The $\pi\pi$ and πd system in $\gamma d \to \pi^+\pi^- d$ measured with the NKS2

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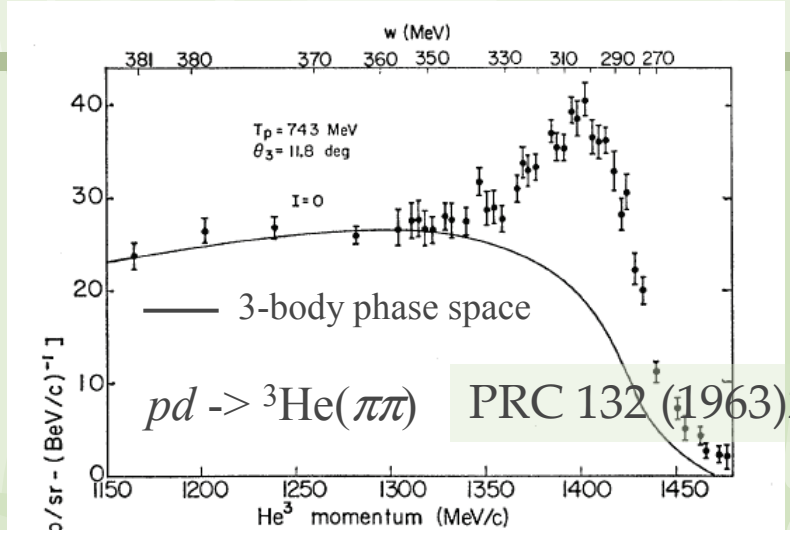
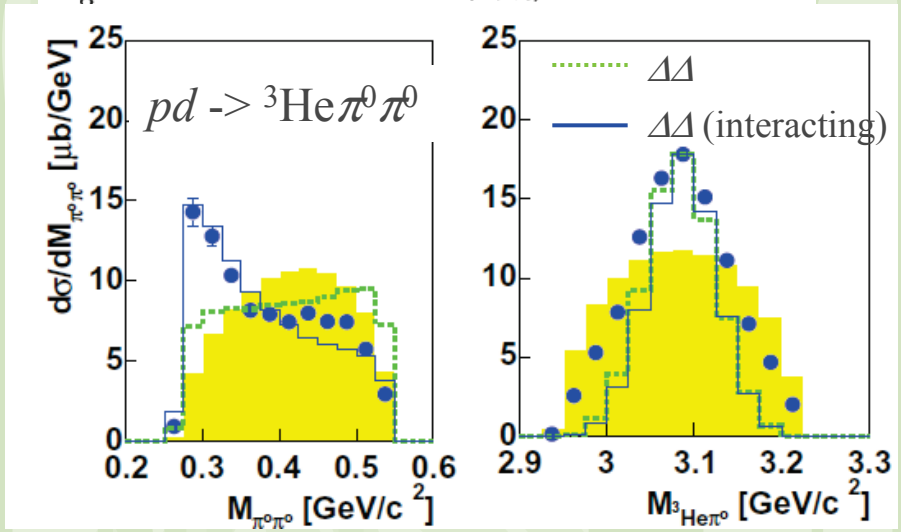
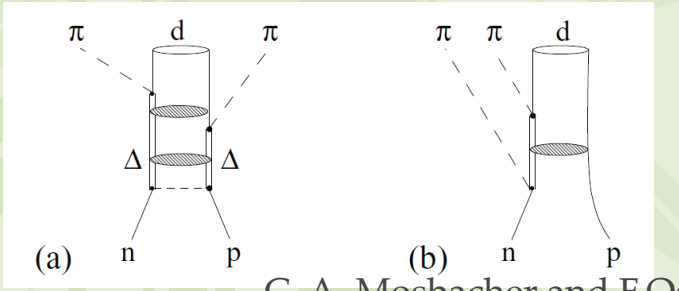
INTRODUCTION

ABC Effect

- Isoscalar mesonic structure in the reaction pd->^{3}He($\pi\pi$) observed in p(d, ^{3}He)X reaction by Abashian, Booth and Crowe. (PRL 7 (1961) 35).
- The origin was firstly considered as a new meson with spin 0 and isospin 0. But turned out to be interacting $\Delta\Delta$
- Exclusive measurements were performed at the CELSIUS-WASA and the COSY-at-WASA







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

arXiv:nucl-ex/0706.4026

Classification of two-baryon states

$\mathcal{D}_{IS}$	$\mathcal{D}_{01}$	$\mathcal{D}_{10}$	$\mathcal{D}_{12}$	$\mathcal{D}_{21}$	$\mathcal{D}_{03}$	$\mathcal{D}_{30}$
BB	NN	NN	NΔ	NΔ	ΔΔ	ΔΔ
Mass formula	A	A	A+6B	A+6B	A+10B	A+10B
Approx. mass	1878	1878	2160	2160	2348	2348

$$M = A + B\,(I(I+1) + S(S+1) - 2)$$

A = 1878 MeV

B = 47 MeV

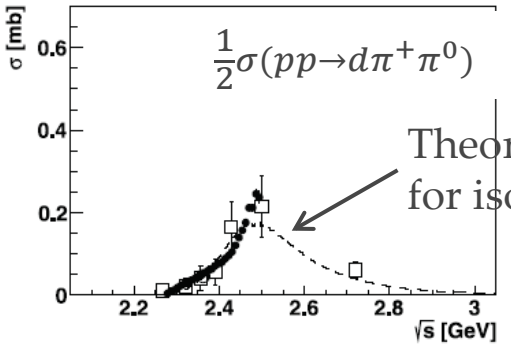
Dyson-Xuong Mass formula
PRL 13 (1964) 815

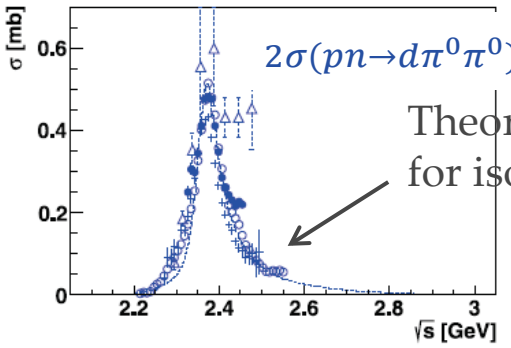
Deuteron $^3S_1$ attractive potential

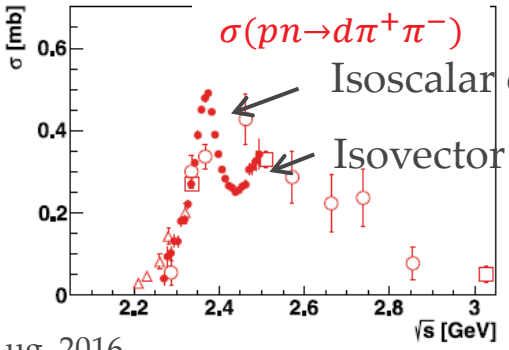
Non attractive $^1S_0$ states: pp, nn, pn

Two-baryon states without strangeness (SU(6) group → isospin-spin SU(4) group: 50-multiplet)
Deuteron and dibaryon can be classified within the same framework

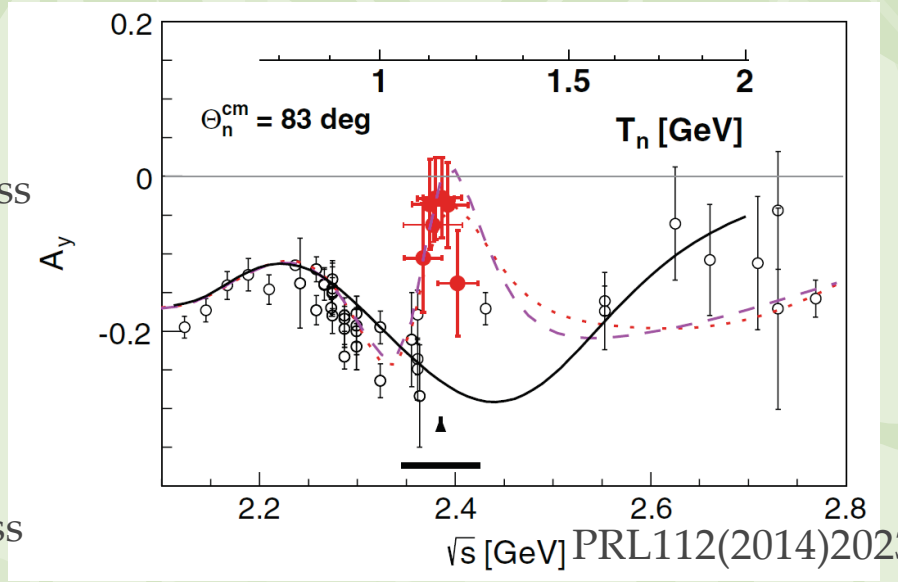
Results from WASA at COSY







PLB721(2013)229



PRL112(2014)202301

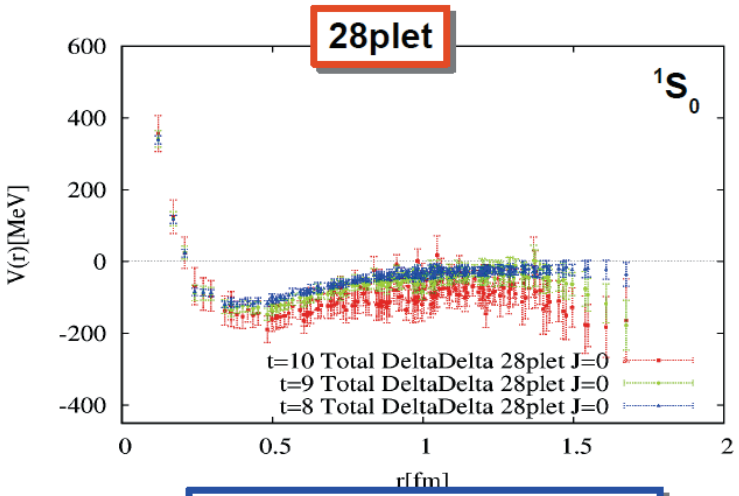
- Left: isospin dependent pN → ππ d cross sections
- Right : Analyzing power Ay in polarized pn elastic scattering

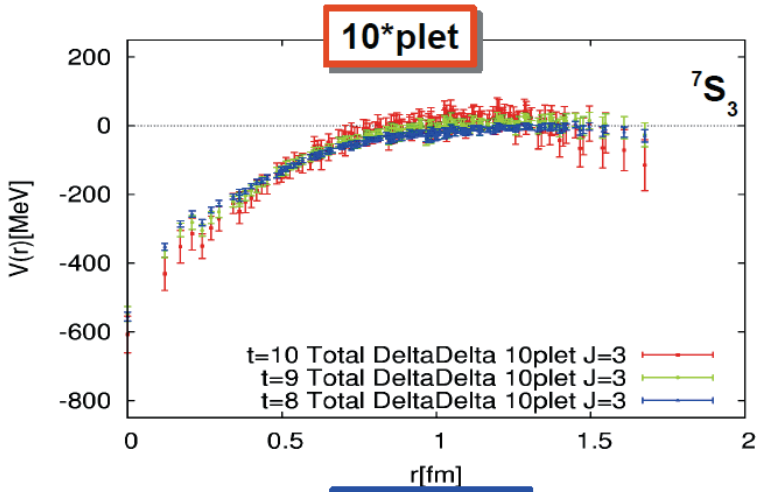
I(J^P) = 0(3$^+$) resonance @ 2380 MeV

ΔΔ attractive force in lattice QCD

▶ N_f = 2+1 full QCD with L = 1.93fm, $m\pi$ = 1015 MeV

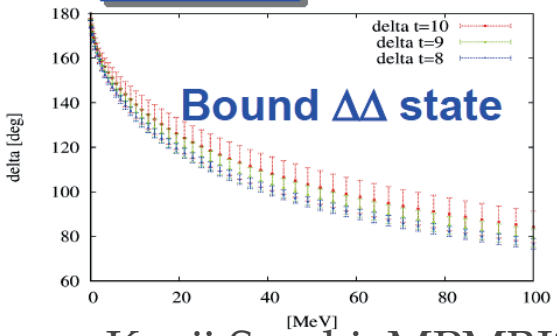
Preliminary!





Δ–Δ(J=0) and Ω–Ω(J=0)

Δ–Δ(J=3)

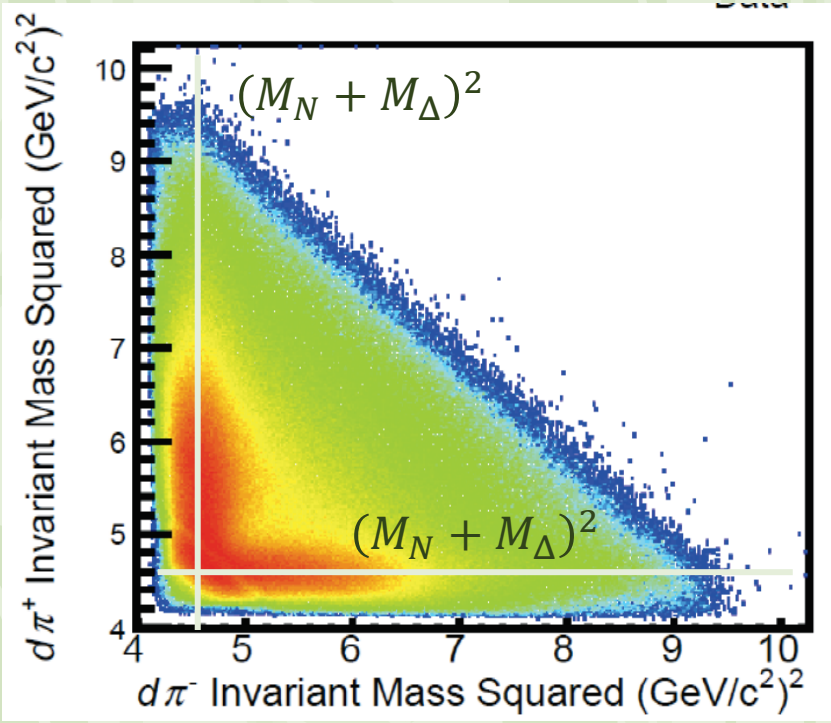


- Short range repulsion and attractive pocket are found in 28plet.
- 10*plet [$J^p(I)=3^+(0)$] is strongly attractive.

Kenji Sasaki, MPMBI2015

Results from CLAS

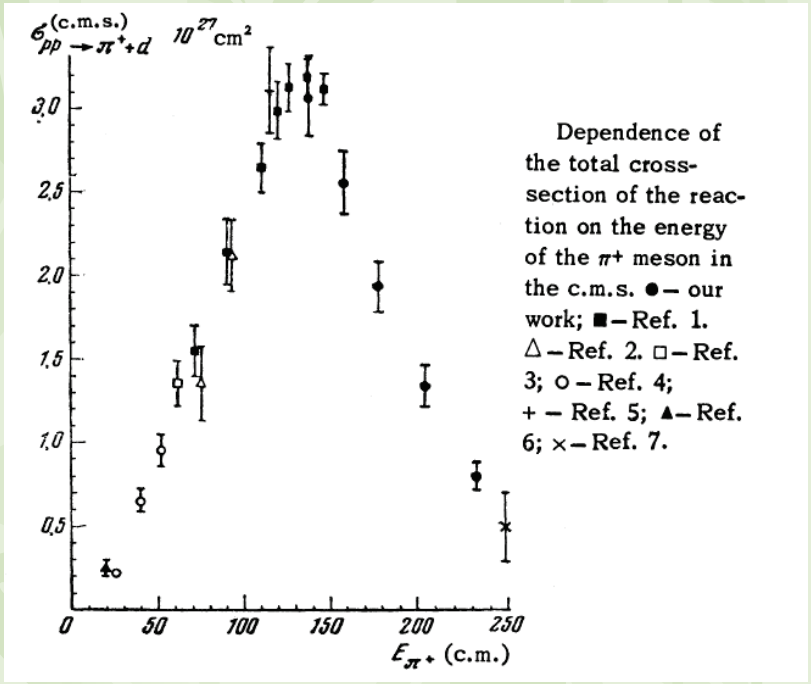
- No hint of $\Delta\Delta$
- Structures found in $d\pi^-$ and $d\pi^+$ invariant masses in $\gamma d \to \pi^+\pi^- d$
- The peaks correspond to the mass peaks of $N\Delta$
- They can be considered as $N\Delta$ dibaryon states (not claimed in the last year)



R. Schumacher, APS meeting (2015)

NΔ (I=1, J = 2) state in single pionic fusion of pp

- NΔ (I=1, J = 2) was reported in single pionic fusion of pp ($pp \rightarrow \pi^+ d$)
- The mass corresponds to 2160 MeV/c^2 (presumably an input parameter of Dyson-Xuong mass formula)



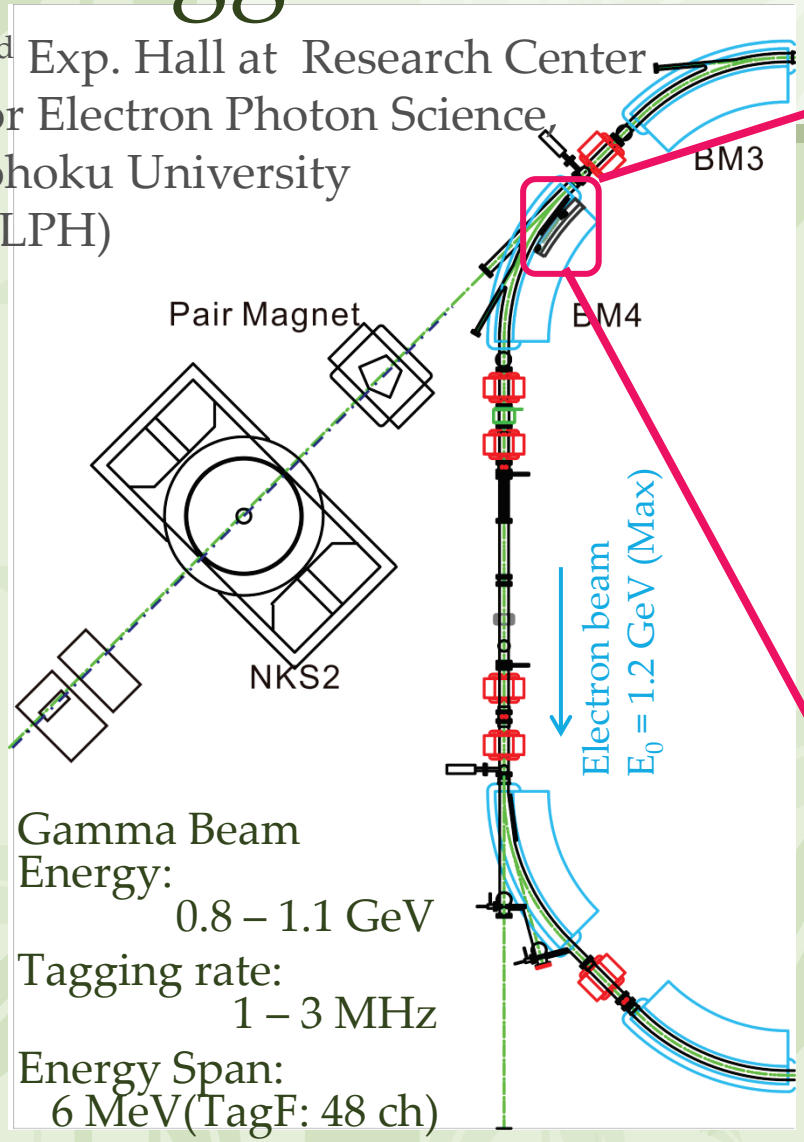
B. S. Neganov and L. B. Parfenov Sov. Phys. JETP 34 (1958)767

Obtained by detailed balance of $\sigma(\pi^+ d \rightarrow pp)$

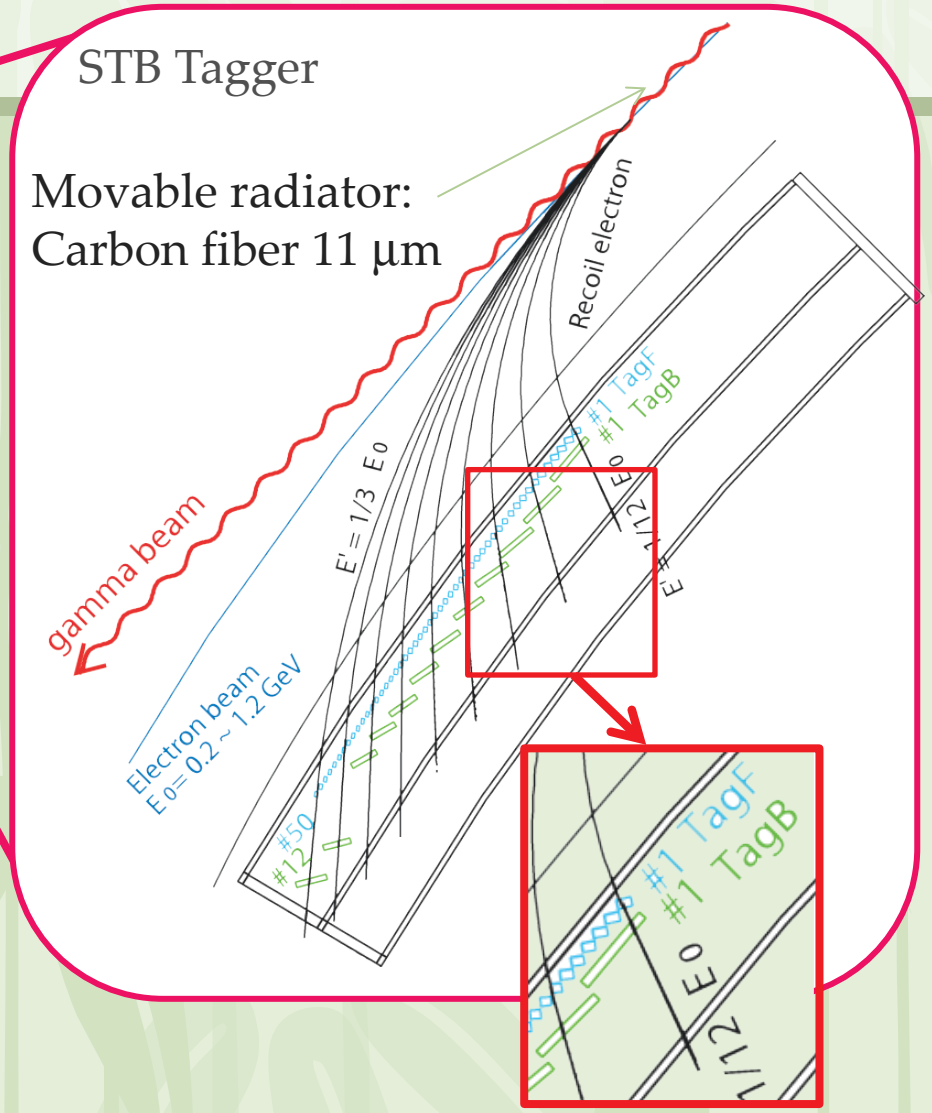
ANALYSIS OF THE NKS2 DATA

Tagged Photon Beam Line at ELPH

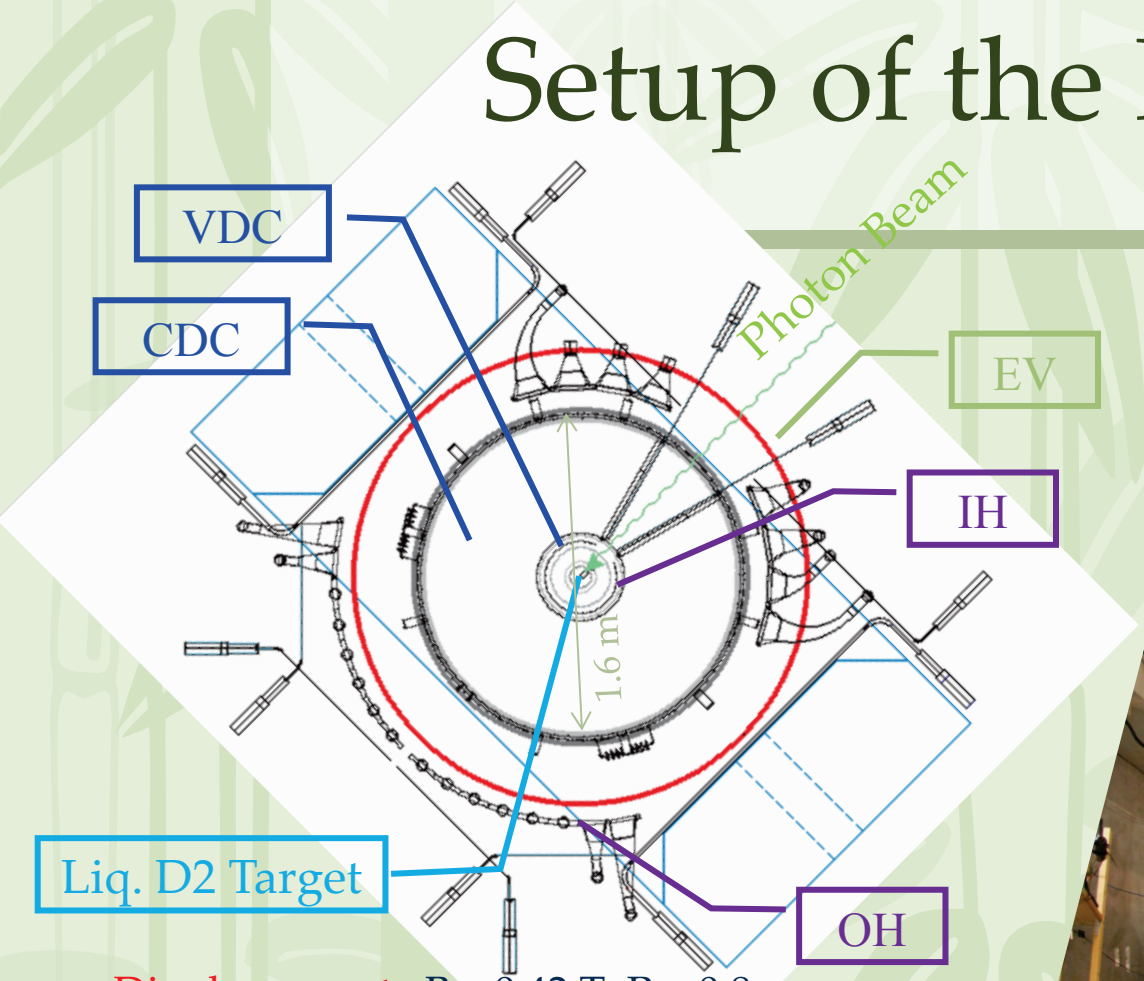
2nd Exp. Hall at Research Center For Electron Photon Science, Tohoku University (ELPH)

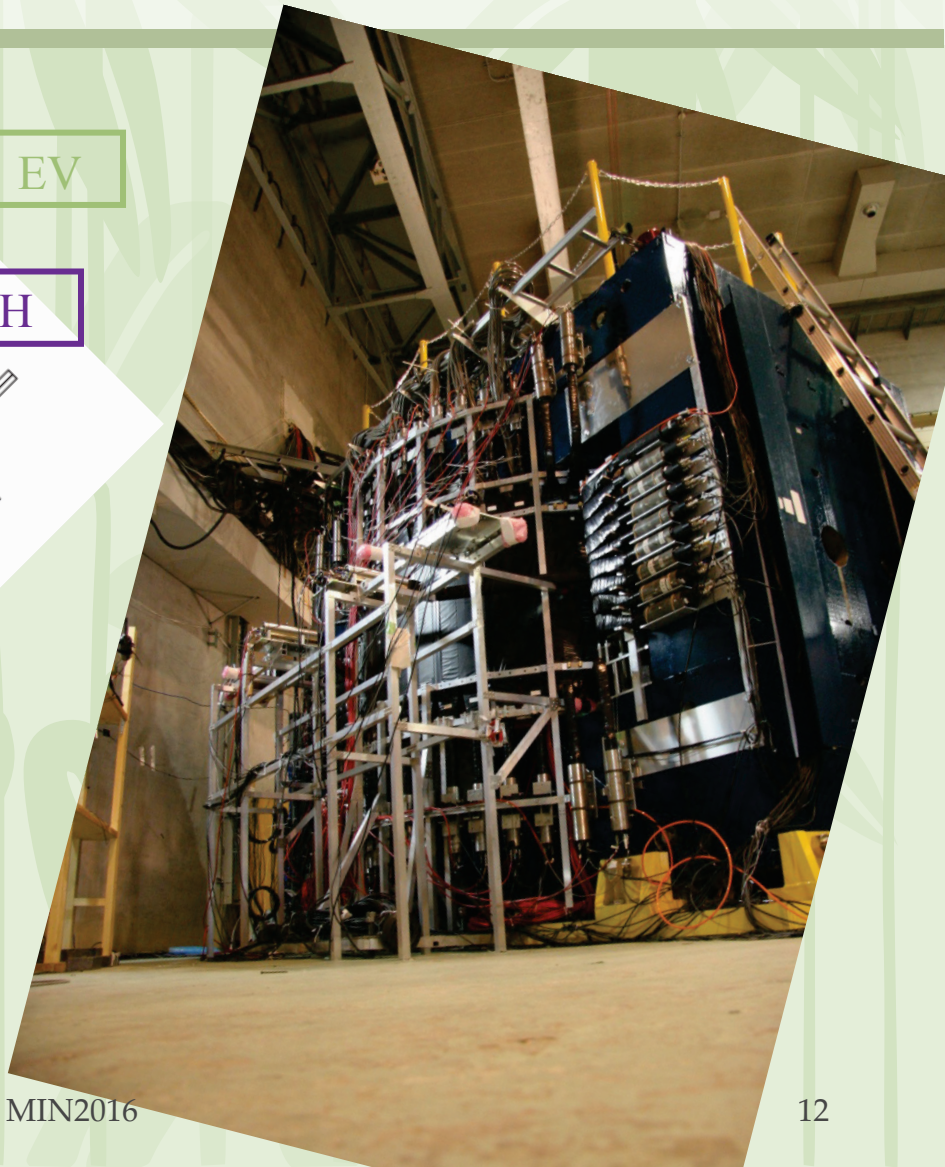


- Gamma Beam Energy: 0.8 – 1.1 GeV
- Tagging rate: 1 – 3 MHz
- Energy Span: 6 MeV(TagF: 48 ch)



Setup of the NKS2





- Dipole magnet : B ~ 0.42 T, R = 0.8 m
- Hodoscopes (IH and OH): TOF measurement
- MWDC's (CDC and VDC) : Tracking for momentum and vertex finding
- EV: Reduction of QED background
- Geometrical acceptance: ~ 1 π sr

Data set

- Aim:
  - Investigation of $\gamma d \rightarrow \Delta\Delta$ or $\Delta N \rightarrow \pi^+\pi^- d$ states

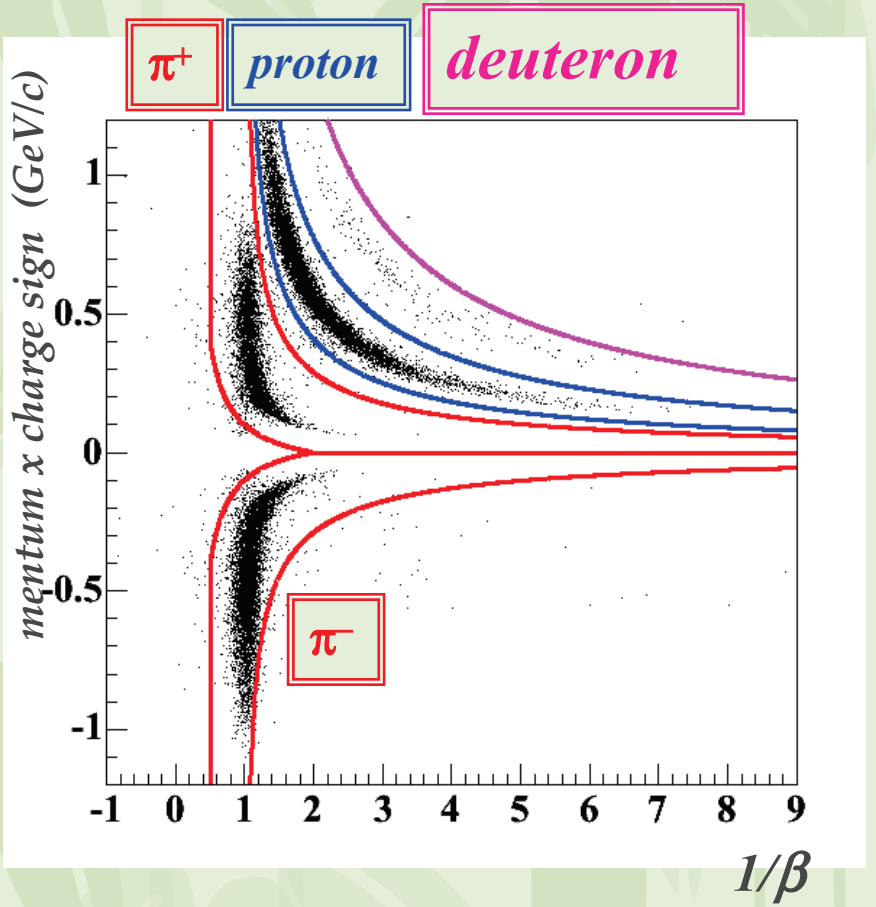
  Identification of "d" for the check of the ABC effect
- Taken in Dec. 2006, Jan. 2007, and Jun. 2007 (Before upgrade of inner detectors)
- Photon Energy range: 0.78 – 1.08 GeV
- Total number of photons: 3.2 x 10^{12}
- Tagged photon intensity: 1.7 MHz (average)
- Target: liq. Deuterium
  - Temperature: 18.8 K
  - Density: 0.172 g/cm^3
  - Deuteron number density: $0.166 \pm 0.005\ \mu b^{-1}$
- Trigger: Two charged particles detected with the NKS2 ⊗ Electron detected at the Tagger
- Three charged particle detected events were collected and analyzed

Particle identification

- TOF measurement + Track length → velocities
- Tracking in the magnetic field → momenta and charge signs

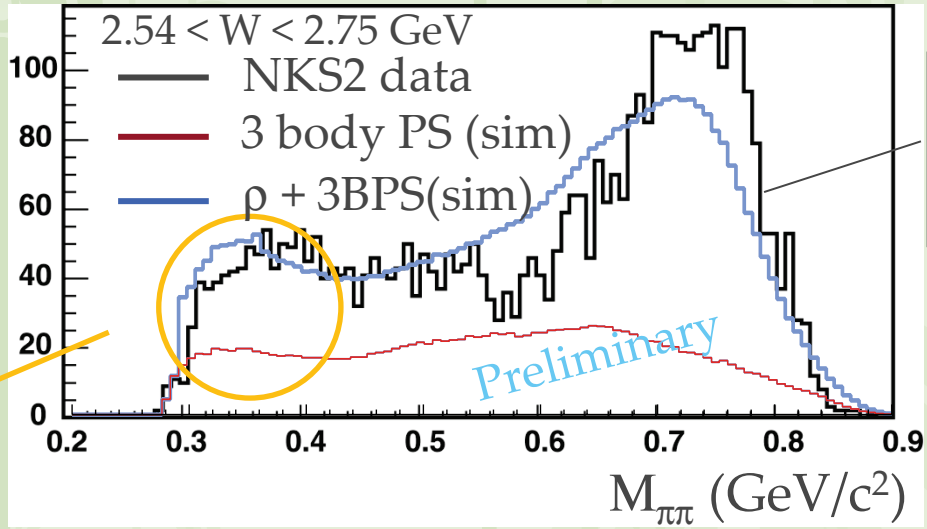
- Momentum and TOF resolution
  - $\sigma_p/p \sim 2\ \%$, $\sigma_{TOF} \sim 0.3$ ns
  - Coverage in forward region

→ The deuteron is identified



Search for state like the ABC effect

- Search for the deuteron in the final state together with $\pi^+$and π^- : $\gamma d \rightarrow d\pi^+\pi^-$ in 0.78 < Eγ < 1.08 GeV → 2.54 < W < 2.75 GeV (> ABC effect region W = 2.46 GeV)
- Simulated invariant mass of $\pi^+\pi^-$
  - Rho meson production + Three body phase space
- No signature in $\pi^+\pi^-$ invariant mass distribution
  - Lower energy region (W ~ 2.46 GeV) should be explored
  - Realistic generator for the rho meson production is required

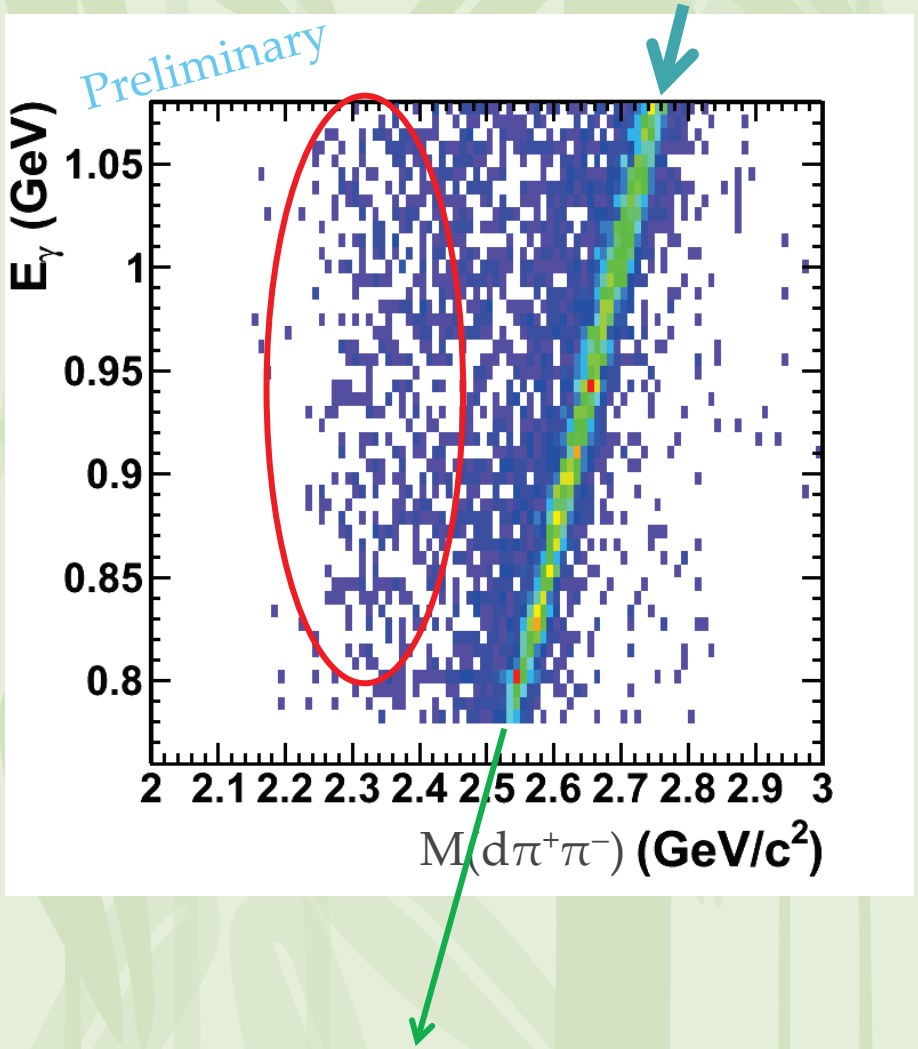


Signature should be here

Mass peak of rho meson is not well reproduced

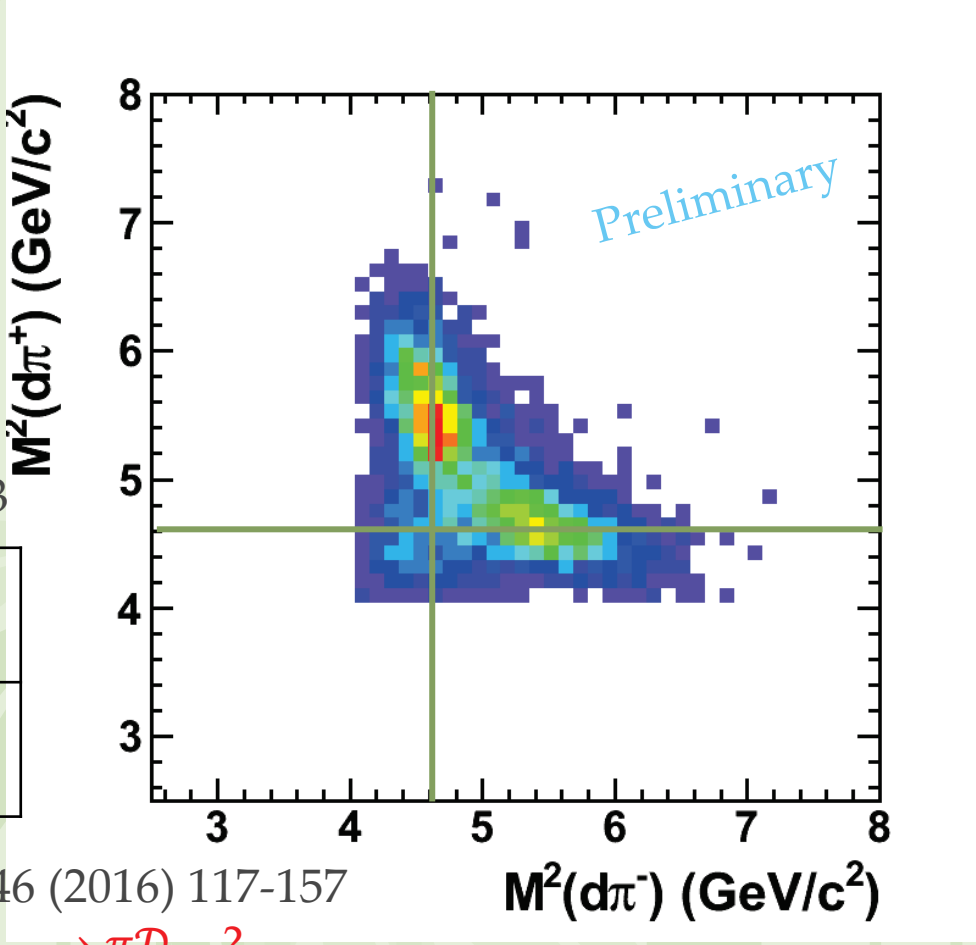
Invariant mass of $d\pi^+\pi^-$

- **A significant locus** corresponding to $\gamma d \rightarrow d\pi^+\pi^-$ reactions (Energy conservation fulfilled)
- Small contribution of π^0missing events
- No significant structure at $M(d\pi^+\pi^-) = 2.38\ \mathrm{GeV/c^2}$
- Signature of $\gamma d \rightarrow \mathcal{D}_{03}(2380)\pi^0 \rightarrow d\pi^+\pi^-\pi^0$ was not found
- Lower photon energy needed to reach $\gamma d \rightarrow \mathcal{D}_{03}(2380) \rightarrow \pi^+\pi^- d$



Invariant mass of $d\pi$

- Dalitz plot of $M^2(d\pi^-)$ and $M^2(d\pi^+)$
- Two significant enhancements at $M^2(d\pi) \sim 4.6$ (GeV/c²)² → 2.15 GeV/c²



Pole positions for NΔ in NPA928(2014)73

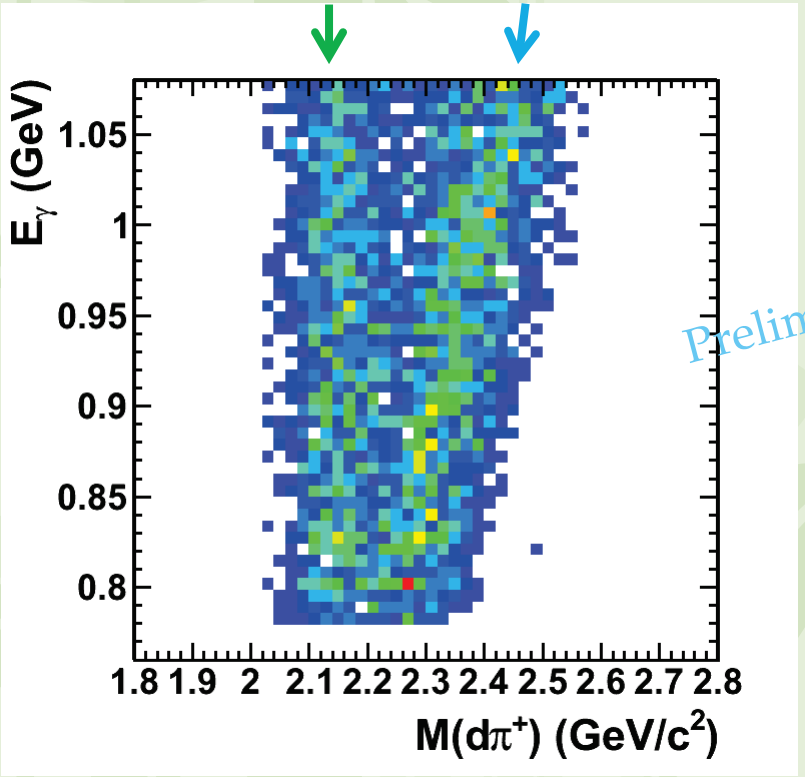
$\mathcal{D}_{12}$ Type I	$\mathcal{D}_{21}$ Type I	$\mathcal{D}_{12}$ Type II	$\mathcal{D}_{21}$ Type II
$2147 - i60$	$2165 - i64$	$2159 - i70$	$2169 - i69$

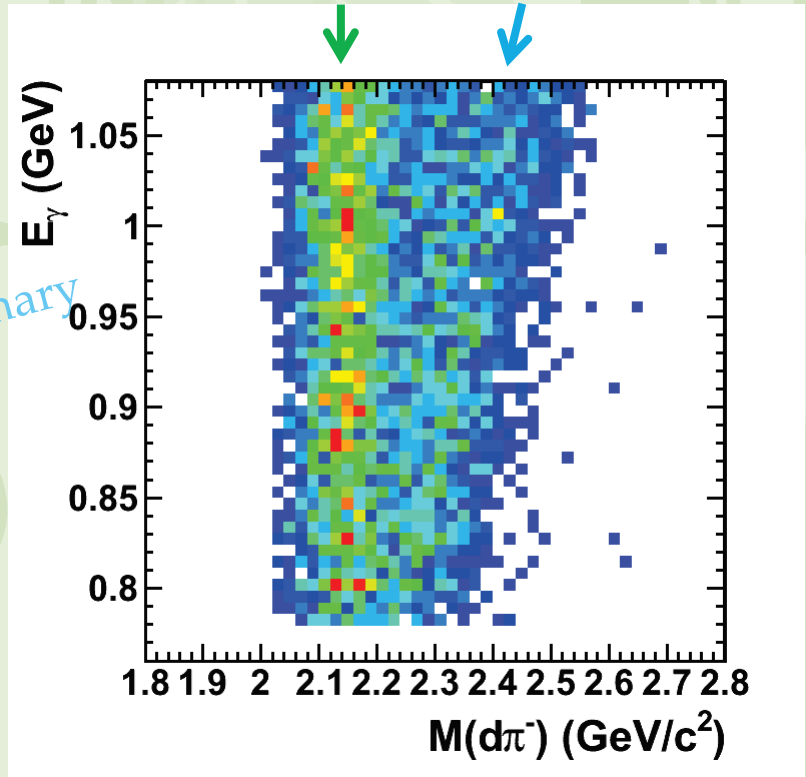
M. N. Platonova and V. I. Kukulin, NPA 946 (2016) 117-157

Decay of a dibaryon to a dibaryon: $\mathcal{D}_{03} \rightarrow \pi\mathcal{D}_{12}$?

Photon energy dependence of invariant mass

- Two bands:
  - Energy independent band: resonance? between d and π
  - Energy dependent band: "change" of the energy independent locus



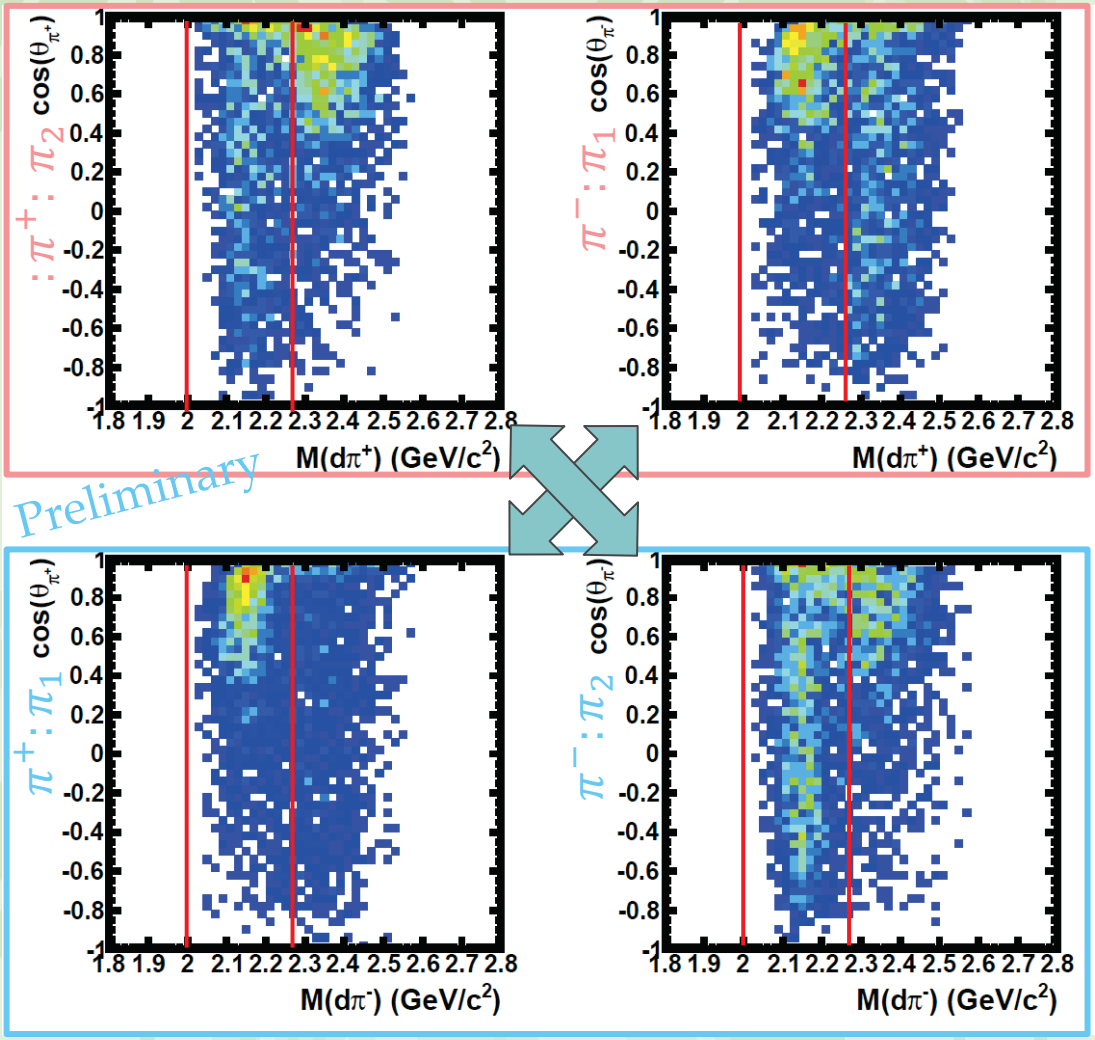


Preliminary

Not from $\mathcal{D}_{03}$ but production of $\gamma d \to \pi(\pi d)$ state

Angular distribution of π

- Emission angle of π in lab. System
- $\gamma d \rightarrow \pi_1(\pi_2 d)$ in $2 < M(\pi d) < 2.25$ GeV/c^2
  - π_1: forward peaking
  - π_2: Broad angular distribution
- Suggesting:
  - π_1: t-channel production
  - π_2: s-channel emission
- For precise angular distributions:
  ← acceptance correction is needed



Summary

- Dibaryon have been one of the interesting theme for quark-hadron physics
- Concrete results were reported by the WASA-at-COSY in the investigation of the ABC effect and they stimulated both experimental and theoretical investigations of dibaryon
- Hint of NΔ state was reported by CLAS at Jlab
- The NKS2 data is being examined for the investigation of
  - M($\pi^+\pi^-$): No significant structure related to the ABC effect. Lower energy region should be explored.
  - M($d\pi^+\pi^-$) : No significant structure for $\mathcal{D}_{03}(2380)$
  - M($d\pi^+$) and M($d\pi^-$): Peak at M ~ 2.15 GeV/c^2 more detailed analysis is needed.
- In any case a refined analysis with simulation is needed for the conclusion.
- Beam time in lower energy region is planned.