YITP workshop on Hadron in Nucleus

$\pi^0\pi^\pm$ photoproduction on the deuteron at ELPH

Univ. of Tokyo, ELPH Tohoku Univ[A], KEK[B], Yamagata Univ.[C]

Shin'ichi Masumoto, Takatsugu Ishikawa[A], Kyoichiro Ozawa[B] ,

Hajime Shimizu[A], Yasuhisa Tajima[C] , Yusuke Tsuchikawa[A], Ryo Hashimoto[C] , Qinghua He[A], Manabu Miyabe[A], Norihiti Muramatsu[A], Hirohoto Yamazaki[A], Ryuji Yamazaki[A], and the Forest Collaboration

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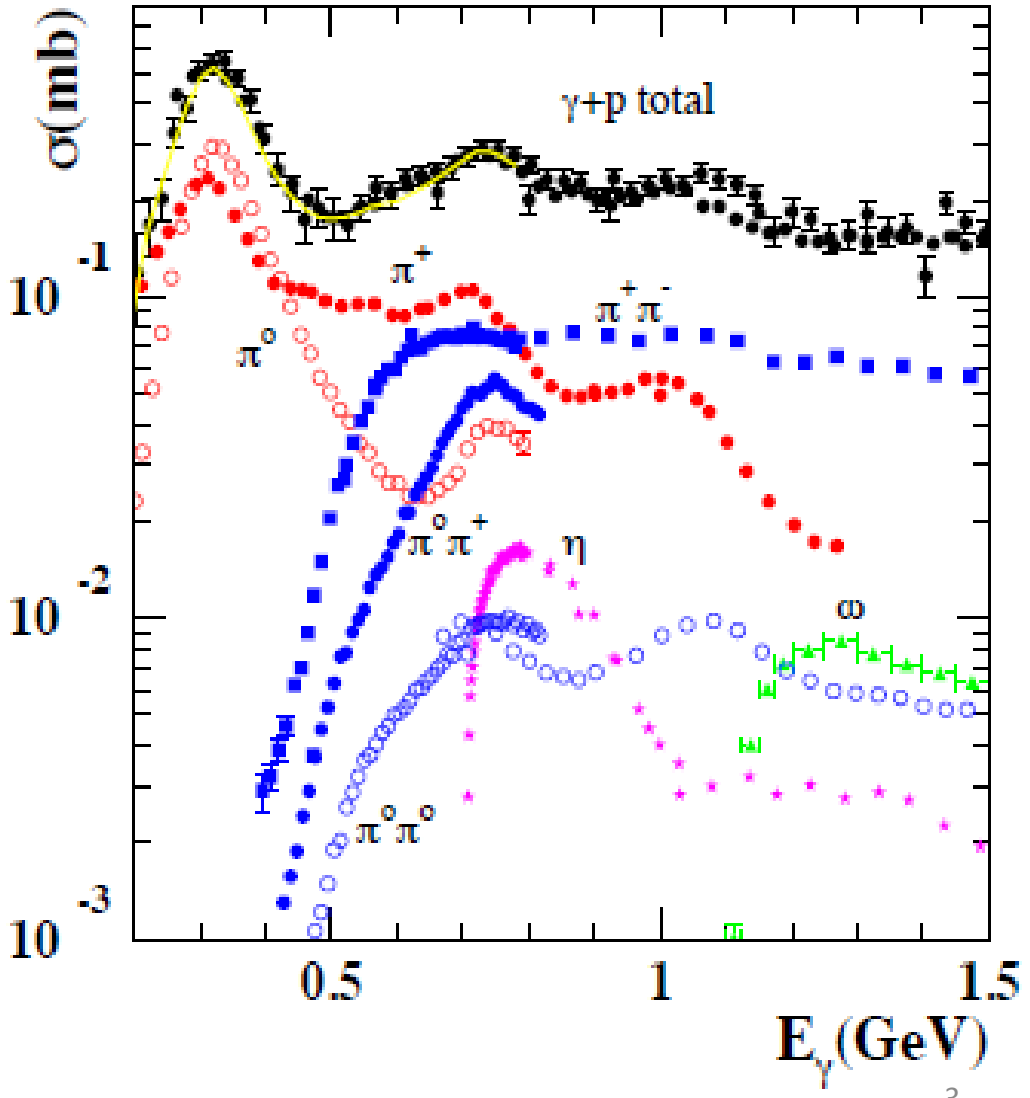
Introduction

- We investigate the highly excited states of baryon resonances by using photon beam.
- The properties of baryons were mainly derived from partial-wave analysis of single π and η production.
- The highly excited baryons do not strongly couple to the πN channel.

⇒multi-meson photoproduction process provides important information on highly excited baryon states.



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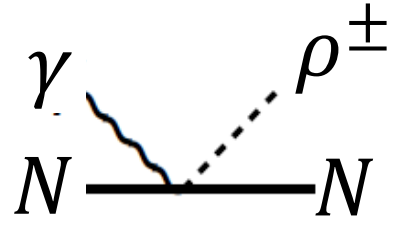
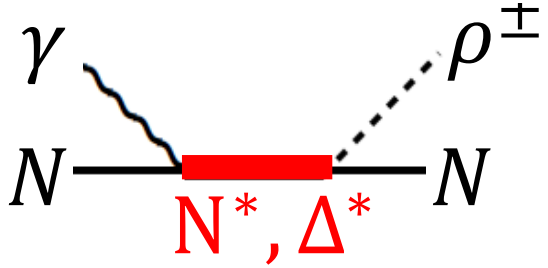
Focus on baryon resonances couple to ρN and $\pi\Delta$ channel using $\gamma N \to \pi^0\pi^\pm N$ reaction

$\rho^\pm N$

$\rho^\pm$ contact term

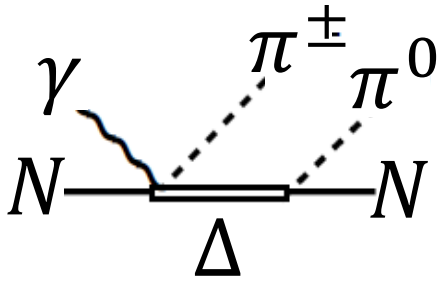


Resonance term

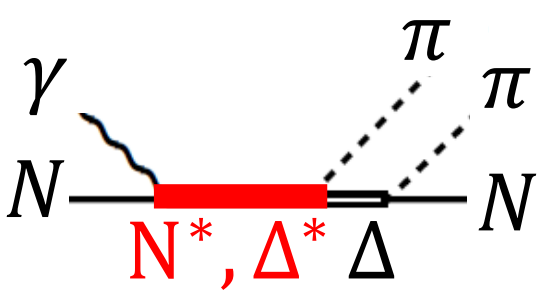


$\pi\Delta$

Δ Kroll-Ruderman



Resonance term



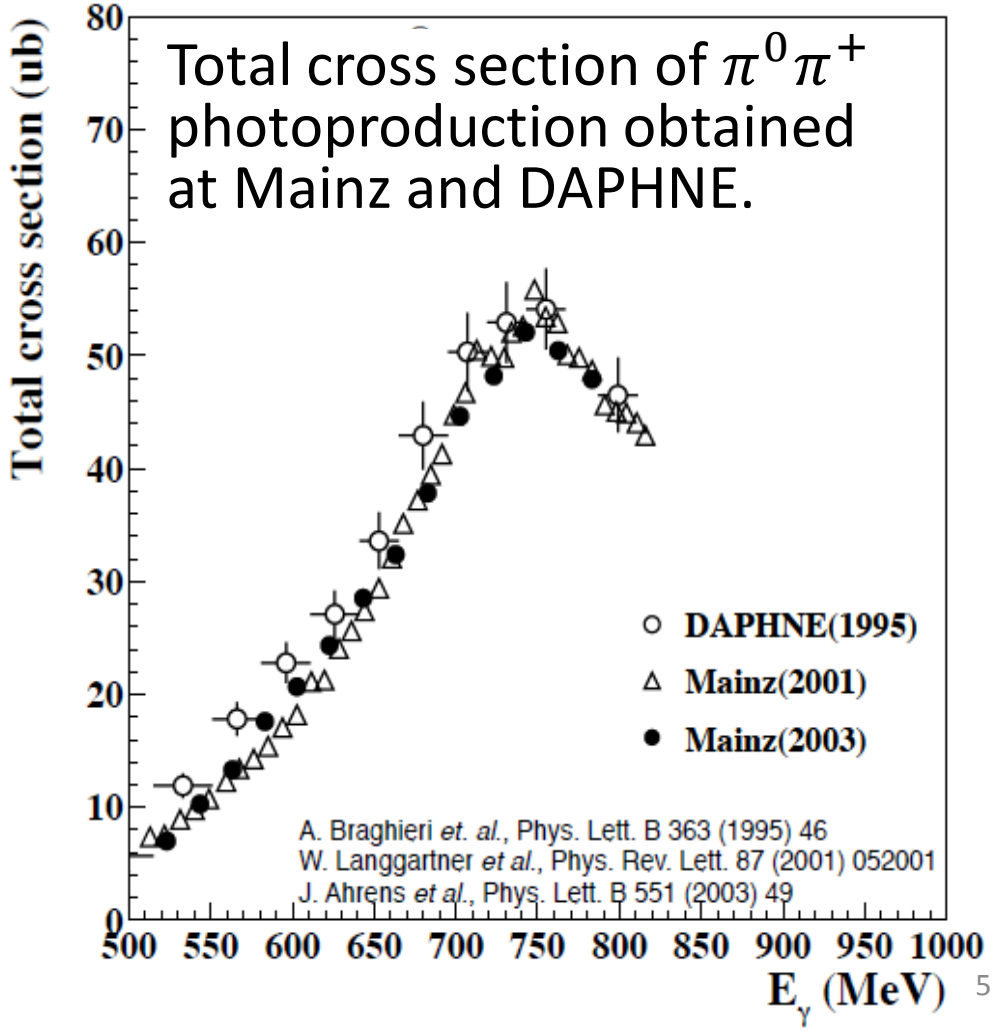
Particle	$L_{2I,2J}$	status	$N\pi$	$\Delta\pi$	$N\rho$
$N(939)$	P_{11}	****			
$N(1440)$	P_{11}	****	****	***	*
$N(1520)$	D_{13}	****	****	****	****
$N(1535)$	S_{11}	****	****	*	**
$N(1650)$	S_{11}	****	****	***	**
$N(1675)$	D_{15}	****	****	****	*
$N(1680)$	F_{15}	****	****	****	****
$N(1700)$	D_{13}	***	***	**	*
$N(1710)$	P_{11}	***	***	**	*
$N(1720)$	P_{13}	****	****	*	**
$\Delta(1232)$	P_{33}	****	****		
$\Delta(1600)$	P_{33}	***	***	***	*
$\Delta(1620)$	S_{31}	****	****	****	****
$\Delta(1700)$	D_{33}	****	****	***	**
$\Delta(1750)$	P_{31}	*	*		

Focus on baryon resonances couple to ρN and $\pi\Delta$ channel using $\gamma N \rightarrow \pi^0\pi^\pm N$ reaction

- The total and differential cross section of $\pi^0\pi^+$ photoproduction for photon energies from 300 to 800 MeV have been reported by Mainz and DAPHNE.

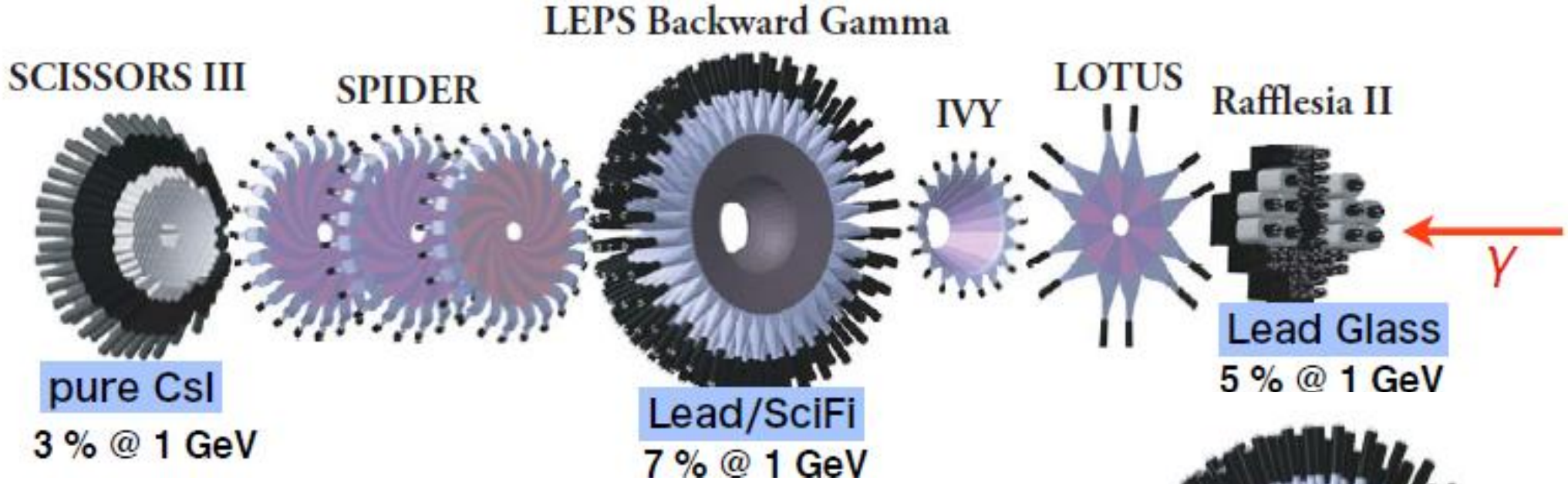
- Measurement of $\pi^0\pi^-$ photoproduction has not been reported.

⇒The precise measurements of the $\pi^0\pi^\pm$ photoproduction for photon energies more than 800 MeV are important to study the properties of 2nd and 3rd resonance region.

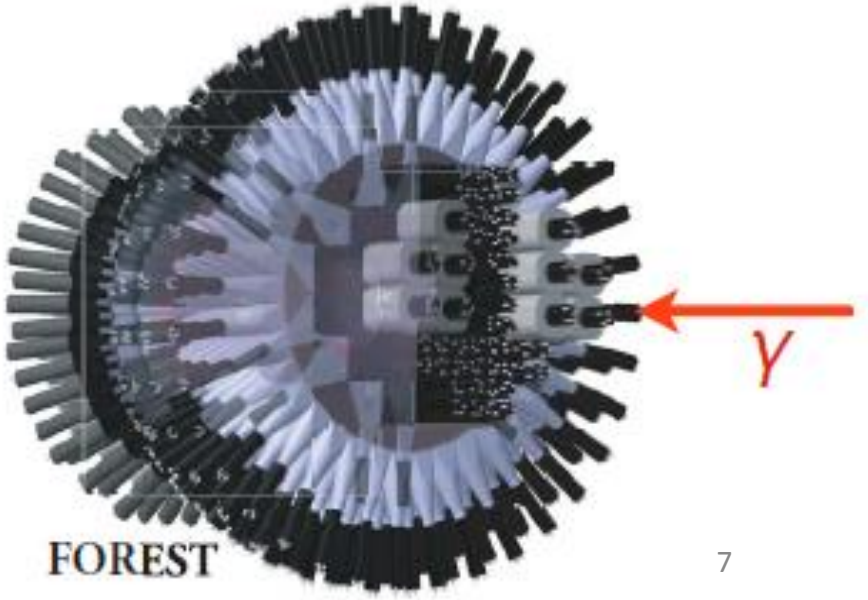


Analysis of $\gamma N \rightarrow \pi^0 \pi^{\pm} N$ on the proton and deuteron

Experimental setup



- Bremsstrahuling tagged photon beam : 570～1150 MeV (ΔE =1～2 MeV)
- Hydrogen/deuteron target
- Three type of calorimeters : acceptance ～ 90%
- Plastic scintillation counters are placed in front of each calorimeters.



Analysis procedure of $\gamma N \rightarrow \pi^0 \pi^{\pm} N$

1. Particle identification

   Detection of all emitted particles ($\pi^0 \rightarrow \gamma\gamma$, $\pi^{\pm}$, proton/neutron) are required.
   - $\pi^0 \rightarrow \gamma\gamma$ selection.
   - Proton/charged pion identification.
   - Neutron identification.

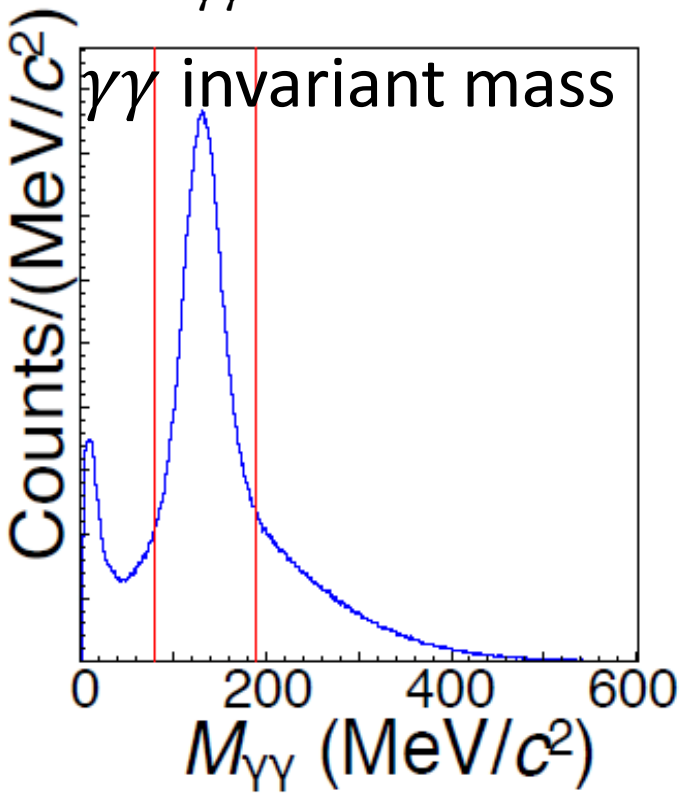
2. Kinematical Fitting
   - Event identification using Chi-square probability test.
   - improve intermediate mass resolution.

3. Acceptance & Efficiency correction
   - Evaluate detection efficiency of proton/neutron/charged pion
   - Total cross section and differential cross section

1. Particle identification

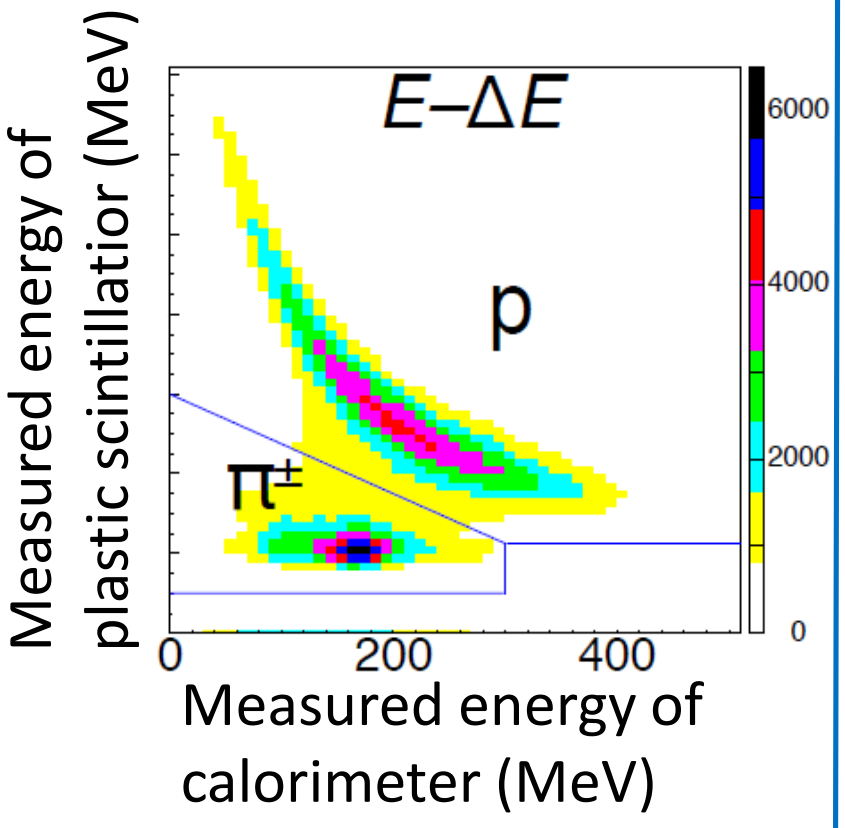
$\pi^0 \rightarrow \gamma\gamma$ selection

- Two neutral particles
- Timing difference of $\gamma\gamma$ < 1.5 nsec.
- $90 \leq M_{\gamma\gamma} < 190$ MeV/c^2



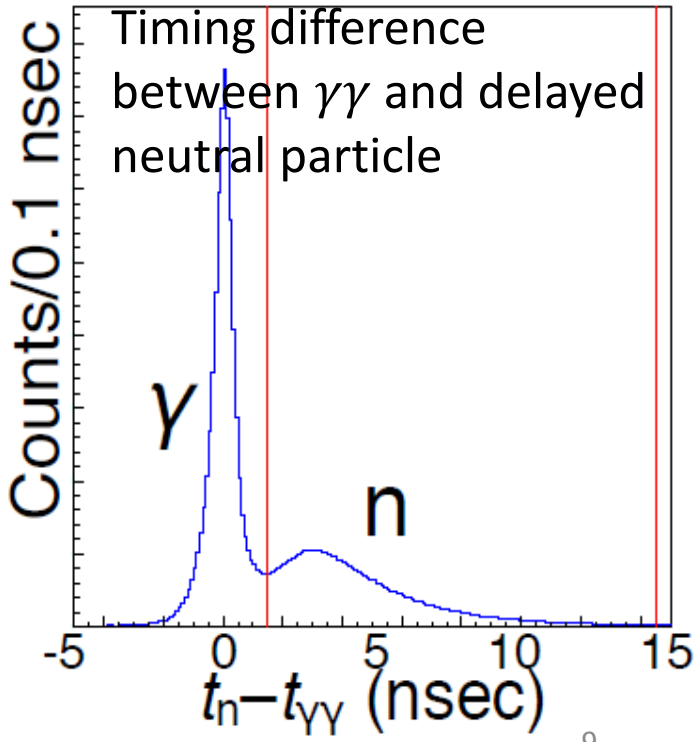
Proton/$\pi^{\pm}$ identification

- Identified by means of ΔE and E correlation.



Neutron identification

- Delayed neutral particle from $\gamma\gamma$ timing [1.5, 15) nsec



2. Kinematical Fitting (4C-fit)

- Event selection using Chi-square test.

Constraints :

$\gamma\gamma$ invariant mass

Energy and momentum conservation

Measurement variables :

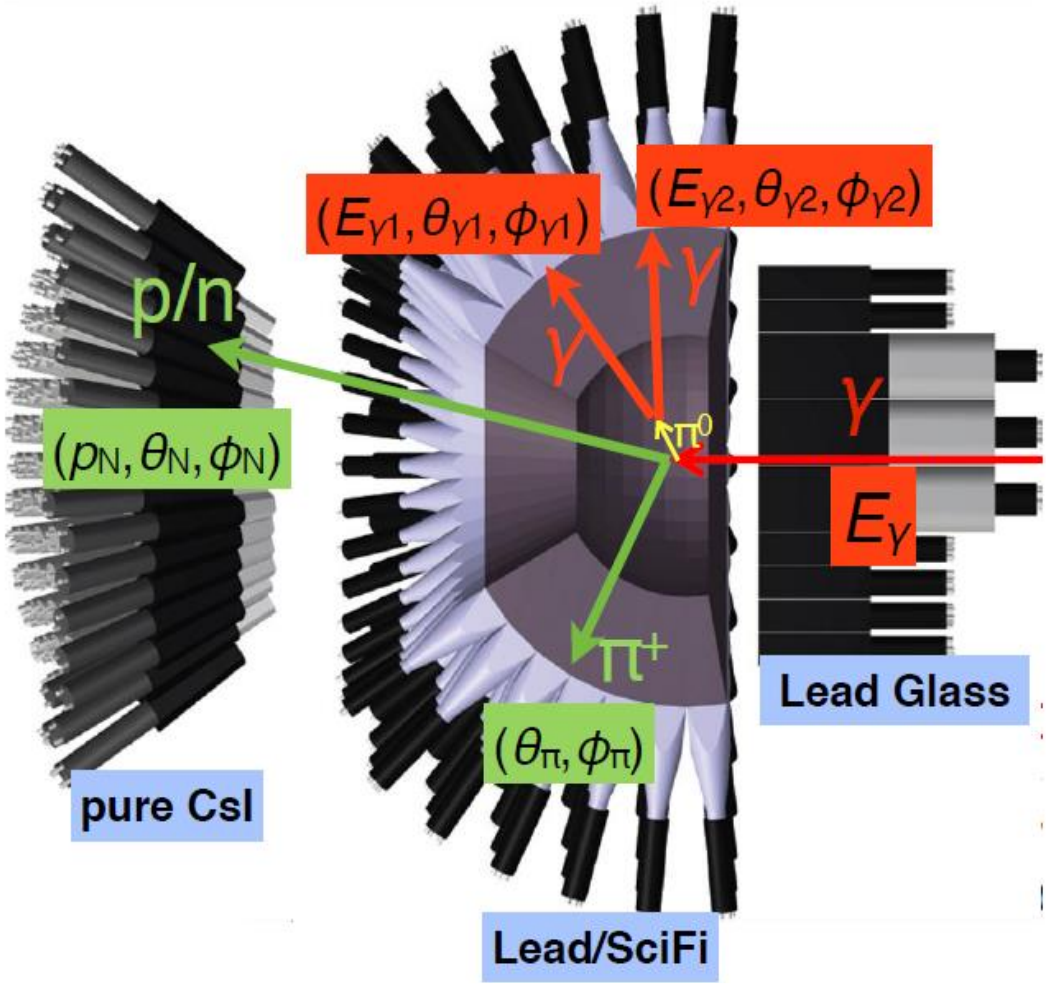
photon beam energy

Momenta of the $\gamma\gamma$

Emitted nucleon momentum

Emitted angle of $\pi^{\pm}$

χ^2 probability $\geqq 0.1$



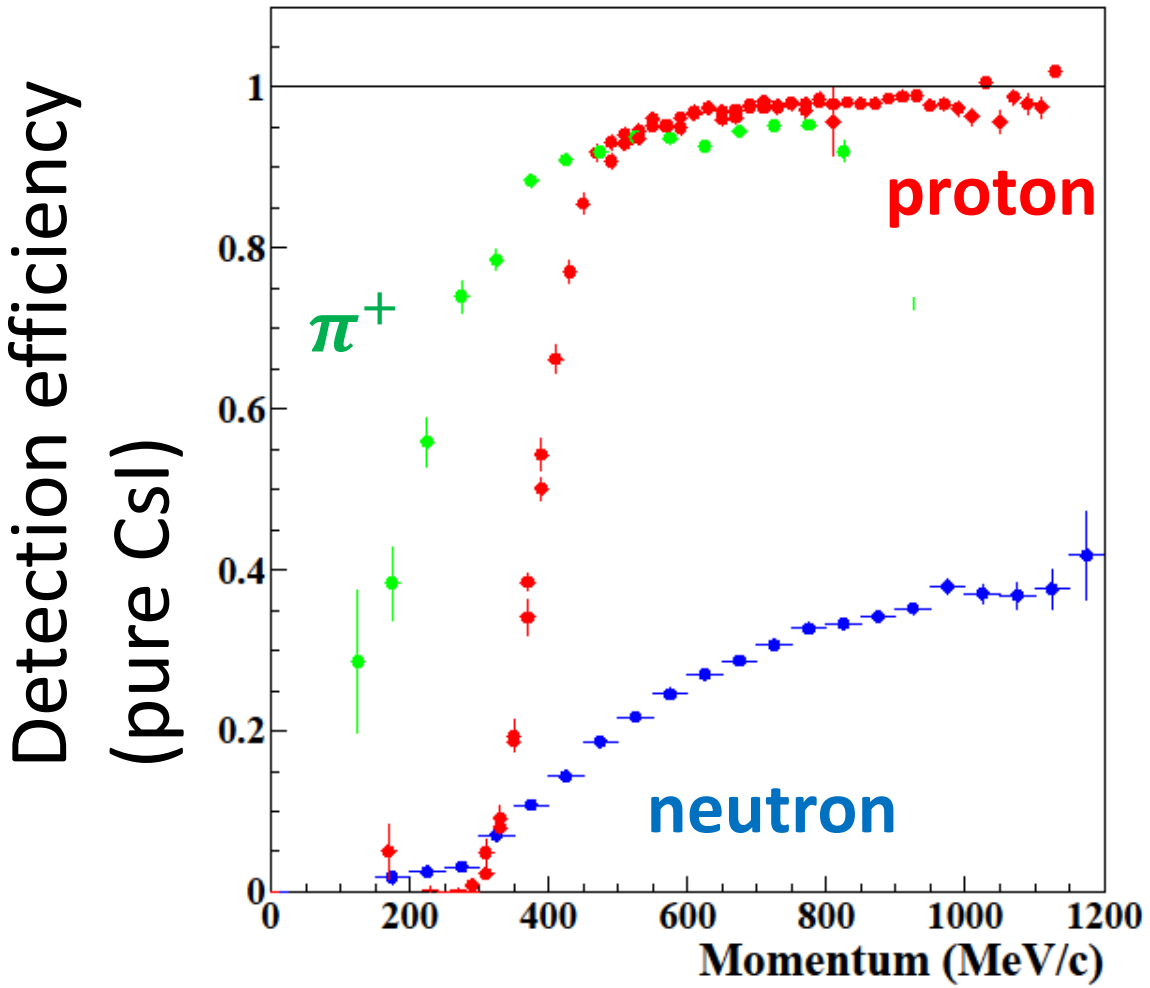
3. Acceptance & Efficiency correction

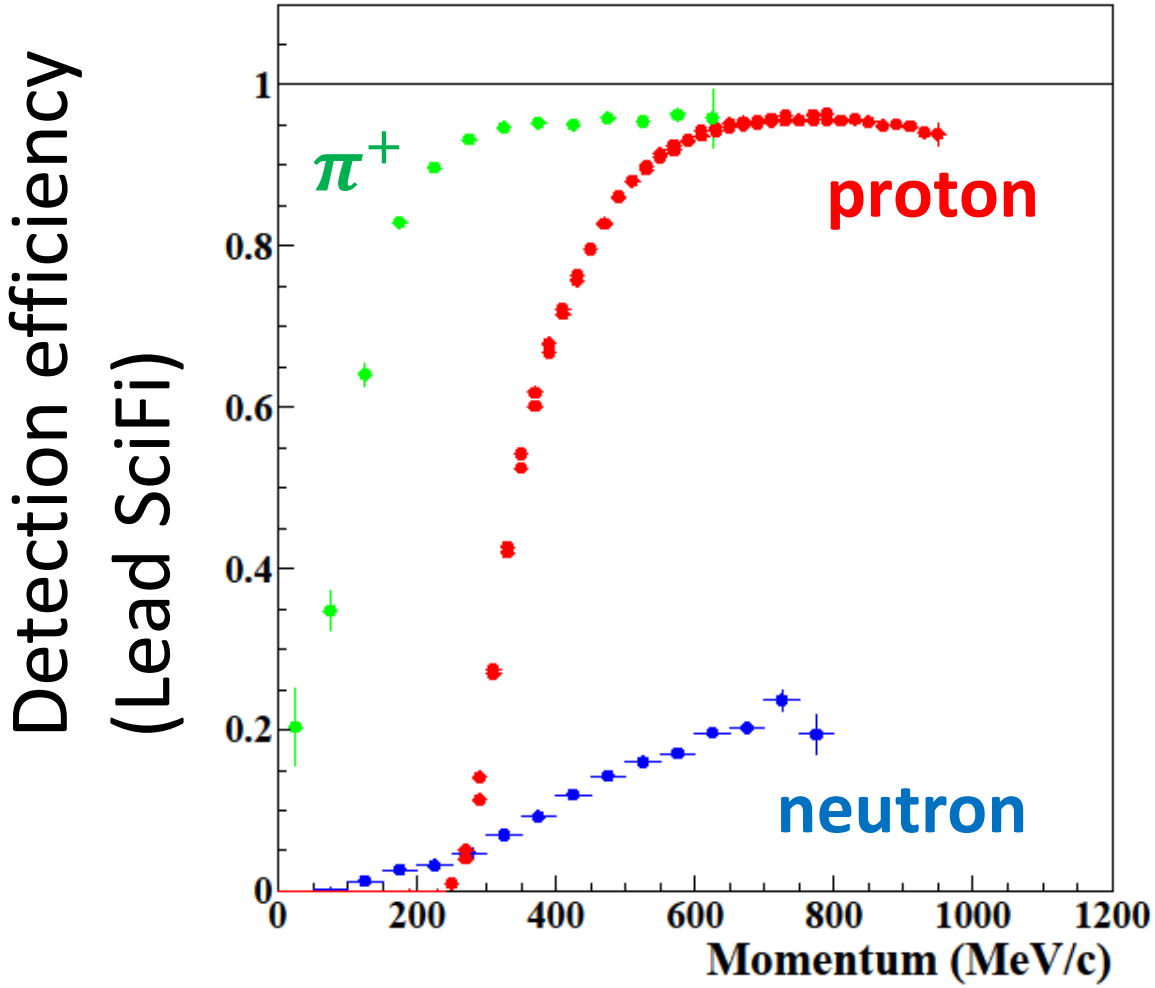
- We evaluate proton, neutron and charged pion detection efficiency of pure CsI and Lead/SciFi calorimeters.

- Proton efficiency is evaluated using missing proton kinematical fit of $\gamma p \rightarrow \eta p$ and $\gamma p \rightarrow \pi^0 p$ reaction on the hydrogen.

- Neutron (charged pion) efficiency is evaluated using missing neutron (charged pion) kinematical fit of $\gamma p \rightarrow \pi^0 \pi^+ n$ reaction on the hydrogen.

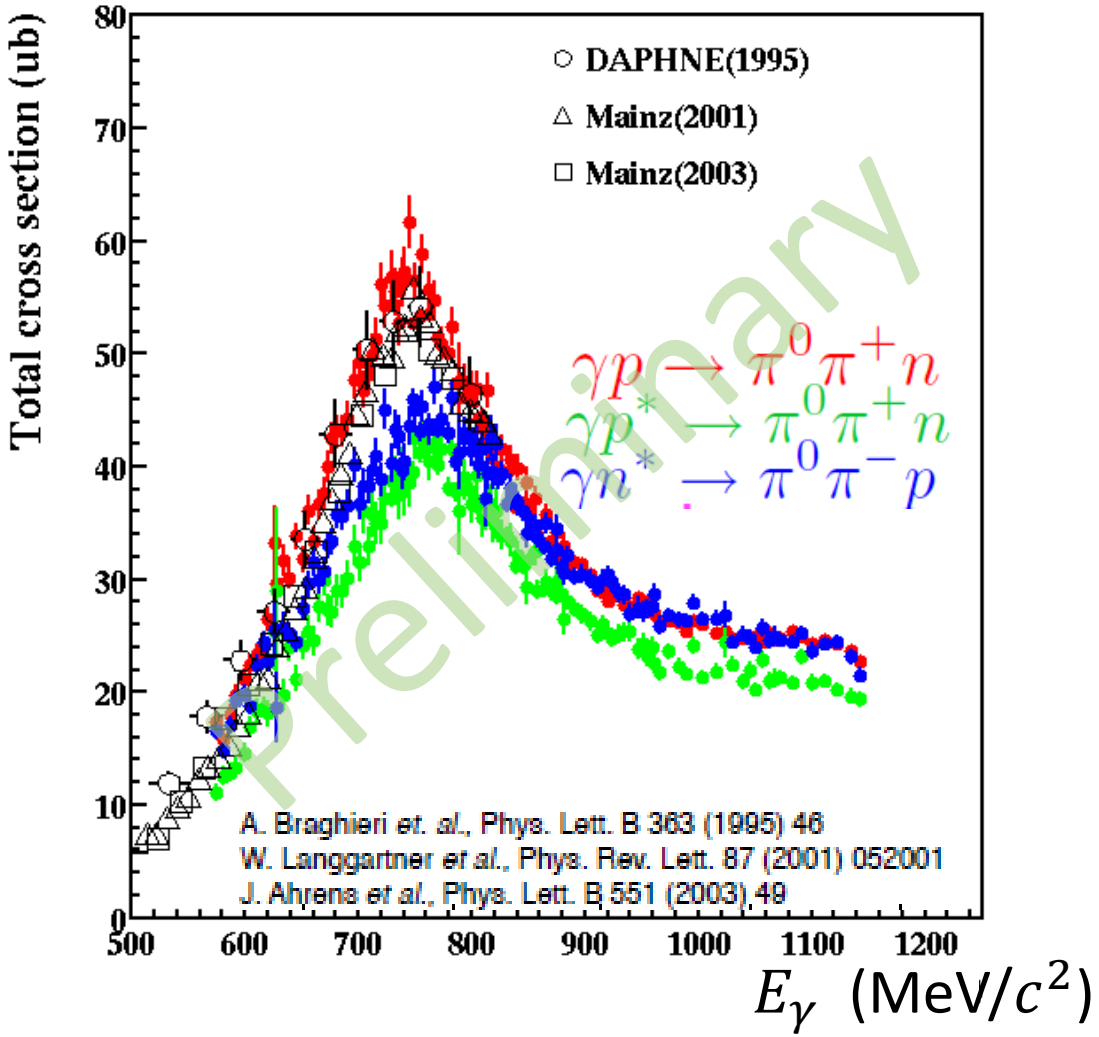
Efficiency Evaluation



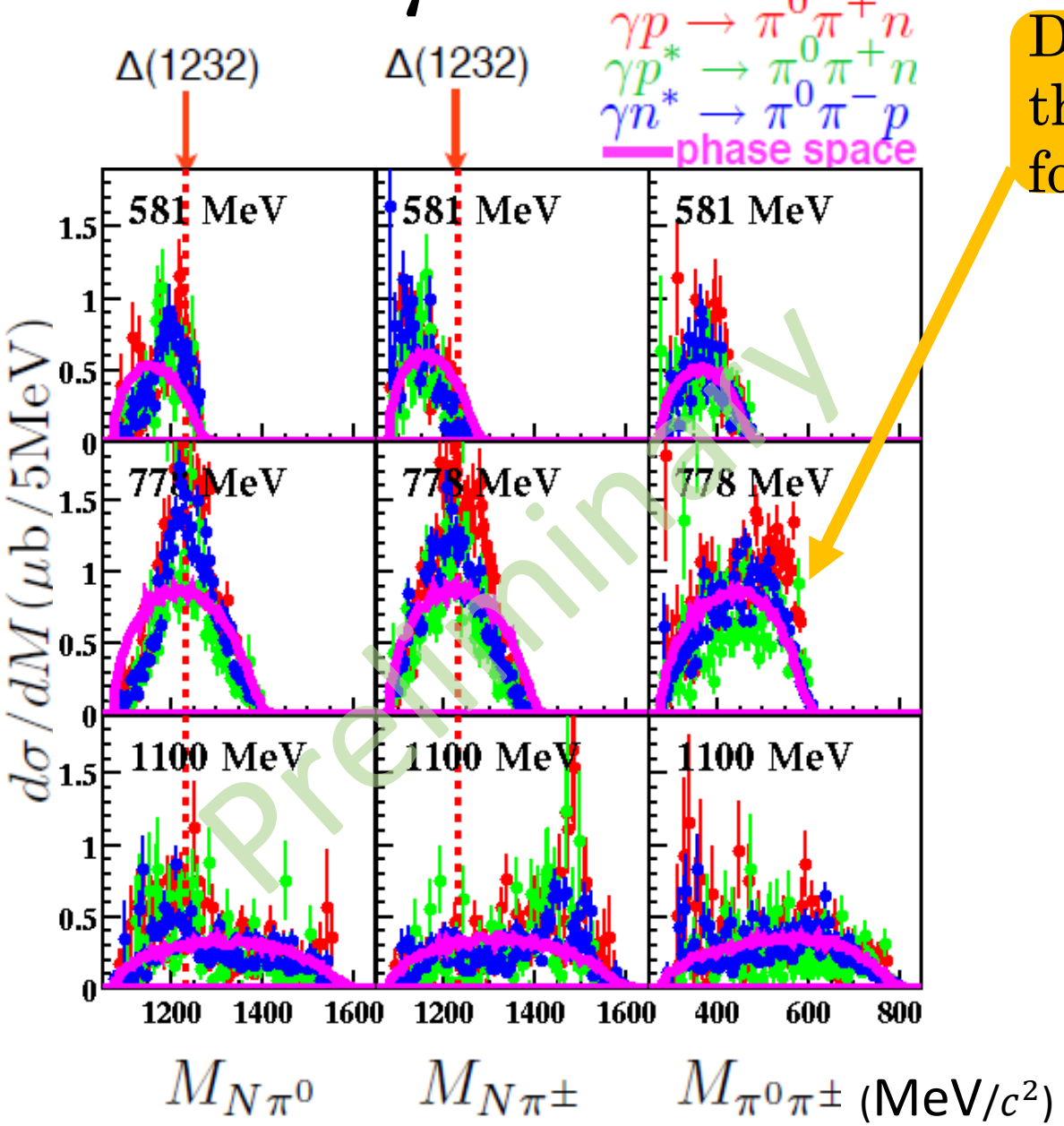


$\gamma N \rightarrow \pi^0\pi^{\pm}N$ cross section

- Acceptance correction using Geant4 based Monte-Calro simulation with obtained detector efficiency.
- Those plots with higher energy above 800 MeV are newly obtained.
- Our data covers 2nd and 3rd resonance region.



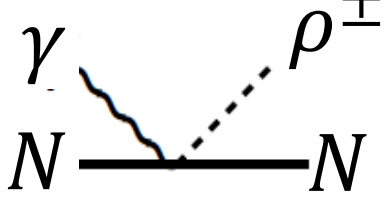
$\gamma N \to \pi^0\pi^\pm N$ cross section



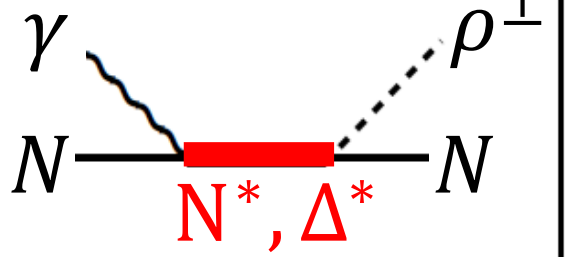
Deviation of the experimental data from the phase space distribution are evidence for meson intermediate states.

$\rho^\pm N$

$\rho^\pm$ contact term

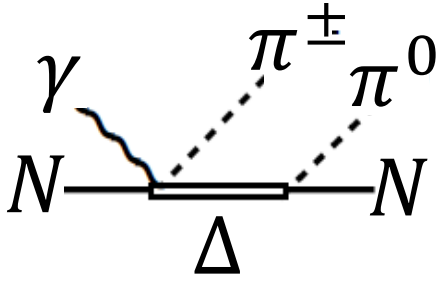


Resonance term

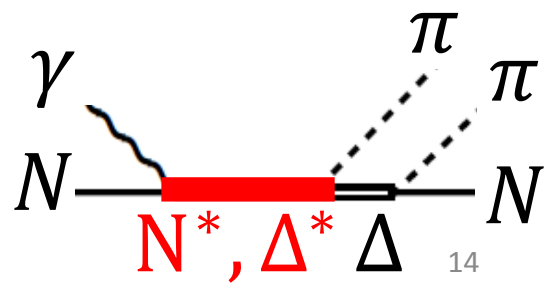


$\pi\Delta$

Δ Kroll-Ruderman



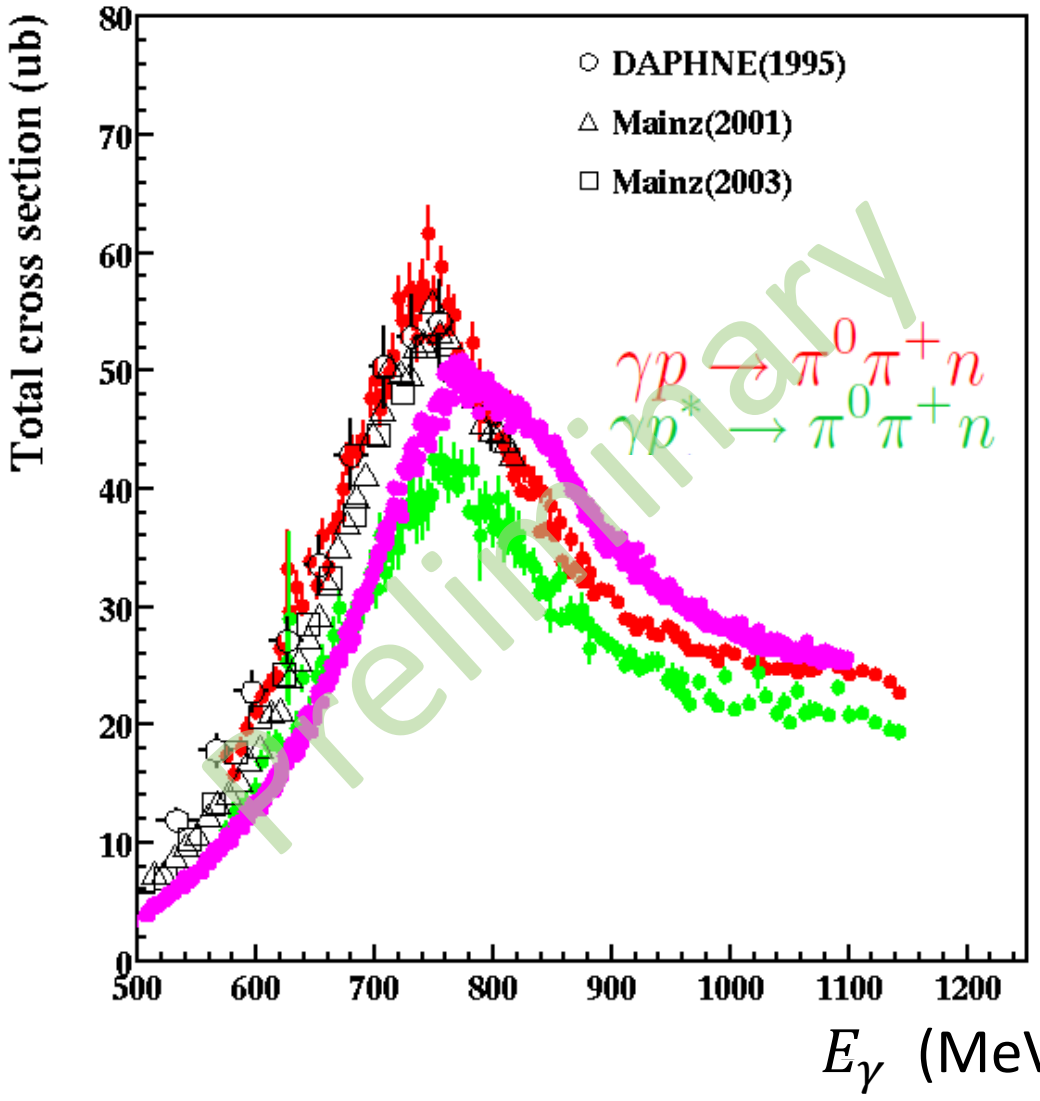
Resonance term



Cross section on the deuteron

- Cross section on the deuteron target is affected by Fermi motion and Final state interaction.
- We evaluate Fermi motion effect using $\gamma p \rightarrow \pi^0 \pi^+ n$ reaction on hydrogen and deuteron.
- Fermi motion effect is evaluate by Monte Calro simulation using nucleon momentum distribution and effective mass of participant.
- In this work, πN and NN rescatterings in the final state are neglected.

Cross section



- Fermi momentum distribution is determined by atomic density and Hulthen's wave function.
- Effective mass of participant

$$m'_{(p)} = \sqrt{\left(m_d - m_{(s)}\right)^2 - 2m_d(E_{(s)} - m_{(s)})}$$

assuming the spectator nucleon is on-shell in the initial state.

● : Estimated $\gamma p^* \to \pi^0\pi^+ n$ cross section on the deuteron using $\gamma p \to \pi^0\pi^+ n$ cross section on the hydrogen.

Summary

- We have measured $\pi^0\pi^\pm$ photoproduction on the hydrogen and deuteron for 570 < E_γ < 1150 MeV.
  - Obtained cross section is consistent with Mainz and DAPHNE data ($\gamma p \rightarrow \pi^0\pi^+ n$).
  - Our data covers 2nd and 3rd resonance region.
  - An enhancement of ρN intermediate state is observed near 2nd resonance region.
  - Fermi motion effect on the deuteron is evaluate by toy Monte-Calro simulation.

- Future plan
  - We need more detail study for Fermi motion effect and final state interaction.