One–pion production in electron and neutrino scattering on nuclei

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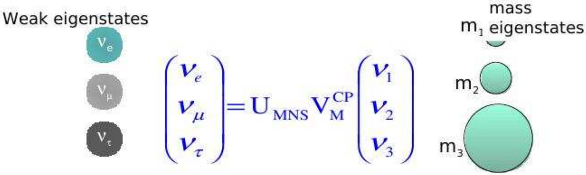
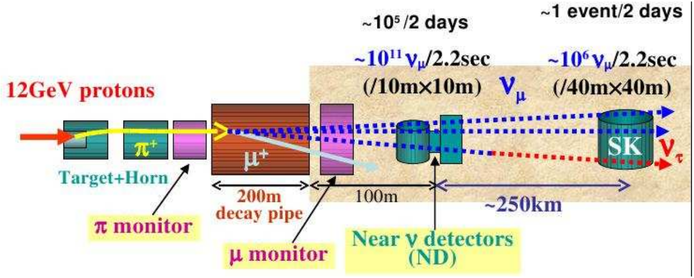
GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

Why to study neutrino-nucleus interactions



Long baseline experiments: (K2K — KEK to Kamiokande)

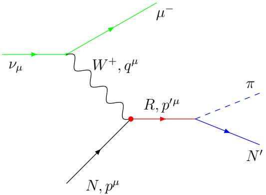


Nearby and faraway detectors: different nuclei as targets, the x-sec did not cancel
background processes are different

One pion production as resonances + background

Neutrino energies > 0.5 GeV
typical xsec $\sim$ *few* $\cdot 10^{-38}$ cm^2

$\nu p \rightarrow \mu^- p \pi^+$ can be described by isobar diagram
as production of $\Delta = P_{33}(1232)$ baryon resonance



Two other channels $\nu n \rightarrow \mu^- p \pi^0$,
$\nu n \rightarrow \mu^- n \pi^+$

Isospin=1/2 resonances also contribute:
$P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$

Theoretical curves are still $<$ the experimental data
$\longrightarrow$ background is needed

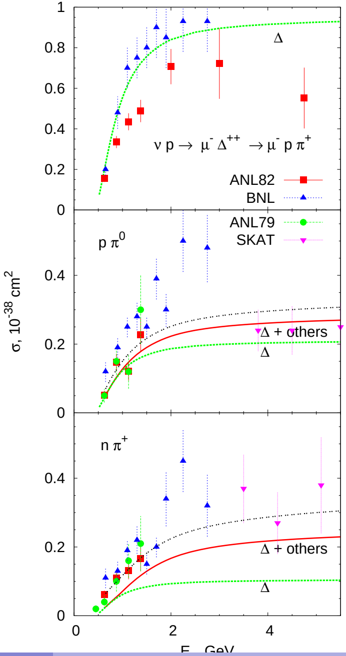
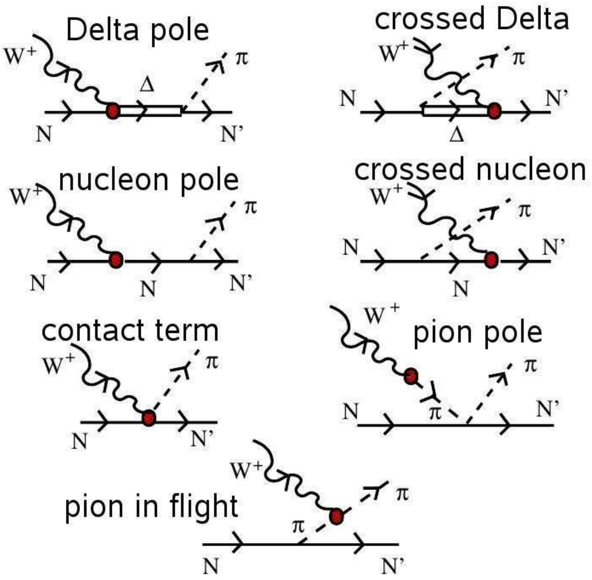


Diagram approach to the 1-pion production



Earlier: only Delta pole (Dp) diagram

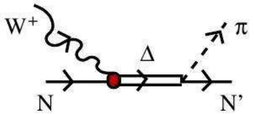
"Background" as exper data – Dp

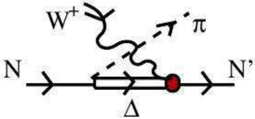
Hernandez, Nieves, Valverde, PRC 76 (2007) 033005

Vertices from $SU(2)$ non-linear sigma-model

phenomenologically extended by introducing form factors, but NO new adjustable parameters

Dp, cDp

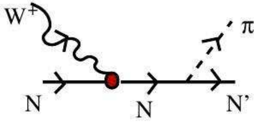


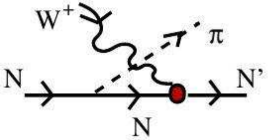


$WN\Delta$: standard parameterization with the form factors

$\Delta N\pi$: standard parameterization
with the the coupling constant determined from the Γ_{tot}

Np, cNp





WNN': point-like vertex extended with the nucleon form factors

$$\mathcal{L} = W^a_\mu \bar{N} \gamma^\mu (1 + g_A \gamma_5) \frac{\tau_a}{2} N \otimes \textit{nucleon form factors}$$

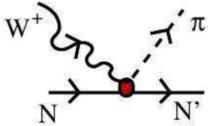
$NN'\pi$: $$\mathcal{L} = \frac{g_A}{2f_\pi} \bar{N} \gamma^\mu \gamma^5 \tau_a \partial_\mu \pi_a N$$

from $SU(2)$ non–linear σ–model

Vertices from non-linear sigma-model

Constants $g_A = 1.23$, $f_\pi = 0.097\ \mathrm{GeV}$, form factors $F_\rho = 1/(1+Q^2/m_\rho^2)$, from vector current conservation $F_{CT} = F_{pF}$ coincide with nucleon FF F_1^V.

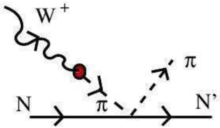
CT (contact term)



including ρ-dominance

$WNN'\pi$: $\mathcal{L} = \frac{1}{2f_\pi}\bar{N}\gamma^\mu W^a_\mu \varepsilon_{abc}\pi_b\tau_c N \cdot F_\rho - \frac{g_A}{2f_\pi}\bar{N}\gamma^\mu\gamma^5 W^a_\mu \varepsilon_{abc}\pi_b\tau_c N \cdot F_{\mathrm{CT}}$

pp (pion pole)

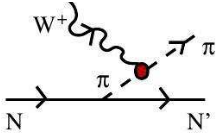


including ρ-dominance

$WNN'\pi$: $\mathcal{L} = -W^\mu_a f_\pi \partial_\mu \pi^a$

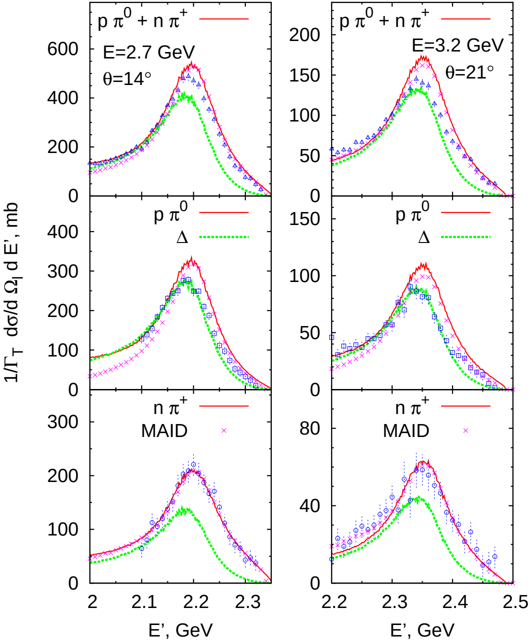
$NN'\pi\pi'$: $\mathcal{L} = -\frac{1}{4f_\pi^2}\bar{N}\gamma^\mu \varepsilon_{abc}\tau_a\pi_b\partial_\mu\pi_c N \cdot F_\rho$

pF (pion in Flight)



$W\pi\pi'$: $\mathcal{L} = W^\mu_a \varepsilon_{abc}\pi_b\partial_\mu\pi_c \cdot F_{pF}$

Electroproduction as benchmark for neutrinoproduction



The same theoretical input but axial part =0

$$e\,p \rightarrow e \quad \begin{matrix} p\pi^0 \\ n\pi^+ \end{matrix}$$

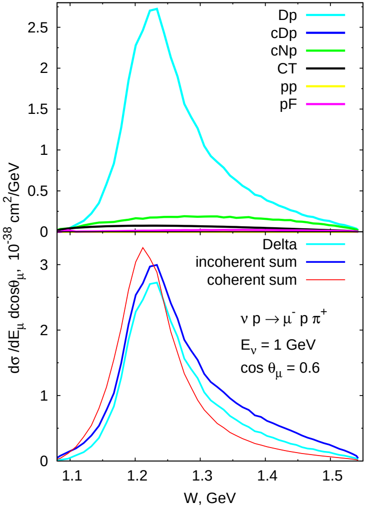
Electroproduction data Galster, 1973

$$\frac{1}{\Gamma_T}\frac{d\sigma}{d\Omega_l dE_l'} = \sigma_T + \varepsilon\sigma_L$$

are described at the same level of accuracy as MAID (a Unitary Isobar Model for Pion Photo- and Electroproduction on the Nucleon) Drechsel et al (Mainz group) 2007

Neutrino–proton

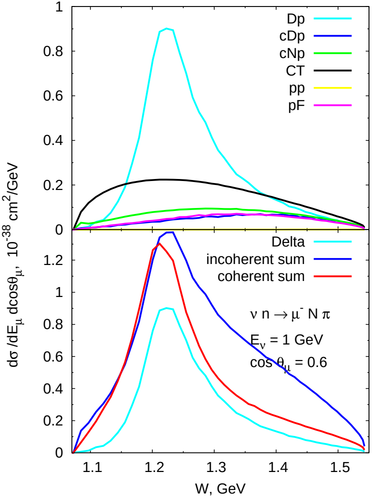
$$\nu p \to \mu^- p \pi^+$$



consistent with negligible background

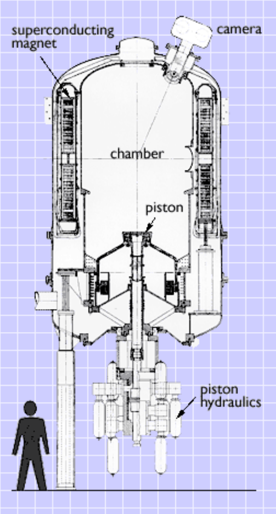
Neutrino-neutron

$$\nu n \to \mu^- (p\pi^0 + n\pi^+)$$



consistent with earlier expectations

Wide-band-beam neutrino experiments on hydrogen and deuterium

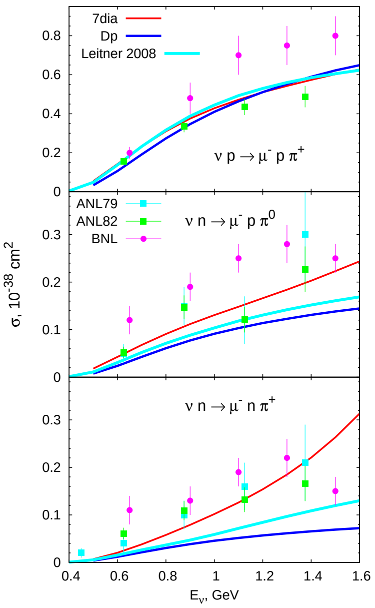


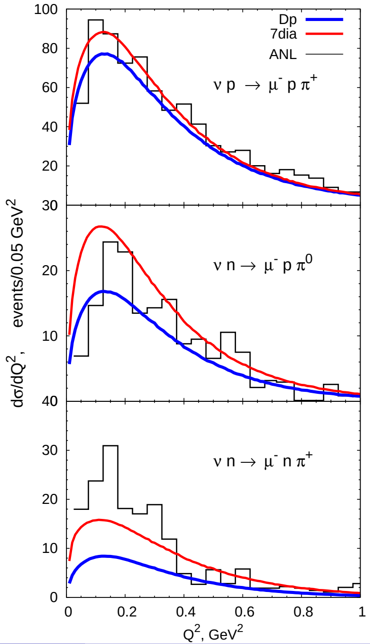
NO modern experiments on protons (hydrogen target) and neutrons (deuterium target)

Old experiments

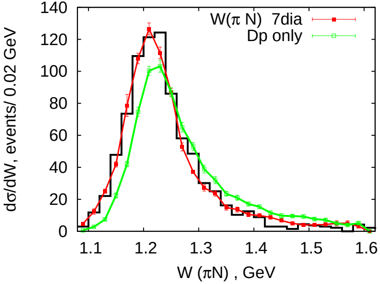
- ANL : Argonne National Laboratory 12-ft bubble chamber, 1970 – 80s experiments with hydrogen and deuterium, $\langle E_\nu \rangle \sim 0.9$ GeV
- BNL : Brookhaven National Laboratory 7-ft bubble chamber, 1974– 90s experiments with deuterium, $\langle E_\nu \rangle \sim 1.6$ GeV

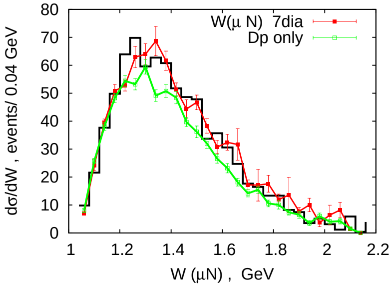
Neutrino–nucleon interactions





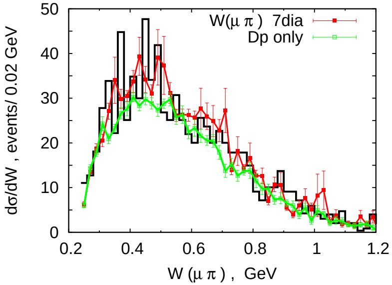
Various invariant mass distributions





$\nu p \to \mu^- p \pi^+$

$W(\mu N)$ and $W(\mu\pi)$ distributions calculated theoretically for the first time



experimental data — ANL

Neutrino–nucleus interactions

The nuclear effects (initial and final state interactions) are described within

Institut für Theoretische Physik, JLU Giessen

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

GiBUU — the semiclassical transport model in coupled channels — simulates the transport of hadrons through nuclear matter in space and time

GiBUU describes several reactions both in resonance and high energy regions:

- heavy ion collisions AA
- pion–induced reactions πA
- photon–induced reactions γA
- electron–induced reactions $e^- A$
- neutrino–induced reactions νA
  - pole mechanism for resonances (13 resonances) $+$ MAID–based phenomenological model for noninterfering background
  - Hernandez–Nieves–Valverde model of Delta + background through several diagrams, including interference effects

Open source code: http://gibuu.physik.uni-giessen.de/GiBUU/

Conclusion and Outlook

- Accurate knowledge of neutrino–nucleus interactions is prerequisite for modern neutrino oscillation experiments
- Nonresonant background gives noticeable contribution, especially for neutron target
- Background model based on nonlinear $SU(2)$ sigma-model is implemented in the GiBUU code
- Good agreement with electroproduction data as benchmark for further neutrino calculations. Detailed description of neutrino reactions.