Recent results from NA61/SHINE at the CERN SPS

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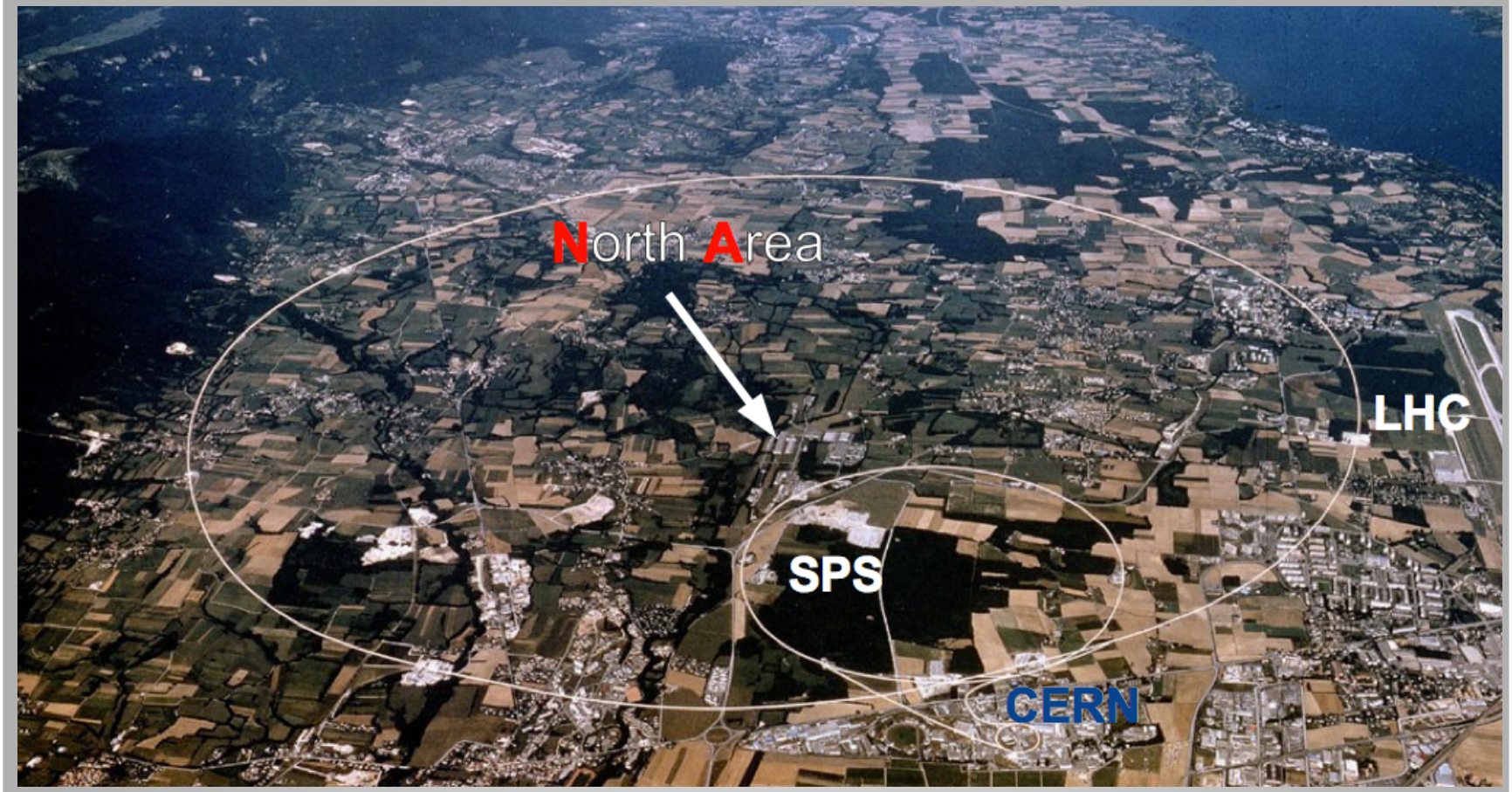
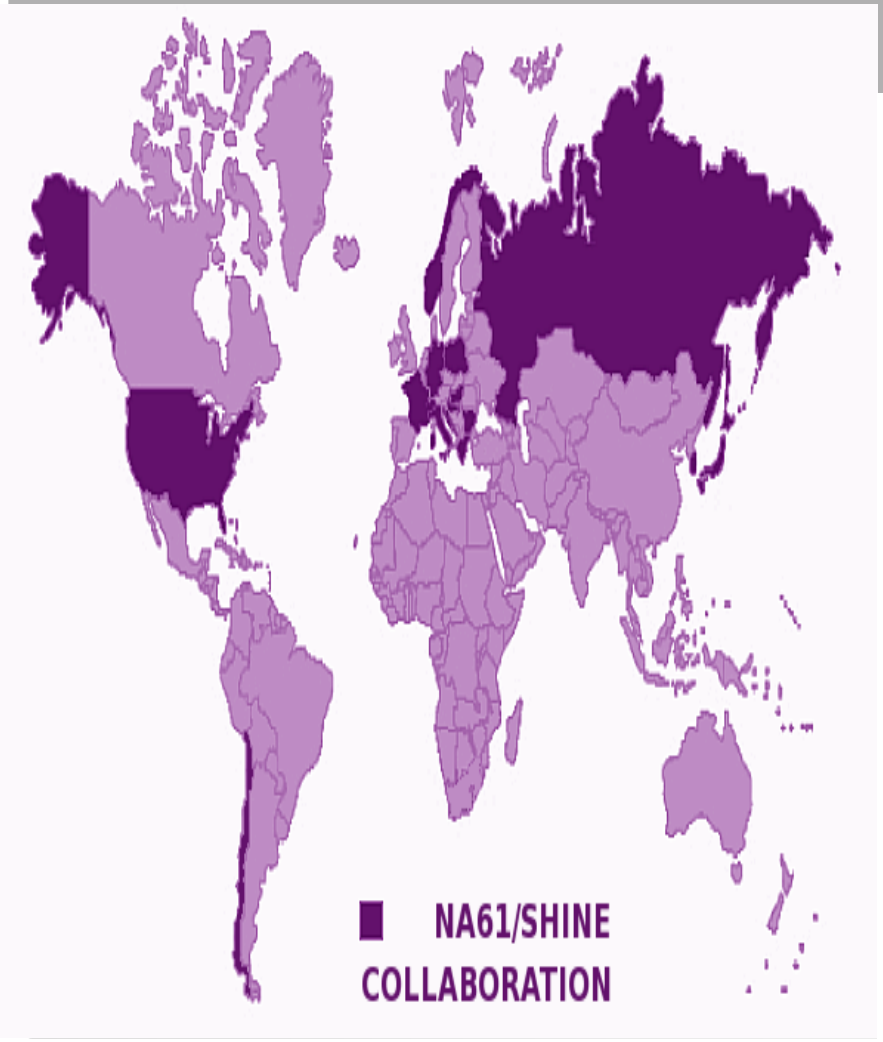
The main part of this contribution is devoted to looking at the NA61/SHINE experiment through the prism of the needs of neutrino oscillation experiments. An overview is shown of the results on hadron production measurements from p+C interactions at 31 GeV/c registered during 2007. In addition, the new preliminary results from 2009 data are presented.


North Area
LHC
SPS
CERN



ETH, Zurich, Switzerland
Fachhochschule Frankfurt, Frankfurt, Germany
Faculty of Physics, University of Sofia, Sofia, Bulgaria
Karlsruhe Institute of Technology, Karlsruhe, Germany
Institute for Nuclear Research, Moscow, Russia
Institute for Particle and Nuclear Studies, KEK, Tsukuba, Japan
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Wigner Research Centre for Physics of the Hungarian Academy of Sciences, Budapest, Hungary
LPNHE, University of Paris VI and VII, Paris, France
University of Silesia, Katowice, Poland
Rudjer Boskovic Institute, Zagreb, Croatia
National Center for Nuclear Research, Warsaw, Poland
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
Jan Kochanowski University in Kielce, Poland
University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
University of Warsaw, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
The Universidad Tecnica Federico Santa Maria, Valparaiso, Chile

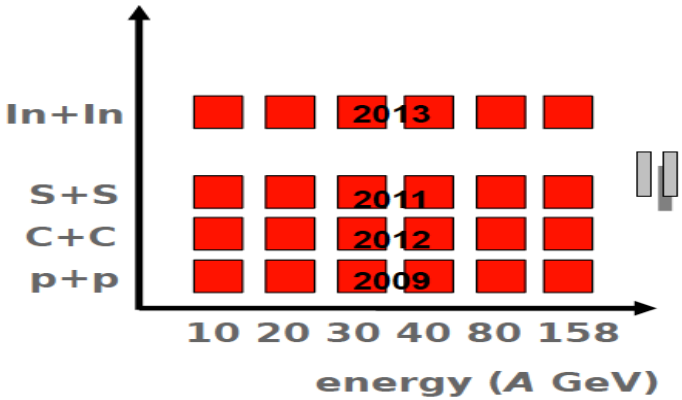
Outline

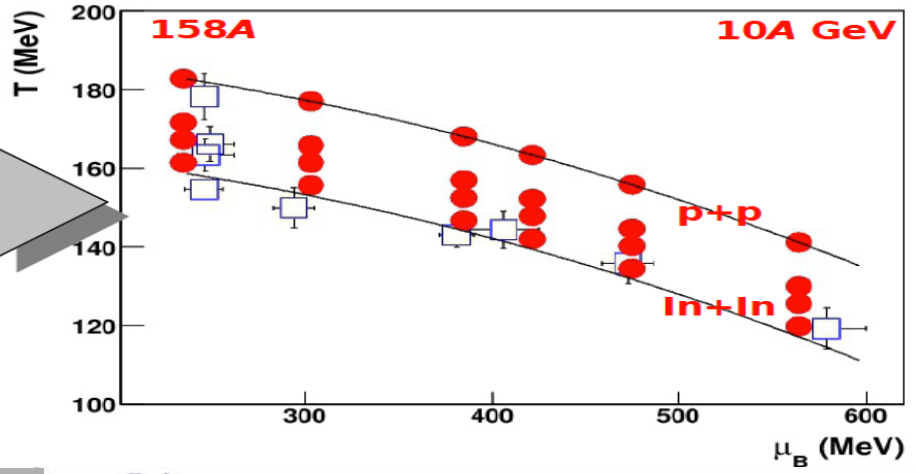
- **Physics Program**
  - Physics of strongly interacting matter
  - Data for Neutrino and cosmic ray experiments
- **NA61/SHINE detector**
- **Particle Identification**
- **Selected results** from 2007 and 2009 runs
- **Status and plans**

Physics Program (I)

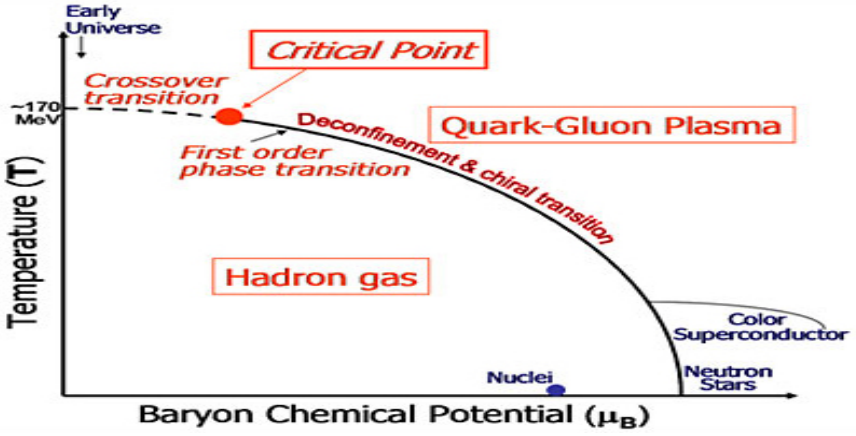
SHINE NA61

Search for the critical point of strongly interacting matter





Precision measurements:
Study properties of the onset of deconfinement



= $2 \cdot 10^6$ registered collisions

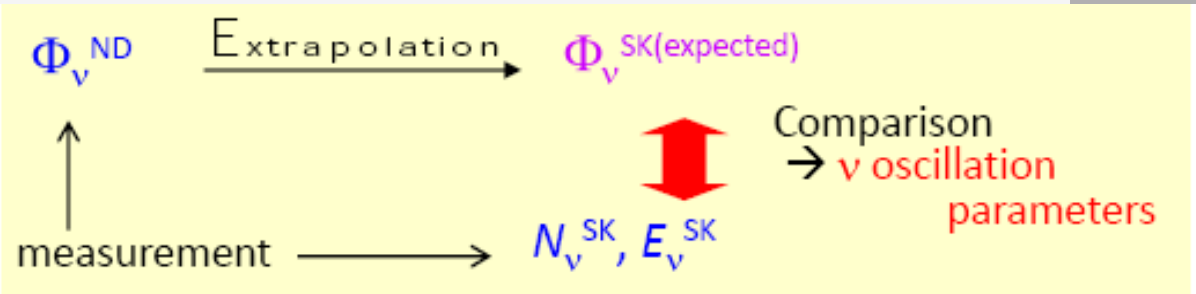
Physics Program (II)

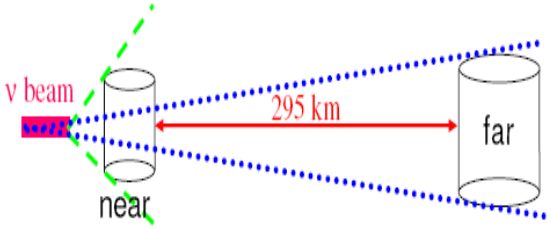
Accelerator long baseline oscillation neutrino experiments

- Tokai to Kamioka

Main aims of T2K:

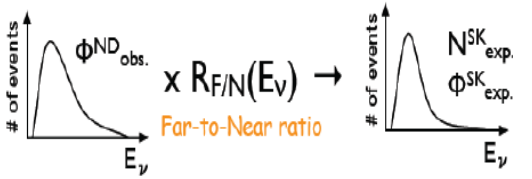
- o Search for and measurement of the $\nu_\mu \rightarrow \nu_e$ appearance
  - » improved sensitivity to the so far unknown mixing angle θ_{13}
- o Refinement of ν_μ disappearance measurements
  - » improved determination of θ_{23} and Δm^2_{23}





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

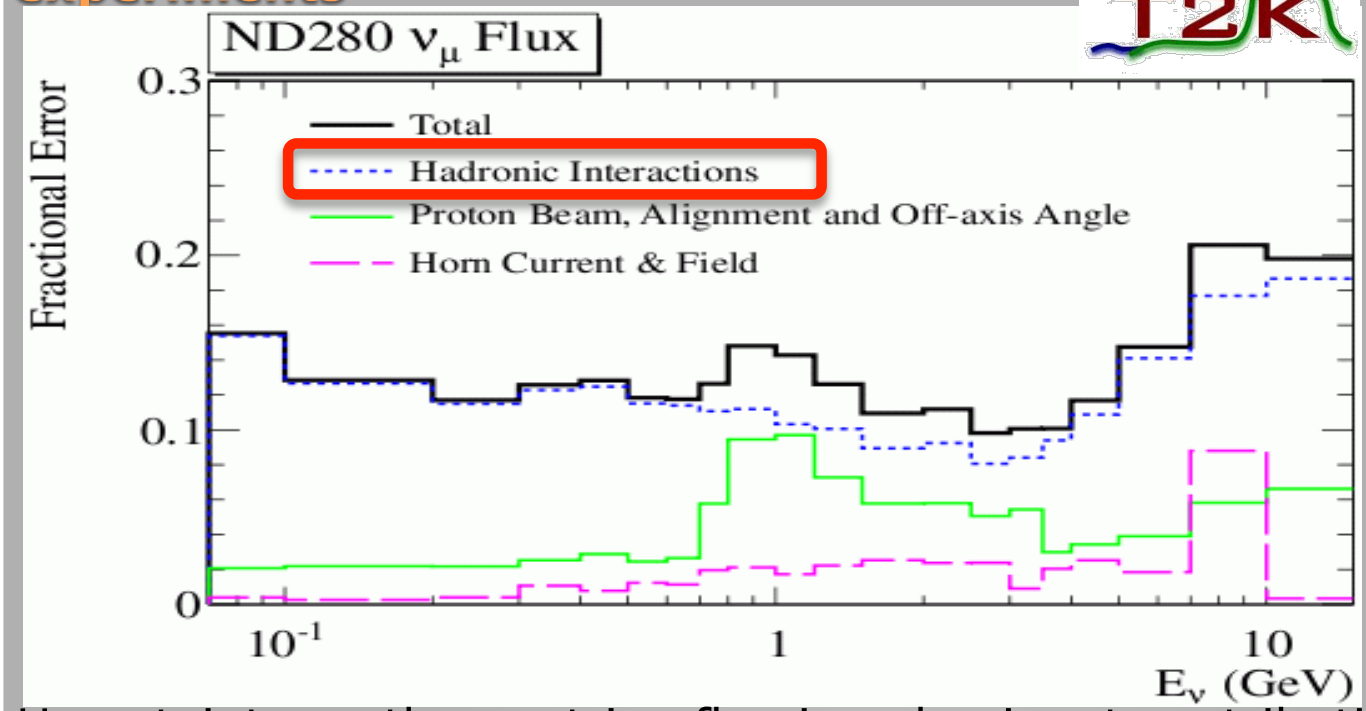
Extrapolated at SK ← $\Phi^{SK}_{\mu,e}(E_\nu) = R_{\mu,e}(E_\nu) \times \Phi^{ND}_{\mu,e}(E_\nu)$ → Measured at ND



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

Physics Program (II)

Accelerator long baseline oscillation neutrino experiments



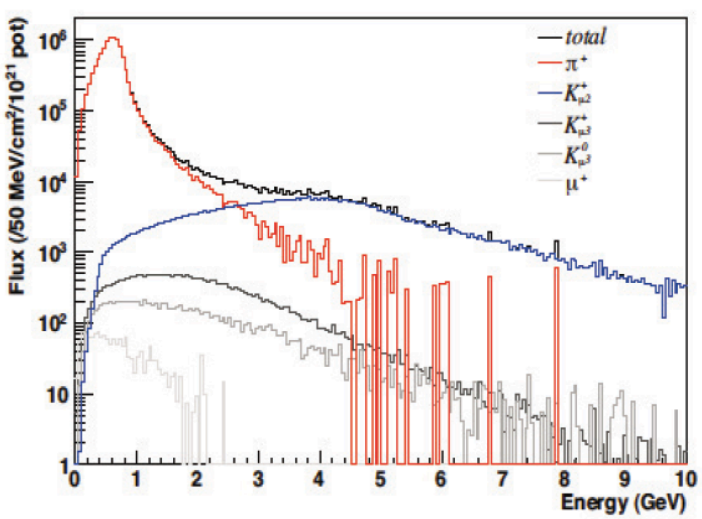
Uncertainty on the neutrino flux is a dominant contribution to systematic errors of ν oscillation parameters measurement: 10 – 20 %

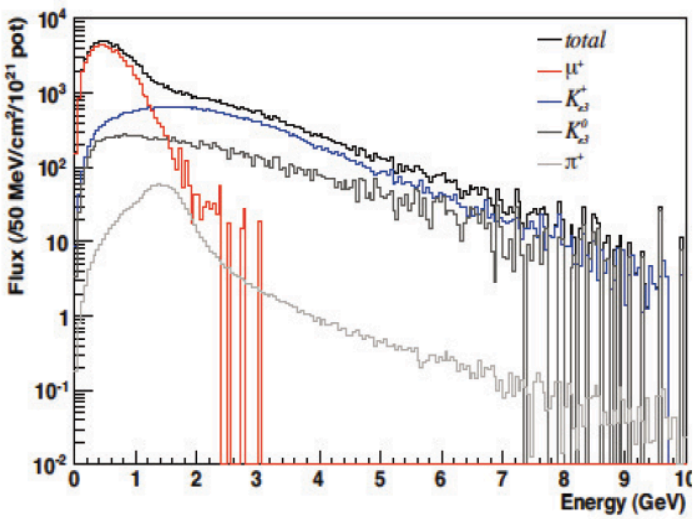
Uncertainty on hadronic interactions is dominant contribution to the flux uncertainty

Physics Program (II)

Accelerator long baseline oscillation neutrino experiments

- It is of importance to measure charged **pions and kaons**, neutral kaons, and lambda hiperons because these particles contribute directly or via decays to the neutrino production

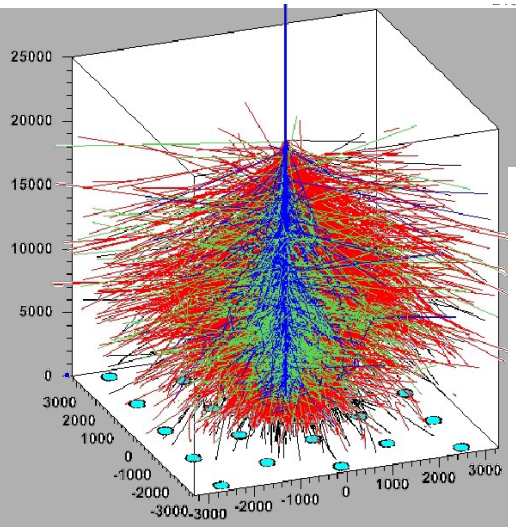


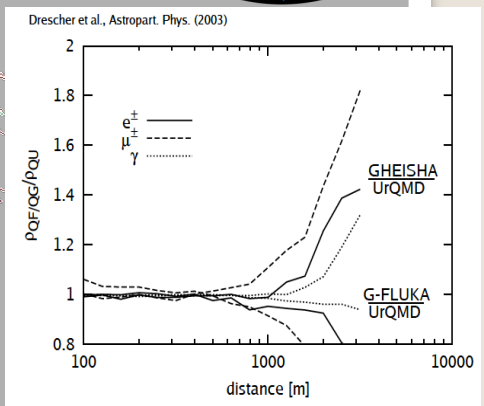


ν_μ(left) and ν_e (right) energy spectrum at T2K far detector. JNUBEAM simulations.

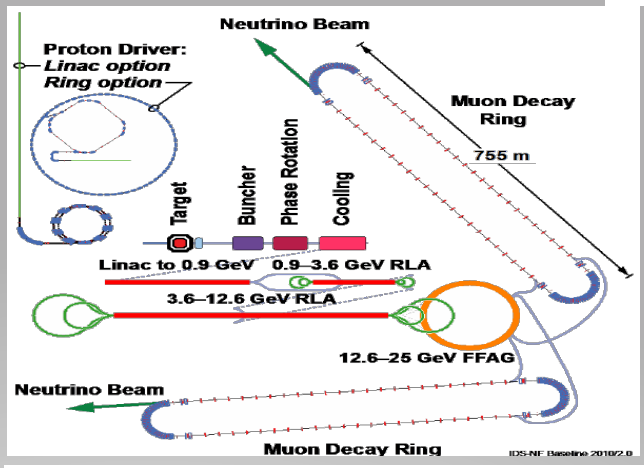
Physics Program (III)
Other applications

- **Cosmic ray physics**
  - Transition between low- and high-energy models
  - Need phenomenological calibration

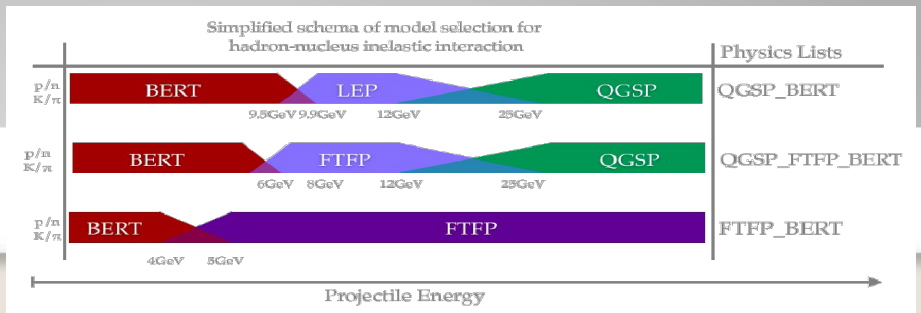




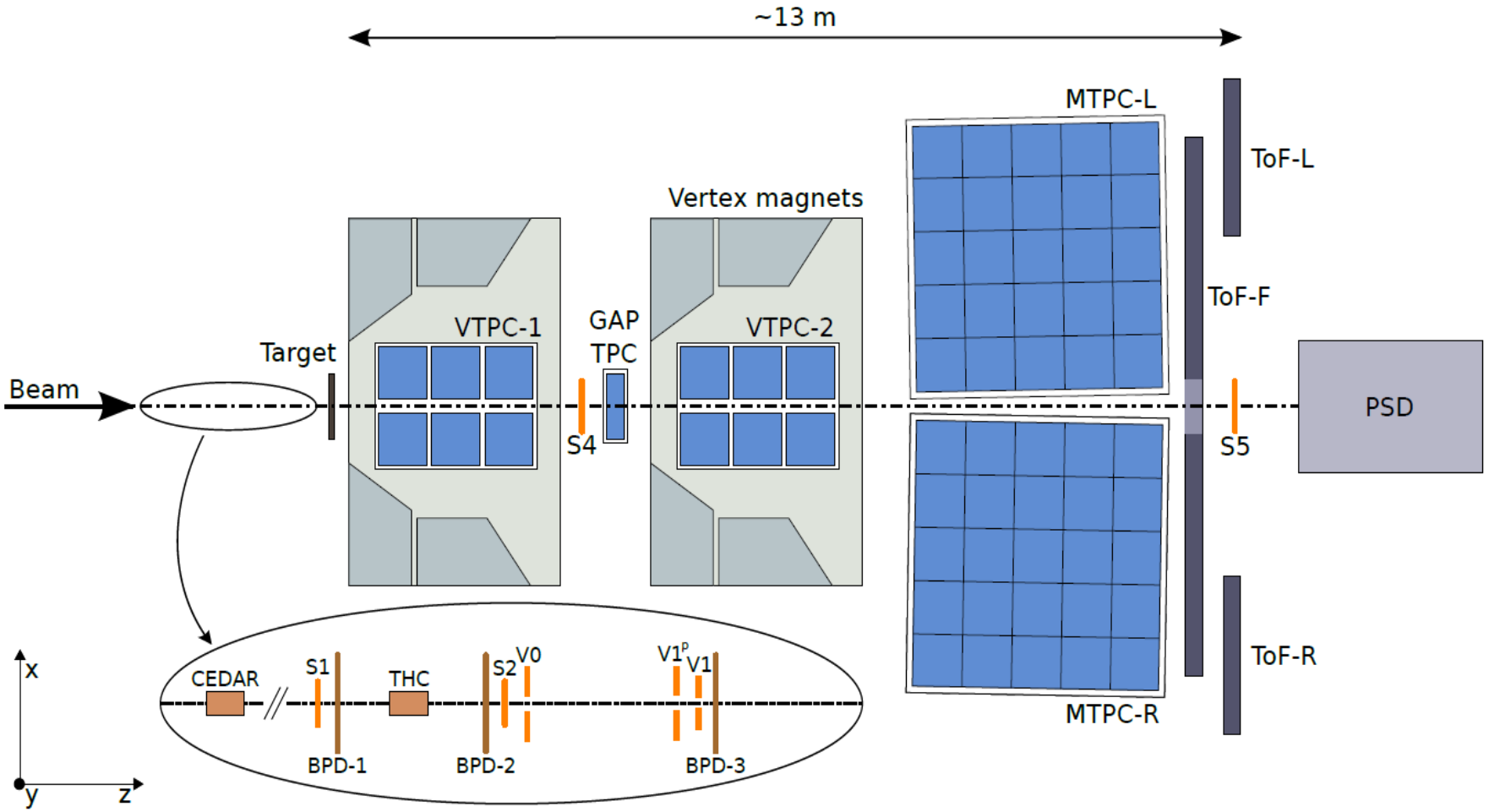
- **Neutrino Factory**



- **MC Generators**



NA61/SHINE DETECTOR



Two types of measurements were done for T2K:

31GeV/c protons on Carbon:

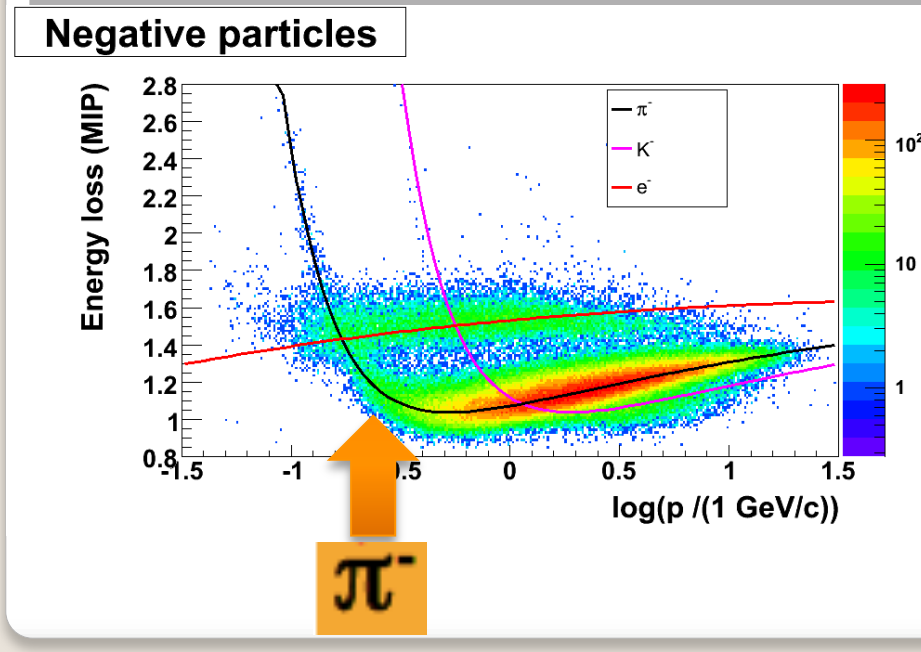
1). Thin target (4% λint)- studies of primary interactions
2). Replica of the T2K target (1.9λint)- production of all hadrons along the target

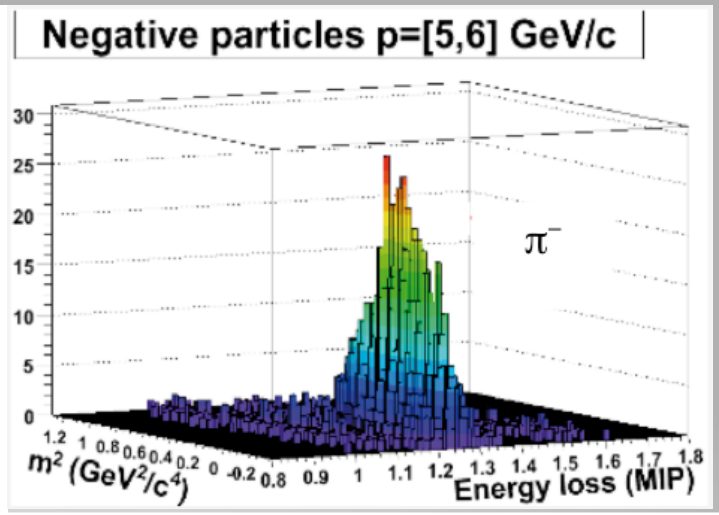
Year	Thin target	T2K Replica	Status
2007	$6.3 * 10^5$	$2.3 * 10^5$	Published
2009	$4.4 * 10^6$	$2.4 * 10^6$	Being analyzed
2010		$10 * 10^6$	Under Calibration

Particle Identification (I)

Analysis of negatively charged particles (h- analysis)

- Possible without PID because most of produced negatively charged particles at 30GeV proton carbon interactions are PI-





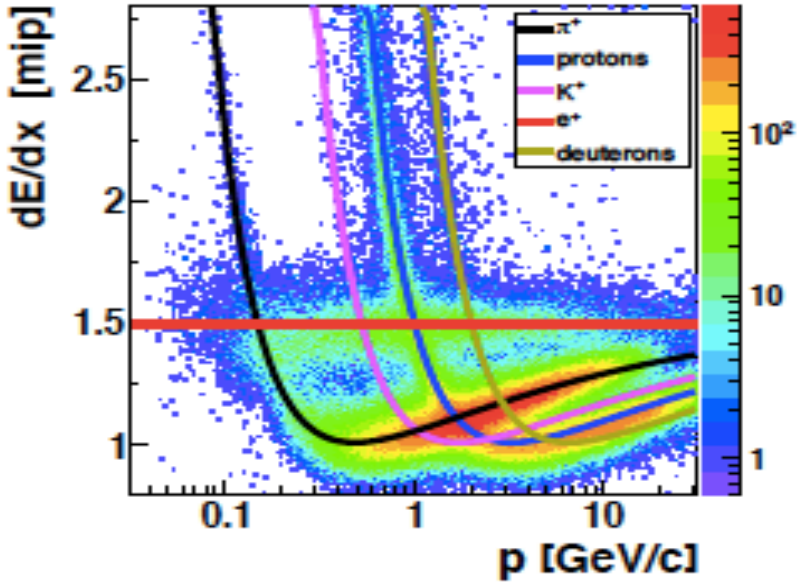
example

Particle Identification (II)

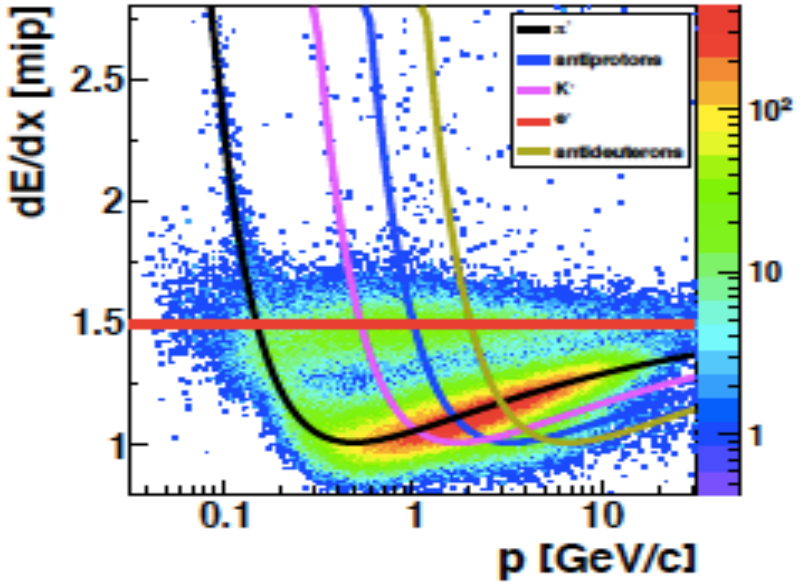
dE/dx at low momentum (below ~1GeV/c)

For region p=[1, 4]GeV/c Bethe Bloch curves crosses each other making particle separation not reliable → additional information from ToF

Positive particles

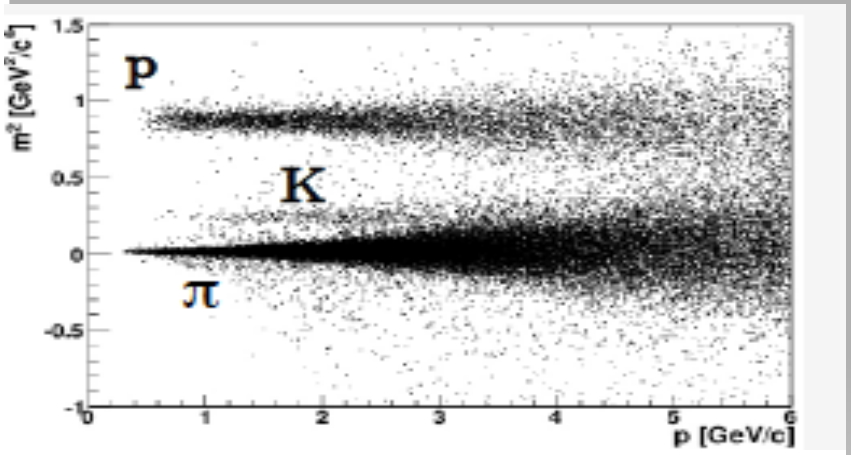


Negative particles



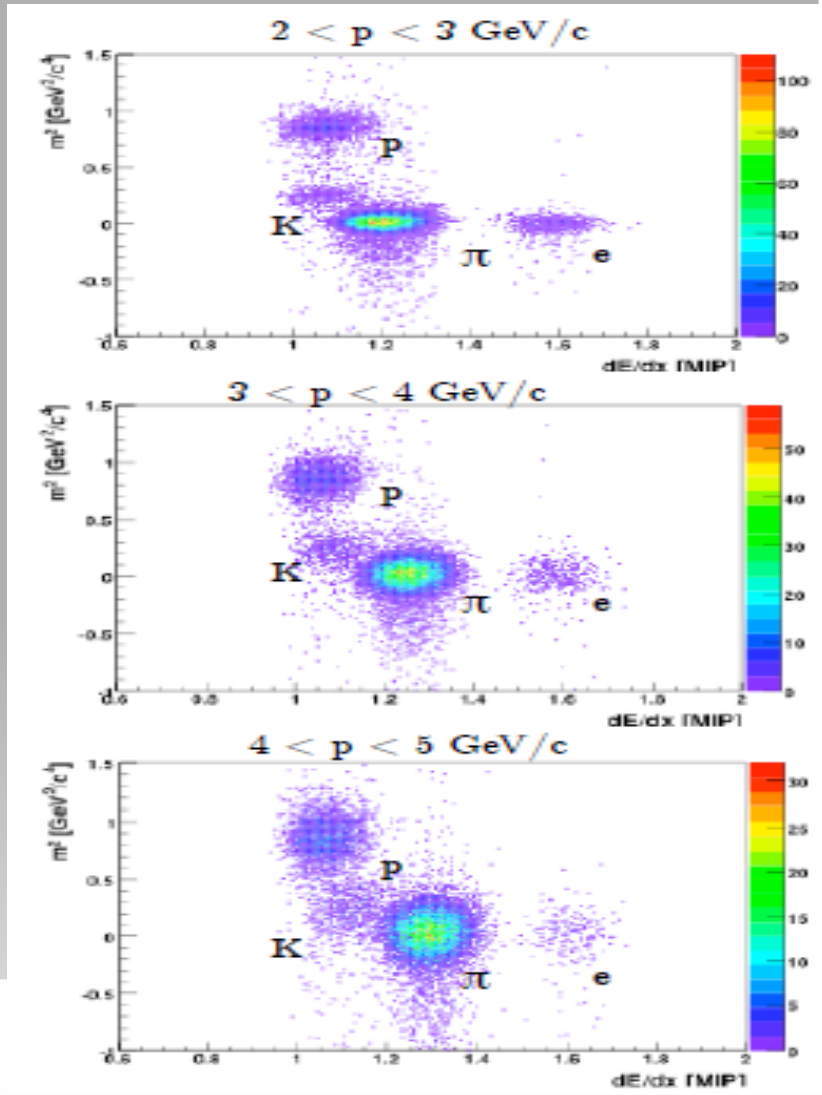
Particle Identification (III)

Combined energy loss and Time of Flight (ToF) measurements



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

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.



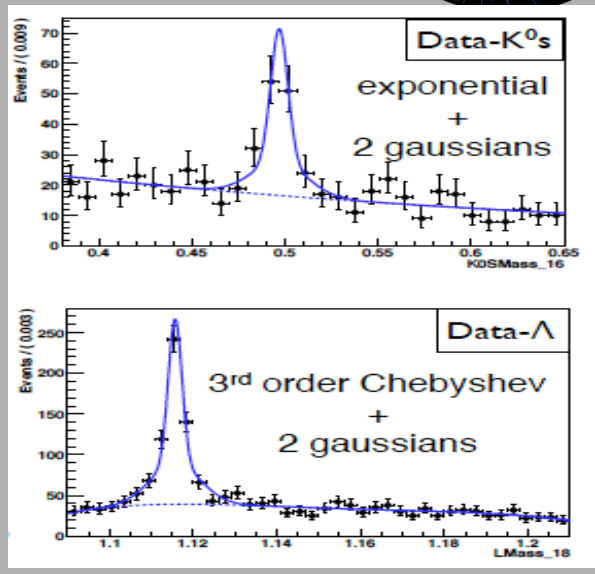
Particle Identification (III)

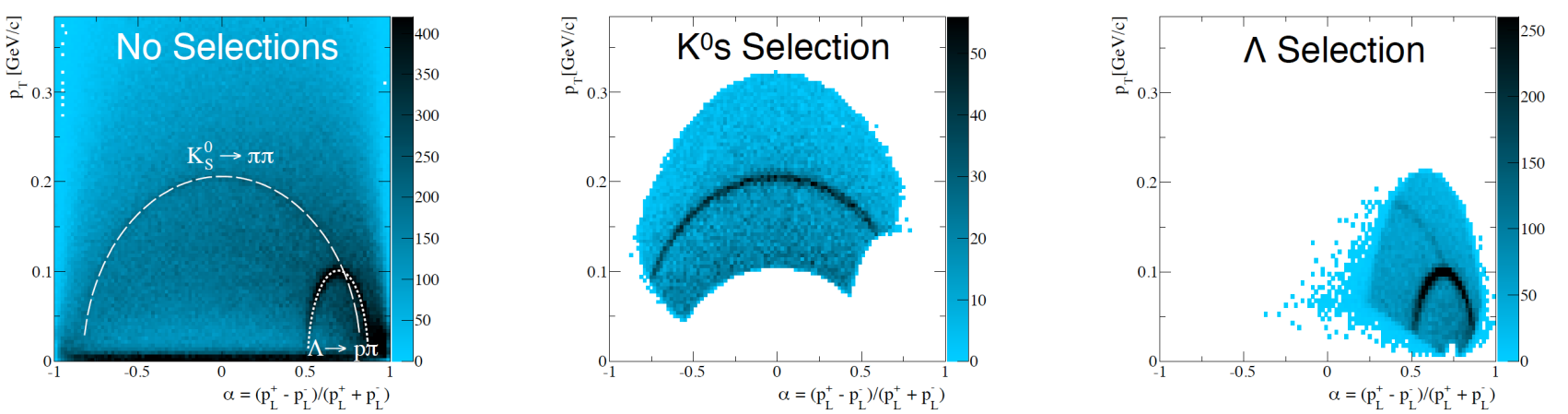
SHINE NA61

K^0_S and Λ particle identification through the study of the invariant mass distributions

$$K^0_s \rightarrow \pi^+ + \pi^-, \Lambda \rightarrow p + \pi^-$$

2007 results recently published (Phys. Rev. C89, 025205, 2014).



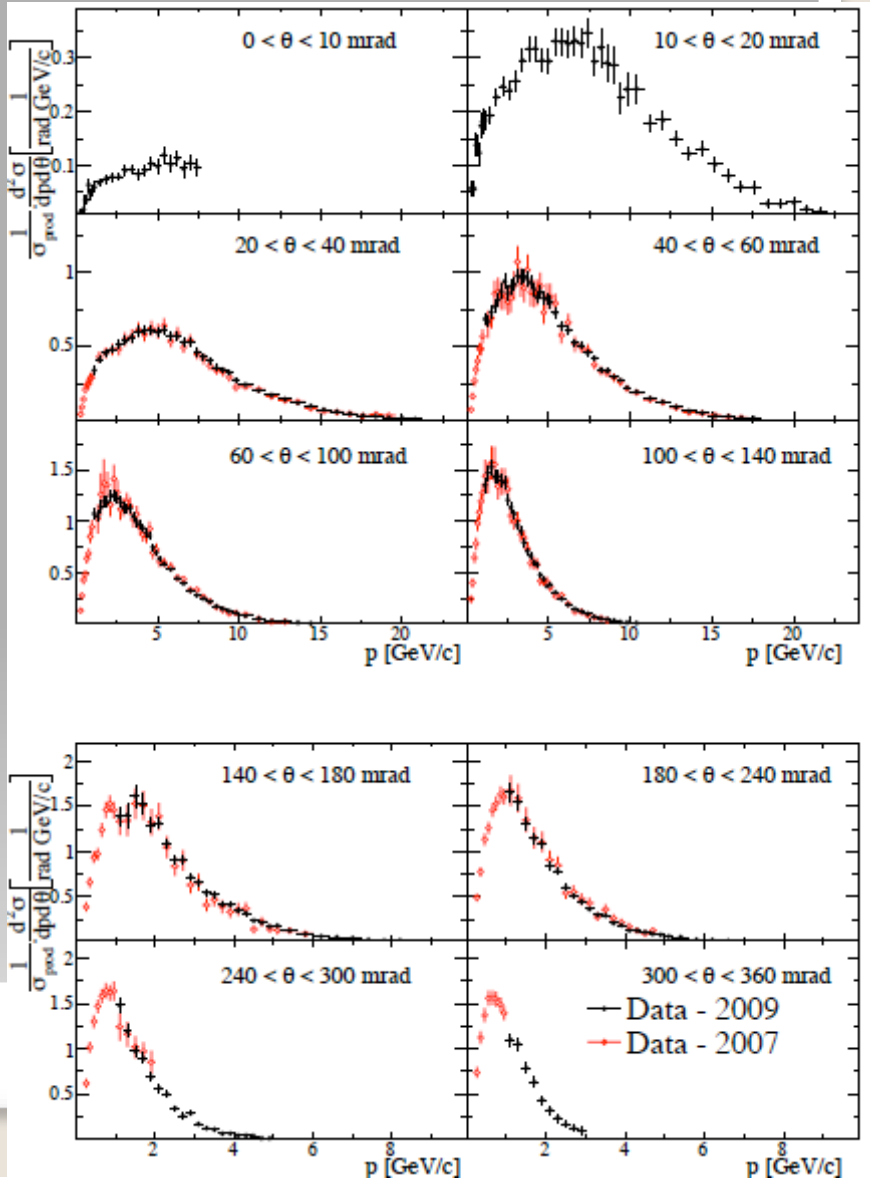


• Selected results

•π^+ multiplicities in p+C at 31 GeV/c from dE/dx +ToF analysis from 2009 data compared to 2007 results

•Total error plotted

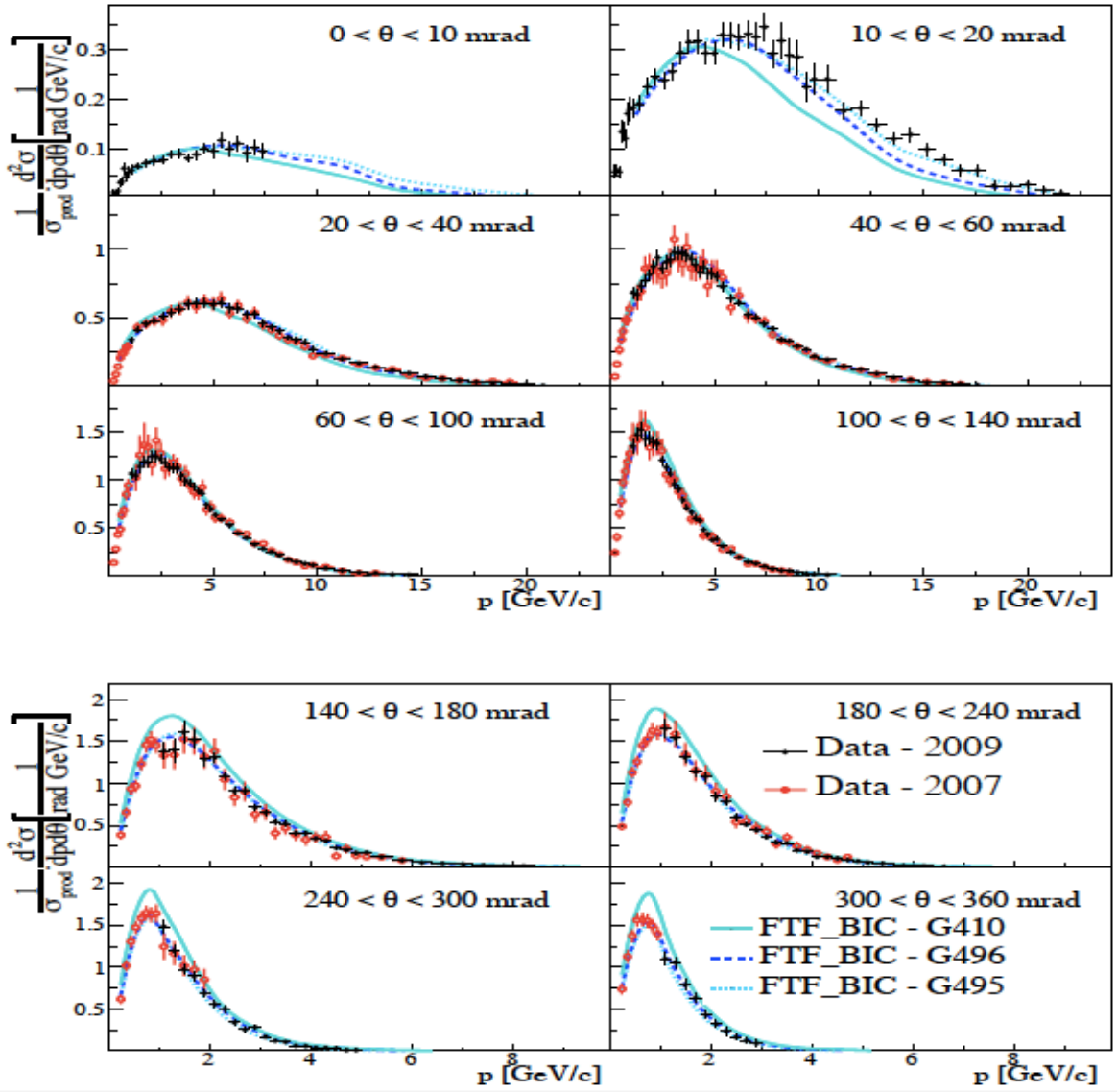
•Improved statistical precision with 2009 data



Selected results

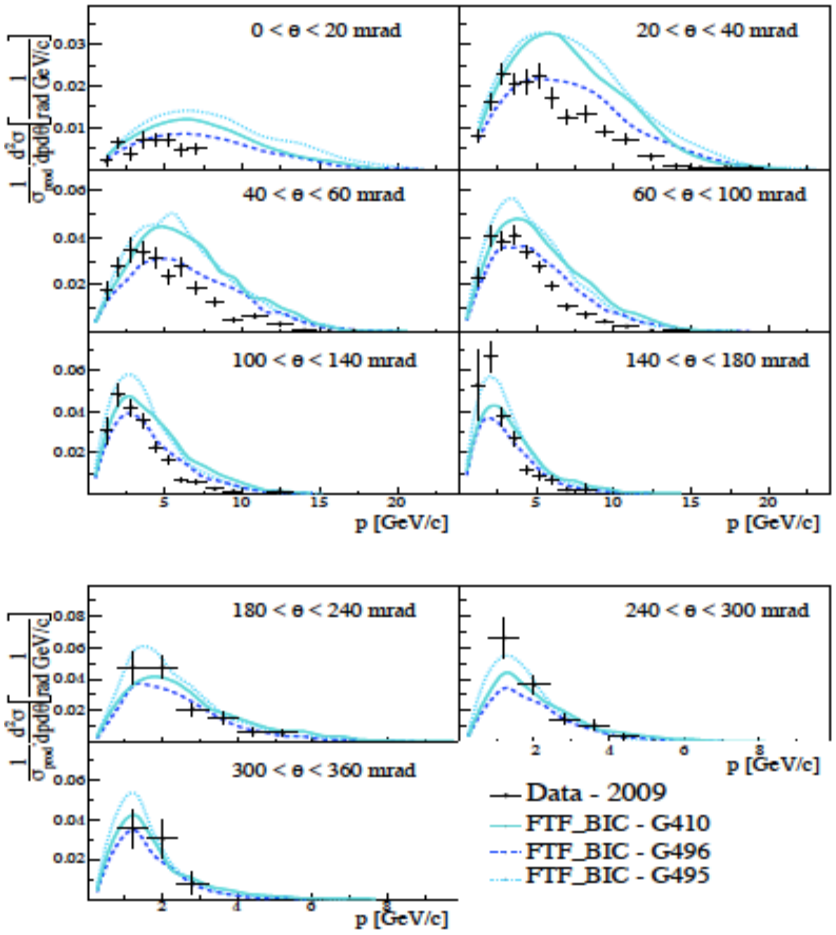
n+

SHINE NA61

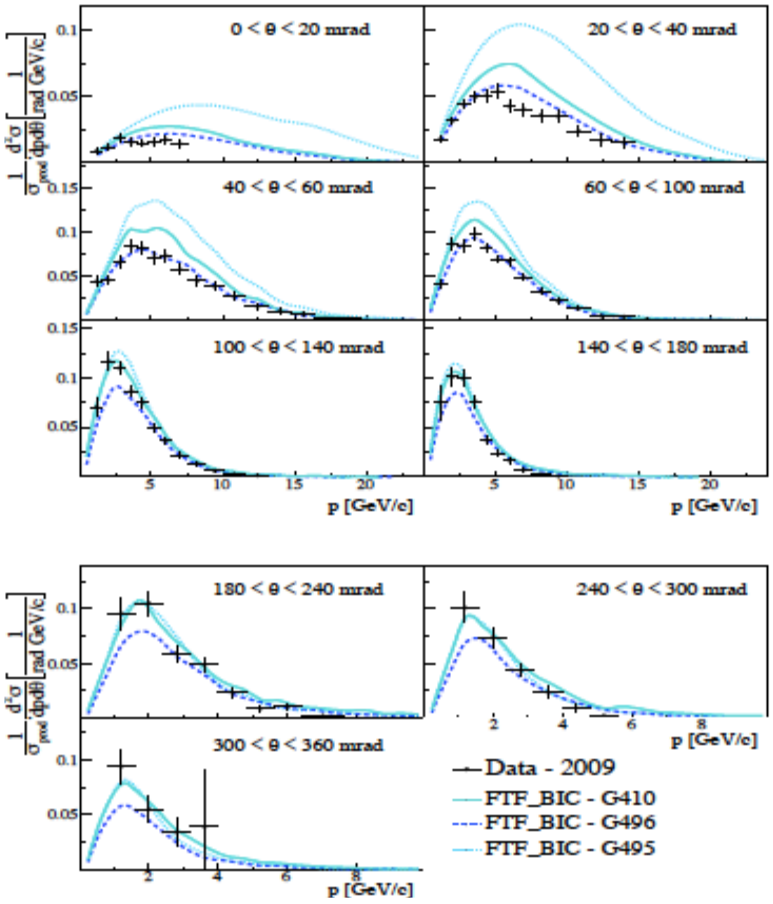


Selected results

K-



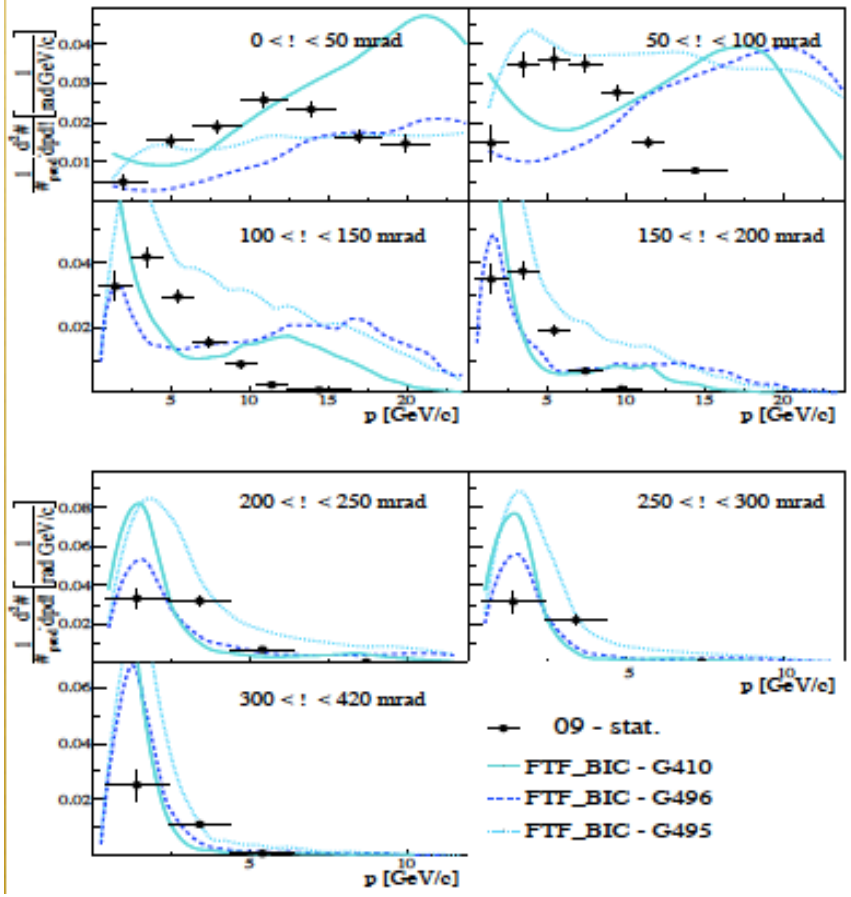
K+



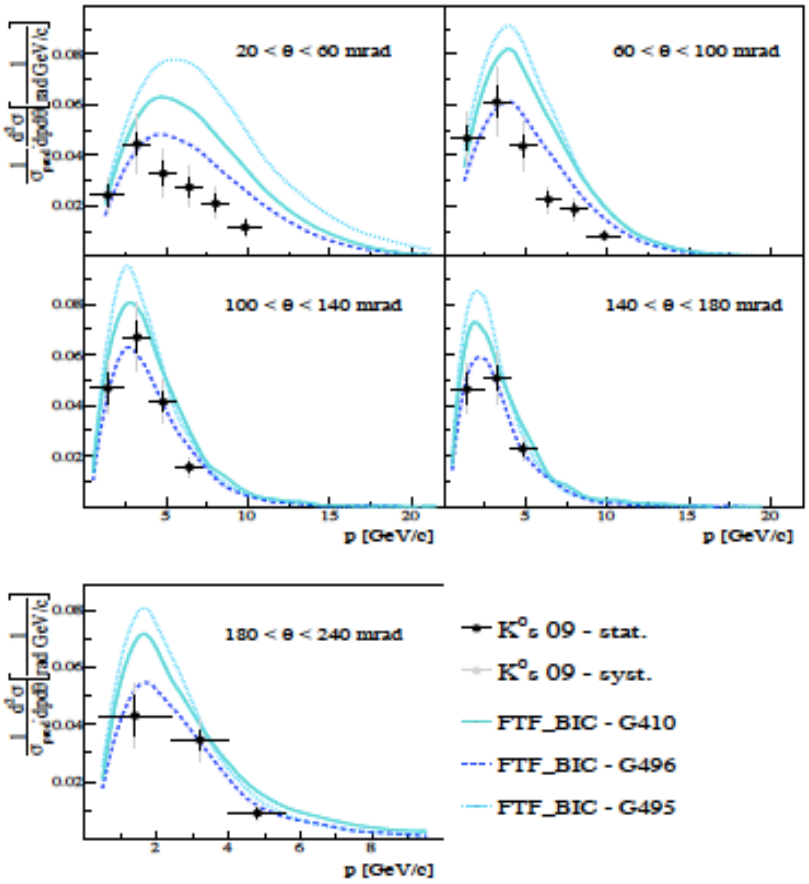
Selected results

SHINE NA61

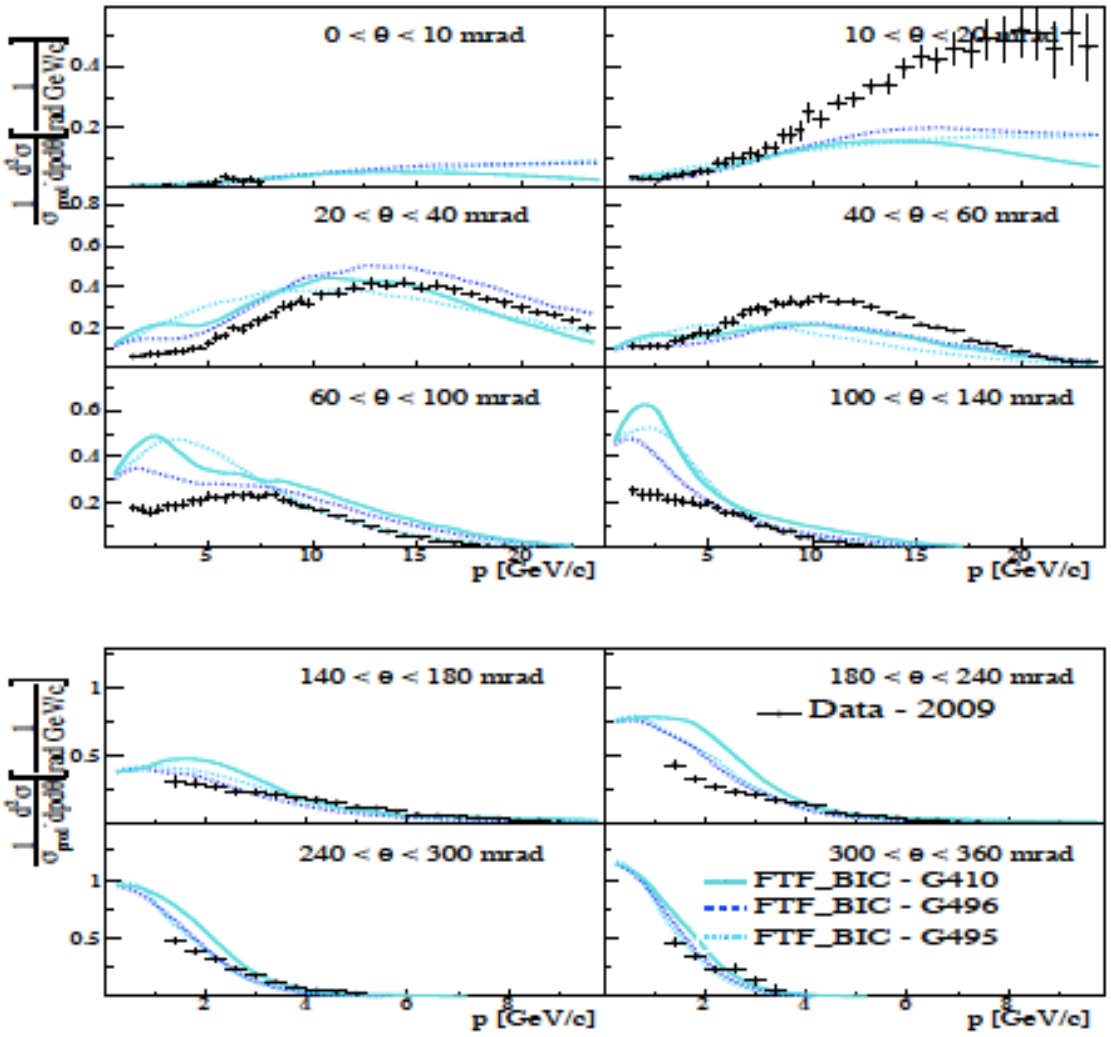
Λ



K^0_S



Selected results

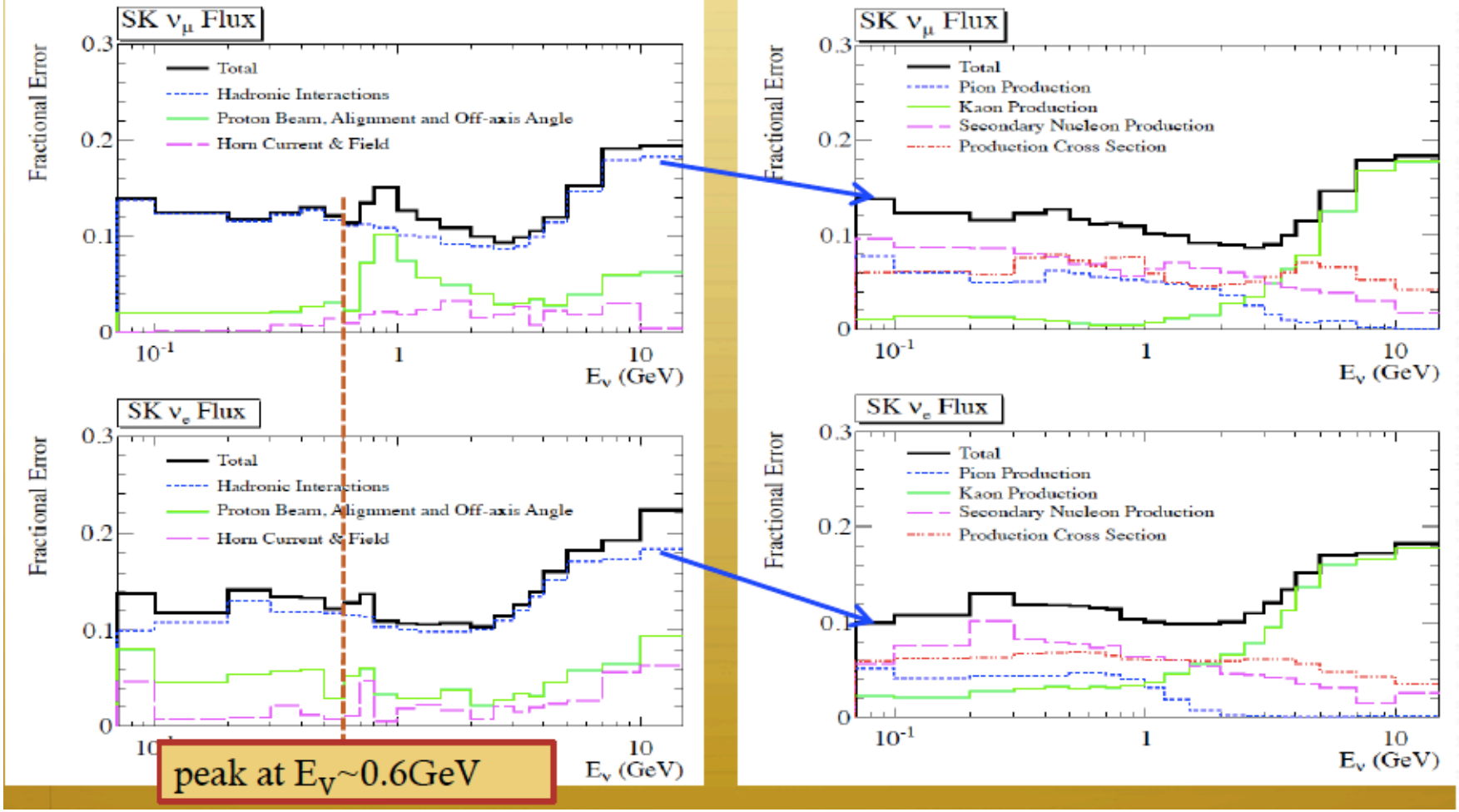


proton

Impact of the NA61/SHINE

(Phys.Rev. D87, 012001, 2013)

Used $\pi^{\pm}$, K^{+} measurements from 2007 run of NA61



peak at E_V~0.6GeV

- **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

New NA61 results based on data 2009.
Precision improved by a factor 2-3 as compared to the pilot data 2007 (used so far by T2K)

NA61 will study properties of the transition between hadron gas and quark-gluon plasma in order to establish fundamental features of strongly interacting matter