# Coherent π<sup>+</sup> Photoproduction on <sup>3</sup>He

Meson-Nucleon Physics and the Structure of the Nucleon

May 31- June 4, 2010 Williamsburg, VA

Rakhsha Nasseripour and Barry Berman The George Washington University





# <u>Physics Motivation</u> $\gamma + {}^{3}He \rightarrow \pi^{+} + t$

Comparing an elementary meson production process on a free nucleon  $(\gamma + p \rightarrow \pi^{+} + n)$  with the same process on the nucleus

- Useful in developing our understanding of the nuclear structure and long-range part of the nucleon-nucleon interaction described by the one-pion-exchange model.
- A good tool to explore the importance of the pion cloud and thus to investigate the contribution of mesonic degrees of freedom
- To investigate the contribution of the 2- and 3-body mechanisms to the reaction and to further constrain the theoretical calculations.

<sup>3</sup>He and the triton are the lightest nuclei for which one can observe coherent photoproduction with charge exchange and a well defined final state that can be easily identified.

- First experiment by O'Fallon et al. in 1965 showed that the cross section could be described by that for a single free proton times the square of the nuclear-matter form factor for <sup>3</sup>He, modified by the appropriate kinematic factors. (Phys. Rev. 141, 3 (1965))
- In 1979, Argan et al. obtained the matrix element for threshold pion photoproduction and compared it with scattering data on the proton and showed that a unique form factor cannot account for both processes. This implies that many-body contributions to pion photoproduction affect the two reactions differently. (Phys. Rev. C20, 1 (1979))

#### **Theoretical Calculations and Previous Measurements**



Calculations: Lazard and Maric, Nuovo Cim. <u>A16</u>, 605 (1973).

Data: Bachelier et al., Phys. Lett. <u>B44,</u> 44 (1973) (Orsay).



**Calculations:** Sanchez-Gomez and Pascual, Nucl. Phys. <u>B9</u>, 153 (1969), (Valencia).

Data : Bellinghausen et al., Nucl. Phys. <u>A470</u>, 429 (1987), (Bonn).

### **Theoretical Calculations and Previous Measurements**

Data: N. d'Hose, Ph.D. Thesis, Saclay 1988. Calculations: Kamalov, Tiator, and Bennhold, Few-Body Systems <u>10</u>, 143 (1991)



#### **Theoretical Calculations and Previous Measurements**



Calculations: Kamalov, Tiator, and Bennhold, Phys. Rev. Lett 75, 7 (1995) Data: Bachelier et al., Phys. Lett. <u>B44,</u> 44 (1973) (Orsay). Nucl. Phys. A251, 433 (1975).

## Experiment with CLAS at JLab

Six separate spectrometers sconsist of DC, EC, CC, SC with Toroidal Magnetic field





Nearly  $4\pi$  multilayer spectrometer, for PID and particle tracking over full angular range. Identify  ${}^{3}\text{He}(\gamma, t\pi^{+})$  reactions by identifying the coincident tritons and pions in the CLAS

#### Particle Identification and Event Selection for $^{3}He(\gamma, t\pi^{+})$



15 20

# Missing Mass Spectra



## Simulation and Acceptance Corrections:

Monte-Carlo simulation of phase-spacedistributed  $t\pi$ + events within  $4\pi$  sr, using the standard CLAS simulation package.





#### Acceptance correction factors

## Cross Sections (Angular Dependence)

Acceptance corrected and Normalized to the photon flux and target density



11

## Cross Sections (Energy Dependence)

Acceptance corrected and normalized to the photon flux and target density



### Comparison of the Model Calculations with the Energy-Dependence of Measured Cross Sections from CLAS



Model is extended with MAID to higher energies (DWIA + 2-body).

**Calculations:** *Tiator and Kamalov (2010).* 

Data: CLAS





**Calculations:** Tiator and Kamalov (2010)

Data: CLAS (open circles) d'Hose et al. (filled circles)

Models need to be further developed.

## Models Including the Meson Exchange Currents (MEC):

Very First attempt to include a two-body MEC for pion photoproduction. One pion is exchanged between the two nucleons.



In this model the formalisms for pion photoproduction amplitude with binding-induced contributions were given.

The rescattering of pion was not included.

No actual numerical calculations is performed.

A. S. Raskin, E. L. Tomusiak, and J. L. Friar, Few-Body Systems 17, 71 (1994).

## Models Including the Meson Exchange Currents (MEC):

This model includes pre- and post-absorption of a photon on a two-body System with the excitation of the nucleon resonances N\*



D. Drechsel, L. Tiator and M. Beyer, Phys. Lett. 108B, 3 (1982)

## Models Including the Meson Exchange Currents (MEC):



#### Data: Dunn et al., Phys. Rev. C27, 71 (1983) and Juster et al., Phys. Rev. Lett. 55, 2261 (1985)

Strueve, Hajduk, Sauer, and Theis, Nucl. Phys. A465, 651 (1987)

Models for pion photoproduction from <sup>3</sup>He can be improved by including more processes. For example:

- 1) Single pion rescattering
- 2) Two-body MEC
- 3) Three-body MEC

The MEC processes become more important especially at high momentum transfers.

The three-body processes are only possible with MEC.



Strong evidence from analyzing CLAS data in other channels for example  $\gamma^{3}$ He $\rightarrow$ ppn,  $\gamma^{3}$ He $\rightarrow$ pd, and  $\gamma^{4}$ He $\rightarrow$ pt that 3-body contributions become more important especially around 0.6-0.8 GeV.

S. Niccolai et al. Phys. Rev. C70, 064003 (2004) R. Nasseripour et al. Phys. Rev. C80, 044603 (2009) Y. Ilieva et. al. Eur. Jour. Phys. (2009)

# Summary:

- We have extracted the cross sections for coherent π<sup>+</sup> photoproduction on <sup>3</sup>He for photon energies between 0.5 and 1.5 GeV and pion scattering angles between 40 and 140 deg.
- These results are the first to be reported on the  ${}^{3}\text{He}(\gamma, t\pi^{+})$  channel with incident photon energies above 450 MeV.
- Theoretical calculations to date cannot explain the large cross sections except at backward angles, showing that additional components must be added to the model.
- Models can be further developed by including the meson exchange currents in the two- and three-body processes. These processes are expected to be important especially at large momentum transfers. Because the momentum is shared between the three nucleons of the triton final state.
- A PRC paper is in preparation for publication.

# Meson Exchange Currents (MEC):

Various contributions to the NN Bremsstrahlung including meson exchange current.



This model was used to calculate the isobar excitation in proton-proton bremsstrahlung. Model includes form factors for the exchange of  $\pi$ - and  $\rho$ -mesons.

#### L. Tiator, H.J. Weber, and D. Drechsel, Nucl. Phys A306, 468 (1978).

# Meson Exchange Currents (MEC):

Differential cross section for pp bremsstrahlung as a function of photon energy.



L. Tiator, H.J. Weber, and D. Drechsel, Nucl. Phys A306, 468 (1978).

## Momentum Transfer Dependence



### Energy Dependence at a Fixed Momentum Transfer



**Calculations:** *Tiator and Kamalov (2010)* 



# Meson Exchange Currents (MEC):

The most complete model including MEC, was used to calculate the <sup>3</sup>He charge form factors and investigate the effect of the  $\Delta(1236)$  isobar on the 3-nucleon system.



Ch. Hajduk and P. U. Sauer, Nucl. Phys. A322, 329 (1979)

# Meson Exchange Currents (MEC):

<sup>3</sup>He charge form factor



Data: R. G. Arnold et al. Phys. Rev. Lett. 40, 1429 (1978)

Ch. Hajduk and P. U. Sauer, Nucl. Phys. A322, 329 (1979)