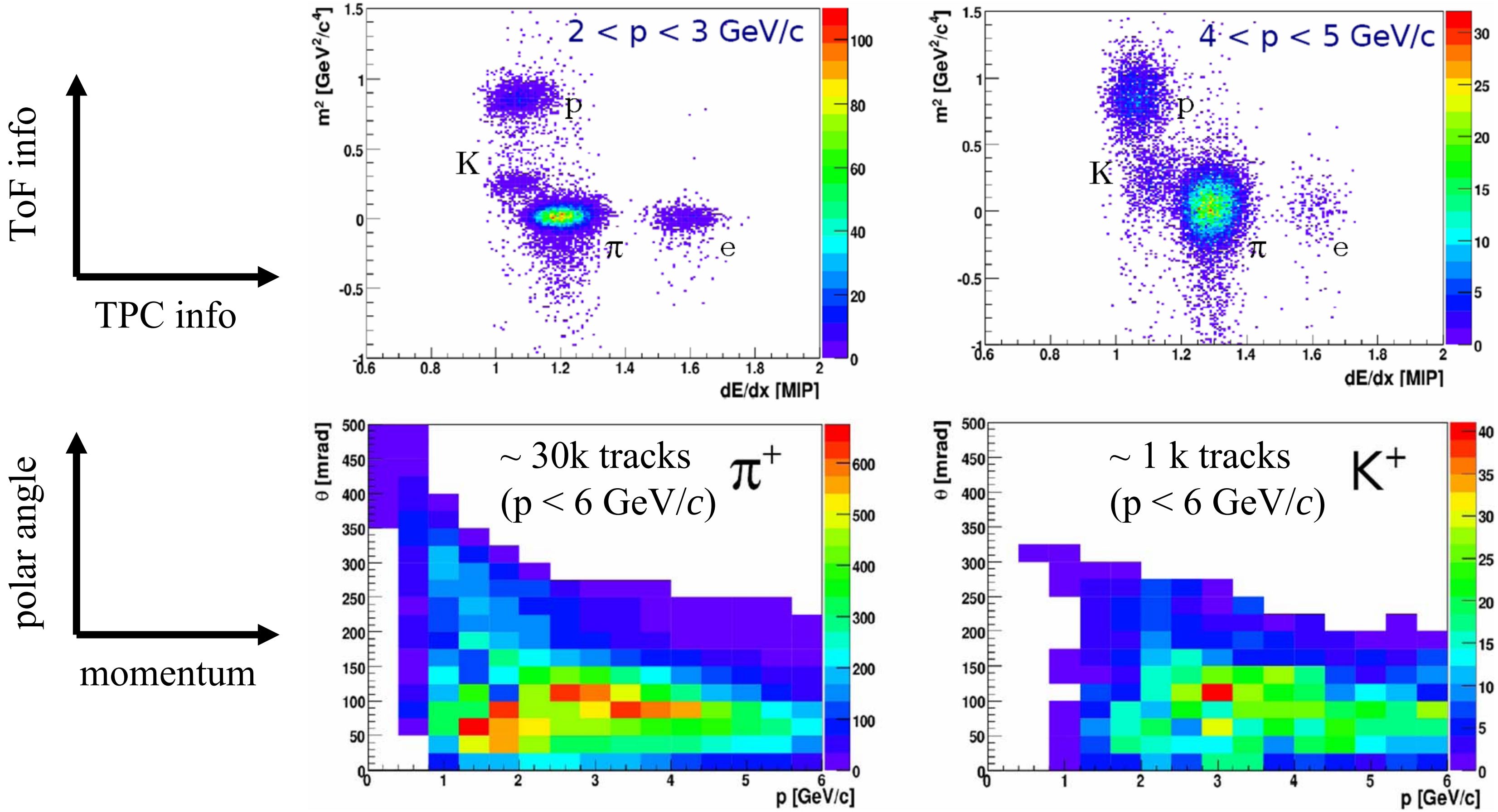
Bethe-Bloch curves (dE/dx) for different particles



σ(dE/dx)/<dE/dx> < 5 %

Identified particle spectra

by combining dE/dx and ToF information we can select high purity π / K / p samples



Raw spectra: no corrections for acceptances nor trigger normalization; particles are required to be measured in the TPCs and to reach the ToF walls for identification

NA61 has full coverage of the T2K hadron beam phase space with PID

π spectra analysis

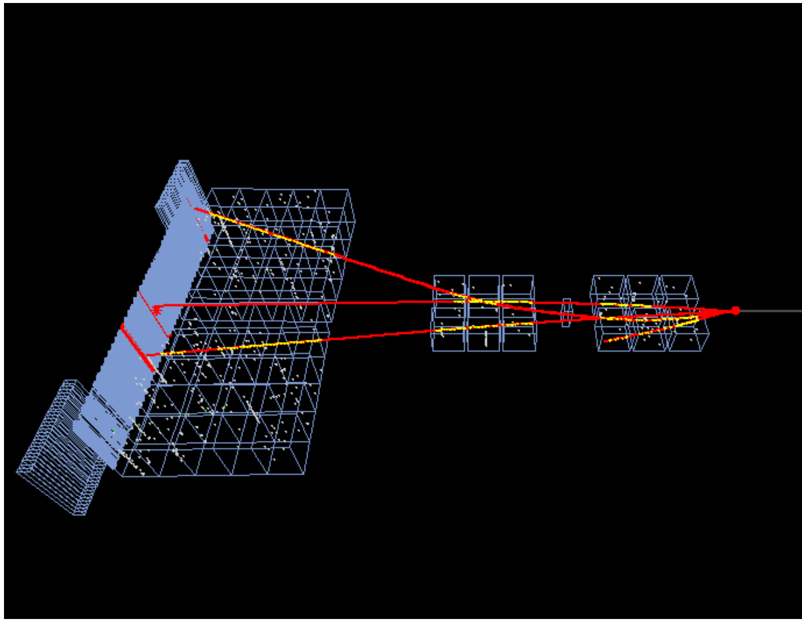
Different analysis procedures adopted depending on the kinematical region covered:

1) negative hadrons: at this beam energy (31 GeV/c) most (> 90%) negative hadrons are π^- with small K^- contamination (< 5%)
pure tracking with no PID, large acceptance, global MC correction

2) p < 1 GeV/c PID based on dE/dx only (below cross-over region in dE/dx)

3) p > 1 GeV/c PID combined ToF – dE/dx analysis (π / K / p separation)
particles must reach the ToF, reduced acc.; factorize all corrections (i.e. acc., recon. eff., decays, etc.), some corrections estimated directly from data, rely less on MC

Typical p+C event at 31 GeV/c



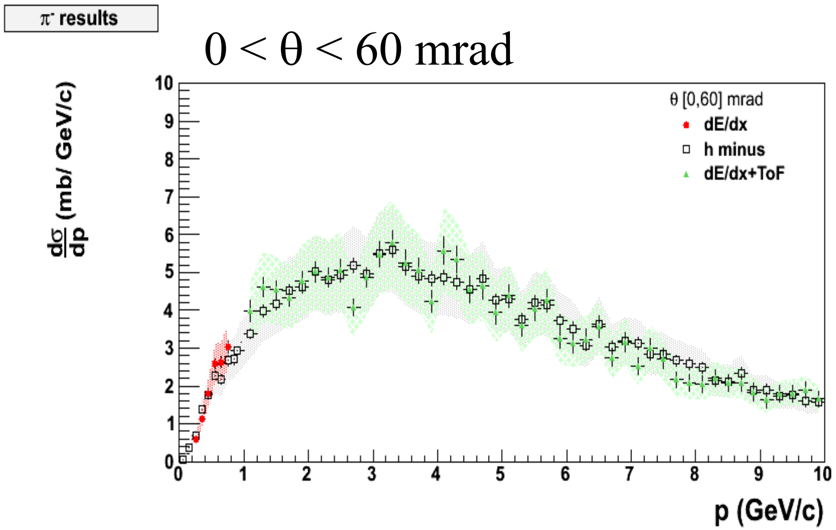
π^- analysis

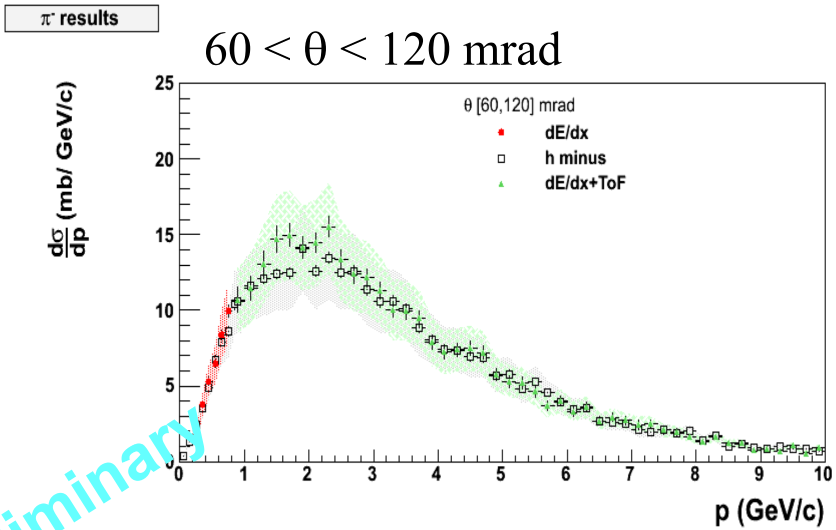
all 3 methods used

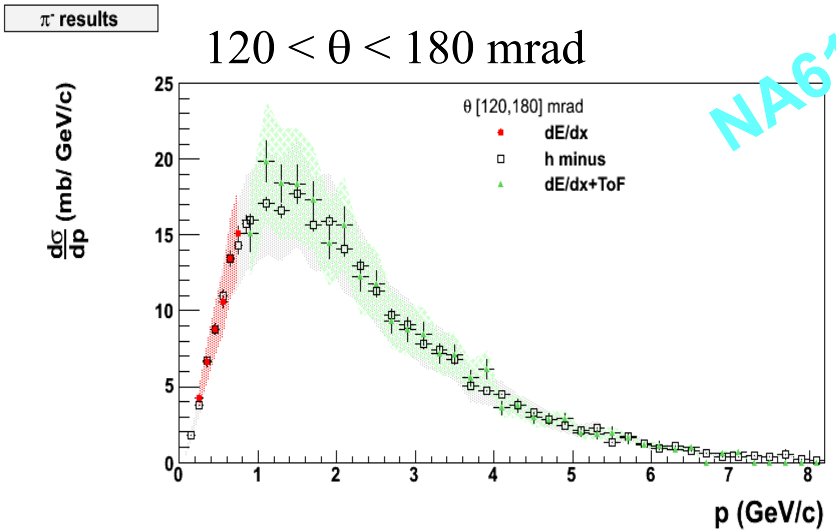
π^+ analysis

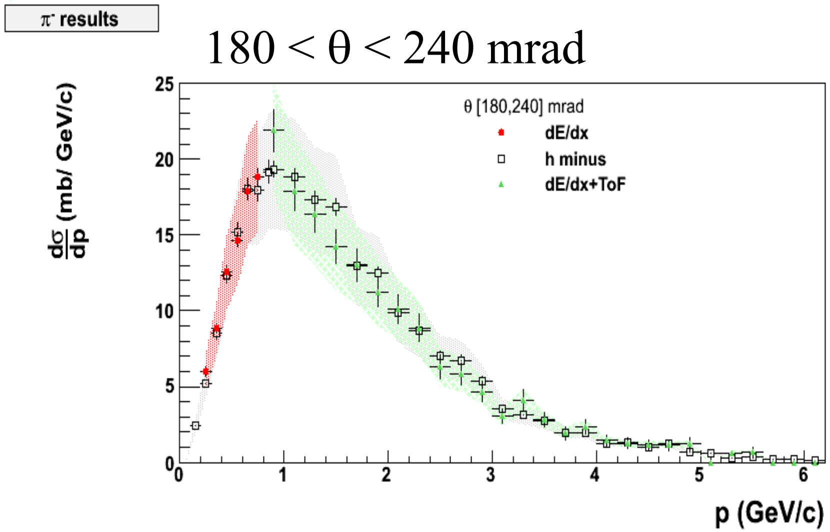
only methods with PID (2 & 3)

Preliminary π⁻ spectra



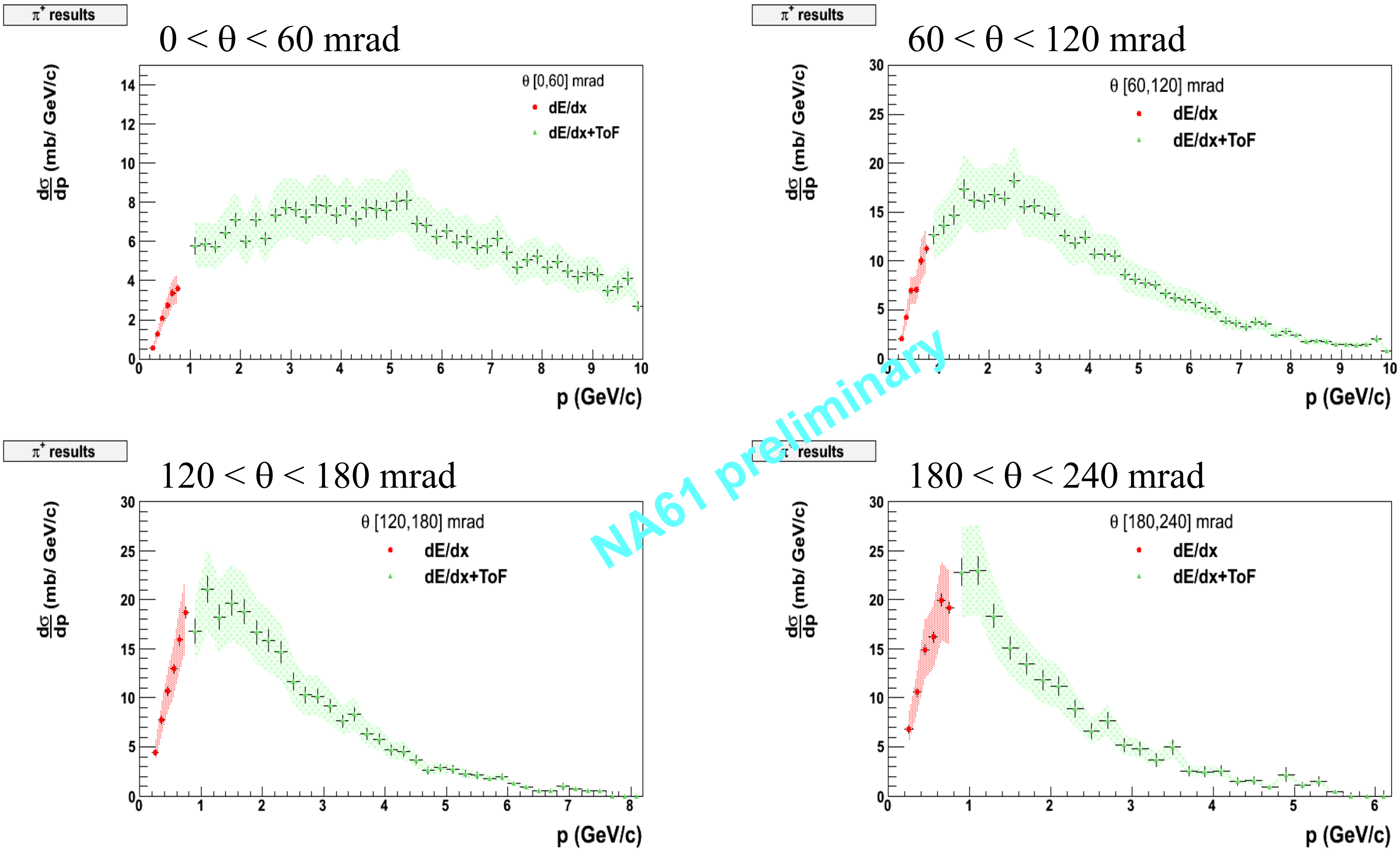






different approaches yield consistent results within **20% systematic errors**
work is in progress to reduce the current systematical uncertainties

Preliminary π^+ spectra



continuity observed in the distributions (different analyses)

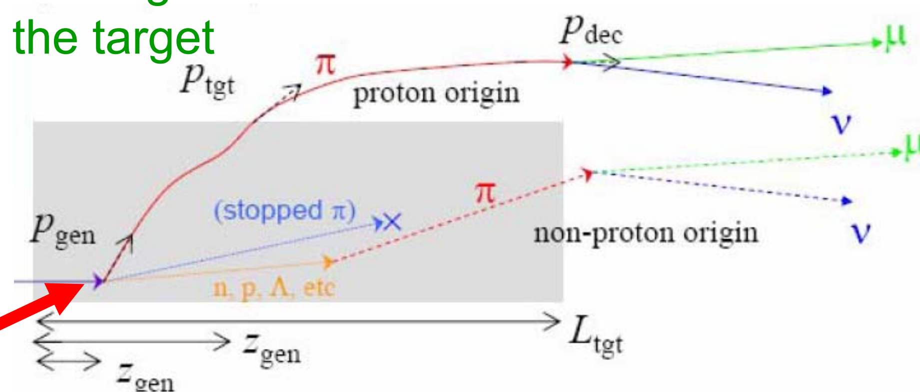
same **20% systematic errors** as for π^- spectra

Particle production off T2K replica target

T2K replica target data will allow for the study of secondary interactions:

we see only particles coming out of the target

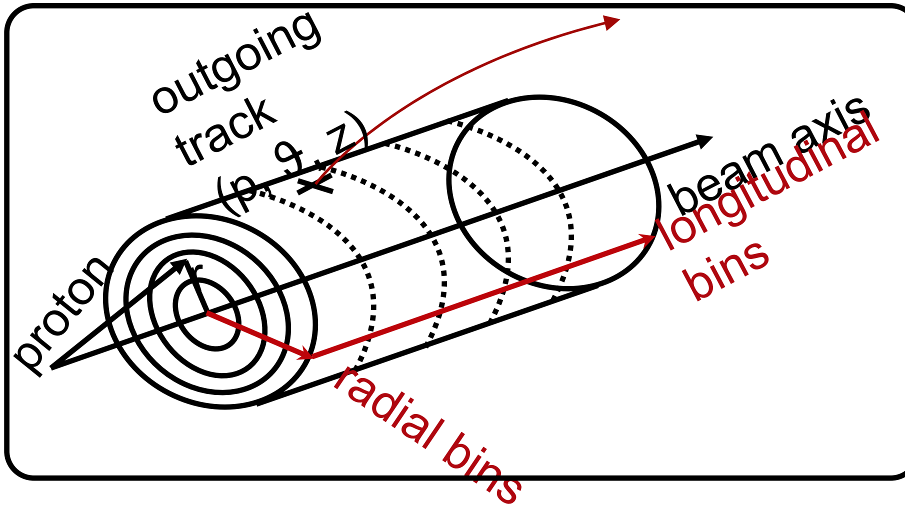
we do not see what happens inside the target



depending on the hadronization model (and target geometry and beam energy) around 30 – 50 % π, K come from re-interactions

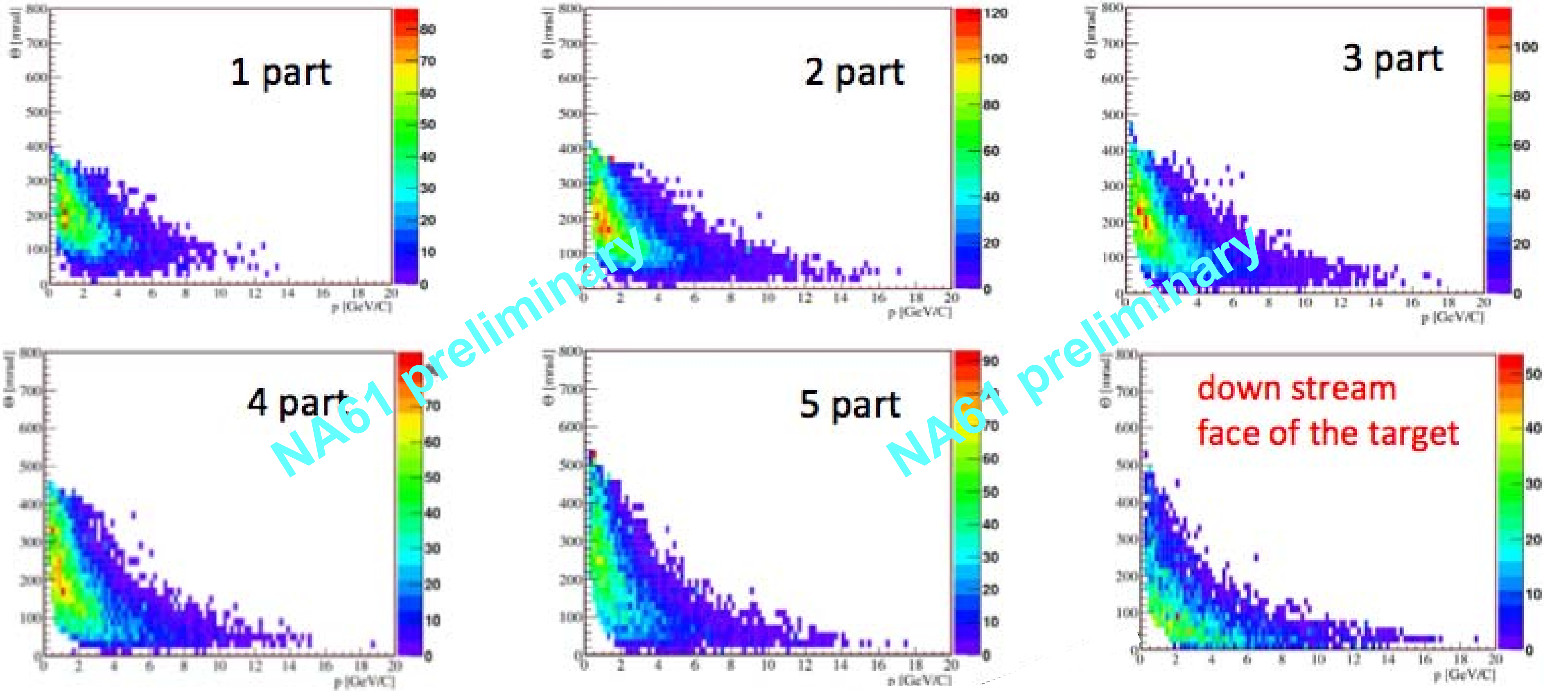
current analysis strategy:

- provide momentum and angle of all tracks at the target skin
- back tracking to the target skin starting from first measured point
- ToF PID assume all tracks come from center of target
- divide the target in 5 longitudinal bins
- divide the target in 3 radial bins
- use to tune re-interactions



h⁻ spectra off T2K replica target

h⁻ p / θ distributions for 5 longitudinal bins + target downstream face measured at target skin with correction procedures similar to the thin target h⁻ analysis



The p / θ distributions changes along the target

Longitudinal distribution sensitive to:
- target geometry
- re-interactions
- target interaction length

Summary

NA61 detector is a large acceptance particle spectrometer at the CERN/SPS with very good PID capabilities, which will precisely measure particle production off a variety of targets with different beams.

To achieve the NA61 – T2K goal
perform cross section measurements to 5% or better

First round of hadro-production measurements for T2K (data taking)
to be completed in 2010

Preliminary π^+ and π^- spectra (thin target) already released
We have full coverage of T2K phase space !
Different analysis procedures adopted: they lead to consistent results (20% sys.)

Work is ongoing to finalize the thin target analysis
- reduce the systematics
- include 2009 data
- extract kaon spectra

Understanding of data taken with T2K replica target is progressing