Inelastic neutrino scattering

Monte Carlo event generator

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Motivation

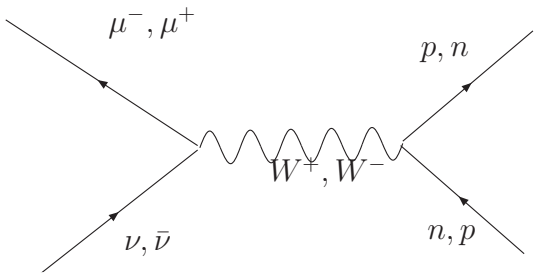
Why a new Event generator?

- the original motivation: to improve NUX+FLUKA scheme (no resonance production)
- a new treatment of the resonance region
  - only Δ resonance: nuclear effects should smear out other resonances
  - average treatment of them should be sufficient - **Quark-Hadron duality**
- a tool to investigate nuclear effects (e.g spectral function, nuclear potential)

Quasi-elastic charge current scattering

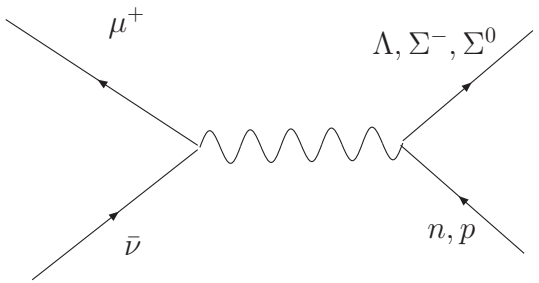
Quasielastic scattering:

$$\nu_\mu + n \rightarrow \mu^- + p$$
$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$$



Quasi-elastic strange particle production

$$\begin{aligned} \bar{\nu}p &\rightarrow \mu^+\Lambda \\ \bar{\nu}n &\rightarrow \mu^+\Sigma^- \\ \bar{\nu}p &\rightarrow \mu^+\Sigma^0 \end{aligned}$$

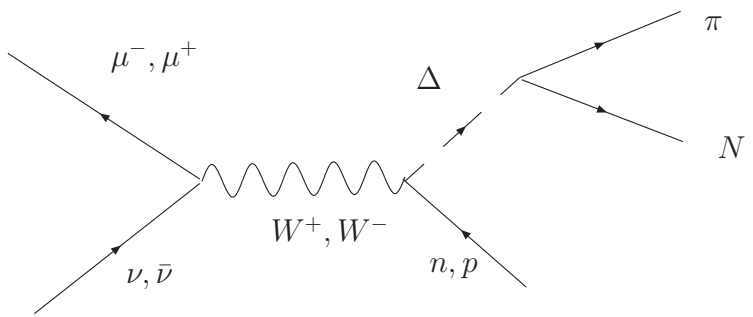


Δ resonance excitation

Four Δ charge states: Δ^{++}, Δ^{+}, Δ^{0}, Δ^{-}

Charge Current

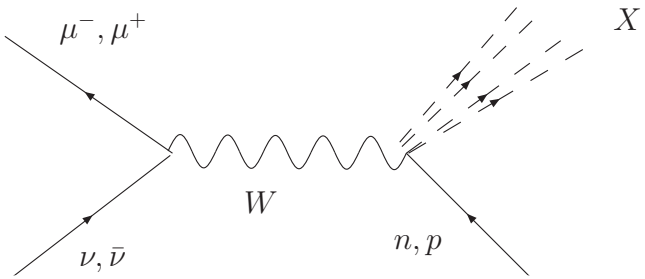
- $\nu_\mu + p \to \mu^- + p + \pi^+ \quad \bar{\nu}_\mu + p \to \mu^+ + p + \pi^-$
- $\nu_\mu + n \to \mu^- + n + \pi^+ \quad \bar{\nu}_\mu + p \to \mu^+ + n + \pi^0$
- $\nu_\mu + n \to \mu^- + p + \pi^0 \quad \bar{\nu}_\mu + n \to \mu^+ + n + \pi^-$



Deep Inelastic scattering

Deep inelastic scattering (DIS)

$$\begin{aligned} \nu + n &\rightarrow \mu^- + X^+ \\ \nu + p &\rightarrow \mu^- + X^{++} \end{aligned}$$



Fragmentation algorithm

Cross section for scattering on quark q_i (valance or sea quark)

$$\frac{d^2\sigma^{\nu q_i \rightarrow \mu q_j}}{dW d\nu} \sim q_i K_i$$

K_i kinematic factor for quark q_i

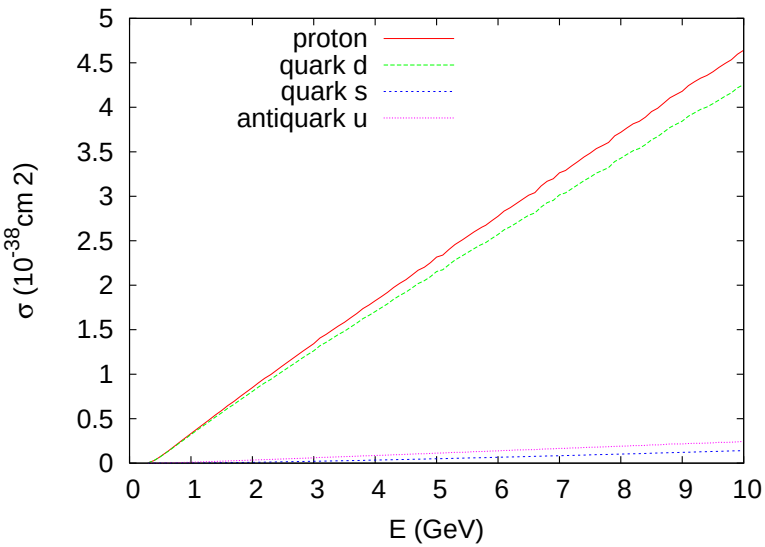
Probability of scattering on parton

Probability of reaction on a quark is given as follows

$$P(q_i) = \frac{\frac{d\sigma^{q_i}(E)}{dW\,d\nu}}{\sum_i \frac{d\sigma^{q_i}(E)}{dW\,d\nu}}$$

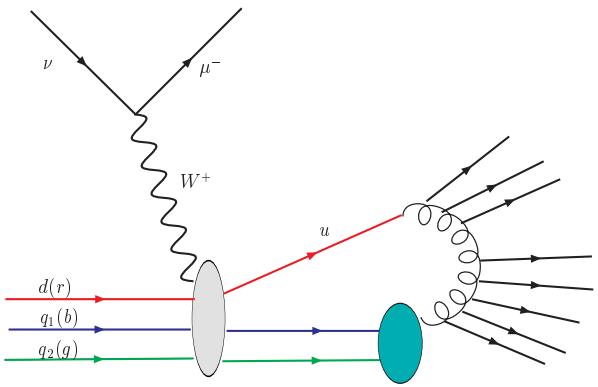
Scattering on proton

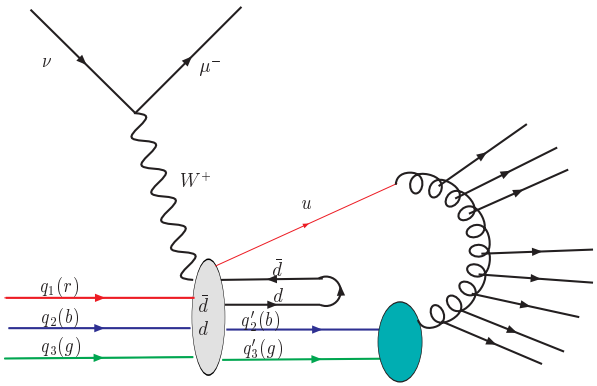
In case of CC neutrino scattering on proton cross section is a sum of contribution from quark d, quark s, and anti-quark u

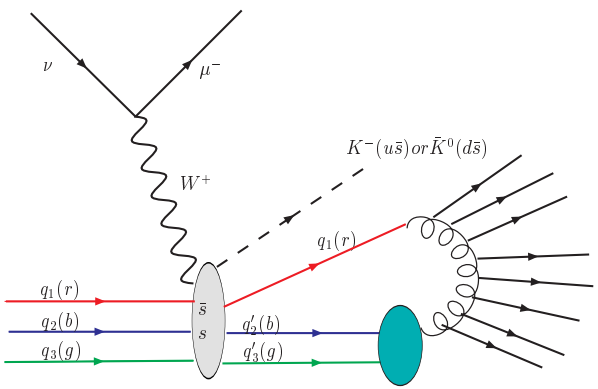


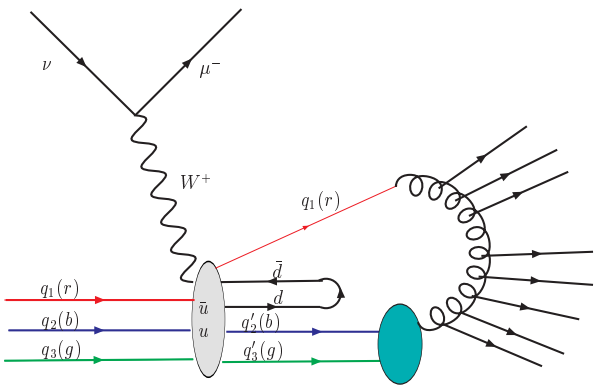
Scattering on given quark

Illustration of the scattering on parton inside nucleon for CC interaction (fragmentation $\rightarrow$ PYTHIA6)







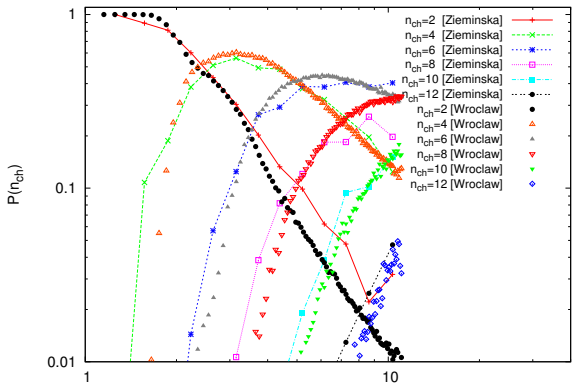


Reconstruction of final state

Charged hadrons multiplicity for $\nu p \to \mu^- X^{++}$

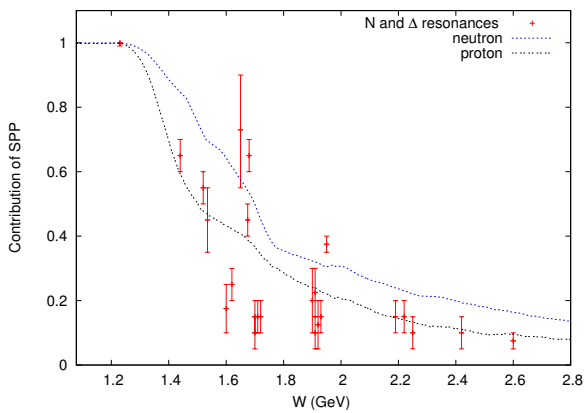
$$P(n_{ch}) = \frac{\sigma(n_{ch})}{\sum\limits_{n_{ch}} \sigma(n_{ch})}$$

(D. Zieminska et al. Phys. Rev. D27, 47(1983))



Single pion function vs. resonances elasticity

Single pion function can be compared with elasticity of resonances: $\Gamma(N\pi)/\Gamma_{total}$



Δ excitation and spp channel of DIS

Smooth transition from Δ excitation to DIS single pion channel

- Transition form RES to DIS with respect to hadronic invariant mass $W \in (1.3, 1.6GeV)$.
- It is a smooth transition, but it is not linear as a function of invariant mass.
- Non-resonant background is a small admixture of DIS single pion channel in Δ region.

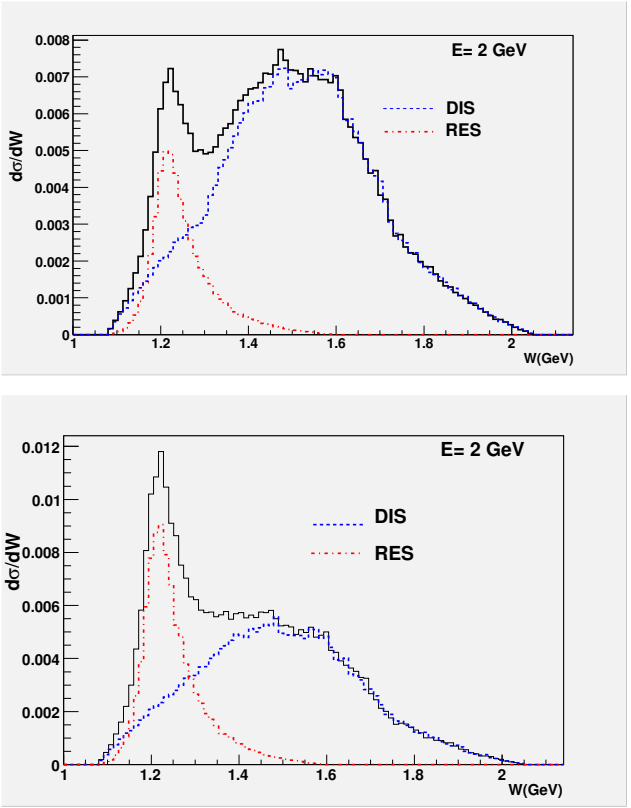
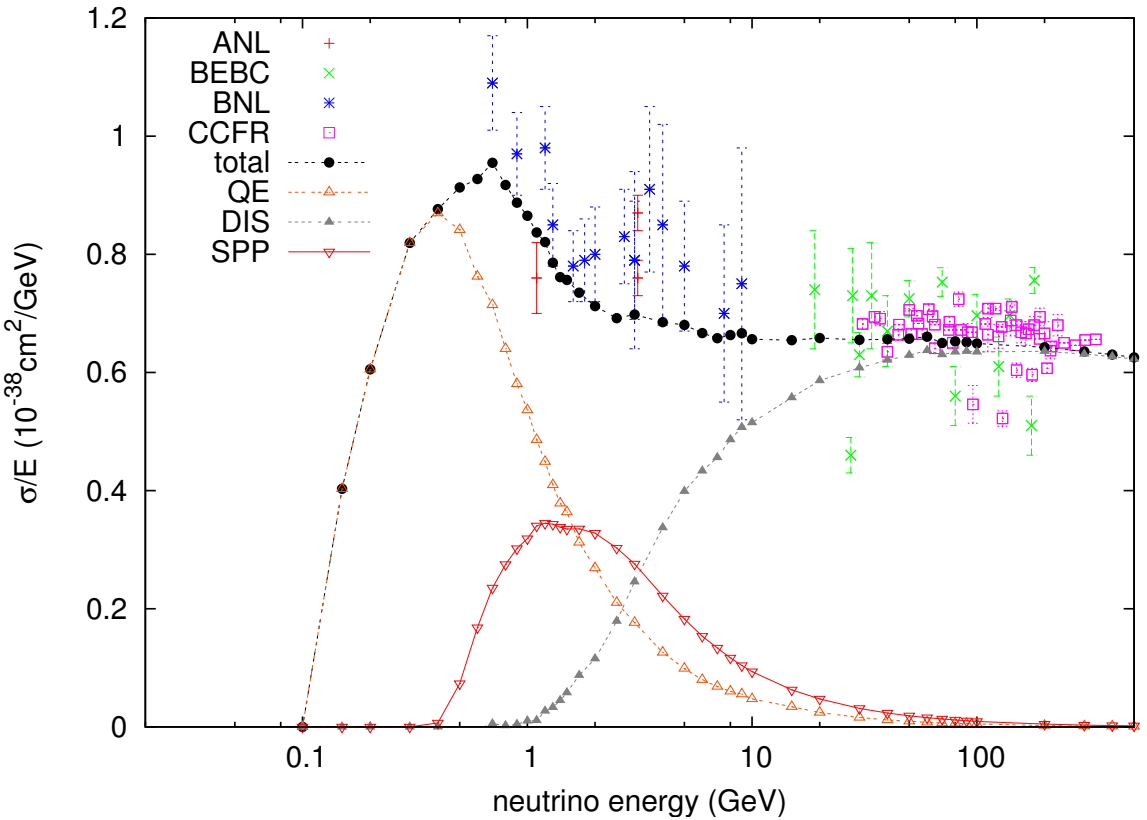


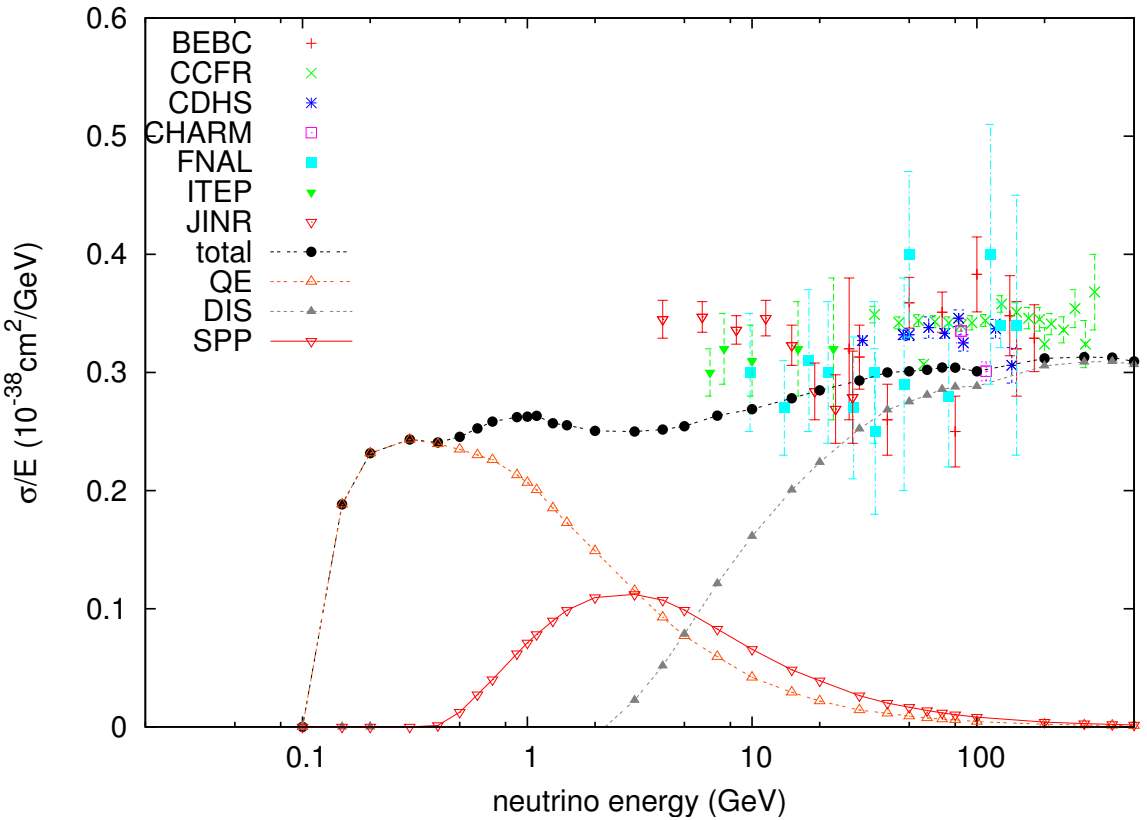
Figure: Differential cross section as a sum of contributions form DIS and RES. Top figure $\nu n \rightarrow \mu^- \pi^+ n$, and bottom $\nu n \rightarrow \mu^- \pi^0 p$.

Charge Current cross section $\nu N \rightarrow \mu^- X$



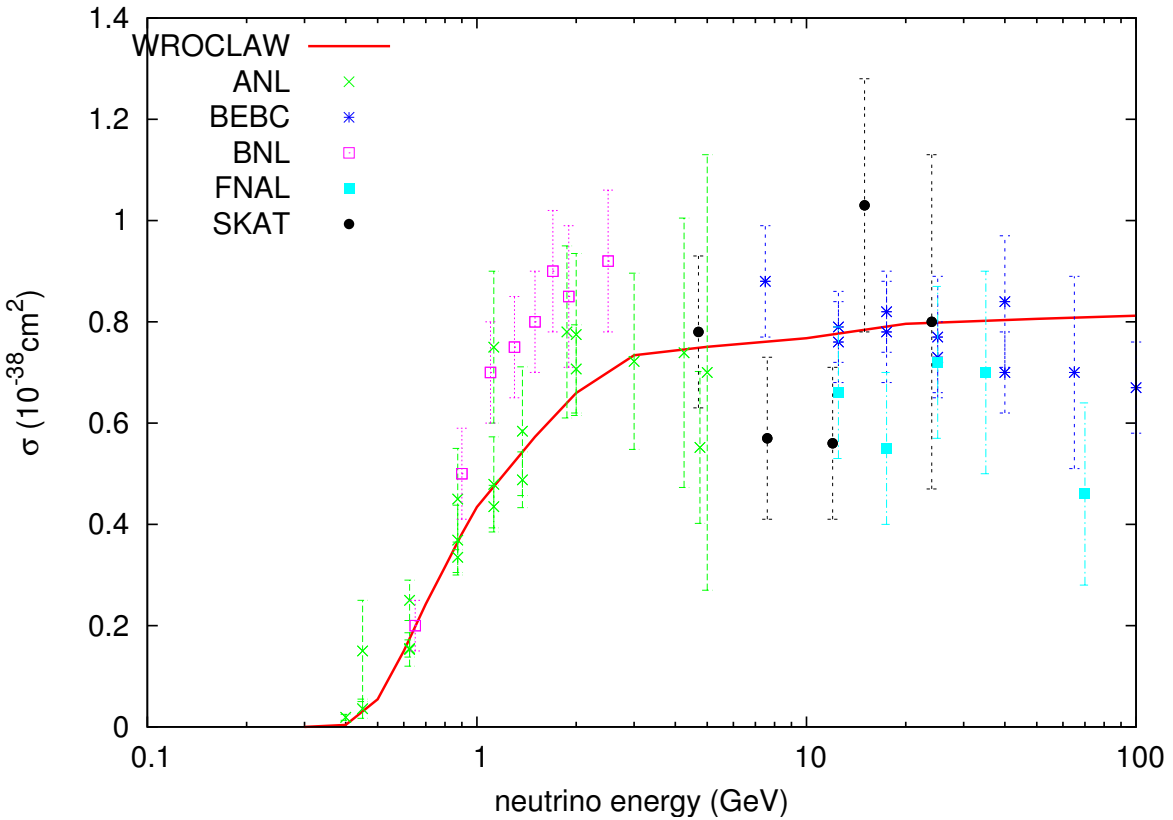
ANL: Barish 1976 PL B66,291, Barish 1979 PR D19,2521 (Hydrogen,Deuterium); BEBC: Bosetti 1977 PL B70,273, Colley 1979 ZP C2,187, Bosetti 1982 PL B110,167, Parker 1984 NP B232,1 (Neon-H2); BNL: Baltay 1980 PRL 44,916 (Ne-H2), Baker 1982 PR D25,617 (Deuterium); CCFR: MacFarlane 1984 ZP C26,1, Berge 1987 ZP C35,443, Auchincloss 1990 ZP C48,411, Seligman 1996 Nevis Report 292 (Iron)

Charge Current cross section $\bar{\nu}N \longrightarrow \mu^+ X$



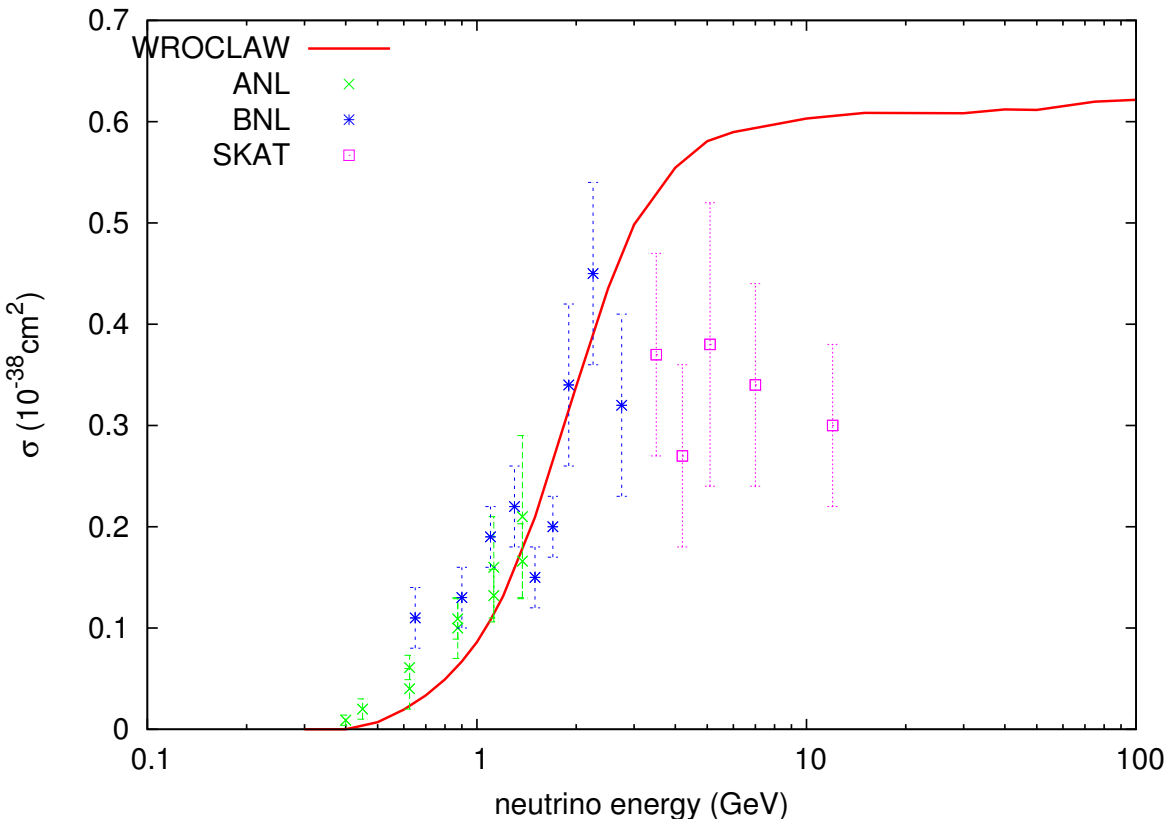
BEBC: Bosetti 1977 PL B70,273, Colley 1979 ZP C2,187, Bosetti 1982 PL B110,167 (Neon-H2); CCFR: Auchincloss 1990 ZP C48,411, Seligman 1996 Nevis Report 292 (Iron); CDHS: Berge 1987 ZP C35,443 (Iron); CHARM:Jonker 1981 PL B99,265, Allaby 1988 ZP C38,403 (Marble); FNAL: Taylor 1983 PRL 51,739, Asratyan 1984 PL 137B,122 (Neon-Hydrogen); ITEP: Vovenko 1980 SJNP 30,527 (Iron); JINR: Anikeev 1996 ZP C70,39 (Aluminium)

Charge Current cross section $\nu p \longrightarrow \mu^- \pi^+ p$



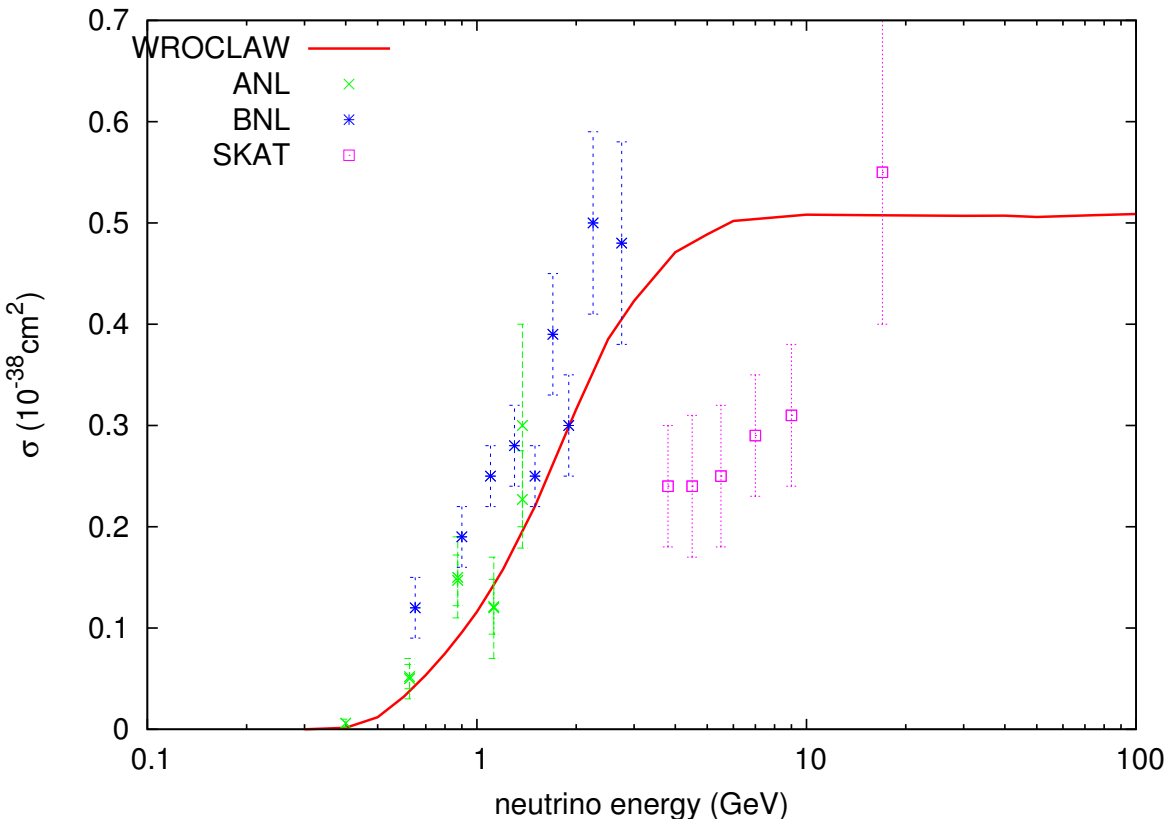
ANL: Radecky 1982 PR D25,1161, Campbell 1973 PRL 30,335, Barish 1979 PR D19,2521 (Hydrogen,Deuterium); BEBC: Allen 1986 NP B264,221 (Hydrogen), Allasia 1990 NP B343,285 (Deuterium); BNL: Kitagaki 1986 PR D34,2554 (Deuterium); FNAL: Bell 1978 PRL 41,1008 (Hydrogen); SKAT: Grabosch 1989 ZP C41,527 (Heavy Freon-CF3BR)

Charge Current cross section $\nu n \longrightarrow \mu^- \pi^+ n$



ANL: Radecky 1982 PR D25,1161, Barish 1979 PR D19,2521 (Hydrogen,Deuterium); BNL: Kitagaki 1986 PR D34,2554 (Deuterium); SKAT: Grabosch 1989 ZP C41,527 (Heavy Freon-CF3BR)

Charge Current cross section $\nu n \longrightarrow \mu^- \pi^0 p$



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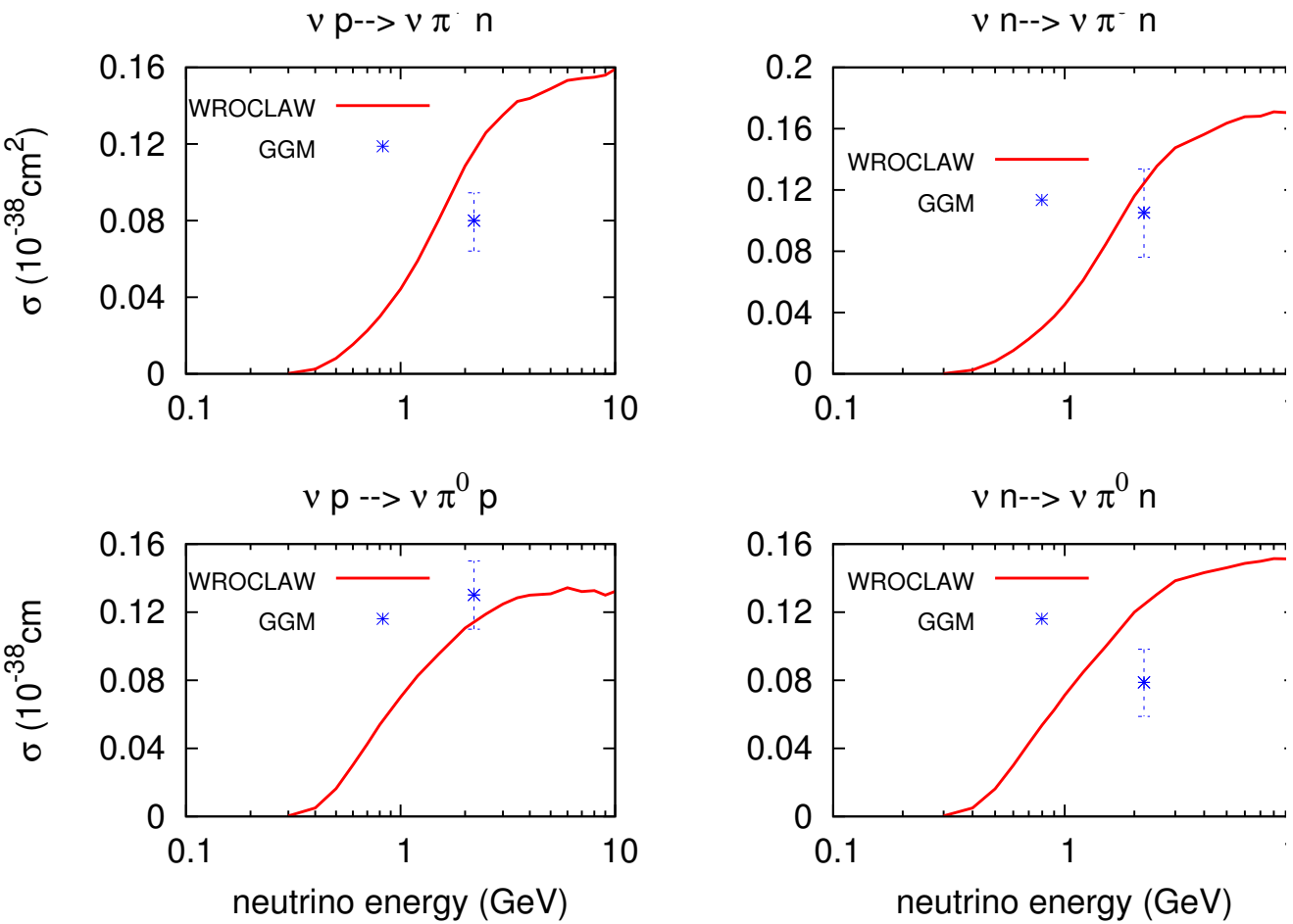
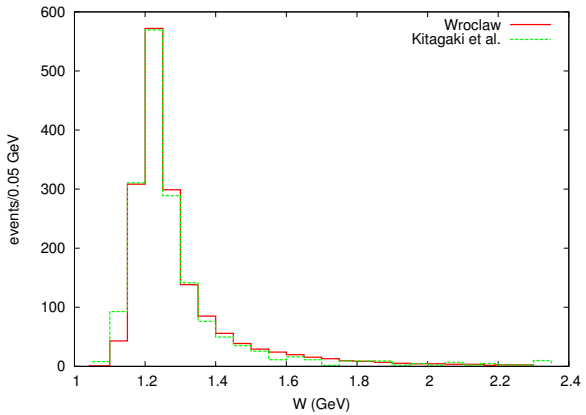
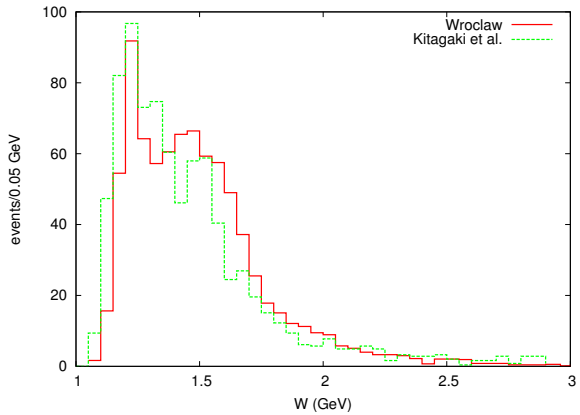
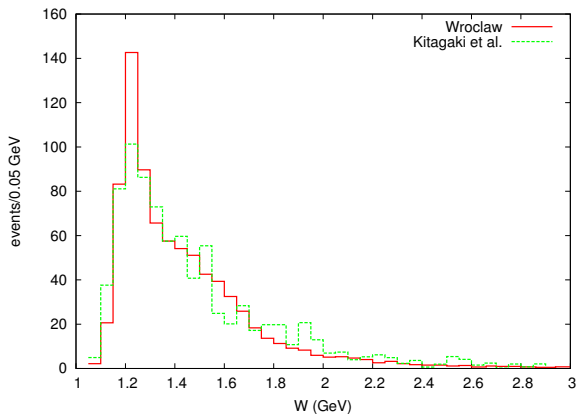
Neutral Current SPP cross section



Differential cross section as a function of W







Conclusions

- The event generator for deep inelastic scattering works in agreement with data
- The mechanism of combining Δ excitation with DIS single pion production gives results with nice agreement with data