Pion Production Measurement in NA61/SHINE Experiment

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11th International Workshop on Meson Production, Properties and Interaction
KRAKÓW, POLAND
10 - 15 June 2010

Outline

- Introduction
- NA61/SHINE
  - Fixed target experiment at CERN SPS
  - Detector based on the NA49 apparatus
- Physics Program
  - Physics of strongly interacting matter
  - Data for neutrino and cosmic ray experiments
- NA61 detector
- Particle identification
- Preliminary results from 2007 pilot run
  - π- and π+ inelastic differential cross sections in polar angle intervals from p+C@31 GeV/c
- Status and plans

Introduction

Why meson production in proton Carbon interactions in the interval 20-100 GeV is important ?

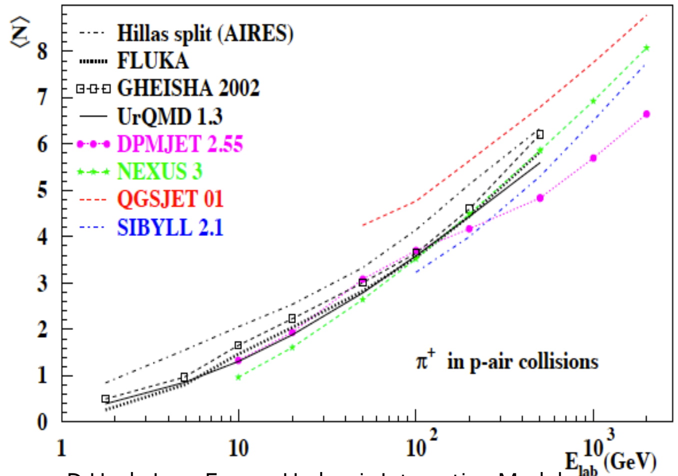
1. This is the transition region between low energy and high energy MC models

2. In this region even predictions from low energy models differ a lot

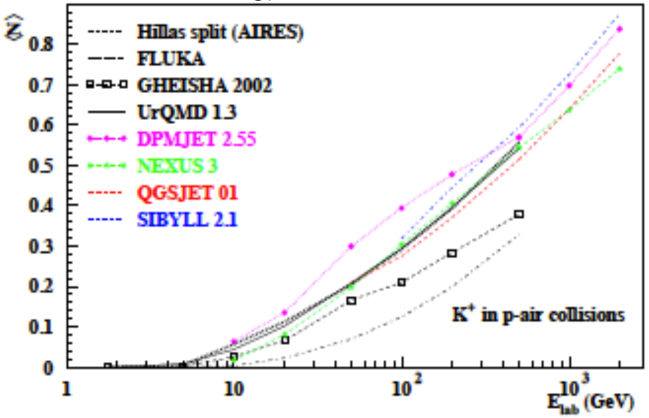
3. This region is not covered by experimental data
   1. NA49 – **pC @ 158GeV/c**
   2. HARP (2 -15 GeV/c) **pC <15GeV/c** (limitted phase space)
   1. MIPP (20 - 120 GeV/c) **Preliminary pC @ 120GeV/c**

Additional measurements in this region are necessary

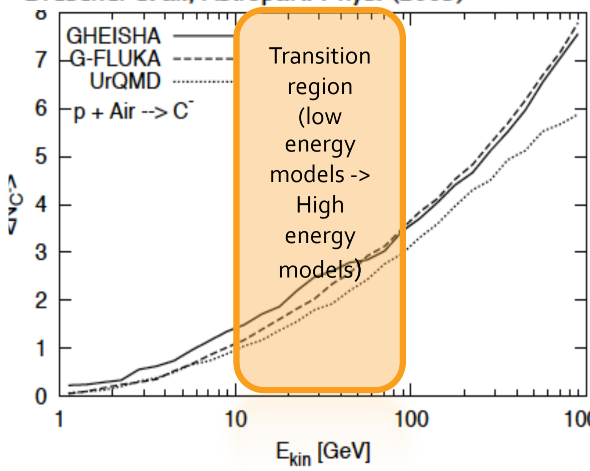
- **mesons (π+,π-, K+, K-) differential cross section in wide phase space range**



D.Heck, Low-Energy Hadronic Interaction Models

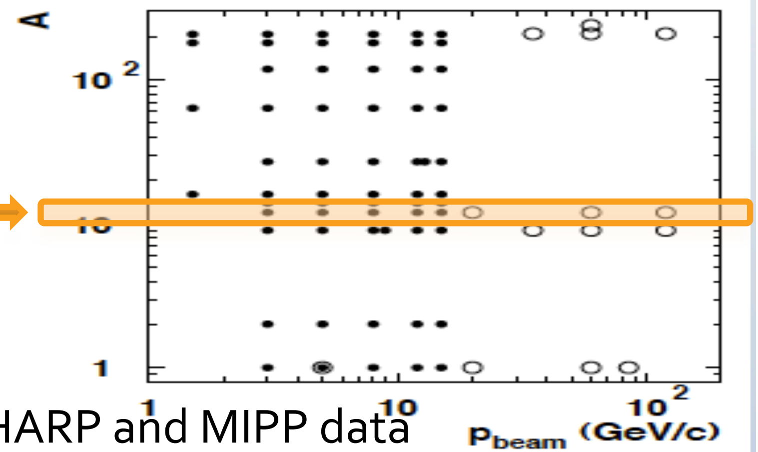


Drescher et al., Astropart. Phys. (2003)



The mean multiplicity of negatively charged hadrons is plotted as a function of the incident kinetic energy

12

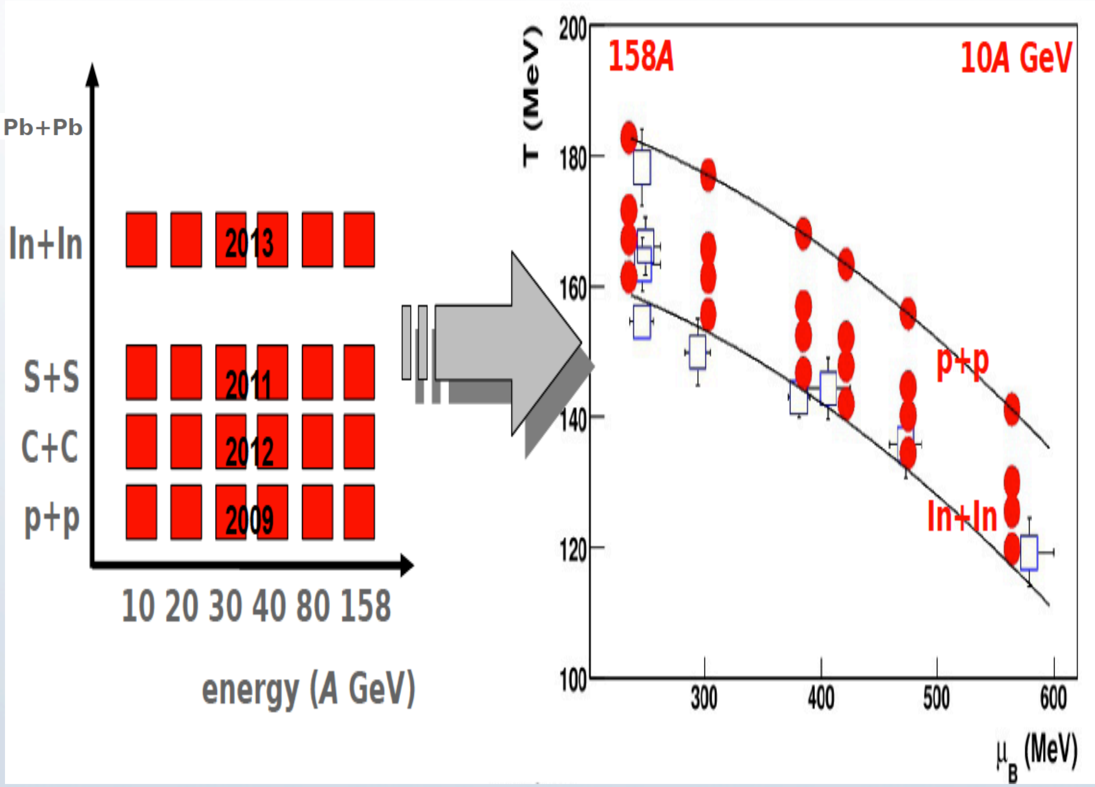


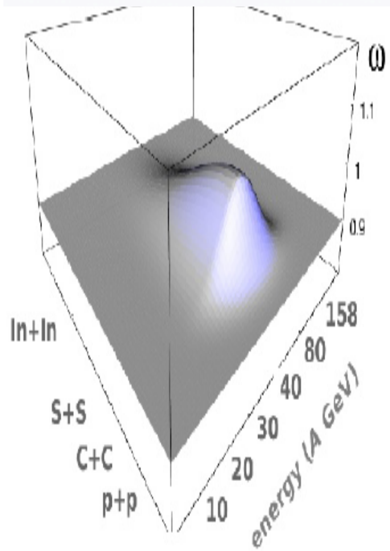
HARP and MIPP data

NA61/SHINE Physics program

- Physics of strongly interacting matter

➢ Search for the critical point of strongly interacting matter





Search for the hill of fluctuations

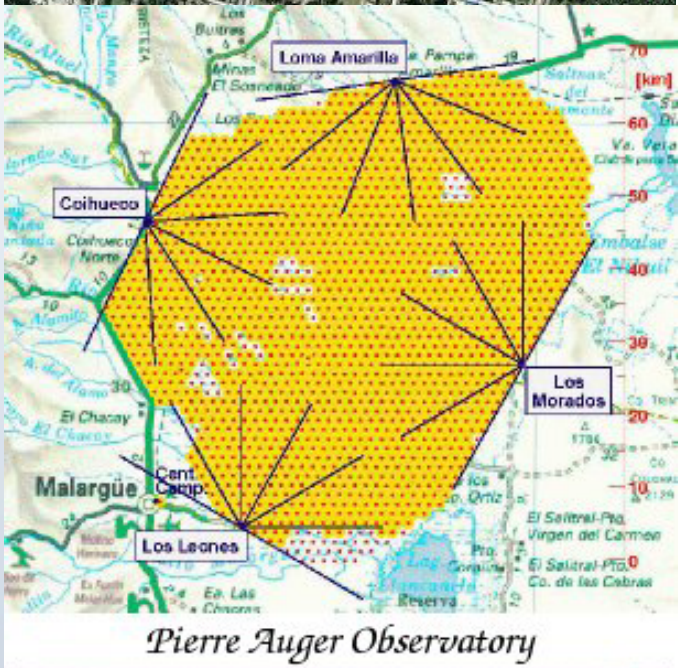
Discovery potential

➢ Precision measurements:

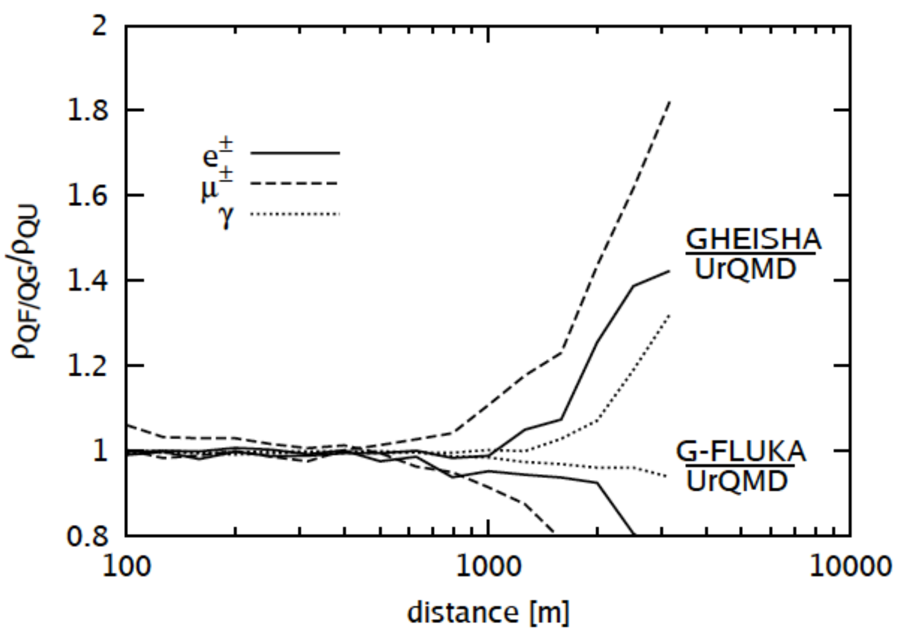
➢ Study properties of the onset of deconfinement

☐ = $2 \cdot 10^6$ registered collisions

- Hadron production in showers not entirely understood
- Transition between low- and high-energy interaction models
- Need phenomenological calibration



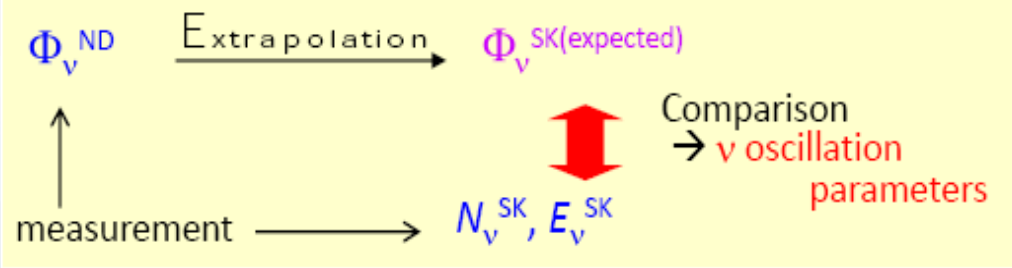
Drescher et al., Astropart. Phys. (2003)



NA61/SHINE Physics program – T2K

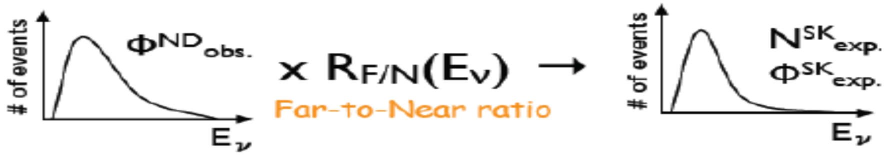
Main aims of T2K:

- o Search for and measurement of the $\nu_\mu \rightarrow \nu_e$ appearance
  - » improved sensitivity to the so far unknown mixing angle θ_{13}
- o Refinement of ν_μ disappearance measurements
  - » improved determination of θ_{23} and Δm^2_{23}



Both analysis rely on the ν spectra measured at SK and the predicted spectra at SK:

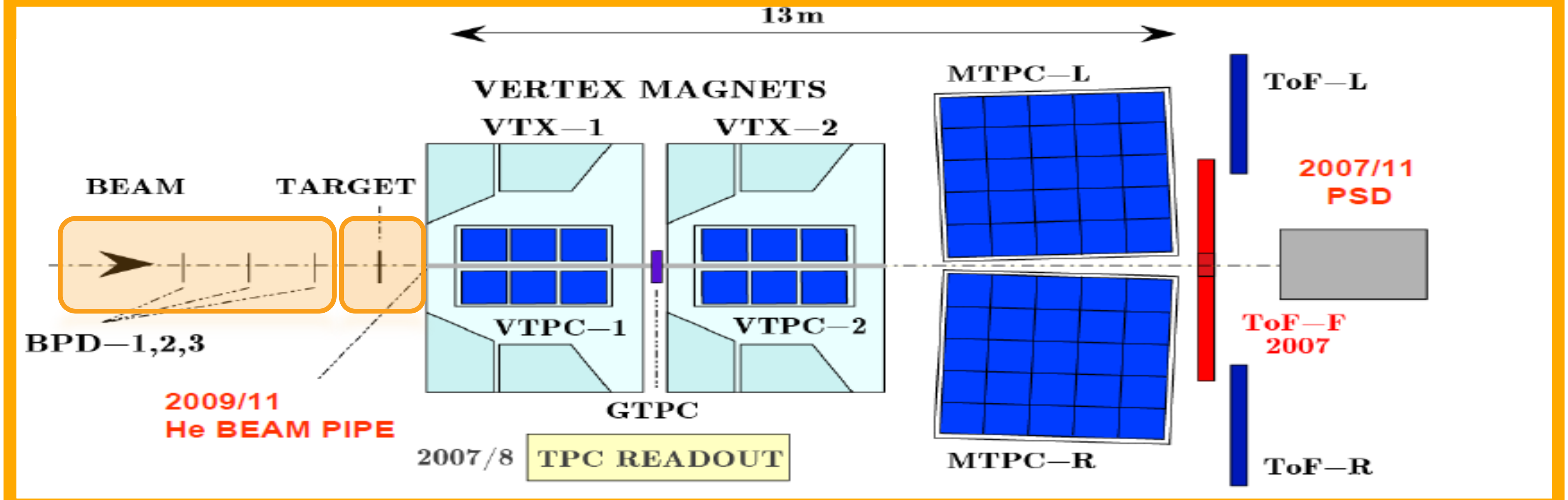
Extrapolated at SK ← $\Phi^{SK}_{\mu,e}(E_\nu) = R_{\mu,e}(E_\nu) \times \Phi^{ND}_{\mu,e}(E_\nu)$ ← Measured at ND



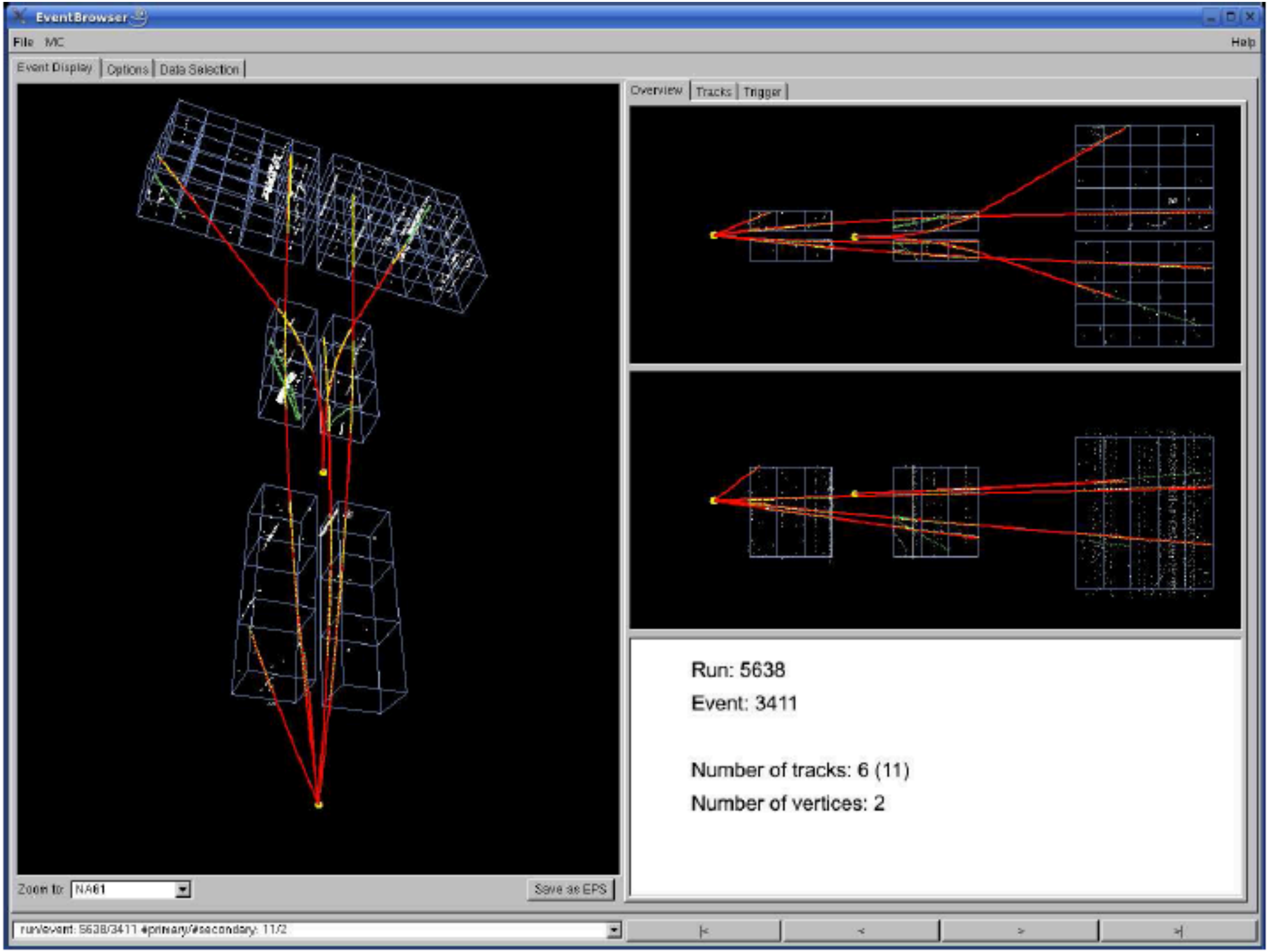
$$R_{F/N}(E_\nu) = \left.\frac{\Phi^{SK}(E_\nu)}{\Phi^{ND}(E_\nu)}\right|_{\text{hadron-production distribution}}$$

to predict the ν flux correctly details of ν parent hadro-production kinematics needed

NA61 detector

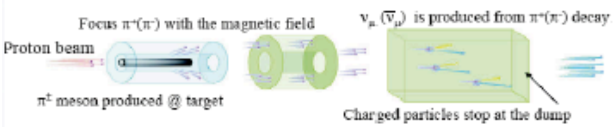


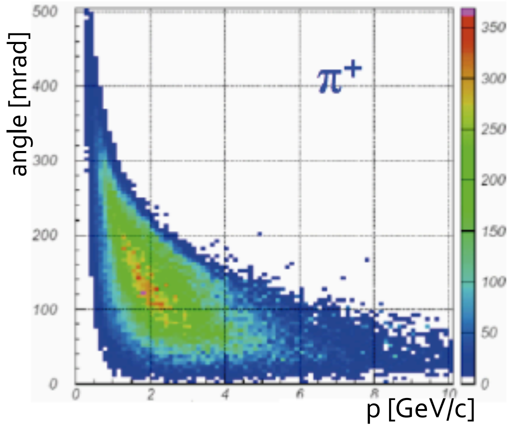
- Large Acceptance Spectrometer for charged particles
- **TPCs** as main tracking devices
- 2 dipole magnets with bending power of max 9 Tm over 7m length (2007 run:1.14Tm)
- **New ToF-F to entirely cover T2K acceptance**
- High momentum resolution $\sigma p/p^2 = 10^{-4}$ GeV/c
- Good particle identification **(PID) :** $\sigma(dE/dx)/\langle dE/dx\rangle \approx 0.04$, $\sigma(minv) \approx 5$ MeV
- Good ToF resolution: **σ(ToF-L/R)=60 ps, σ(ToF-F)<=120 ps**

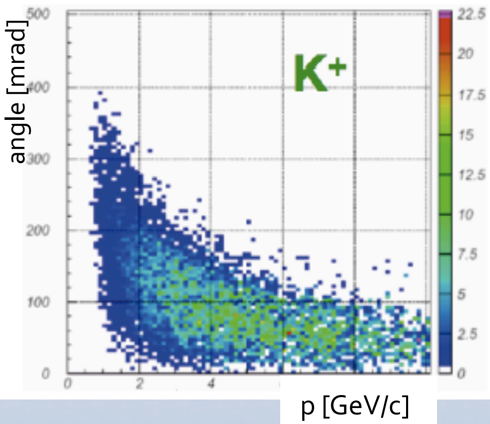

Event Browser
File MC
Help
Event Display
Options
Data Selection
Overview
Tracks
Trigger
Run: 5638
Event: 3411
Number of tracks: 6 (11)
Number of vertices: 2
Zoom to: NA61
Save as EPS
run/event: 5638/3411 #primary/#secondary: 11/2

NA61 detector – FOF-F

T2K phase space

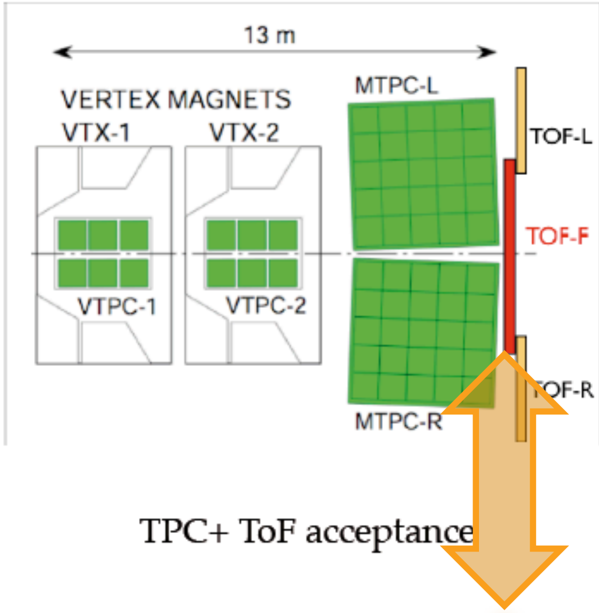






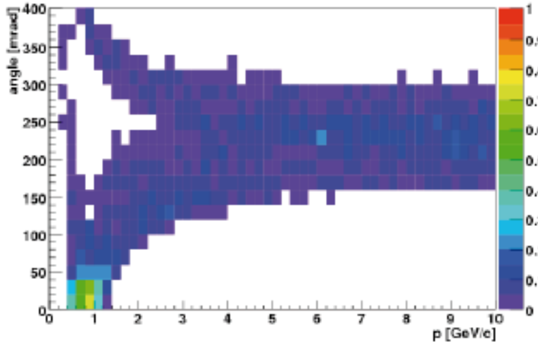
Pions and kaons producing neutrinos seen by T2K (JNUBEAM simulations)

NA61 acceptance

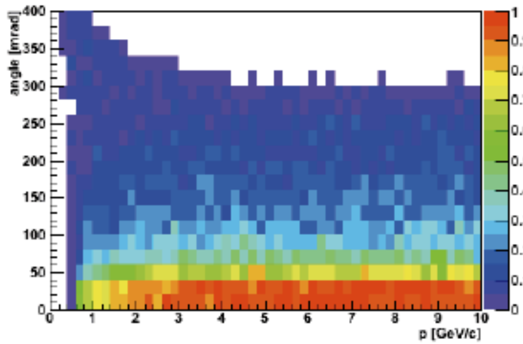


TPC+ ToF acceptance

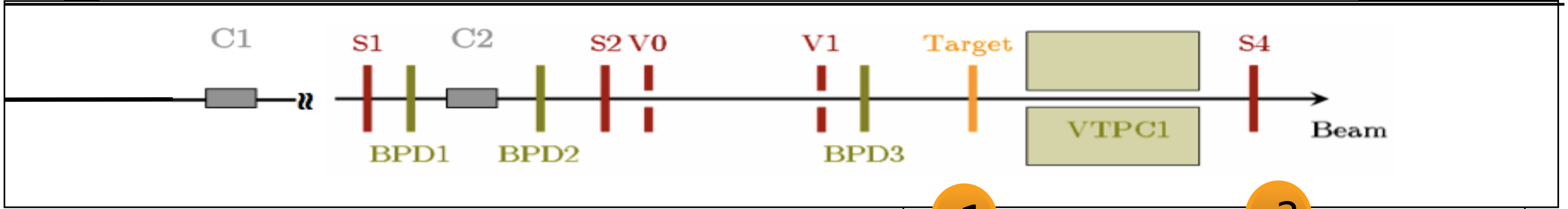
NA61 with ToF-L,R only



NA61 with the new ToF-F



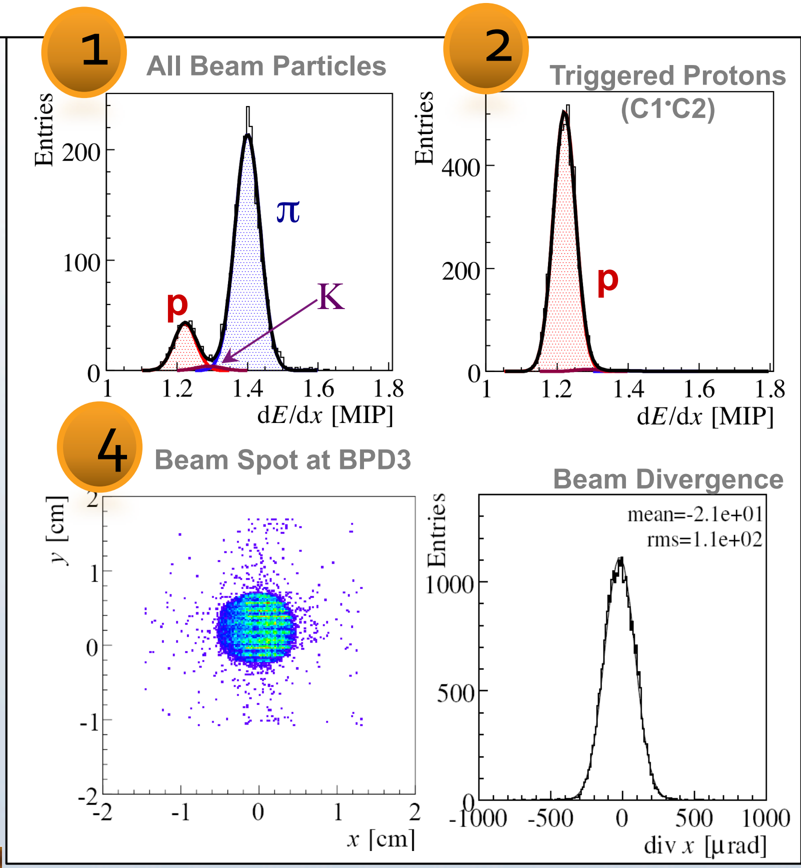
Setup of Beam Line

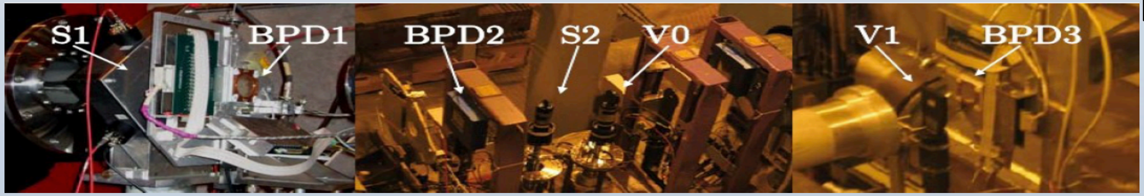


1. Secondary hadron beam composed of 83.7% π^+ 14.7% p and 1.6% K^+
2. Proton beam particles identified by CEDAR (C1) and threshold Cerenkov counters (C2)
3. Incoming p then selected by several scintillator counters (S1, S2, V0, V1)

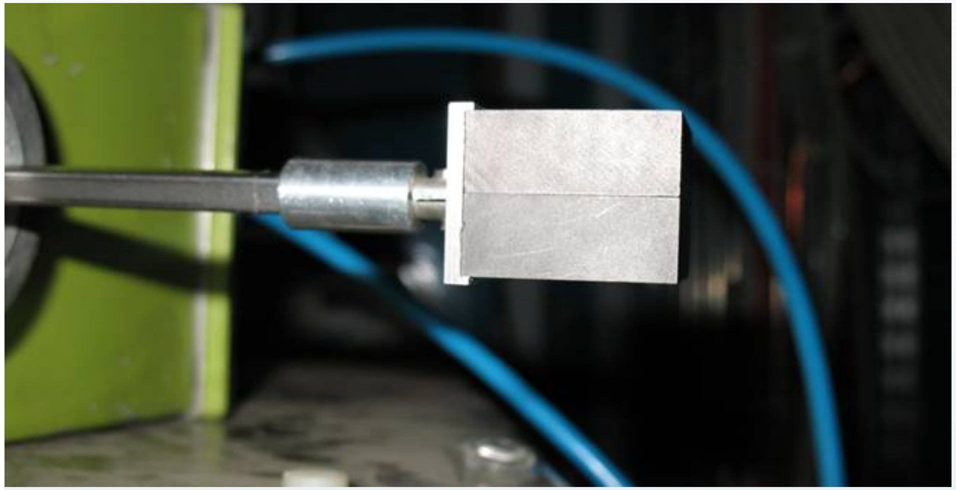
→ beam defined as B = S1•S2•$\overline{\text{V}}$•C1•$\overline{\text{C2}}$

4. Trajectory of beam particles measured by the beam position detectors (BPD-1/-2/-3)
5. 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 Gev protons (2 weeks)

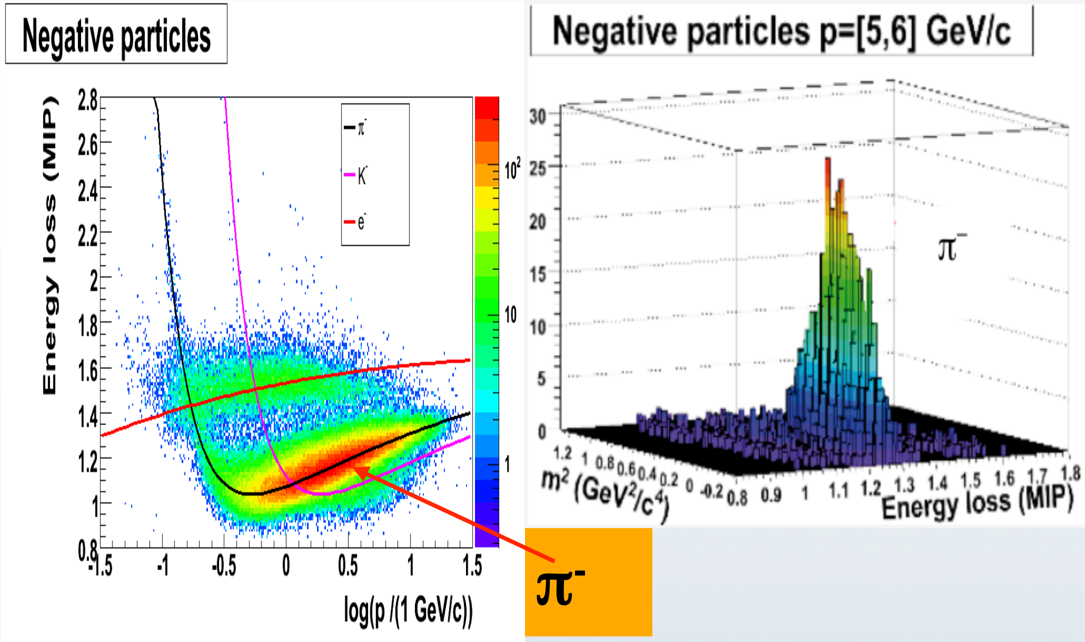
Thin target: ~670k triggers Replica target: ~230k triggers

Empty target: ~80k triggers

Particle Identification Strategies (1/3)

❖ **Analysis of negatively charged particles (h- analysis):**

(T.Palczewski, Soltan Institute for Nuclear Studies)

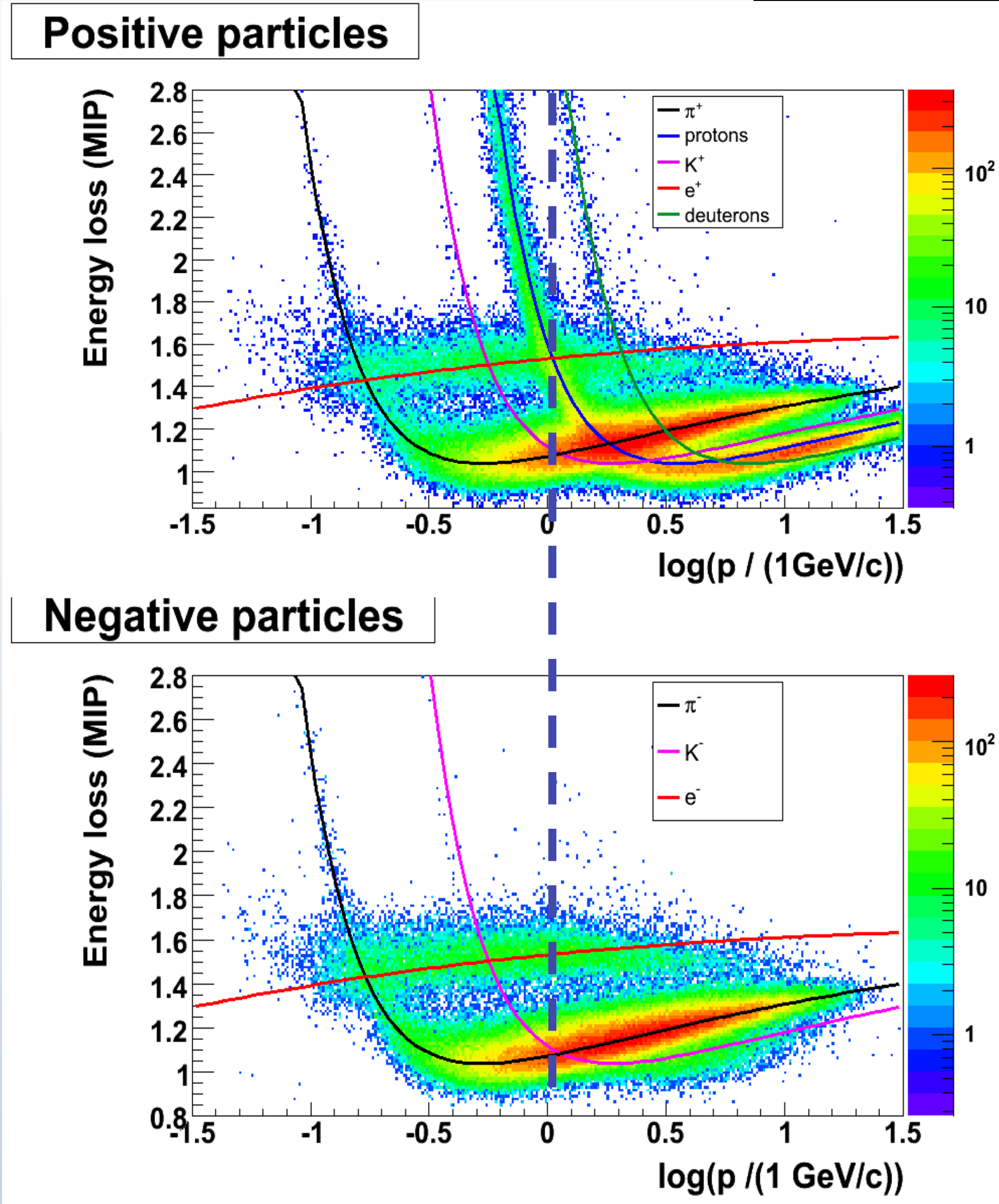


- The analysis of negatively charged particles from the primary vertex can be done even without PID studies because most of produced negatively charged particles at 30 GeV proton carbon interactions are π^- **mesons**.

- The remaining fraction includes K^-, e^- and negligible number of anti-protons. This admixture can be corrected using Monte Carlo Simulation.
- Venus-GHEISHA and Geant Monte Carlo simulation chain is used to calculate corrections for
  - geometrical acceptance,
  - reconstruction efficiency,
  - kinematic smearing,
  - decays
  - and non pion contamination
- Finally corrected spectra of π^- **mesons in broad momentum range** are obtained.

Particle Identification Strategies (2/3)

- **Energy loss measurements:**
  - below 1GeV/c dedicated dE/dx analysis to identify pions (M.Posiadala, University of Warsaw)
  - 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 (Silvestro Di Luise, ETH Zurich) Not yet finalized

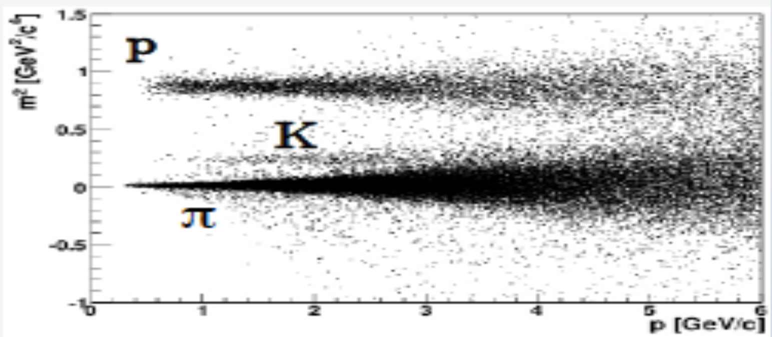


Particle Identification Strategies (3/3)

- **Combined energy loss and Time of Flight measurements :**

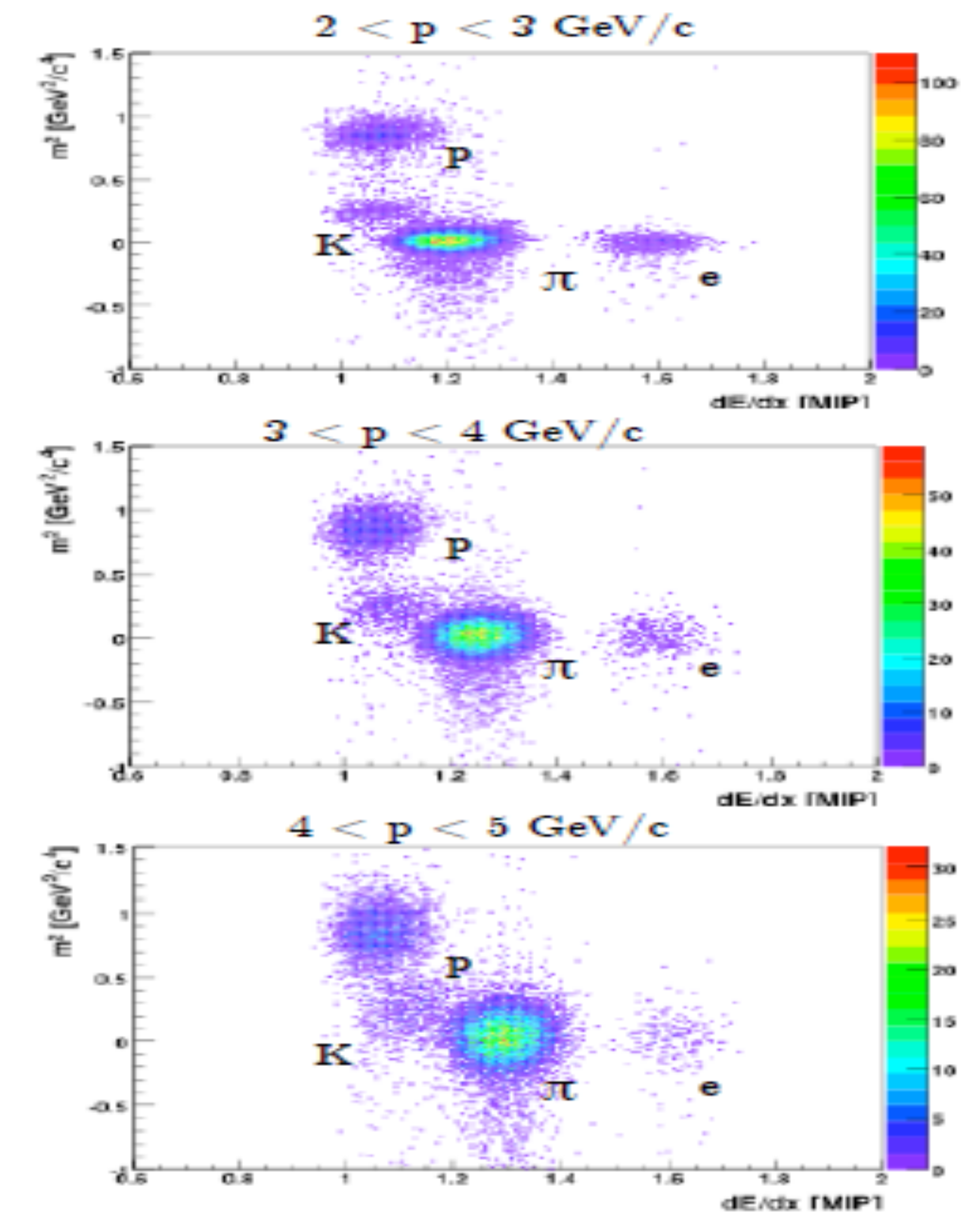
(S.Murphy, UniGe-DPNC)

- p~[1-6] GeV/c Time of Flight (ToF) measurements

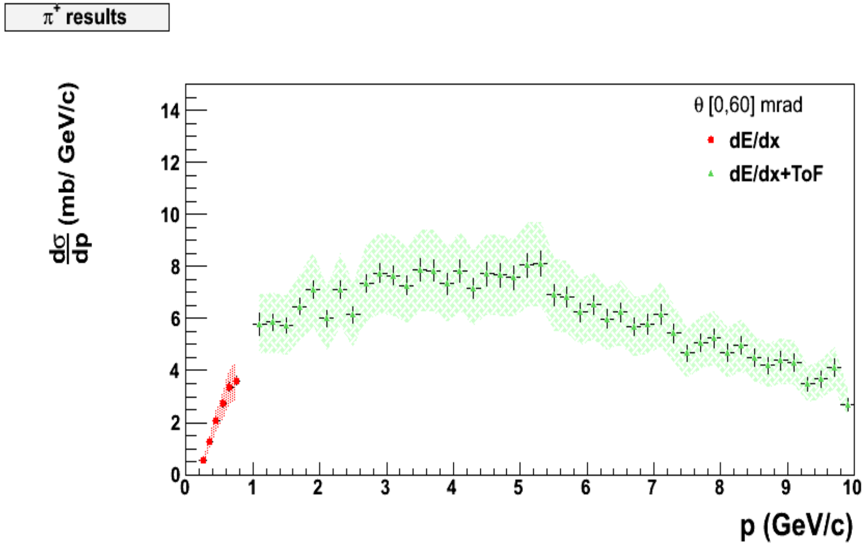


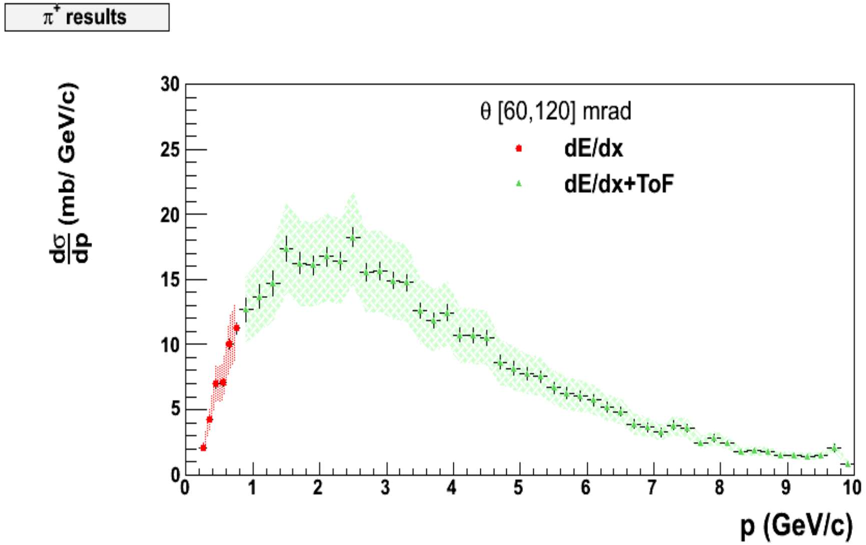
$$m^2 = p^2 \left[\frac{c^2 t^2}{l^2} - 1 \right]$$

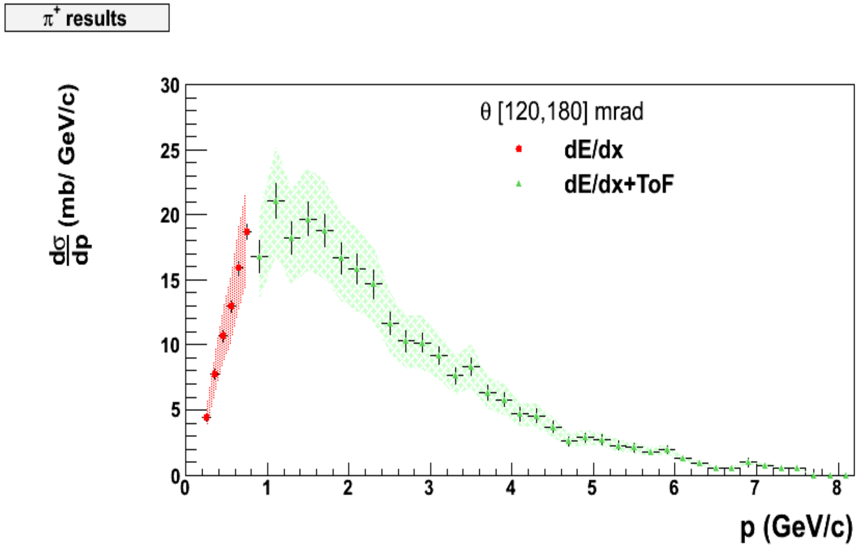
particle momentum (p) and track length (l) are precisely measured in the TPCs tracks are then extrapolated to the ToF and associated to a scintillator which gives a value for t.

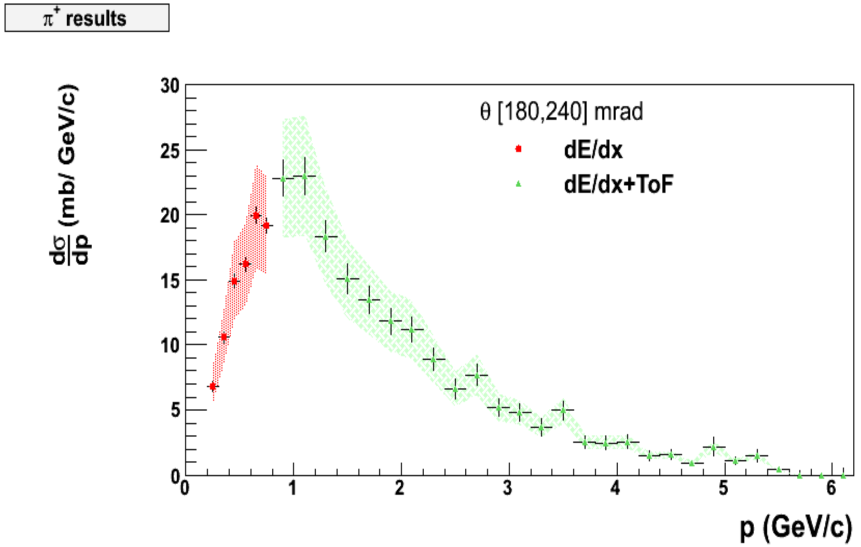


Preliminary results – π+

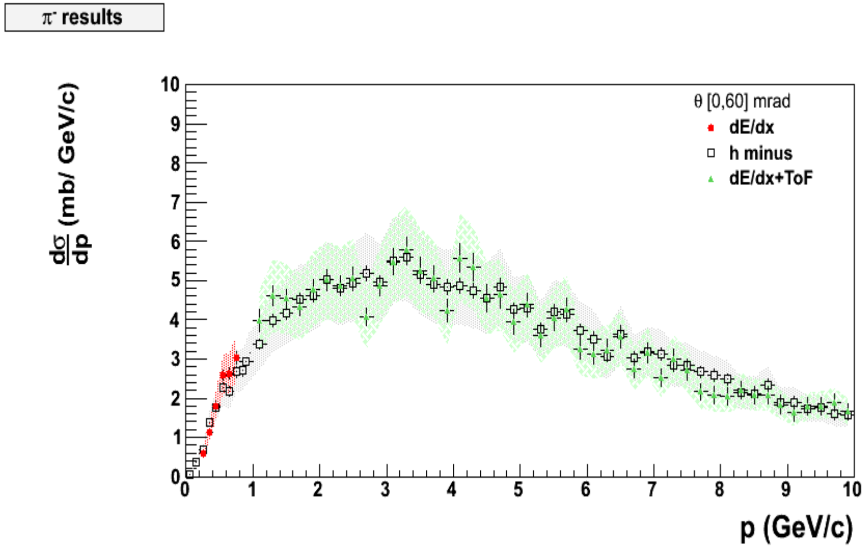


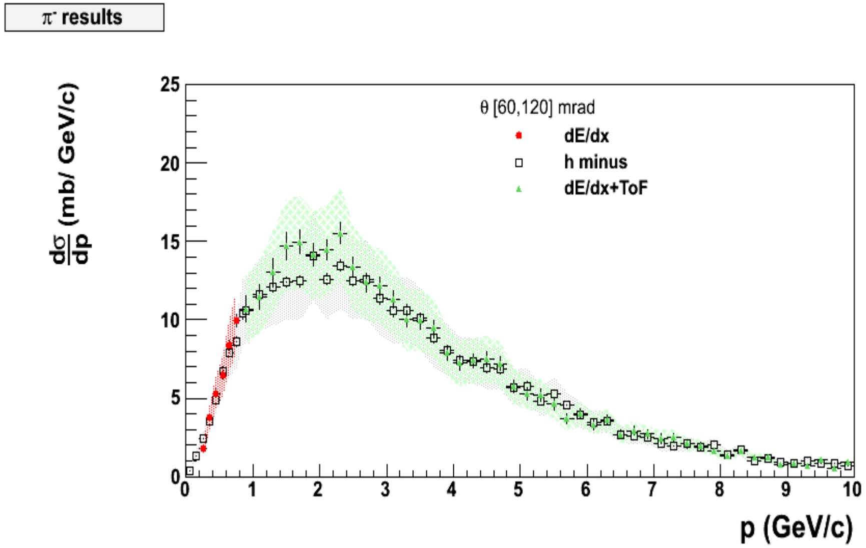


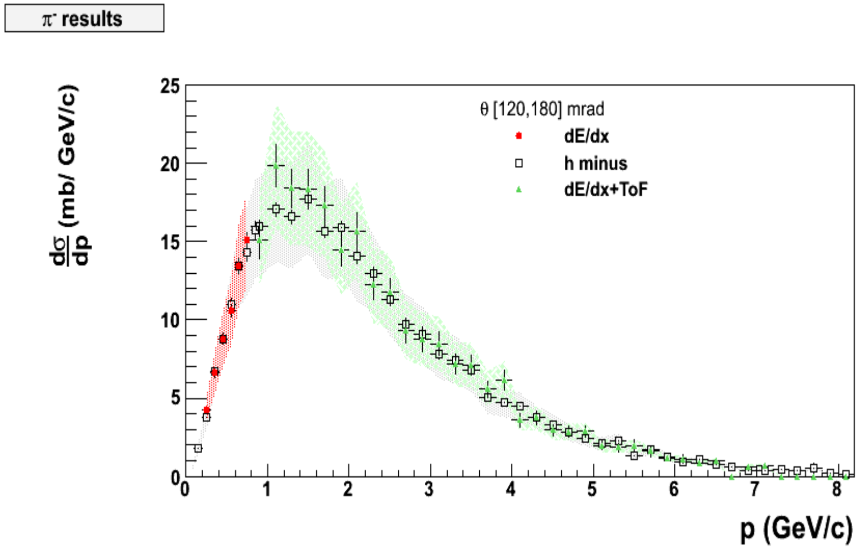


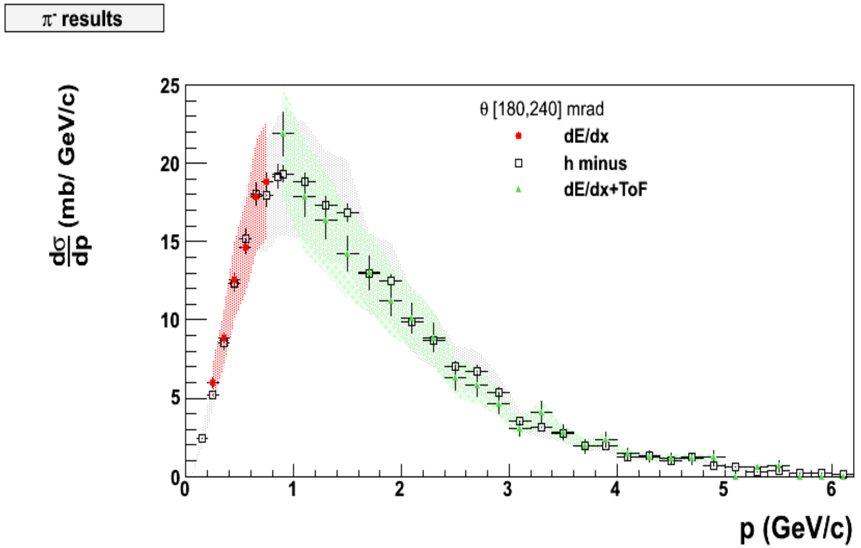


Preliminary results – π-

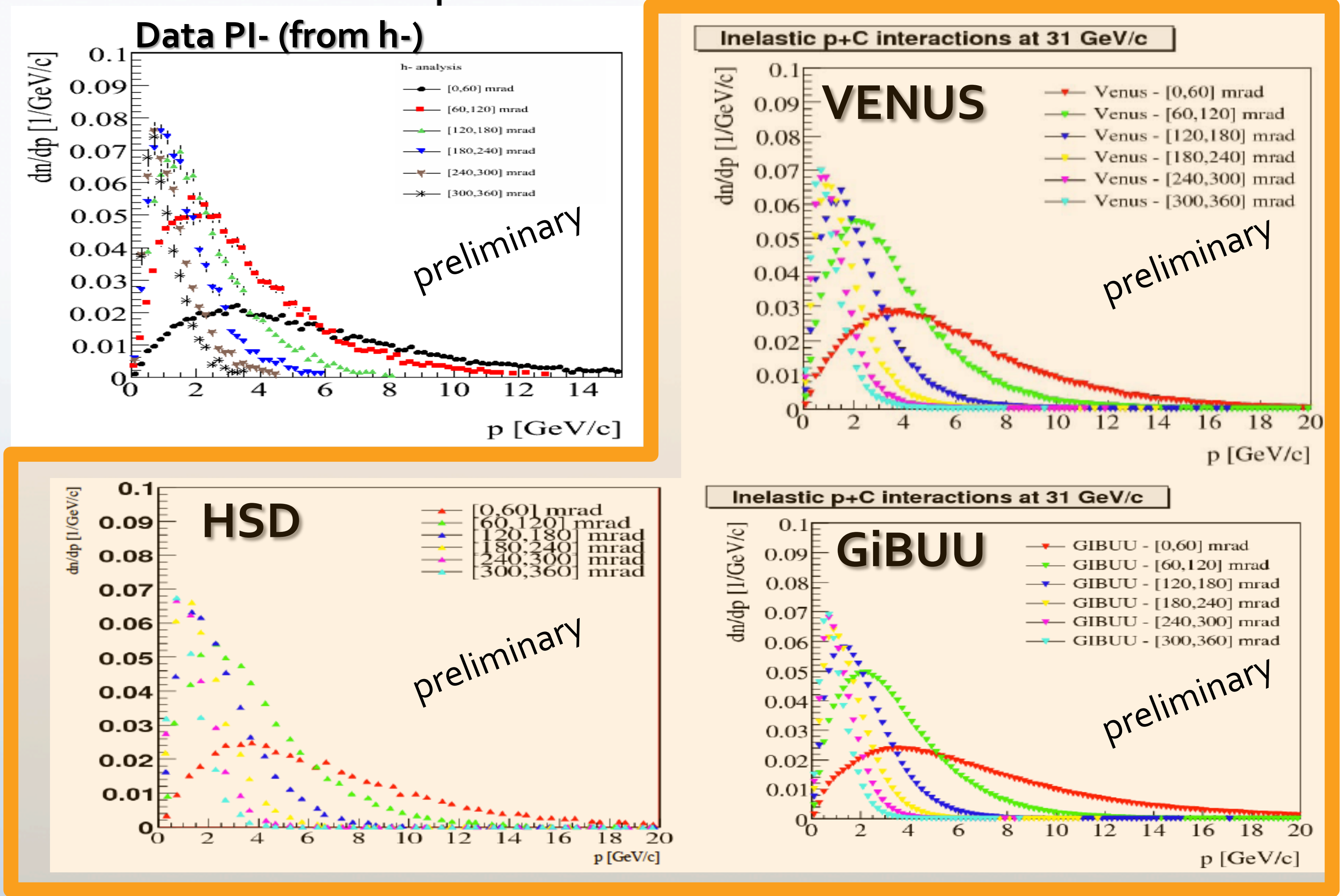








Model predictions – π-



The general trends of the obtained distributions
are similar to that generated using monte carlo models
VENUS, HSD, GiBUU, UrQMD, Geant4, FLUKA

MC

Status and Plans

- **NA61/SHINE is a large acceptance hadron spectrometer at the CERN SPS** which precisely measures the particle production needed for T2K experiment and cosmic ray experiments
  - Thin target: for the determination of inclusive cross sections
  - T2K replica target: for the study of secondary interactions in the T2K target

- Preliminary π+ π- inelastic differential cross sections in polar angle intervals were obtained (thin carbon target)

- The work to minimalize systematic biases is in progress.

- The dependence on the details of the MC generators is also under study.

- In 2009 year three weeks were dedicated for T2K measurements. We registered 6 milion interaction triggers for the thin target and 4 milion for the T2K replica target. (calibration is in progress, available soon for analyses)

- Increased statistics will allow us to obtain kaon cross-section results

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
Jagellionian 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
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

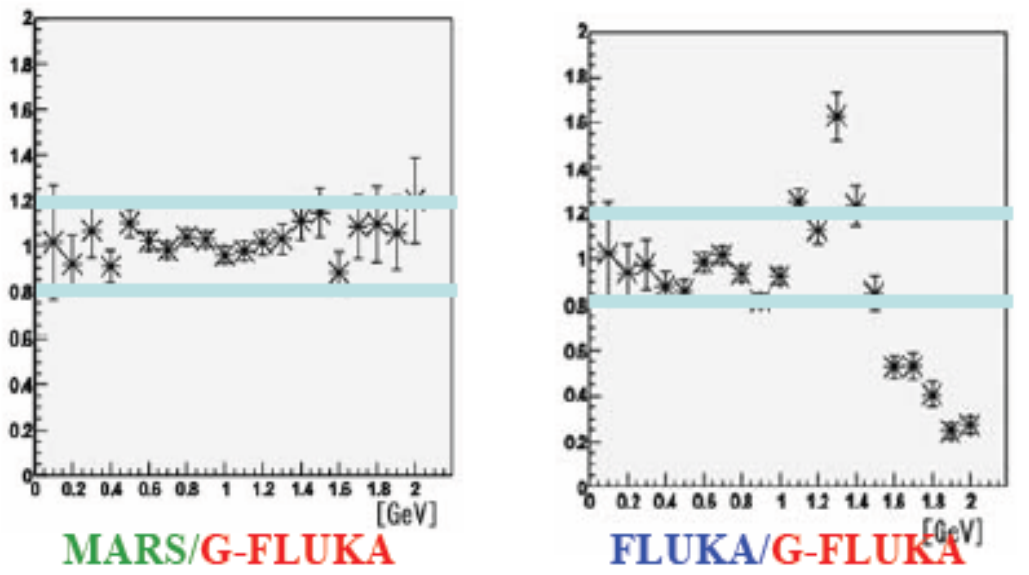
Thank you

Backup slides

dependence from hadron production models

Ken Sakashita – T2K, NA61 collaboration

Ratios of F/N ratios



Differences between hadron production models

$\delta R\nu_\mu \sim 20\%$

20% for $E_\nu < 1$ GeV

aim: **$\delta R\nu_\mu < 3\%$**

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 δ(K/π)<10%

Thin carbon target and T2K replica target

Use different methods and cross checks to precisely measure the inclusive p+C cross section with a **Thin Target** over a broad kinematical range and different particles (π, K, p)

Use the measured cross sections as input to the beam MC for generating the primary interaction. Secondary interactions, however, will be described by hadronization models

Compare the MC predictions to the π/K yields measured off C-targets of different lengths (T2K Replica Target) and adjust the model accordingly

Measure π/K yields off the **T2K Replica Target**

Use measured π/K yields as input to the beam MC (no simulation of secondary interactions required)

→ Comparison of both approaches at the level of neutrino fluxes will provide an additional estimation of the uncertainty

Claudia Strabel, ETH Zurich
For the NA61/SHINE Collaboration
Lake Louise Winter Institute
14.-20.01.10

Cross section normalization

- The inclusive inelastic cross section of a particle type α can experimentally be expressed by

$$\alpha = \pi,\ K,\ p \qquad \frac{\Delta\sigma^{meas}_{inel,\alpha}}{\Delta p \Delta\theta} = \frac{1}{nN_{Beam}}\frac{\Delta n_\alpha}{\Delta p\Delta\theta} = \frac{N_{trig}}{nN_{Beam}N_{trig}}\frac{\Delta n_\alpha}{\Delta p\Delta\theta} = \frac{\sigma_{trig}}{N_{trig}}\frac{\Delta n_\alpha}{\Delta p\Delta\theta}$$

n: target properties,
N_{beam}: # of incoming beam p,
N_{trig}: # of triggers,
σ_{trig}: trigger cross section,
Δn: # of identified particles
in a given bin p-θ bin

– σ_{trig} thus involves the trigger rate and the target properties

$$\sigma_{trig} = \frac{1}{n}\frac{N_{trig}}{N_{beam}} = \frac{1}{\rho L_{eff} N_A/A} P_{int}$$

$$L_{eff} = \lambda_{abs}(1 - e^{-L/\lambda_{abs}})$$
$$\lambda_{abs} = \frac{A}{\rho N_A \sigma_{trig}}$$

ρ: density, L: length
N_A: Avogadro const.
A: Atomic number
L_{eff}: effective length
λ_{abs}: abs. length

- The real interaction probability (P_{int}) is calculated as the difference of the rate obtained with and without target:

$$P_{int} = \frac{R_{T_{in}} - R_{T_{out}}}{R_{Beam}} = P_{T_{in}} - P_{T_{out}}$$

- Interaction rate (Data):
  - Target out: (1.72 ± 0.01)%
  - Target in: (7.07 ± 0.01)%
  - $L_{eff} = 1.95$ cm

$$\sigma_{trig} = 297.5 \pm 0.7$$

→ $\varepsilon = \frac{R_{T_{out}}}{R_{T_{in}}} = 24.3\%$

High T_{out}/T_{in} rate due to inelastic and elastic interactions in the material of the beamline

Normalization studies done by C.Strabel under supervision of A.Marchioni, ETH Zurich

Inelastic cross section

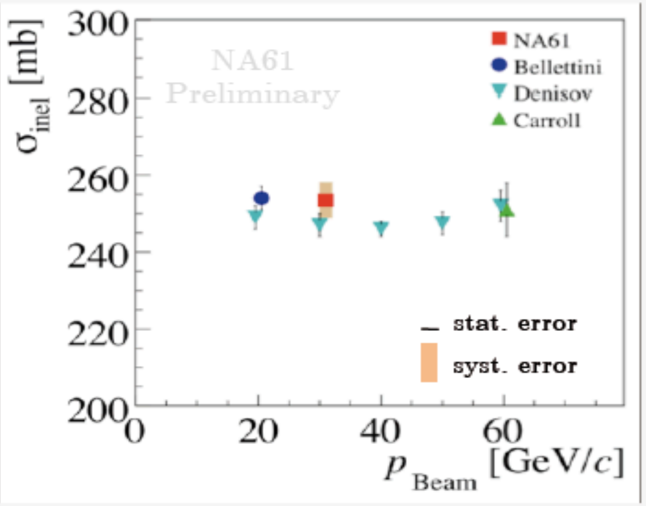
- σ_{inel} can be obtained from the σ_{trig} by applying the following corrections:

1) Subtract the contribution of elastic interactions due to large angle coherent scattering
2) Add the contribution of lost events where a secondary particle hits S4. Here, the major contribution comes from quasi-elastic scattering of the incident protons (σ_{loss-p}). Also secondary pions or kaons hitting S4 have to be taken into account ($\sigma_{loss-\pi/K}$)

→ Corrections have been estimated with Geant4 simulation

σ contribution	value (mb)
$\sigma_{trigger}$	297.5 ±0.7
σ_{loss-p}	5.8 ±0.2
$\sigma_{loss-\pi/K}$	0.6 ±0.06
$\sigma_{elastic}$ contribution	-49.2 ±0.6
σ_{inel}	254.7 ±1.0

NA61 Preliminary



→ Preliminary NA61 value for σ_{inel} is in approximate agreement with previous measurements

Note, that for NA61, Bellettini and Carroll $\sigma_{inel} = \sigma_{tot} - \sigma_{elastic}$, whereas for Denisov $\sigma_{meas} = \sigma_{tot} - \sigma_{elastic} - \sigma_{qe}$

G. Bellettini et al., Nucl. Phys. 79 (1966) 609, S.P. Denisov et. al. Nucl. Phys. B61 (1973) 62, A. Carroll et al., Phys. Lett. B80 (1979) 319 (Recalculated by adding σ_{qe})

Normalization studies done by C.Strabel under supervision of A.Marchioni, ETH Zurich