Coherent Pion Production in the Neutrino-Nucleus Scattering in Few-GeV Region

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Introduction

New neutrino oscillation experiments

(T2K, MiniBooNE, ...)

* Neutrino in few GeV region
* Detection through neutrino-nucleus scattering
* Need reliable model for neutrino-nucleus scattering

Neutrino-nucleus scattering in few GeV region

sub-dominant

* Coherent π production : $\nu A \rightarrow \mu^- \pi^+ A$
  - Hadronic model : Rein and Sehgal, PLB **223**, 29 (1983)
    Singh *et al.*, PRL **96**, 241801 (2006)
    Alvarez-Ruso *et al.*, PRC **75**, 055501 (2007)
  - PCAC : Kartavtsev *et al.*, PRD **74**, 054007 (2006)
    Rein and Sehgal, PLB **657**, 207 (2007)

dominant

* Quasi-elastic : $\nu A \rightarrow \mu^- N(A-1)$
* 1 π production (Quasi-free) : $\nu A \rightarrow \mu^- \Delta(A-1)$
  $\rightarrow \mu^- \pi N(A-1)$

Model

* Elementary process amplitudes ($\nu N \to \mu^- \pi^+ N$)

  $\to$ SL (Sato-Lee) model [PRC **54**, 2660 (1996); **67**, 065201 (2003)]

* Medium effect on Δ (mass and width)

  Final state interaction (π-nucleus optical potential)

  $\to$ Δ-hole model [*e.g.*, Koch and Moniz, PRC **27**, 751 (1983)]

* Nuclear form factor

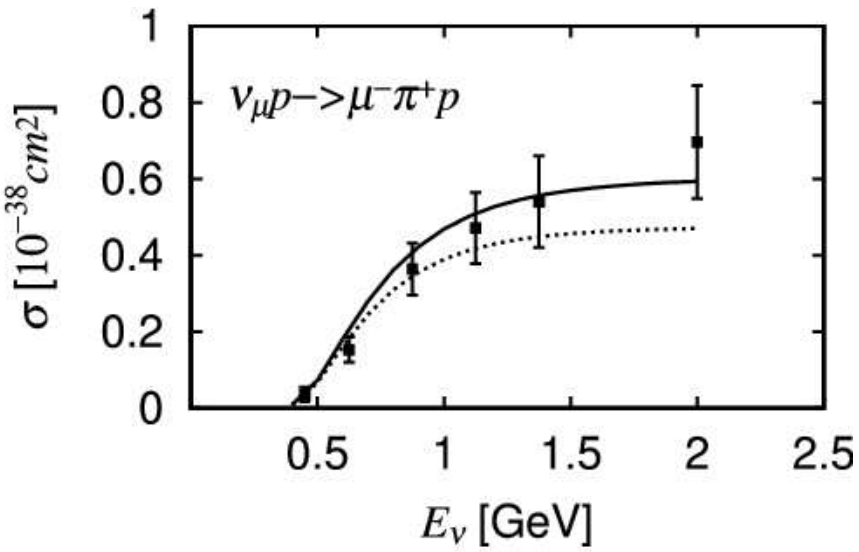
  $\to$ empirical form factor (electron scattering)

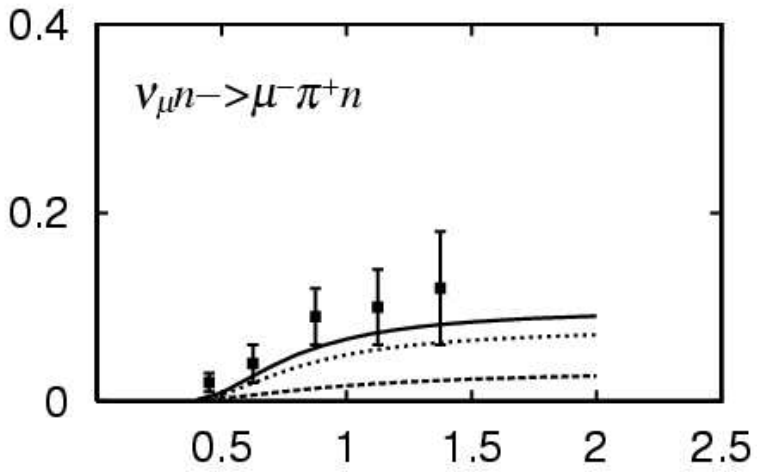
Combine SL and Δ-hole model !

SL model

[Sato and Lee, PRC **54**, 2660 (1996); **67**, 065201 (2003)]

* Model for electroweak π production off nucleon in Δ region
* Non-perturbative amplitudes (π cloud)
* Large amount of data (JLab, BNL) for (γ, π^0) and $(e, e'\pi^0)$ are consistently described





Optical potential for π-nucleus scattering

[Karaoglu *et al.*, PRC **33**, 974 (1986)]

$$U_{\pi A} \sim F(\vec{q})\ \tilde{t}_{\pi N} + W\rho^2$$

$F(\vec{q})$: nuclear form factor for $\vec{q}$ (momentum transfer)

$t_{\pi N}$: πN scattering amplitude (SL model) $\quad \rightarrow \tilde{t}_{\pi N}$

$$\frac{1}{E - m_\Delta - i\Gamma/2} \rightarrow \frac{1}{E - m_\Delta - i\Gamma/2 - H_\Delta - \Sigma_{Pauli} - \Sigma_{spr}}$$

$$\Sigma_{spr} = V_C\ \rho(r) + V_{LS}(r)\ \vec{L}\cdot\vec{S}$$

W : phenomenological term (two-body π absorption)

Parameters (complex) : V_C, V_{LS}, W_s, W_p $\quad \rightarrow \quad$ π-nucleus scattering data

Transition amplitude for $\lambda A \to \pi A$ (λ : external probe)

$$A_{\lambda A \to \pi A} \sim \int d\vec{p}_\pi \; \psi_{\pi A} \; F(\vec{q}) \; \tilde{A}_{\lambda N \to \pi N}$$

$\psi_{\pi A}$: π wave function (final state interaction, $U_{\pi A}$)

$A_{\lambda N \to \pi N}$: $\lambda N \to \pi N$ amplitude (SL model) $\quad \to \tilde{A}_{\lambda N \to \pi N}$

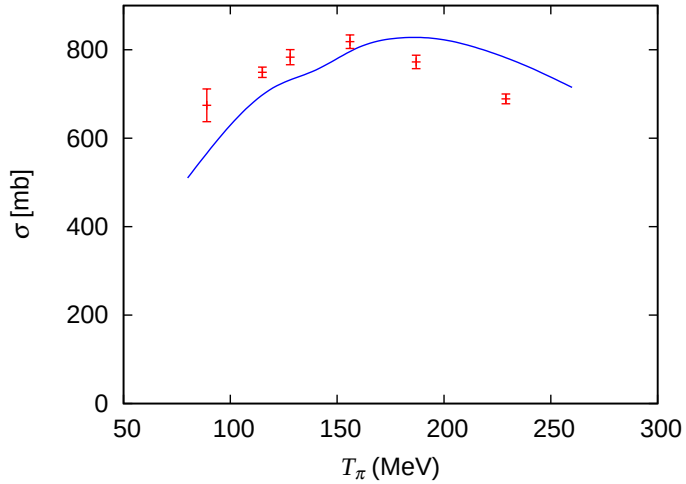
$$\frac{1}{E - m_\Delta - i\Gamma/2} \to \frac{1}{E - m_\Delta - i\Gamma/2 - H_\Delta - \Sigma_{Pauli} - \Sigma_{spr}}$$

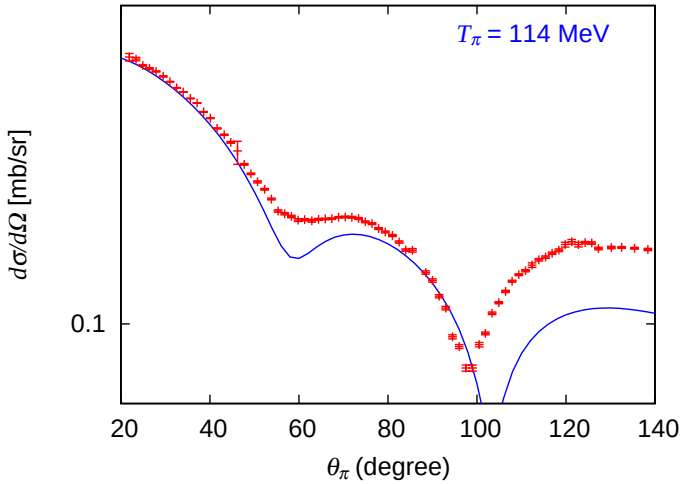
All parameters fixed by π-nucleus data

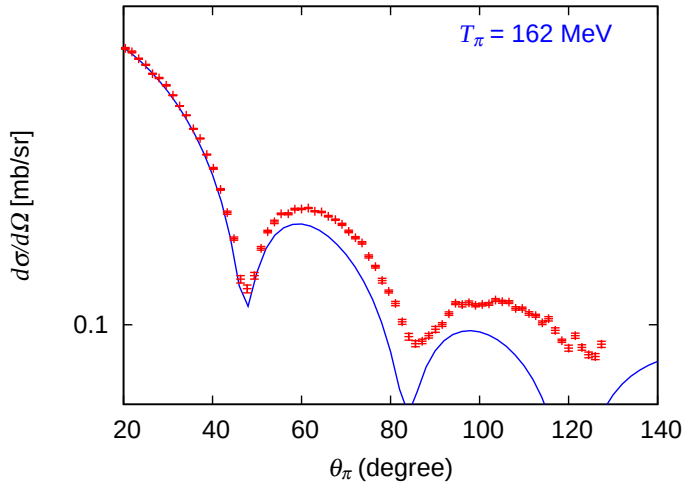
$\to$ parameter-free prediction for $\lambda A \to \pi A$

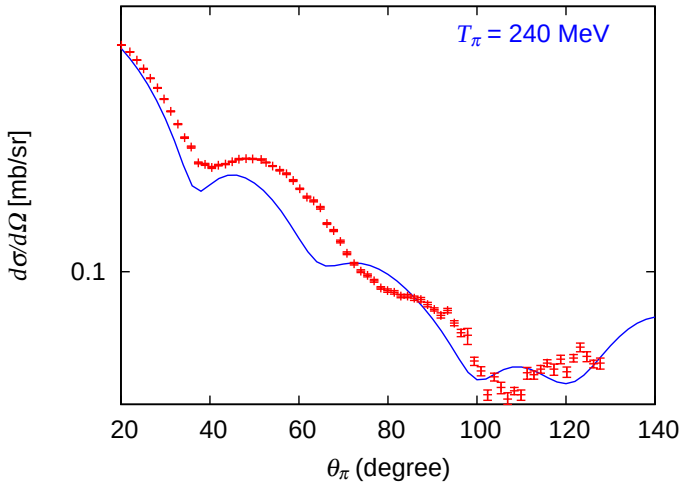
Results

I. π^+ - ^{16}O scattering (Parameters fitted to data)





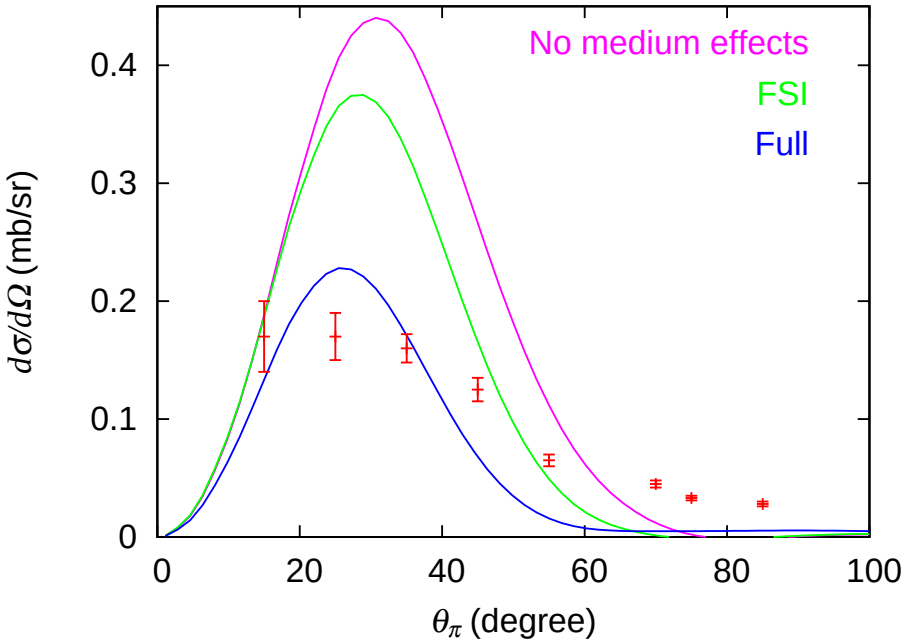




[Data: NPB **76**, 15 (1974); NPA **350**, 301 (1980)]

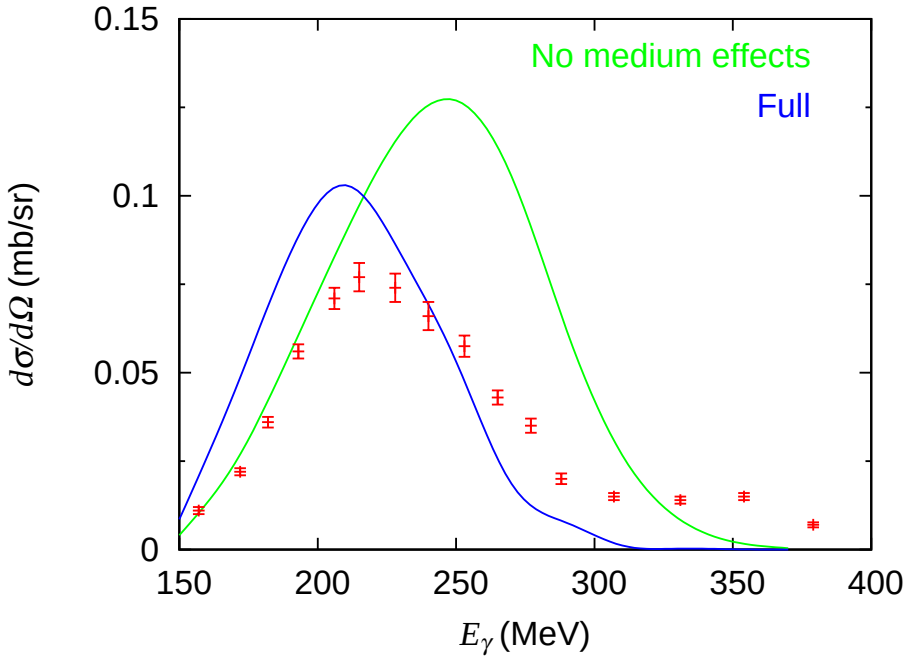
II. Photo coherent π production $(\gamma + {}^{12}\mathrm{C} \to \pi^0 + {}^{12}\mathrm{C}_{g.s.})$

$E_\gamma = 290$ MeV



[Data: Z. Phys.A **311**, 367 (1983)]

$\theta_\pi = 60^\circ$

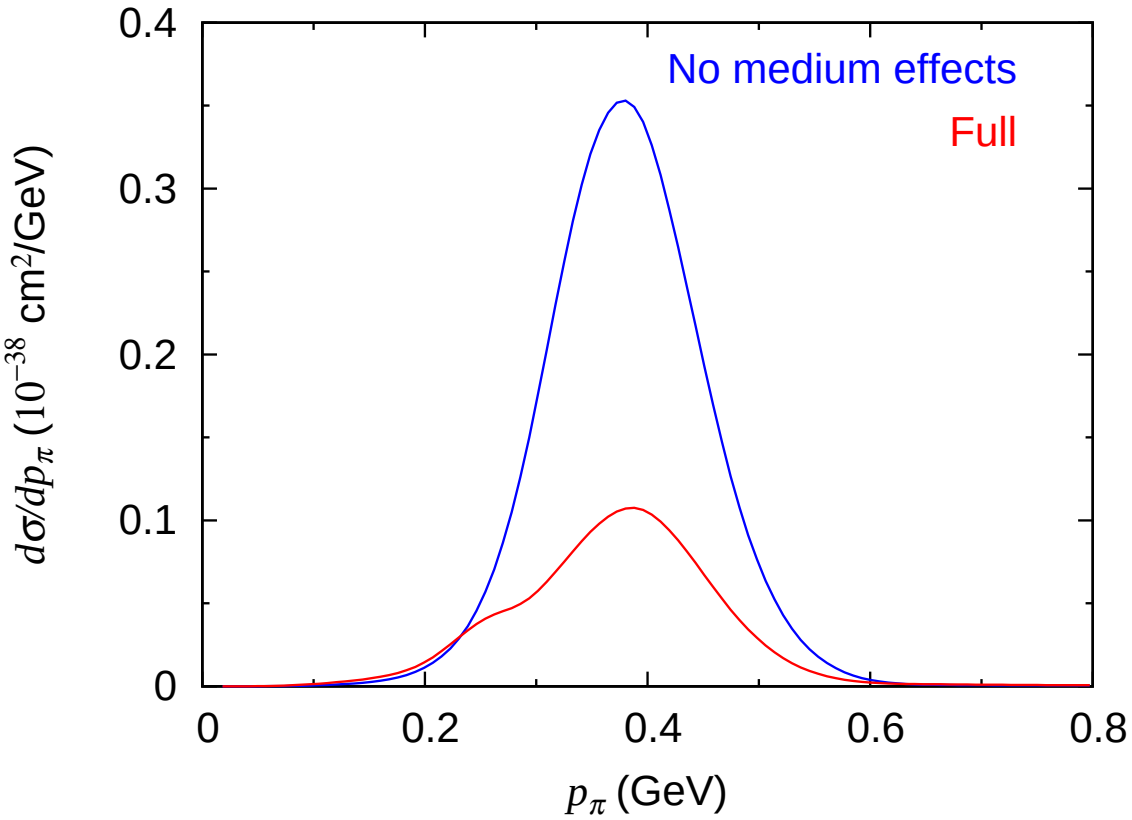


[Data: Schmitz (A2 collaboration), PhD thesis (1996)]

- Parameter-free prediction
- Important medium effects

III. Neutrino coherent π production $(\nu_\mu + {}^{12}\mathrm{C} \to \mu^- + \pi^+ + {}^{12}\mathrm{C}_{g.s.})$

$E_\nu = 1$ GeV



$\sigma_{\mathrm{total}} = 2.1 \times 10^{-40}\mathrm{cm}^2$
$(E_\nu = 1$ GeV$)$

$\sigma_{\mathrm{EXP}} < 7.7 \times 10^{-40}\mathrm{cm}^2$
(spectrum averaged)

[Data: Hasegawa *et al.* (K2K), PRL **95**, 252301 (2005)]

Consistent with data

Different from other calculations (under investigation)

Summary

Development of theoretical model for new neutrino experiments !

SL model + Δ-*hole model* for unified description of:

- π-nucleus scattering
- photo coherent π production
- neutrino coherent π production

Overall, data are reproduced fairly well

particularly, consistent with data from K2K !

Future plan

Short term

Further study on neutrino coherent π production

- Some refinements (parameters ...etc.)
- NC process (MiniBooNE data)
- Anti-neutrino process

After that

Single π production (quasi-free process)