

Study of double pion production on the deuteron

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Outline

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 - YN interaction
 - $\Delta N (\Delta\Delta)$ interaction
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 - Double pion production
 - Double Delta production
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The NKS/NKS2 Collaboration

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P.Bydzovsky, M.Sotona

NOTE:

People who belonged only to the NKS collaboration, only to the NKS2 collaboration and to both collaborations are included in this list.

Introduction

6 Mar. 2008

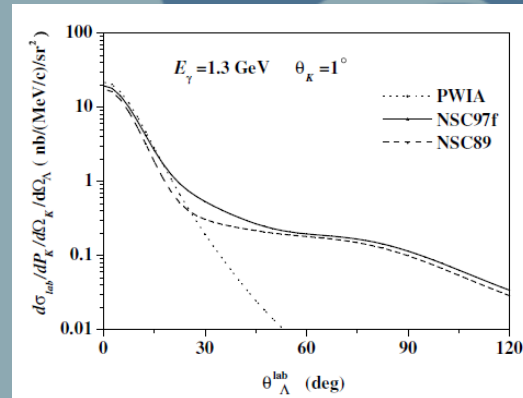
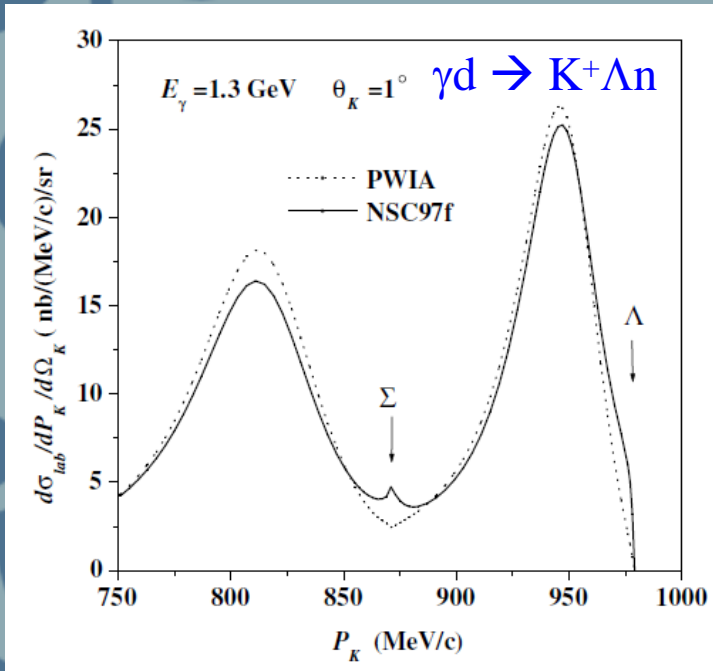
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The deuteron for investigation of FSI

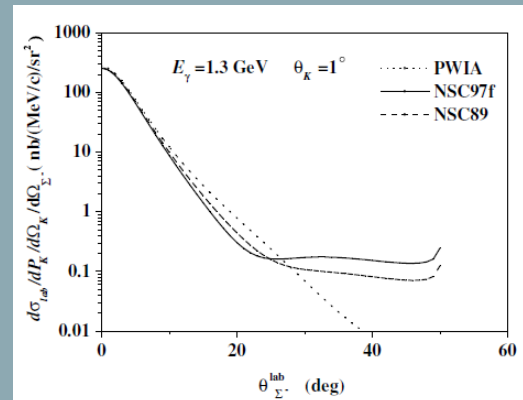
- The deuteron is a loosely bound state of the proton and the neutron and therefore approximated as the nucleon target.
- However, it also holds a possibility to behave as a nuclear target. That is, it suffers the “many body” effect.
- Final state interaction (FSI) is one of the so-called “many body” effect. FSI is a noise for the deuteron to be used as the quasifree neutron target.
- Because FSI occurs in a very short time scale, it is a useful tool for the investigation of interactions between nucleon and short lived particles, such as YN - and ΔN -interactions.
- There is also a possibility of $\Delta\Delta$ -interaction.

YN interaction

- K. Miyagawa *et al.* reported the effect of YN interaction in the final state of $\gamma d \rightarrow K^+ \Lambda n$ and $\gamma d \rightarrow K^+ \Sigma^- p$ reactions.
- A sizable effect at the Σ threshold was interpreted as the $\Lambda N - \Sigma N$ conversion



$\gamma d \rightarrow K^+ \Lambda n$



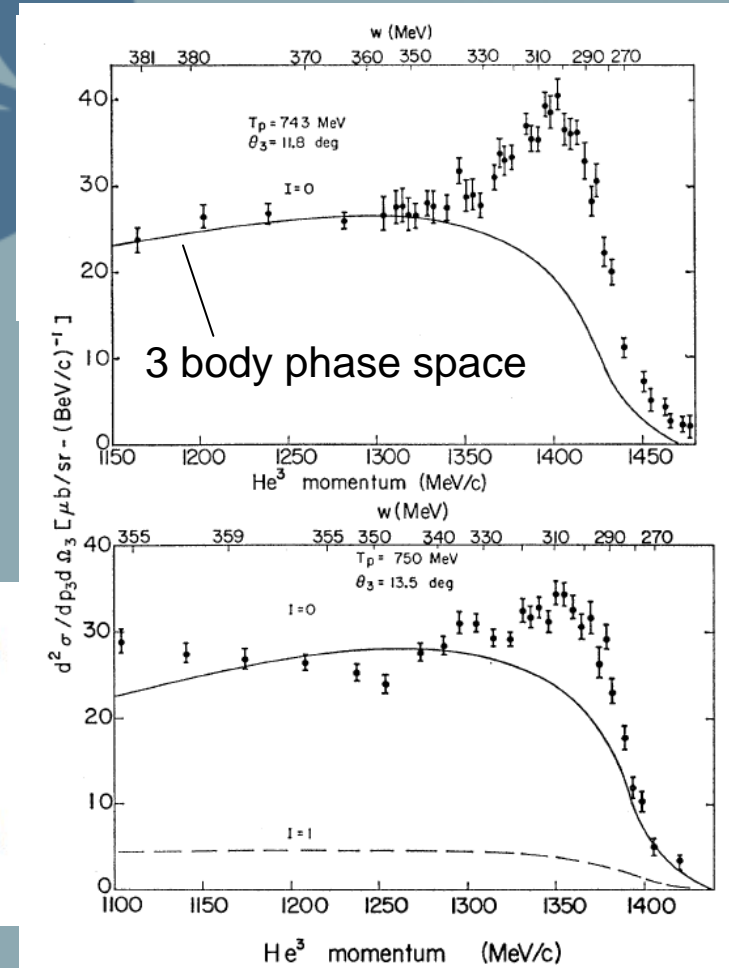
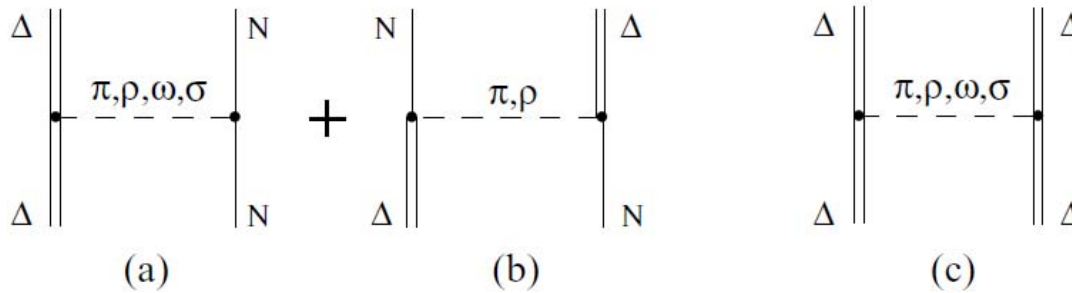
$\gamma d \rightarrow K^+ \Sigma^- p$

K. Miyagawa *et al.*,
nucl-th/0011086

ΔN and $\Delta\Delta$ interaction

- Isoscalar mesonic structure in the reaction $pd \rightarrow {}^3\text{He}(\pi\pi)$ observed in $p(d, {}^3\text{He})X$ reaction by Abashian, Booth and Crowe. (PRL 7 (1961) 35). It was called as *ABC Effect*.
- The double Delta excitation in the intermediate state has been considered as the origin of the ABC Effect (Risser and Shuster PL43B (1973)68).
- Moreover, the final state interaction of Δ - Δ and Δ - N plays an essential role.
- Enhancement of the cross section at $\sqrt{s} = 2M_\Delta$

$\Rightarrow E_\gamma \sim 0.67 \text{ GeV}$ for $\Delta\Delta$ threshold



C. A. Mosbacher and F. Osterfeld, nucl-th/9903064

6 Mar. 2008

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Experiments to be performed at J-PARC

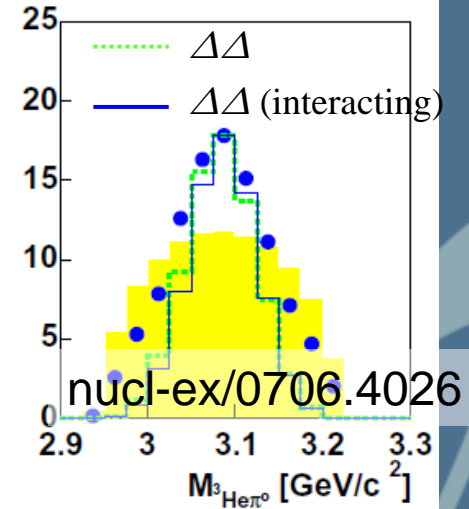
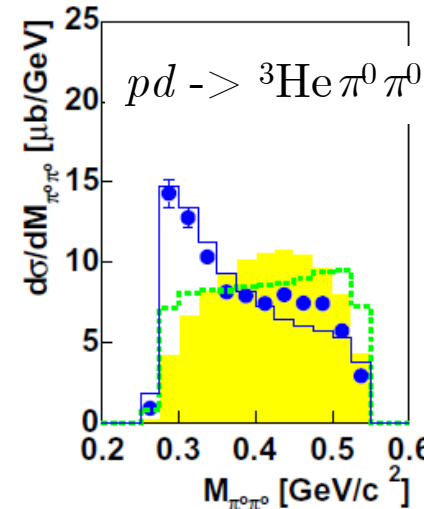
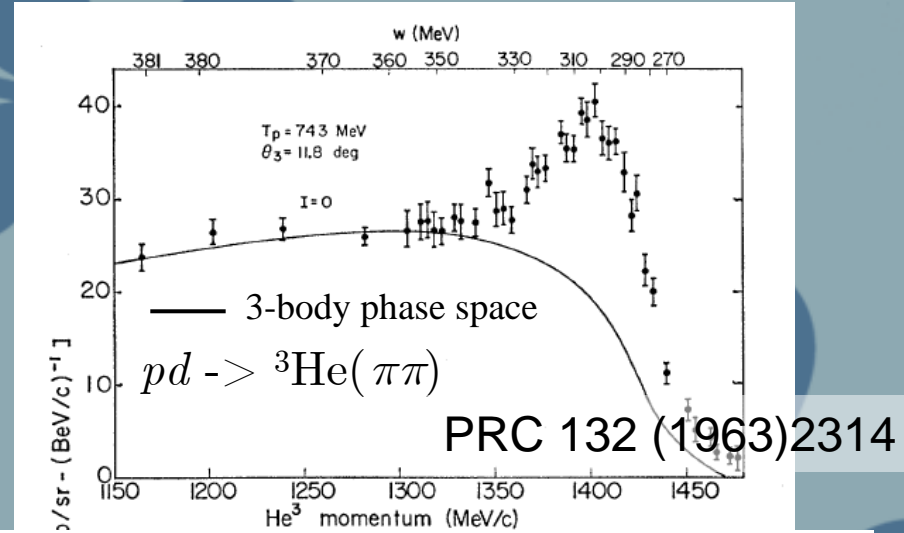
Experiments with hadronic beams

Proton induced reaction

- Genuin ABC effect: Isoscalar mesonic structure in the reaction $pd \rightarrow {}^3\text{He}(\pi\pi)$ observed in $p(d, {}^3\text{He})X$
- Exclusive measurements were performed in the CELSIUS-WASA experiment and planned in the COSY-WASA experiment

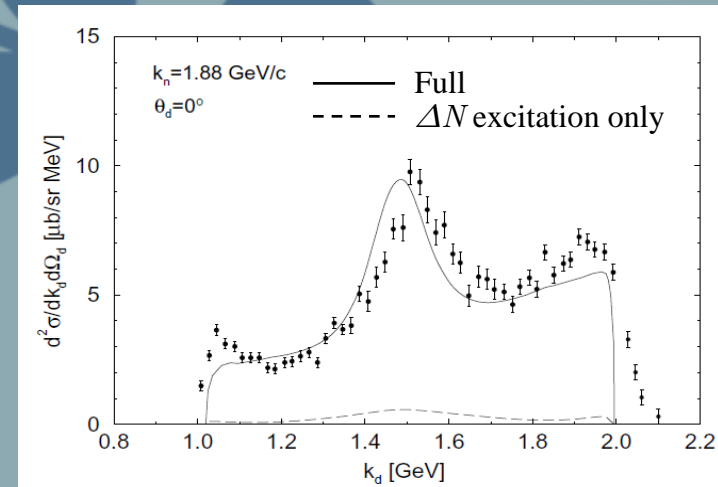
(Polarized) proton beam in the momentum region from 1 to 3 GeV/c

Exclusive measurement of ${}^3\text{He} \pi^+ \pi^-$ final state



Neutron induced reaction

- Neutron induced reaction $np \rightarrow d (\text{mm})^0$ reaction was inclusively measured at SATURNE with neutron beam of $P_n = 1.88 \text{ GeV}/c$.
- Two more experiments have been reported
 - S. Sawada et al., Nucl.Phys.A615:277-290,1997
 - C. L. Horas et al., Phys.Rev.C25:2614-2618,1982
- Deuteron channel have been thoroughly investigated for the search of dibaryon states...
 - No experiment with polarized neutron beam
 - No exclusive measurements



(Polarized) neutron beam
in the momentum region
from 1 to 3 GeV/c
Exclusive measurement

Beam and Detector

(Polarized) proton beam in the momentum region from 1 to 3 GeV/c

Exclusive measurement of ${}^3\text{He}$ π^+ π^- final state

(Polarized) neutron beam in the momentum region from 1 to 3 GeV/c

Exclusive measurement



- Polarized proton
 - Polarized ${}^1\text{H}^+$ source
 - Large duty factor

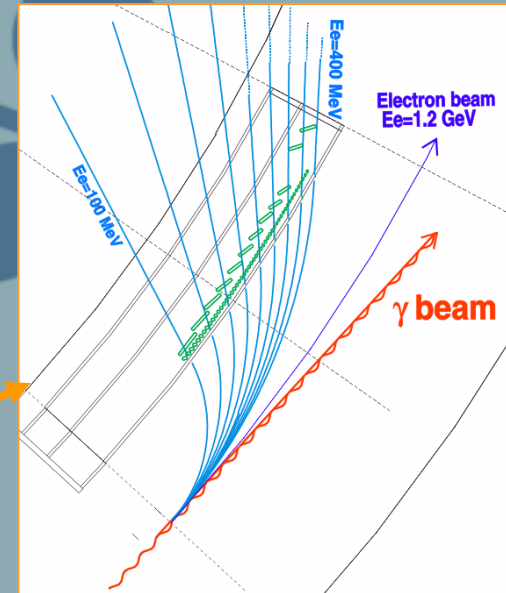
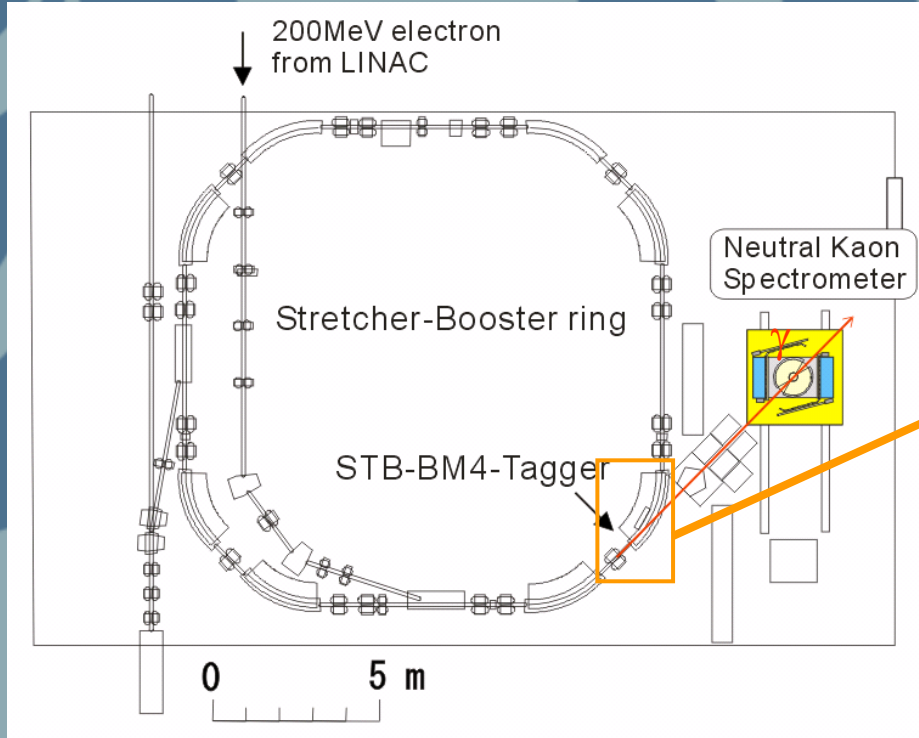
- Polarized neutron
 - Polarized ${}^2\text{H}^+$ source
 - Be target for breakup
 - Large duty factor

Spectrometer for charged particles with large solid angle:
NKS2 is a candidate.

Photon induced reaction

$\gamma d \rightarrow \pi^+ \pi^- p n$ measured
with NKS and NKS2
at LNS-Tohoku

Tagged photon beam at LNS-Tohoku



Stretcher-Booster Synchrotron (STB) at LNS-Tohoku and BM4-Tagger provide the tagged photon in the energy region from 0.8 to 1.1 GeV.

- Energy bin of the tagging counters: 6 MeV

- Intensity (hit rate of the tagging counters): 1.5 ~ 2.5 MHz

- Total number of irradiated photons:

2.64×10^{12} (D_2 target)
 6.77×10^{11} (H_2 target)

Neutral Kaon Spectrometer

- ◆ Dipole magnet 0.5 T
- ◆ CDC (cylindrical drift chamber)
SDC (straw drift chamber)
 - Particle tracking
- ◆ IH (inner hodoscope)
OH (outer hodoscope)
 - Trigger counter
 - Time of flight measurement
- ◆ EV (electron veto counter)
 - e^+e^- background suppression

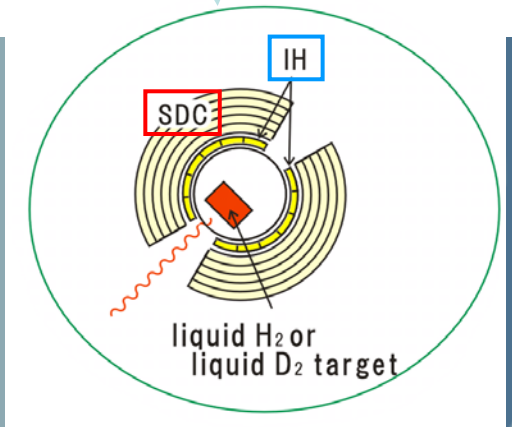
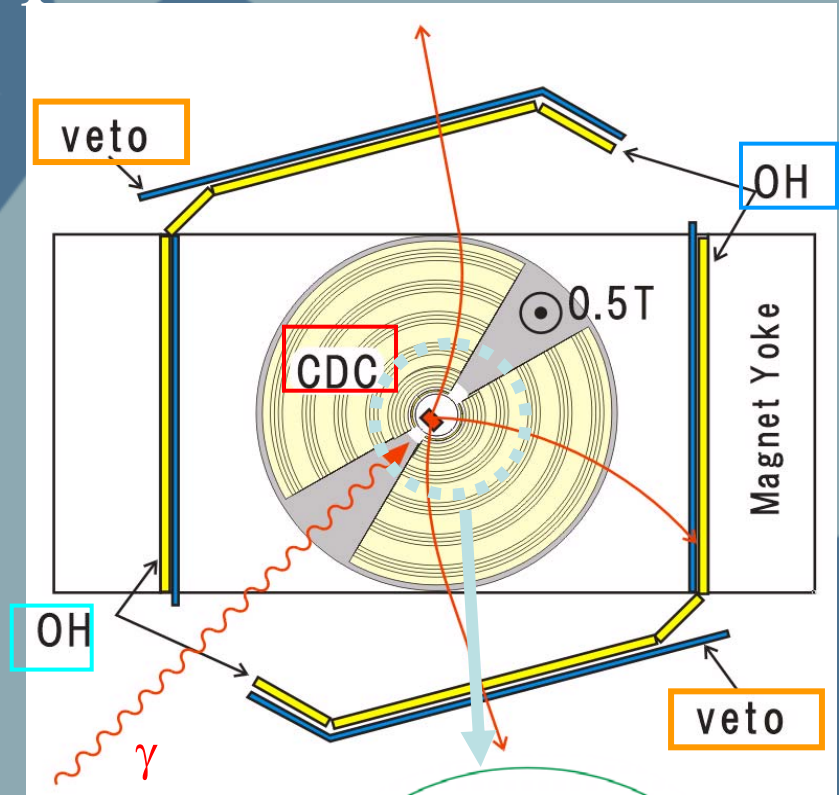
Acceptance $\sim \pi$ sr

Time resolution ~ 0.5 nsec

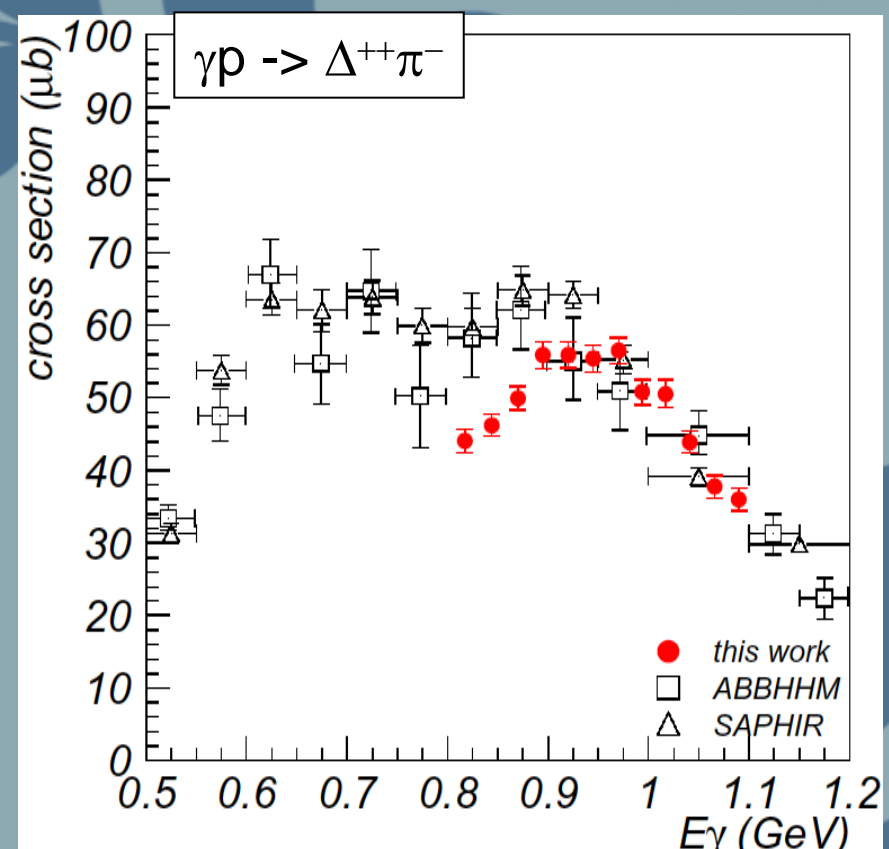
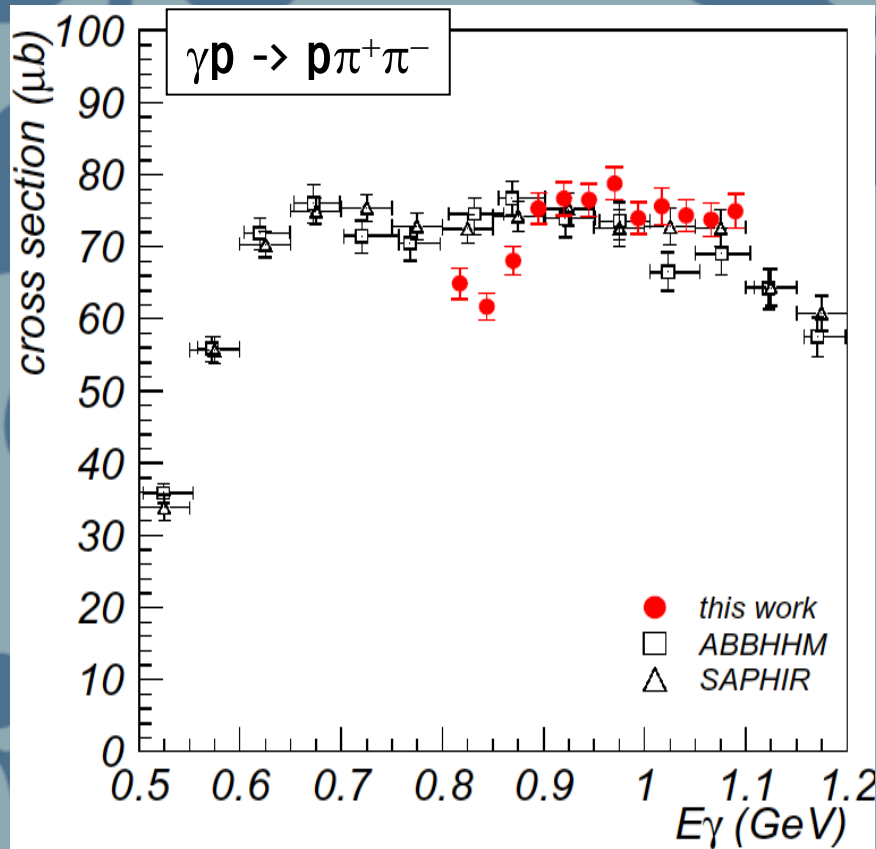
Momentum resolution $\sim 9\%$

No neutron counters:

Detection of p , π^+ , and π^- in the final state of the reaction: $\gamma d \rightarrow pn \pi^+ \pi^-$

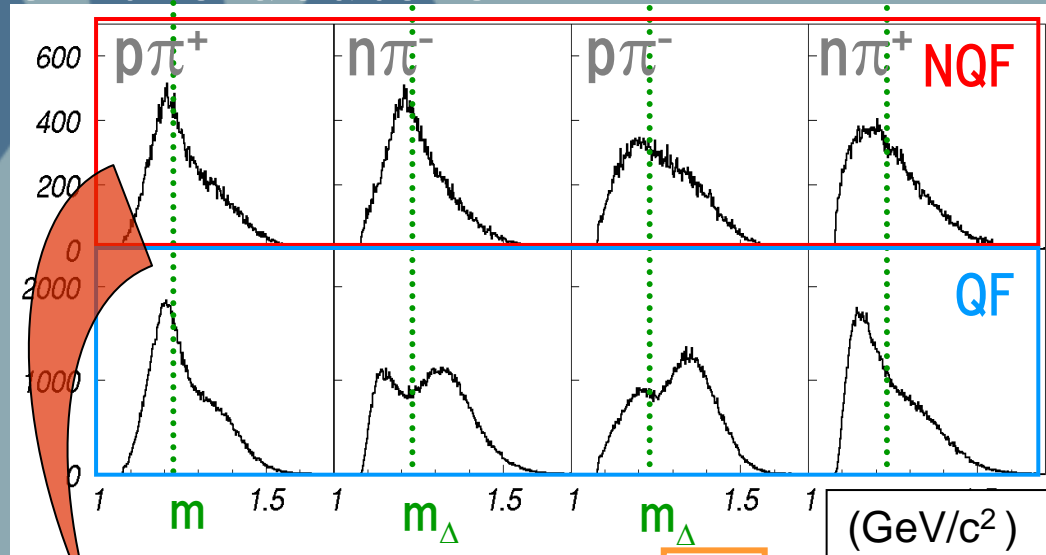
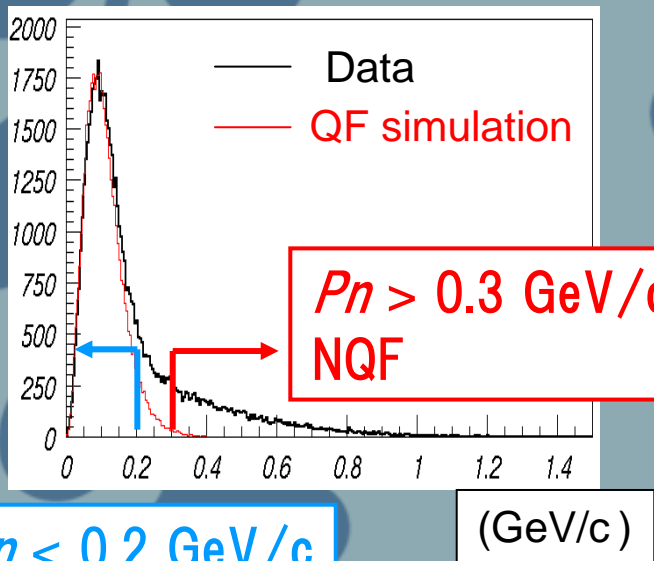


Double pion photoproduction on the free proton

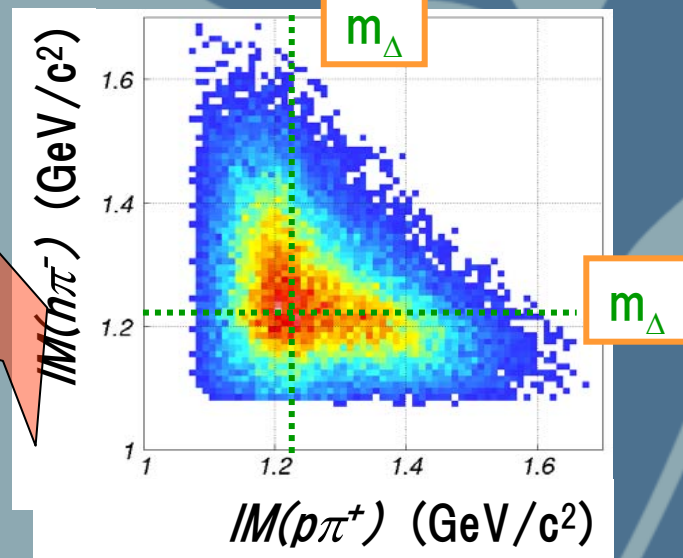


Consistent within the error bars: Small systematic errors in our analysis

Quasifree(QF) and non-quasifree (NQF) processes on the deuteron

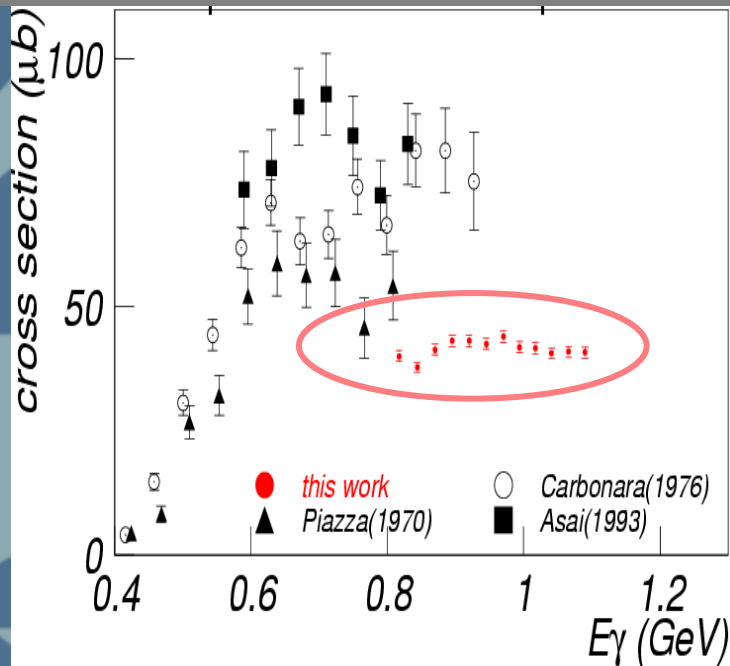


- In the correlation plot of the invariant masses for $p\pi^+$ and $n\pi^-$ systems, the signature of the double Delta ($\Delta^{++}\Delta^-$) excitation can be seen.
- No distinct peak in ($\Delta^+\Delta^0$) excitation.



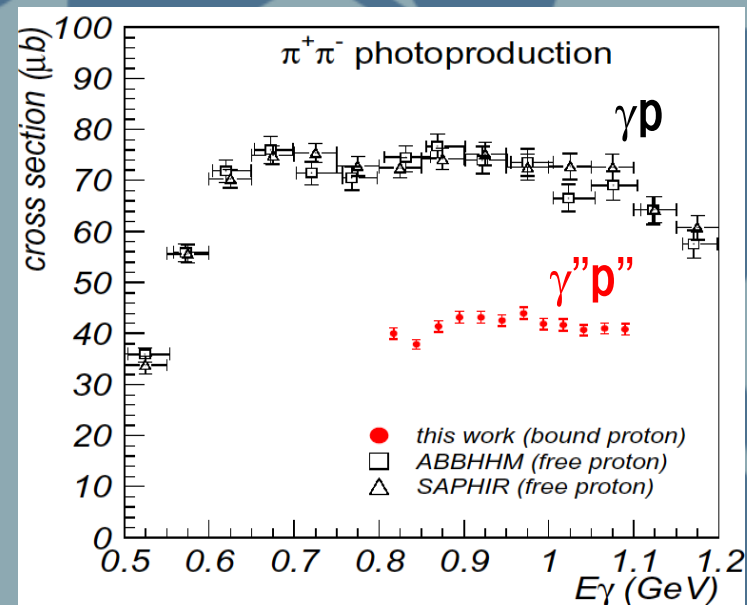
Result from the deuterium target run (QF process)

$\pi^+\pi^-$ photoproduction on the bound proton



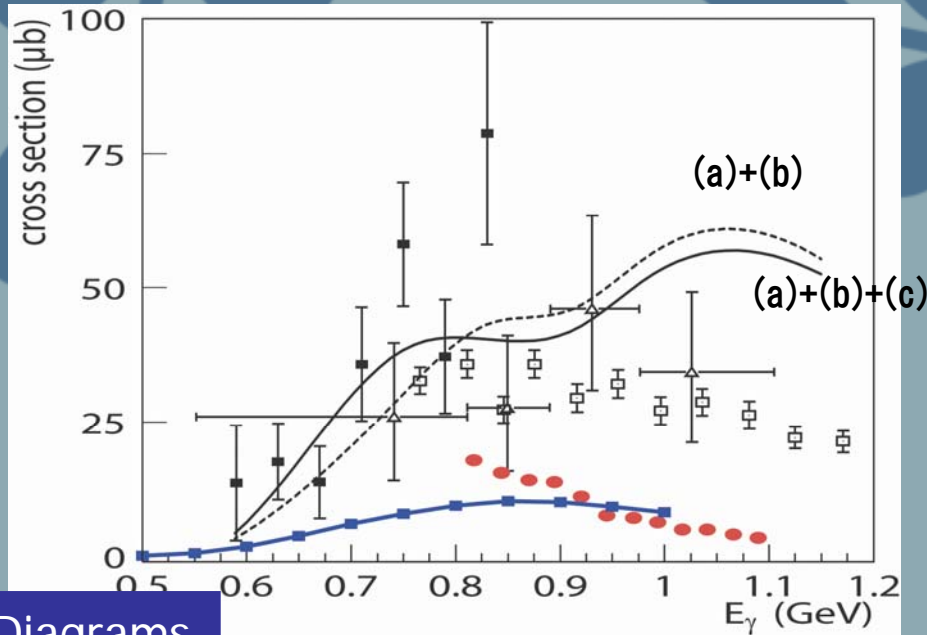
- The obtained cross sections were slightly smaller than the previous data.
- Consistency with Piazza's data

Comparison with the photoproduction on the free proton



- The obtained cross sections were roughly 60 % of the cross sections for the free proton target.

Cross sections for the reaction:

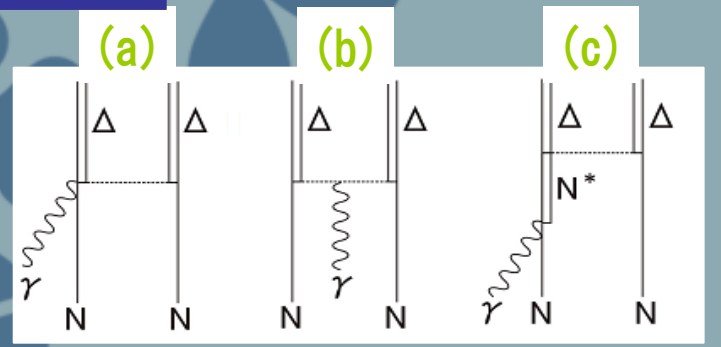


- this work
- Asai (TAGX)
- Wada (SAPHIR, PANIC'96)
- △ Shinozaki (TAGX, private communication)
- J. A. Gomez Tejedor *et al.*
- A. Fix (very preliminary)

Our result shows smaller cross sections than the previous data and the theoretical calculation by J. A. Gomez Tejedor *et al.*

Note that their calculation was based on the models in lower energy, therefore, results in $E > 800$ MeV might contain large uncertainties.

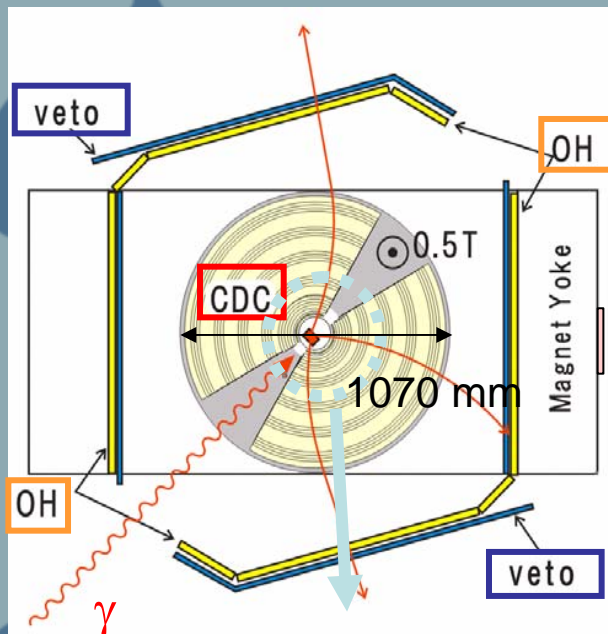
Diagrams



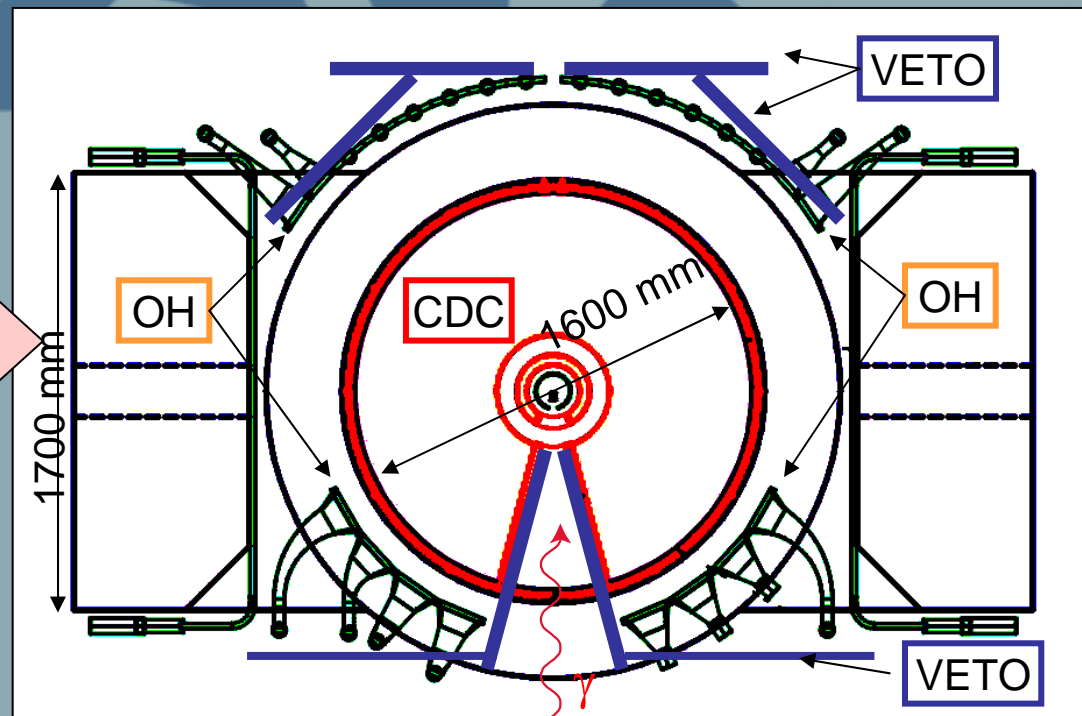
The theoretical calculation by A. Fix consists of only the diagram (a) (very preliminary result).

Upgraded NKS (NKS2)

NKS (2001 ~ 2004)



NKS2 (2005 ~)



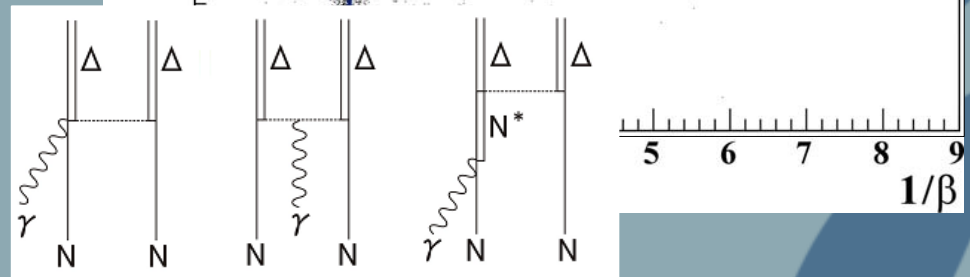
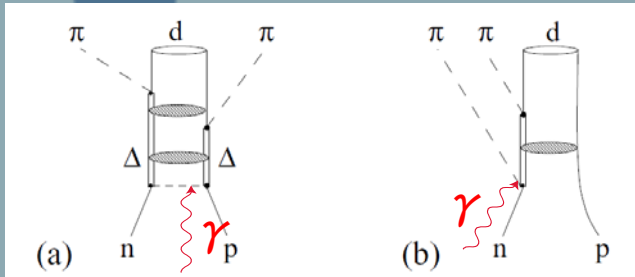
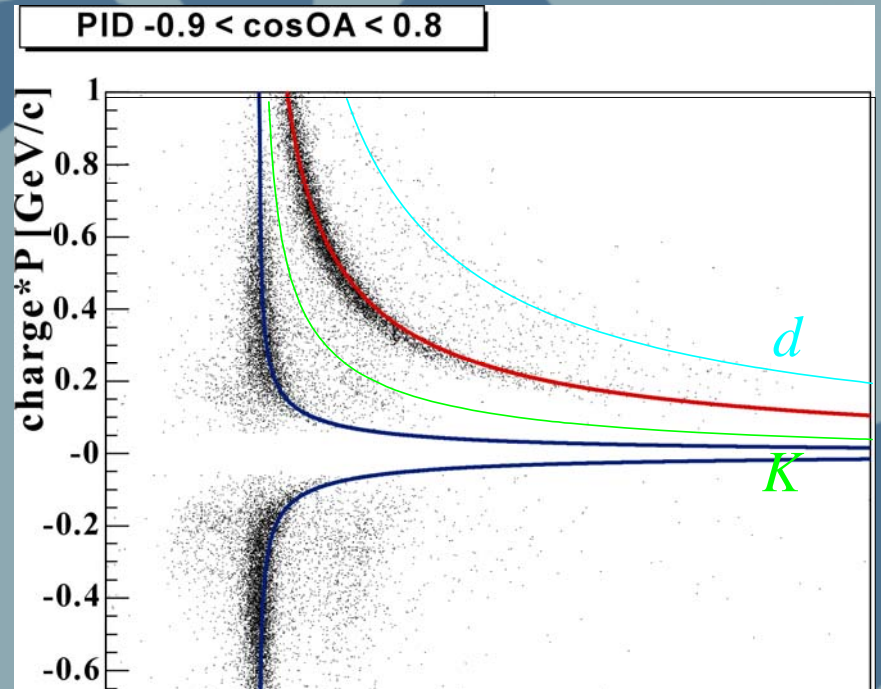
- Larger pole radius -> More precise PID and momentum measurement
- Fiducial volume in the forward region
- Confirmation of the difference between free and quasifree processes
- Measurement including the lower energy region (from 0.55 to 0.92) is planned

Coherent production

- Upgrade from NKS to NKS2 provided us of the better PID.

Locus of the deuteron

- Coherent reaction
- Coherent double pion photoproduction like the ABC effect:



Summary

- The deuteron is a useful tool for the investigation of the interaction between the exotic particles through the final state interaction.
- Double pion production provides us with a stage for the investigation of ΔN - and $\Delta\Delta$ -interactions.
- Both the proton and the neutron induced reactions are to be investigated with exclusive measurement. And the polarized beam opens a new view (spin dependent interactions).
- Photoproduction experiment has been performed at LNS-Tohoku, and the theoretical investigation gets underway.
- The comprehensive understanding of both photo-induced and baryon-induced double pion production processes will reveal the unknown aspect of the two-nucleon system.

Yester I wish yesterday's noise leads tomorrow's discovery. noise.

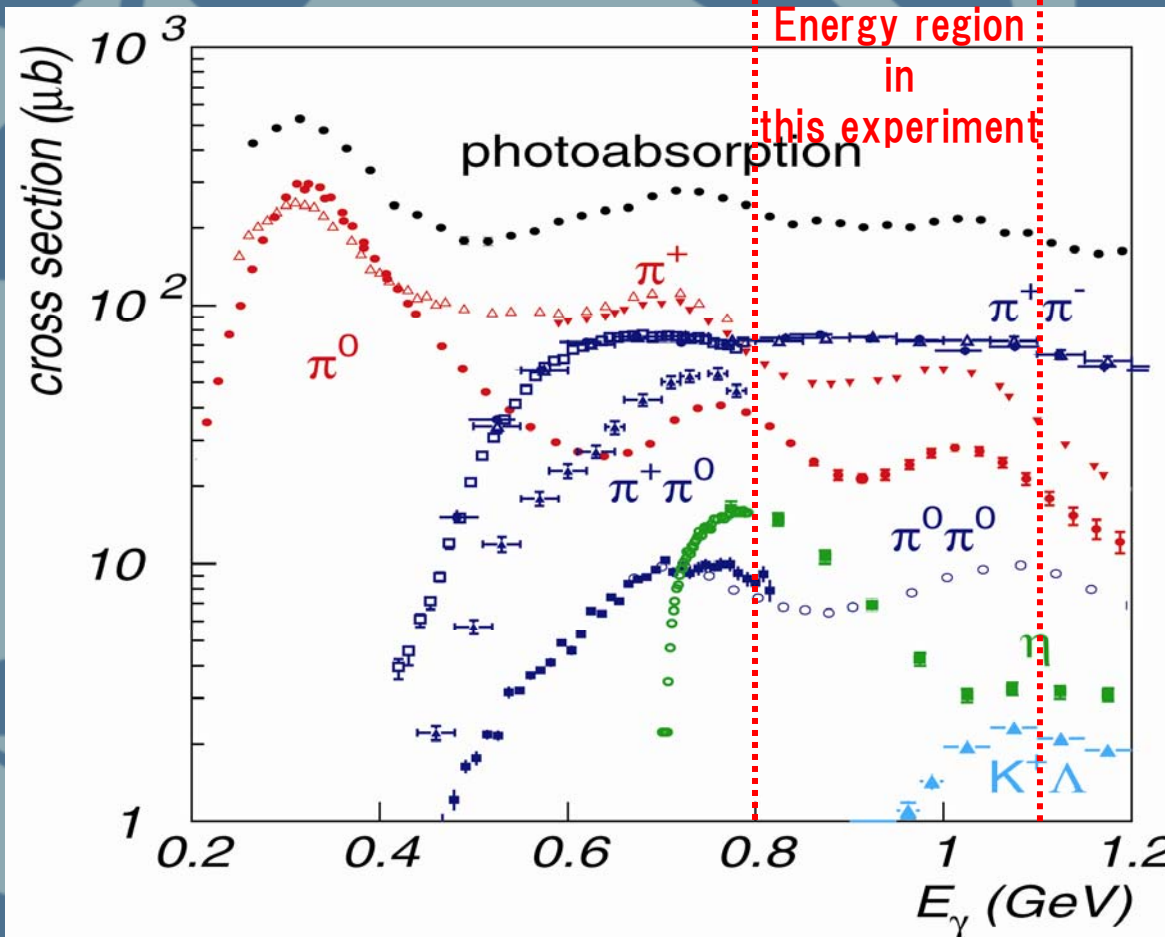


Reserved

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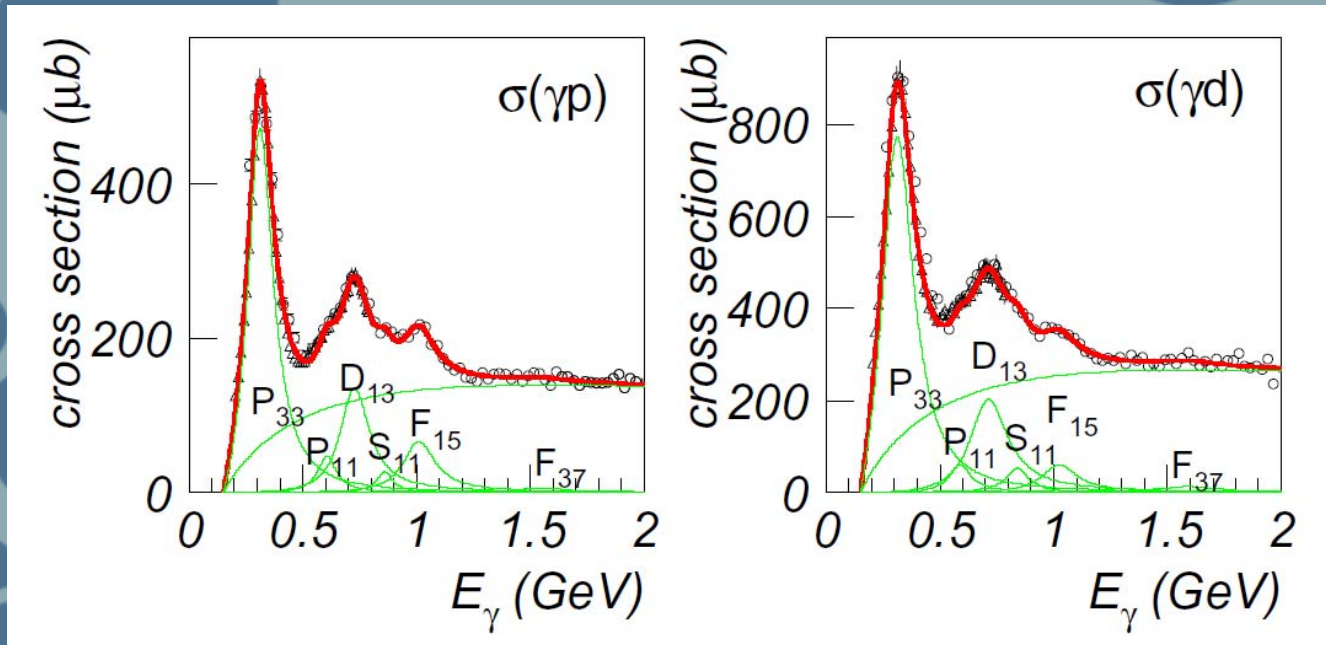
Pion photoproduction on the proton



- The $\pi^+\pi^-$ photoproduction accounts for 30% of the photoabsorption cross sections in the third resonance region.
- It is reasonable to focus on the $\pi^+\pi^-$ production for the investigation of the photoreactions on the deuteron.

Photoabsorption and nuclear resonances on the deuteron

- The second and third resonance on the nucleus: less prominent than on the proton.
- **The same tendency seen on the deuteron.**
 - Nuclear effect ? - the Fermi motion, final state interaction, meson exchange current, Delta-hole etc.
- Search for the missing resonance which couples to the multi-pion channels



Data points:
PRD5(1972)1640
PRC53(1996) 41
Multipole analyses:
PR182(1969)1729
PRC54(1996)1688

Double Delta excitation in NQF process



process

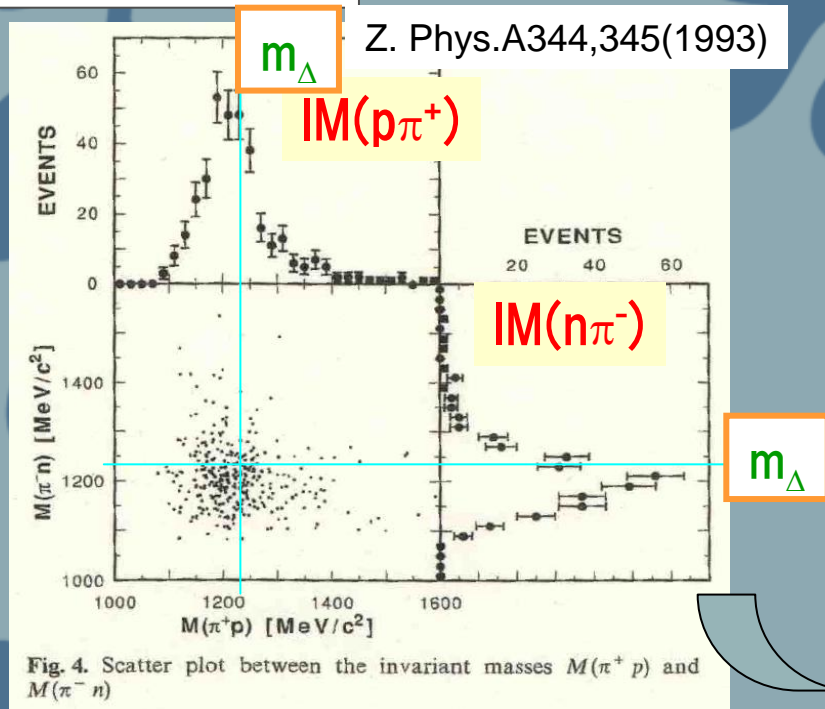
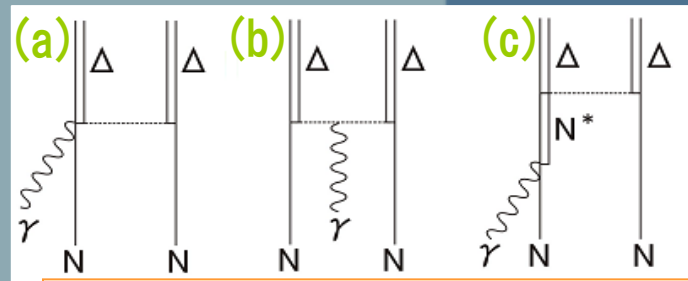
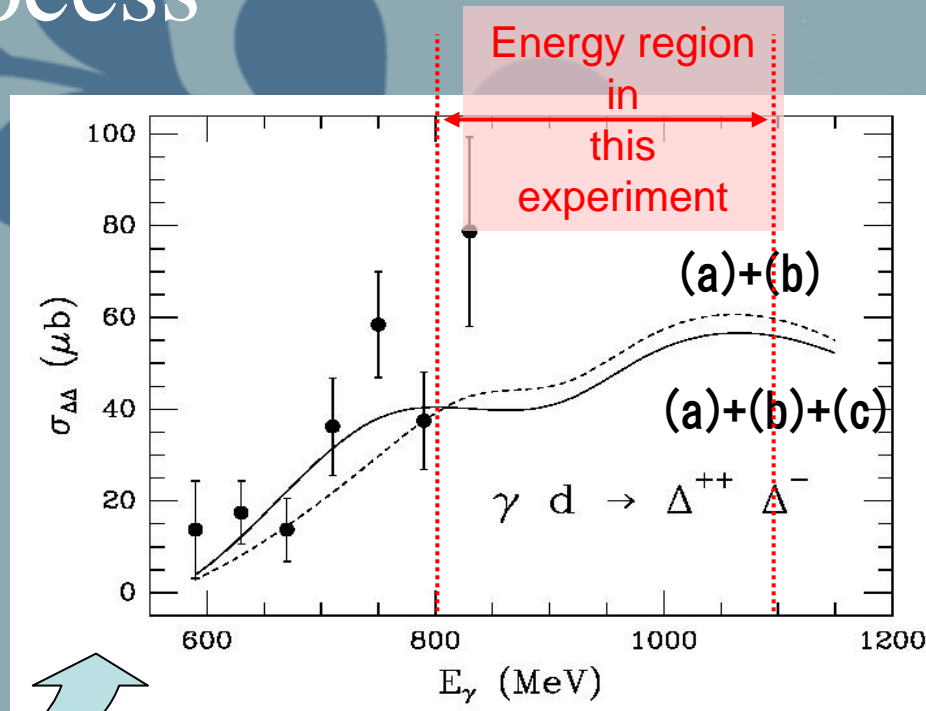


Fig. 4. Scatter plot between the invariant masses $M(\pi^+ p)$ and $M(\pi^- n)$

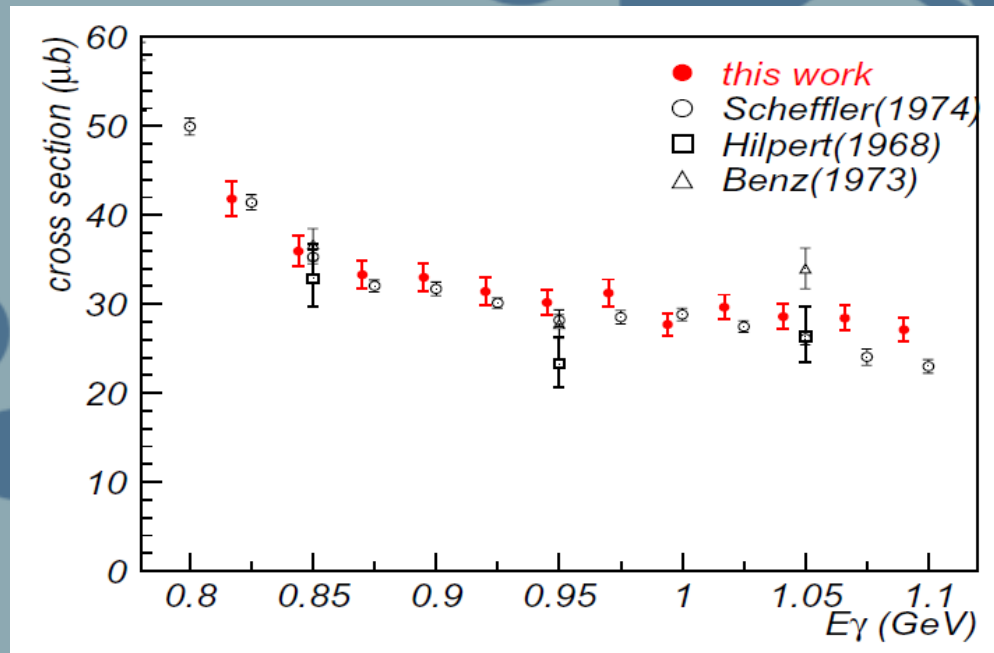


Gomez Tejedor, Oset, Toki, PLB346,240(1995)

Double delta peak was observed with cuts on large momenta for both proton ($p_p > 300$ MeV/c) and neutron ($p_n > 250$ MeV/c)

Single pion photoproduction on the deuteron (QF process)

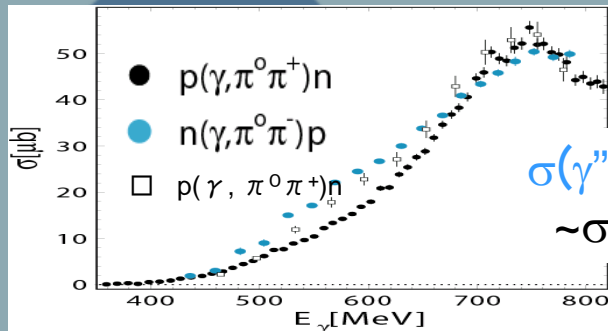
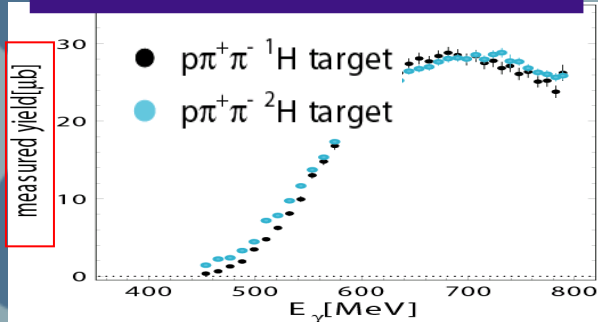
- The reaction $\gamma d \rightarrow pp\pi^-$ (p -spectator) is the simplest channel obtained with NKS from the deuteron target data.



Consistent within the error bars: Small systematic errors in our analysis even for the deuteron target data

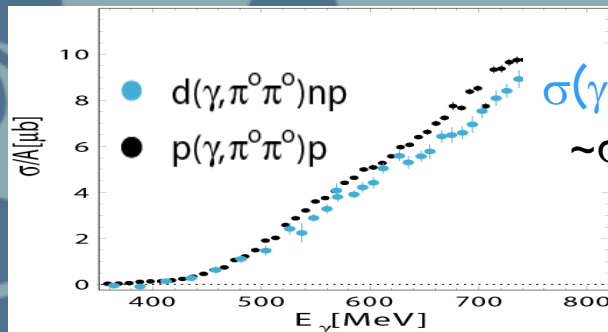
Double pion photoproduction on the deuteron

DAPHNE and TAPS data



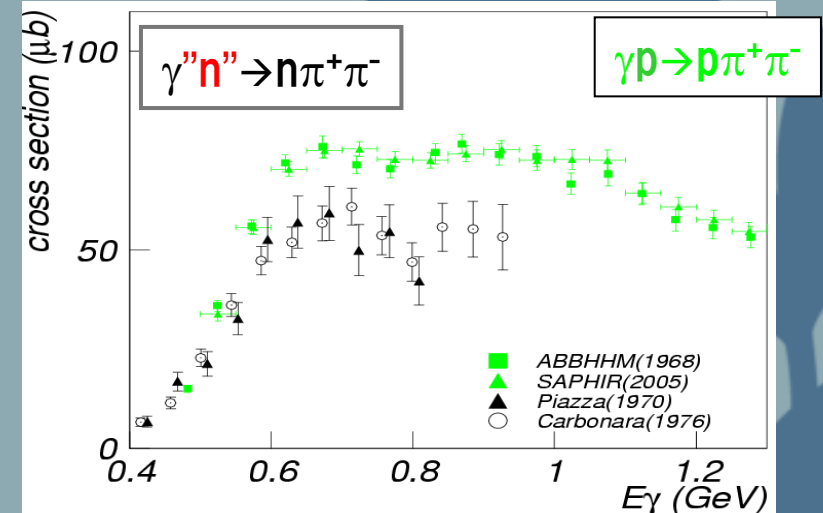
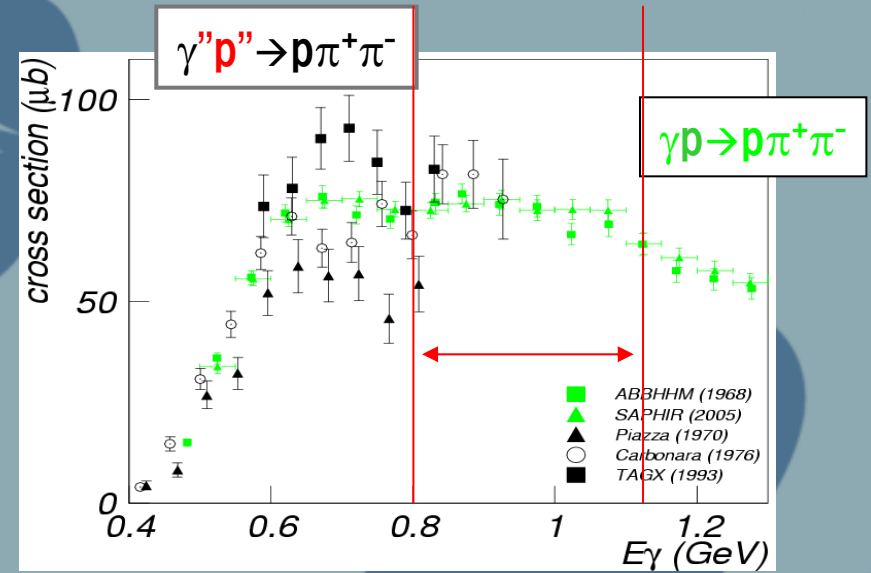
$$\sigma(\gamma n \rightarrow p \pi^0 \pi^-)$$

$$\sim \sigma(\gamma p \rightarrow n \pi^0 \pi^+)$$



$$\sigma(\gamma d \rightarrow pn \pi^0 \pi^0) / 2$$

$$\sim \sigma(\gamma p \rightarrow p \pi^0 \pi^0)$$



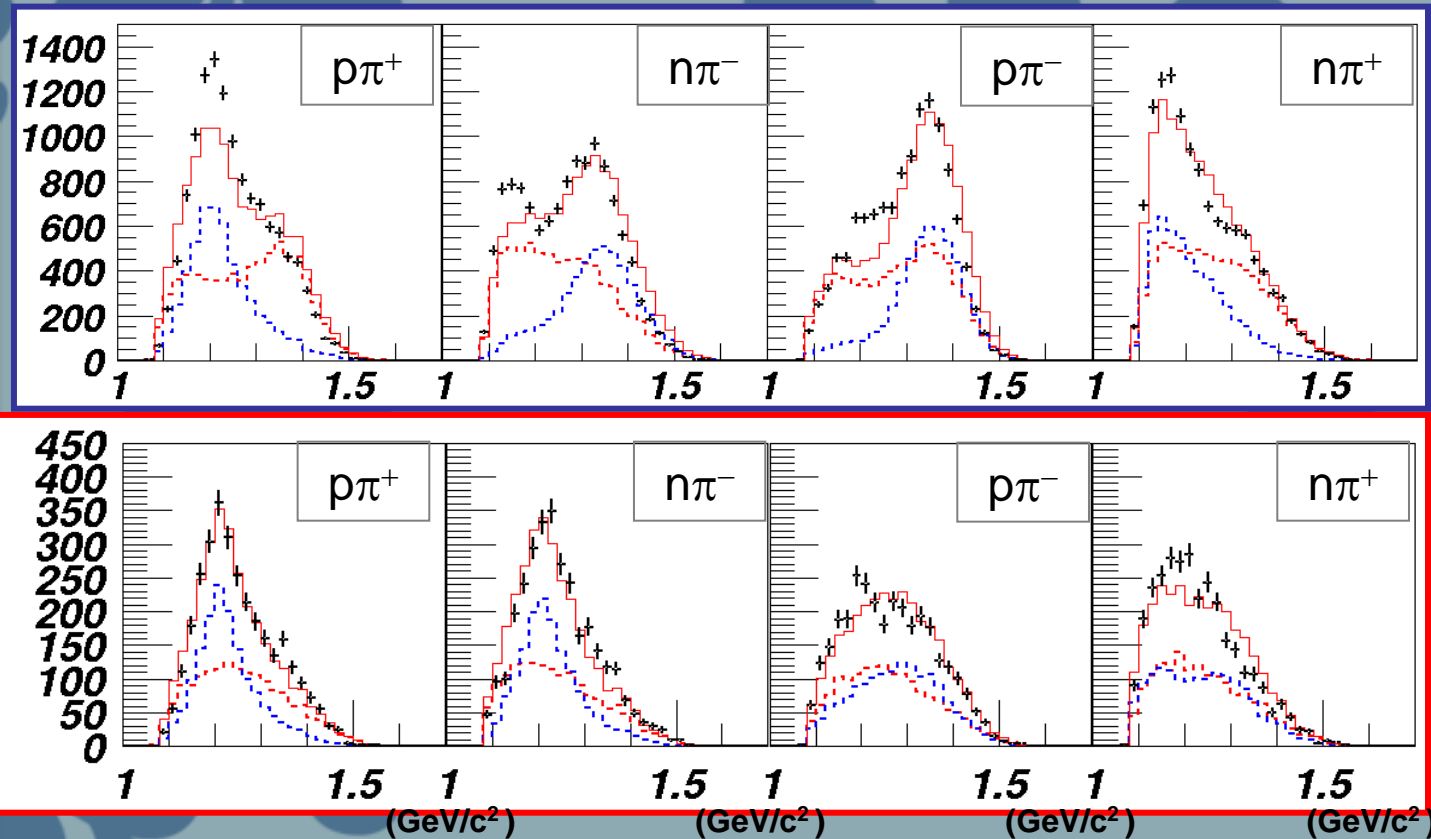
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"N" stands for the bound nucleon in the deuteron

Comparing with experimental data

$E_\gamma = 0.93 - 0.96 \text{ GeV}$



QF kinematics region

$P_n < 0.2 \text{ GeV}/c$

..... $\Delta^{++}\pi^-$
..... 3BPS
——— SUM

NQF kinematics region

$P_n > 0.3 \text{ GeV}/c$

..... $\Delta^{++}\Delta^-$
..... 4BPS
——— SUM

$$\triangleright \text{Exp} = r [\text{sim1}] + (1-r) [\text{sim2}]$$

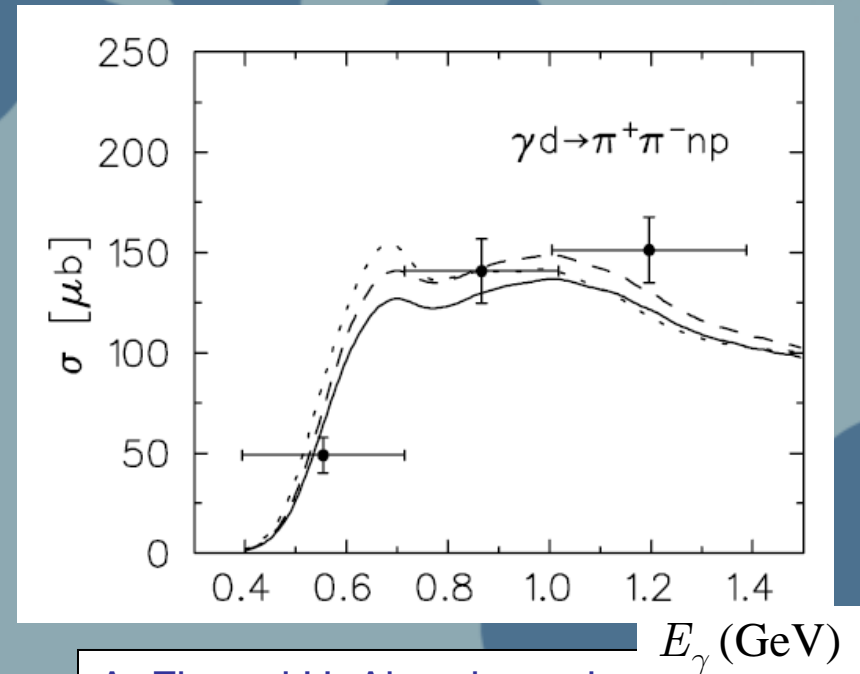
$$\triangleright \eta_{\text{tot}} = r\eta_{\text{sim1}} + (1-r)\eta_{\text{sim2}}$$

QF \rightarrow NQF?

- Spectator model is valid:

$$\begin{aligned}\sigma_p &= \sigma_n \\ \Rightarrow \sigma_d &= \sigma_p + \sigma_n = 2\sigma_p = 150 \\ &\mu\text{b}\end{aligned}$$

- From our result with an assumption: $\sigma_{\text{p}} = \sigma_{\text{n}} = \sigma_{\text{QF}}$
 $\sigma_d = 2\sigma_{\text{QF}} + \sigma_{\text{NQF}} = 105 \mu\text{b}$
- Fix and Ahrenhoevel's calculation with NN-FSI resulted in $130 \mu\text{b}$

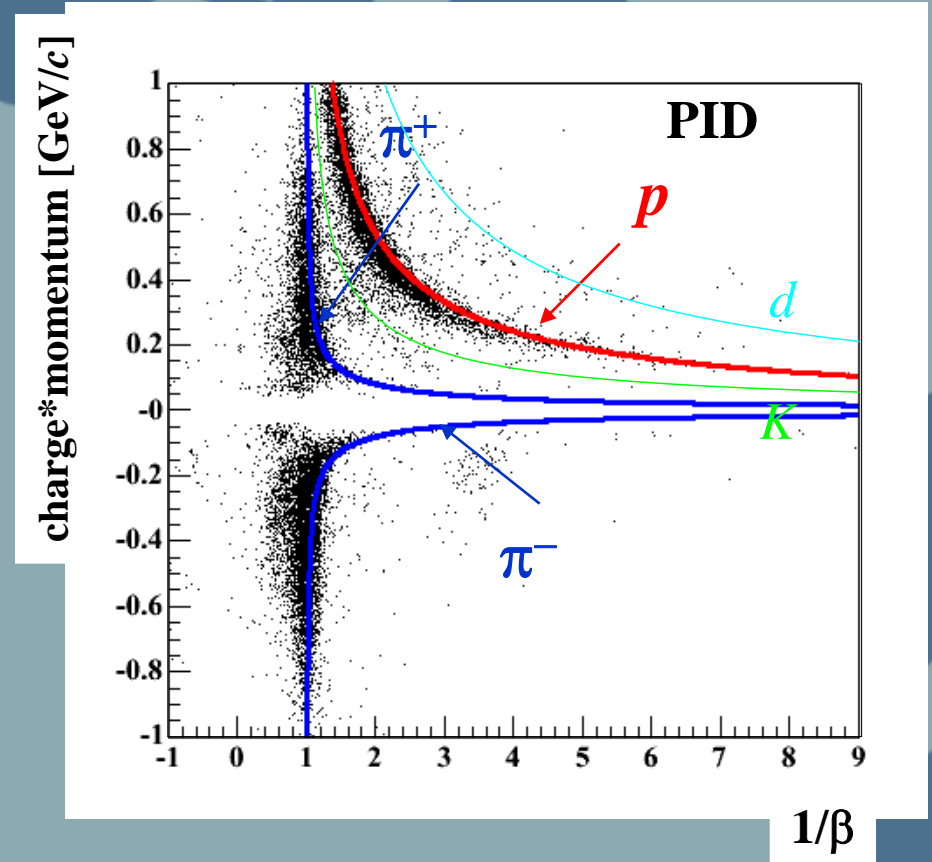


A. Fix and H. Ahrenhoevel,
Eur. Phys. J. A 25, 115 – 135, (2005)

$\pi\text{N-FSI}$ or NN-FSI lead to other non-observable final states?
 $p\pi^- \rightarrow \Delta^0 \rightarrow n\pi^0$ etc.

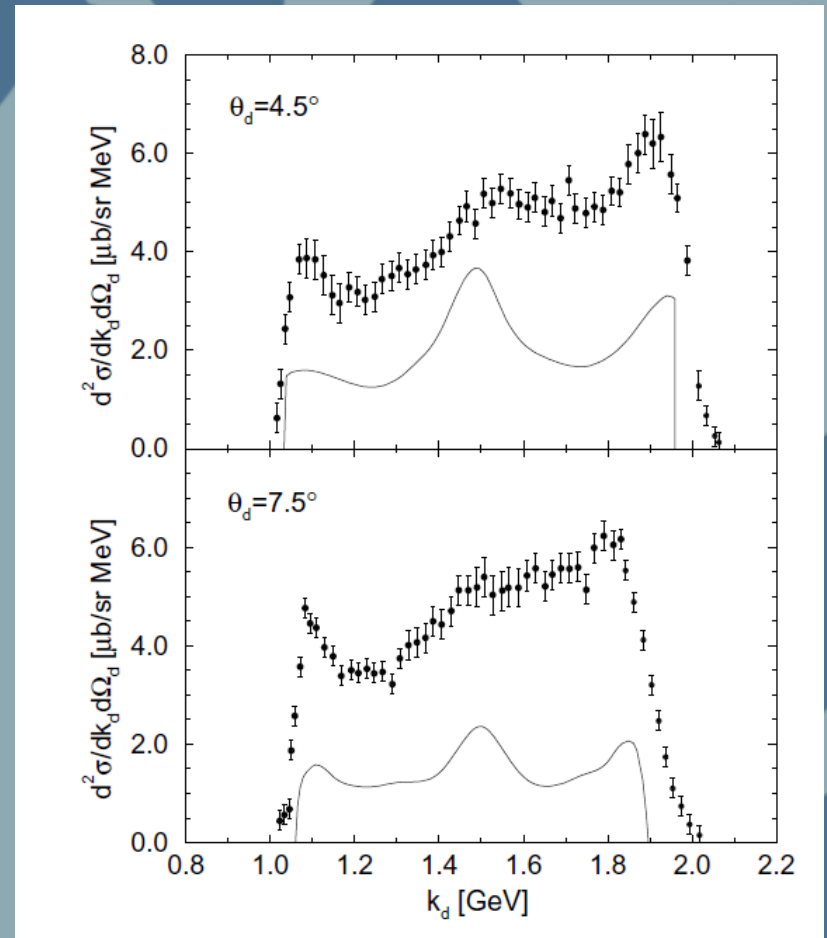
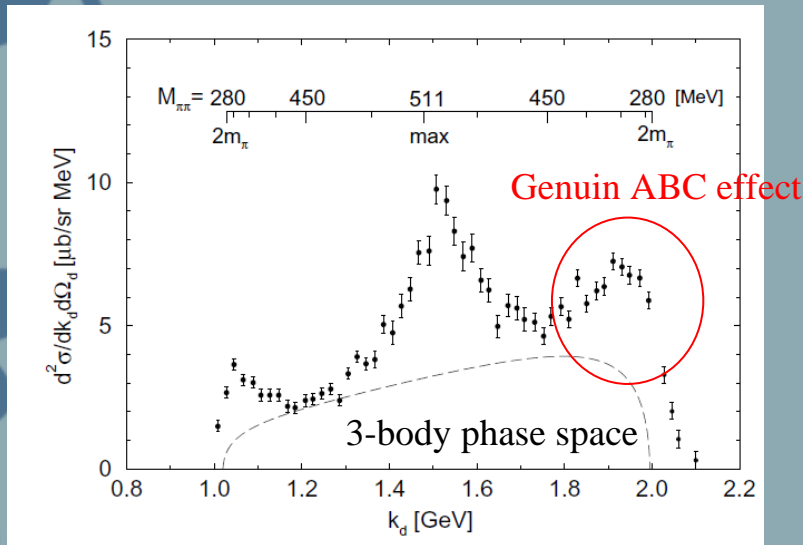
PID with NKS2

- Thanks to the longer TOF length and higher momentum resolution, more precise PID capability is obtained with NKS2.
- Locus for the deuteron can also be seen.
 - Possibility of exclusive observation of the reaction $\gamma d \rightarrow d \pi^+ \pi^-$



Other results by Mosbacher and Osterfeld

- Angular dependence \rightarrow
- Enhancement not only at $M_{XX} \sim 300 - 350 \text{ MeV}/c^2$ but also at $M_{XX} \sim 511 \text{ MeV}/c^2$



Other reactions with charged beam

- $pn \rightarrow d \pi^+ \pi^-$ reaction
 - JINR and DESY with deuterium bubble chambers
 - CELSIUS-WASA
- $\vec{d}d \rightarrow \text{He } \eta$ reaction
 - SPESIII at SATURNE with polarized deuteron beam