NuWro: π production

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Outline

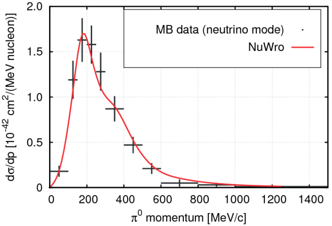
- NuWro π production dilemma
- some comparisons with the data
- a general description of the model
- more details (only if there is time and interest)

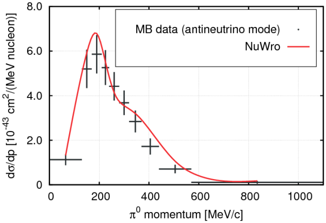
NuWro π production dilemma

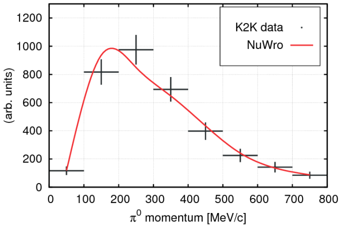
- we know the current model is not sophisticated
- but it gives rather good agreement with the data
- RES/DIS transition region requires a lot of work.

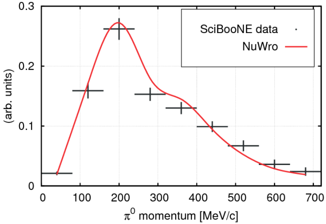
A possible strategy: to implement a better (from theorist point of view) model and to keep two options.

Comparisons. NCπ^0 production.

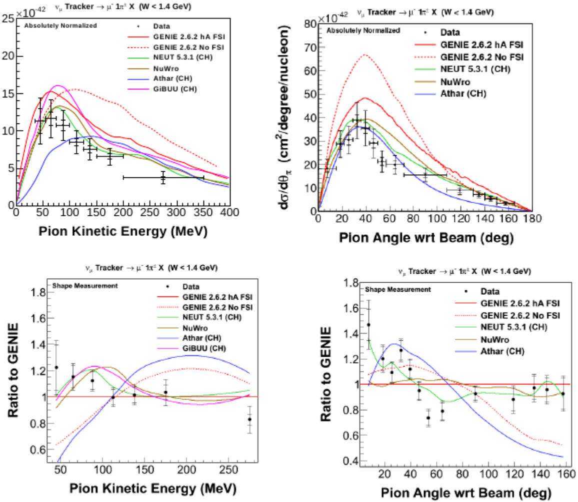








Comparisons. MINERvA CC π^+ data



A desclaimer: no fine tuning was done to arrive at this agreement.

RES@NuWro current model

NuWro definition of RES and DIS is different wrt other MCs.

- RES means $W \leq 1.6$ GeV (W is invariant hadronic mass)
- DIS means $W > 1.6$ GeV
- RES is dominated by Δ excitation
- RES contains a contribution from 2π production
- DIS also contains single pion production (SPP) events
- DIS uses PYTHIA fragmentation routines to produce final states – nothing is done *by hand*
- DIS code works also for $W \leq 1.6$ GeV and is used to model non-resonant background to SPP.

RES@NuWro more details

NuWro reproduces the following cross section

$$\frac{d\sigma^{SPP}}{dW} = \frac{d\sigma^{\Delta}}{dW}(1-\alpha(W)) + \frac{d\sigma^{DIS}}{dW}F^{SPP}(W)\alpha(W)$$

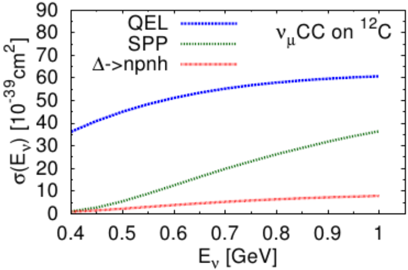
with

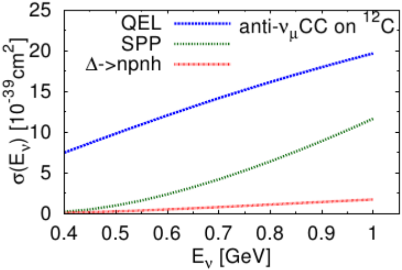
$$\begin{aligned}\alpha(W) &= \Theta(W_{min}-W)\frac{W-W_{th}}{W_{min}-W_{th}}\alpha_0 \\ &+ \Theta(W_{max}-W)\Theta(W-W_{min})\frac{W-W_{min}+\alpha_0(W_{max}-W)}{W_{max}-W_{min}} \\ &+ \Theta(W-W_{max})\end{aligned}$$

$W_{th} = M + m_\pi$, W_{min} and W_{max} define Δ – DIS transition region; default values are $W_{min} = 1.3$ GeV, $W_{max} = 1.6$ GeV.

Nuclear effects

- Fermi motion
- Pauli blocking
- approximate treatment of Δ in-medium selfenergy by subtracting a fraction of pionless decays evaluated after theoretical computations:



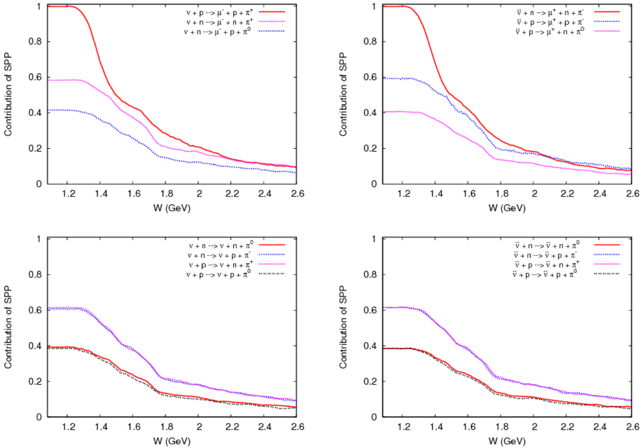


JTS, J.Żmuda, Phys. Rev. C87, 065503 (2013)

Back-up slides (more details)

RES@NuWro one pion functions

$F^{SPP}(W)$ are *one pion functions*. They are defined as probabilities of single π final state in the overall cross section – as given by PYTHIA.



NuWro calculates them at the beginning of every run. It takes ~ 10 seconds.

Nonresonant background parameters

kanał:	$\nu p \to \mu^- p \pi^+$	$\nu n \to \mu^- n \pi^+$	$\nu n \to \mu^- p \pi^0$
α_0	0.0	0.2	0.3
kanał:	$\bar{\nu} n \to \mu^+ n \pi^-$	$\bar{\nu} p \to \mu^+ p \pi^-$	$\bar{\nu} p \to \mu^+ n \pi^0$
α_0	0.0	0.2	0.3

It is consistent with the M_A, $C_A^5(0)$ values obtained from fitting the ANL and BNL data within a model with no background in the Δ^{++} channel.

$N-\Delta$ transition matrix element:

$$\langle \Delta^{++}(p') | V_\mu | N(p) \rangle = \sqrt{3}\bar{\Psi}_\lambda(p') \left[g^\lambda{}_\mu \left(\frac{C_3^V}{M}\gamma_\nu + \frac{C_4^V}{M^2}p'_\nu + \frac{C_5^V}{M^2}p_\nu \right) q^\nu - q^\lambda \left(\frac{C_3^V}{M}\gamma_\mu + \frac{C_4^V}{M^2}p'_\mu + \frac{C_5^V}{M^2}p_\mu \right) \right] \gamma_5 u(p)$$

$$\langle \Delta^{++}(p') | A_\mu | N(p) \rangle = \sqrt{3}\bar{\Psi}_\lambda(p') \left[g^\lambda{}_\mu \left(\gamma_\nu \frac{C_3^A}{M} + \frac{C_4^A}{M^2}p'_\nu \right) q^\nu - q^\lambda \left(\frac{C_3^A}{M}\gamma_\mu + \frac{C_4^A}{M^2}p'_\mu \right) + g^\lambda{}_\mu C_5^A + \frac{q^\lambda q_\mu}{M^2} C_6^A \right] u(p).$$

$\Psi_\mu(p')$ is the Rarita-Schwinger field, and $u(p)$ is the Dirac spinor.

C_3^V, C_4^V, C_5^V known from pion electroproduction due to CVC.

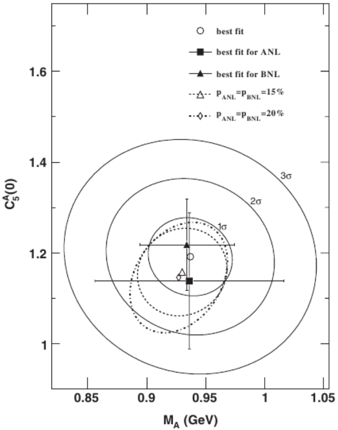
Axial part:

- typically one sets $C_3^A(Q^2) = 0$;
- Adler model suggests $C_4^A(Q^2) = -C_5^A(Q^2)/4$
- PCAC implies $C_6^A(Q^2) = \frac{M^2}{m_\pi^2+Q^2} C_5^A(Q^2)$
- $C_5^A(0)$
  - is either evaluated from the *off-diagonal Goldberger-Treiman relation*

$$C_5^A(0) = \frac{g_{\pi N\Delta} f_\pi}{\sqrt{6}M} \simeq 1.15,$$

  - or is treated as a free parameter
- typically one assumes $C_5^A(Q^2) = C_5^A(0)\left(1 + \frac{Q^2}{M_A^2}\right)^{-2}$.

Values of $C_5^A(0)$ and M_A.



- in order to extract their values overall normalization uncertainty, deuteron nuclear effects, nonresonant background contribution (Nieves et al) should be included in the analysis
- a tension between ANL and BNL pion production data disappear
- on the left, results of simultaneous fit to both data sets

K.M. Graczyk, D. Kiełczewska, P. Przewłocki, JTS, PRD80 093001 (2009)

Values of $C_5^A(0)$ and M_A.

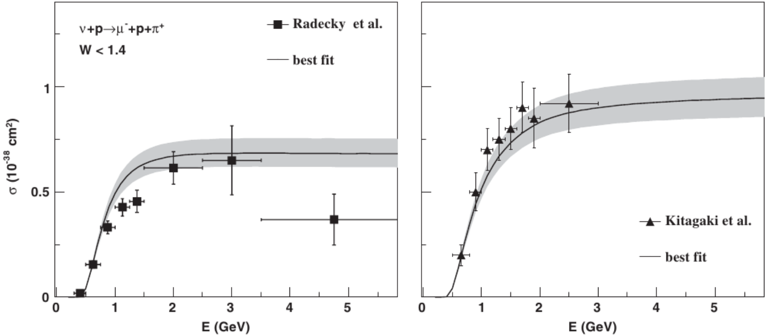


FIG. 5. Total cross section for $\nu + p \rightarrow \mu^- + p + \pi^+$. In the left panel the ANL data [5] with the cut $W = 1.4$ are shown (black squares), while the right panel presents the BNL data [42] (without cuts in W)—black triangles. The overall normalization error is not plotted. The best fit curves were obtained with a corresponding cut in W. The theoretical curves were obtained with dipole parametrization Eq. (32) with $M_A = 0.94$ GeV and $C_5^A(0) = 1.19$. The shaded areas denote the 1σ uncertainties of the best fit. The theoretical curves are not modified by the deuteron correction effect.