Study of non-strange dibaryon resonances via coherent double neutral-pion photoproduction on the deuteron

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resonances in the $\pi^0\pi^0 d$ and $\pi^0 d$ systems for the $\gamma d \rightarrow \pi^0\pi^0 d$ reaction

Introduction/Experiments/Analysis/
Results (cross section and $\pi^0 d$ peak) /Summary

$d^*(2380)$ dibaryon resonance

Observation of the $d^*(2380)$ dibaryon resonance

$pn \to \pi^0\pi^0 d$ reaction (only I=0)

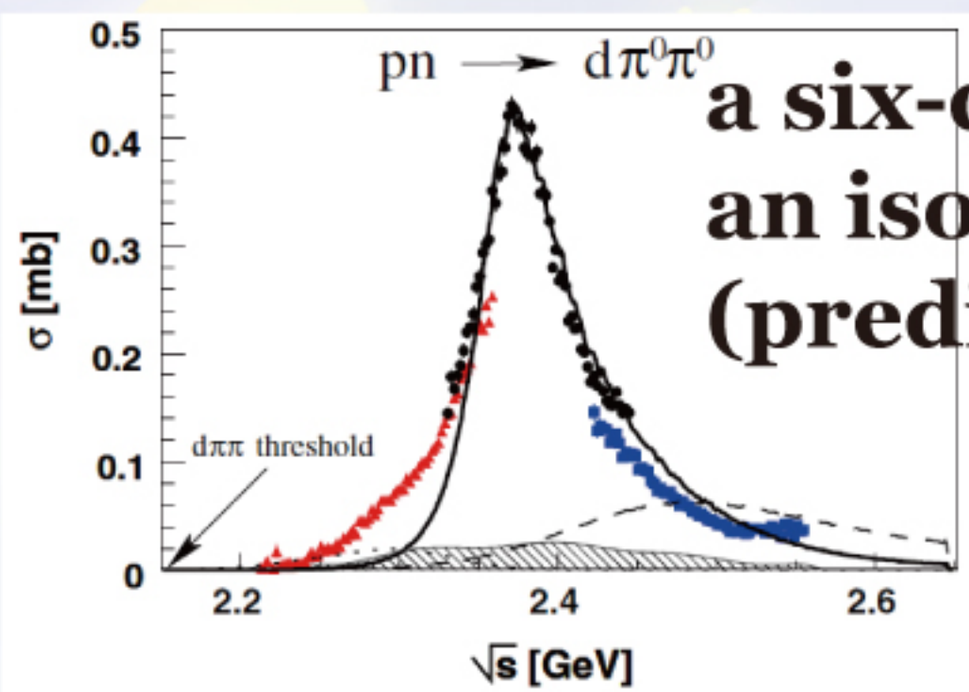
CELCIUS/WASA collaboration

M. Bashkanov *et al.*, PRL102, 052301 (2009).

WASA-at-COSY collabration

P. Adlarson *et al.*, PRL106, 242302 (2011).

peak with a mass m=2.37 GeV and width Γ=0.07 GeV



a six-quark state
an isoscalar ΔΔ quasi-bound state, $\mathcal{D}_{03}$
(predicted by Dyson and Xuong)

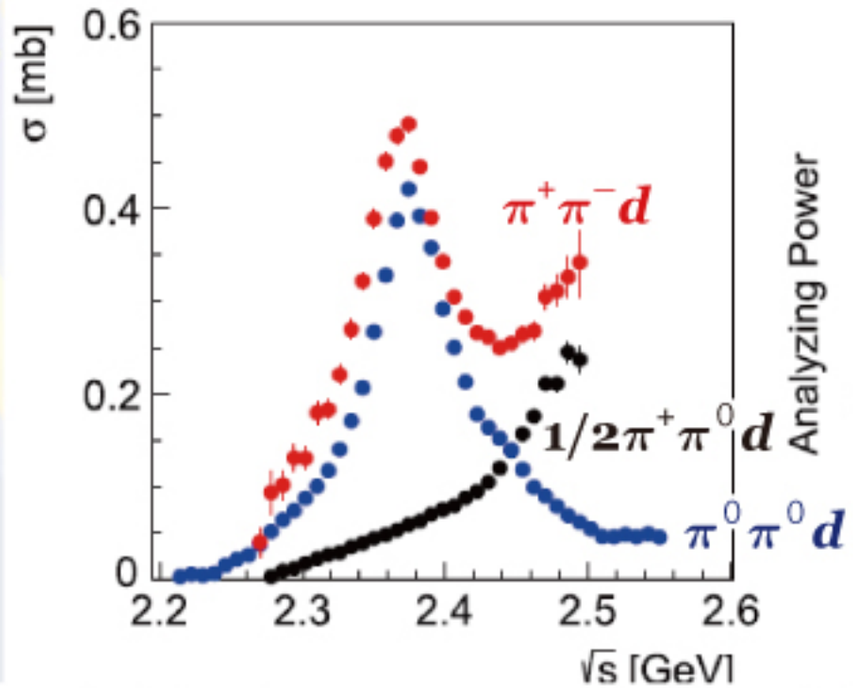
F.J. Dyson and N.-H. Xuong, PRL13, 815 (1964).

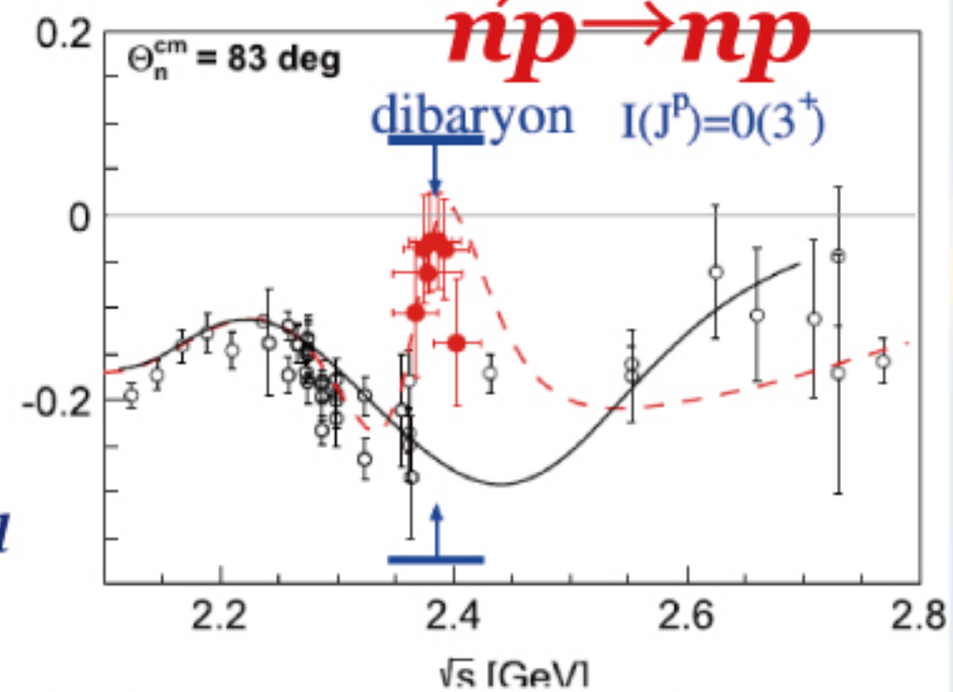
$d^*(2380)$ dibaryon resonance

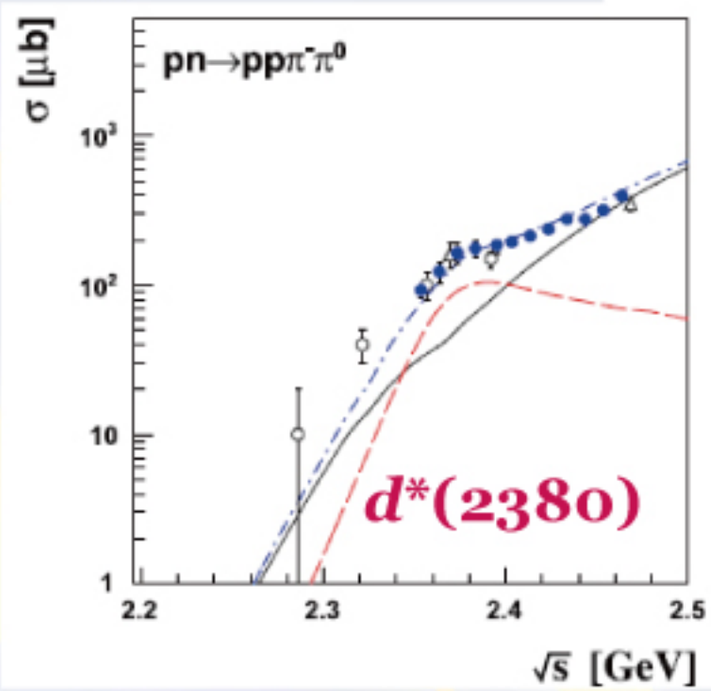
other reactions

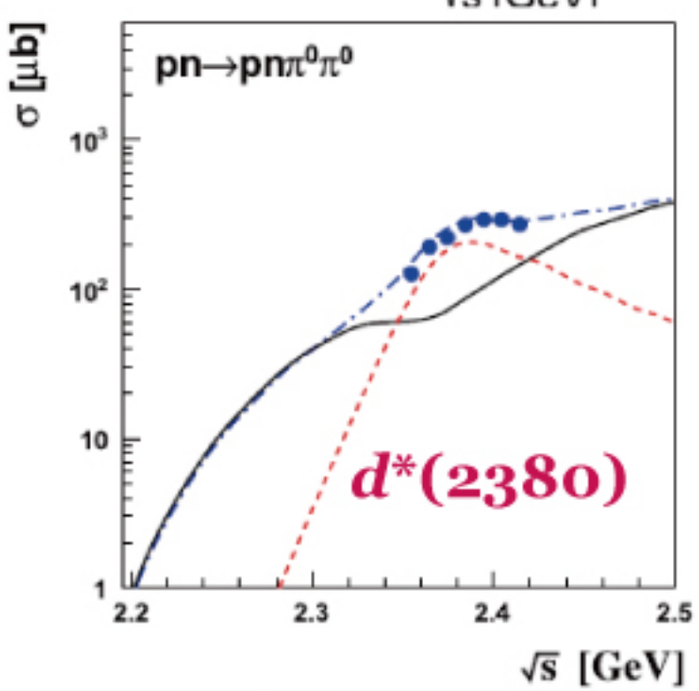
H. Clement *et al.*, Phys. Scr. T 166, 014016 (2015).

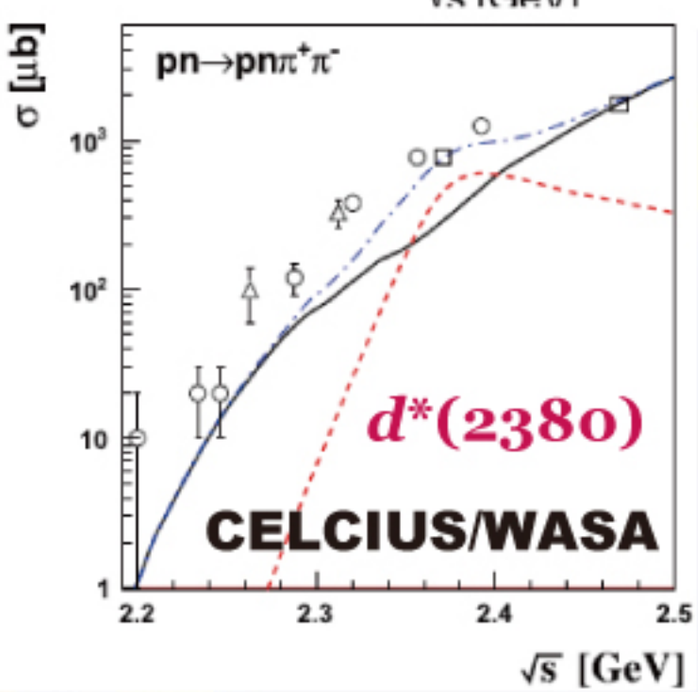
$pn \to \pi^+\pi^- d$
$\to \pi^0\pi^- pp$
$\to \pi^0\pi^0 pn$
$\to \pi^+\pi^- pn$
$\to pn$







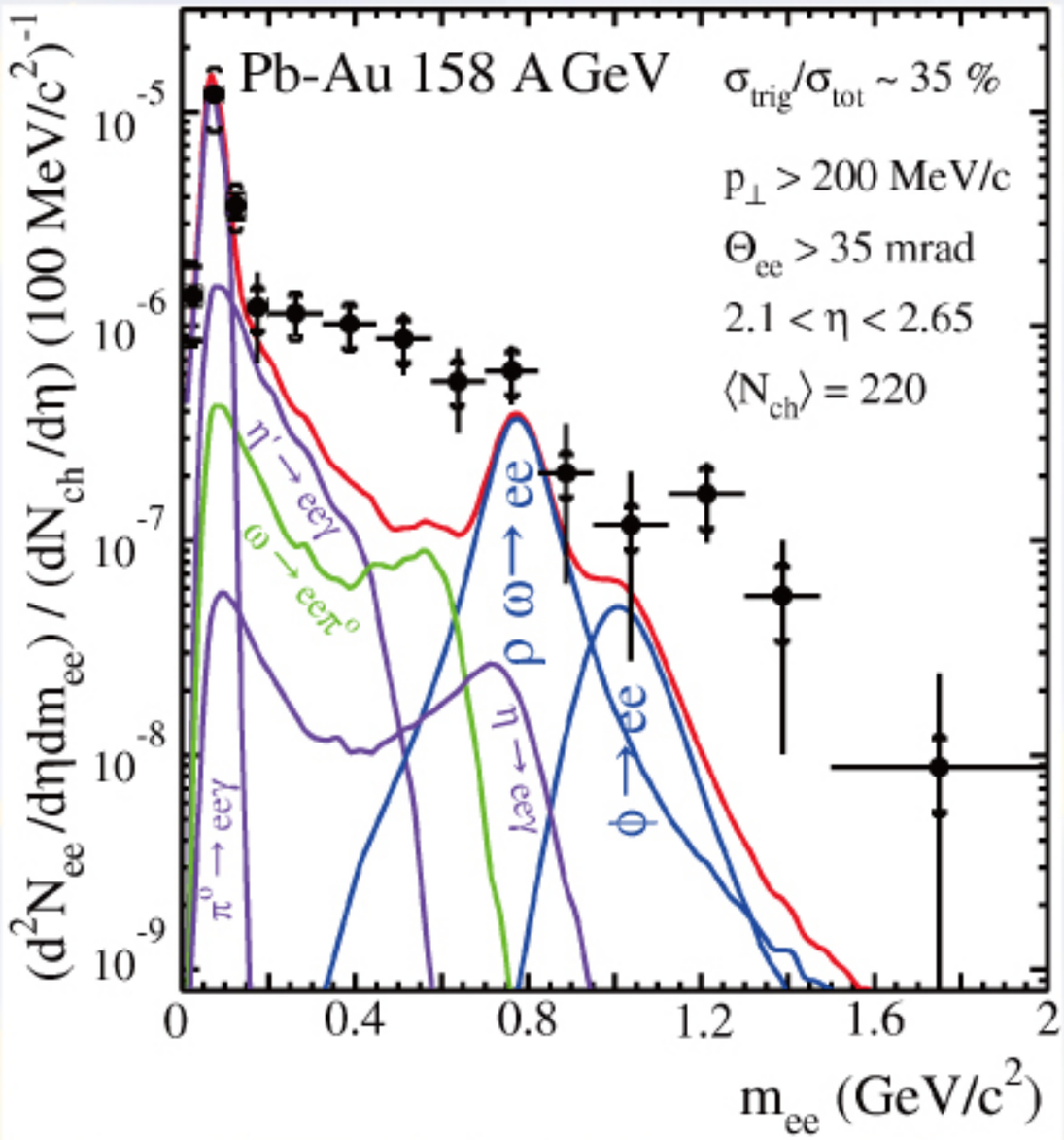




All the evidences were given in the *pn* collision
Nearly all the observation was made by the WASA-at-COSY collaboration.

$d^*(2380)$ dibaryon resonance

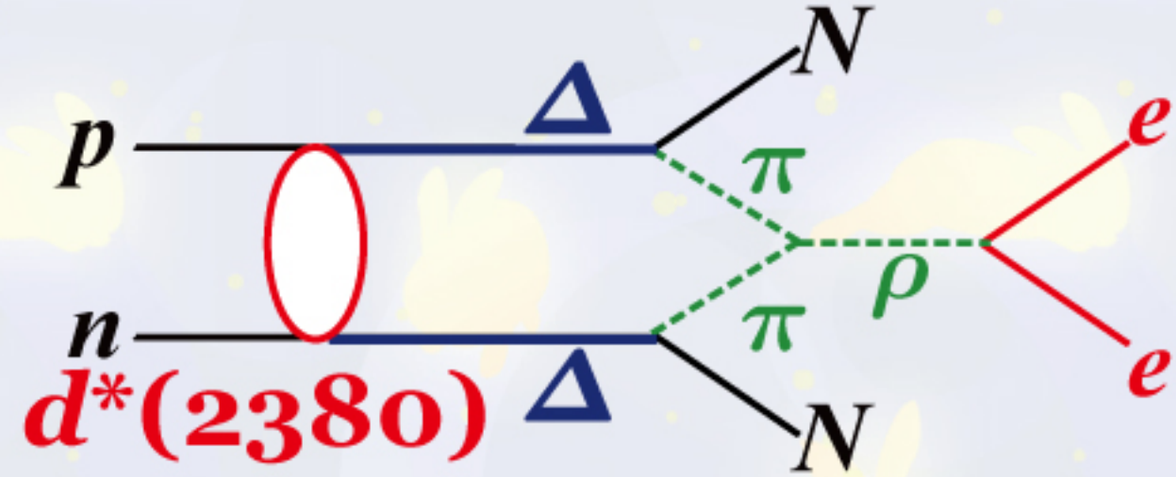
DiLepton Spectroscopy (DLS) puzzle



G. Agakichiev et al. (CERES collaboration), Phys. Lett. B 422, 405 (1998).

1) medium modification of vector mesons

2) $d^*(2380)$ production



M. Bashkanov and H. Clement, Eur. Phys. J. A 50, 107 (2014).

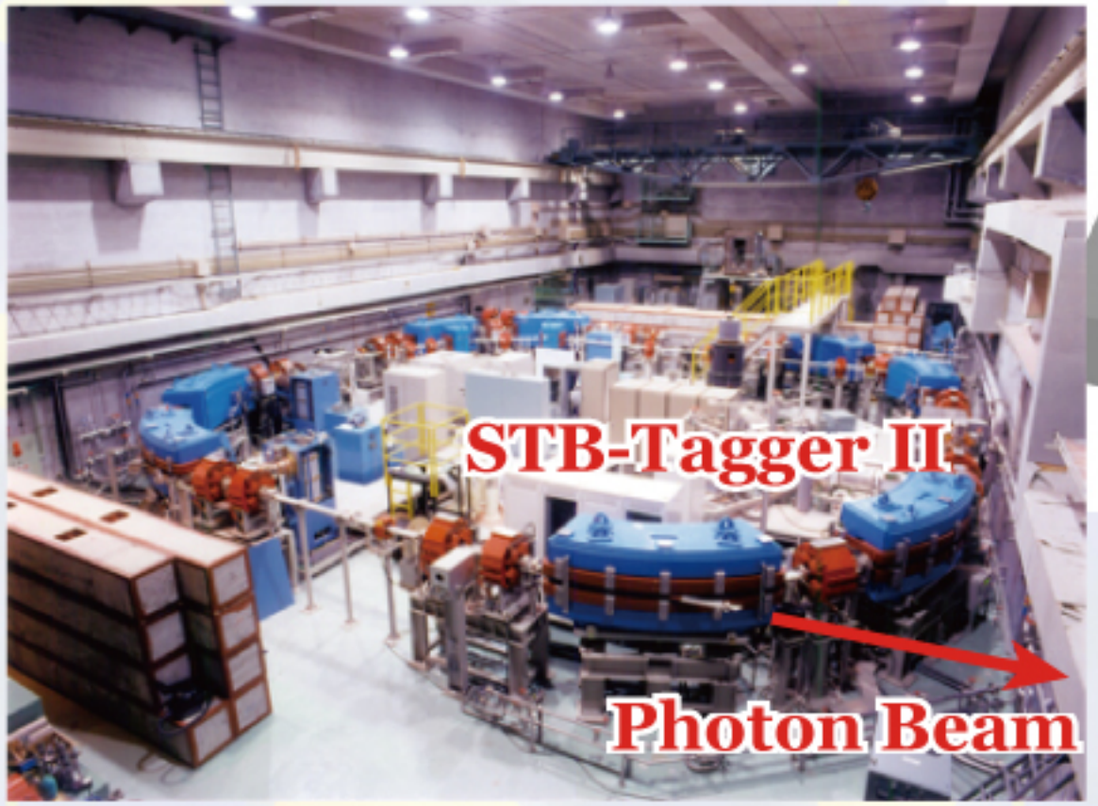
s channel photoproductoin of $d^*(2380)$ ~ size

→we study the $\gamma d \to \pi^0 \pi^0 d$ reaction for the first time

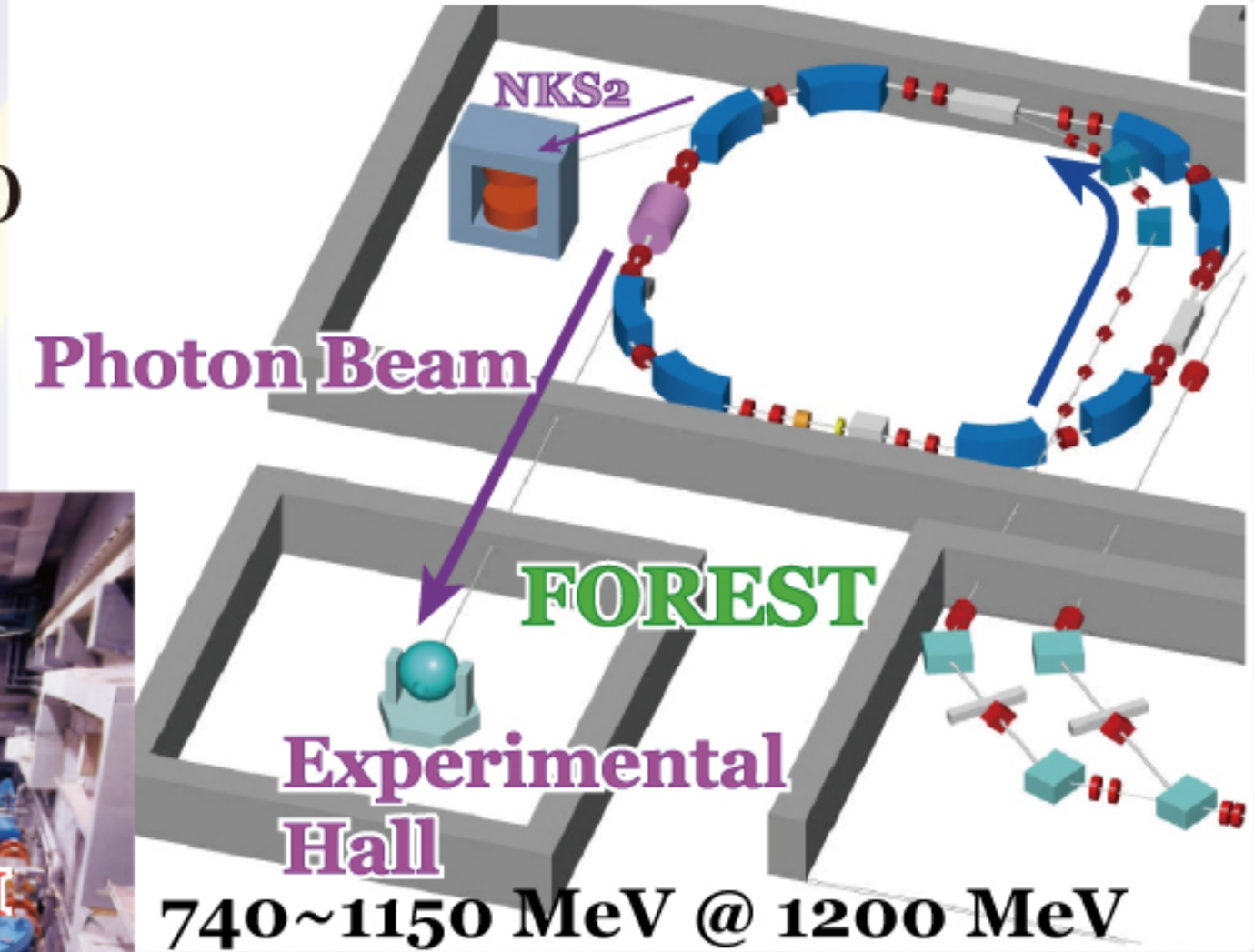
Accelerator

Electron Beam
- LINAC 150 MeV
- Booster Ring 1200 MeV (max)

Photon Beam
- Bremsstrahlung
- Tagged



1.3 GeV Booster STorage Ring



740~1150 MeV @ 1200 MeV

~20 MHz (photon: 10 MHz)

$W_{\gamma d}$=2.50~2.80 GeV

570~890 MeV @ 930 MeV

~2.8 MHz (photon: 1.2 MHz)

$W_{\gamma d}$=2.38~2.61 GeV

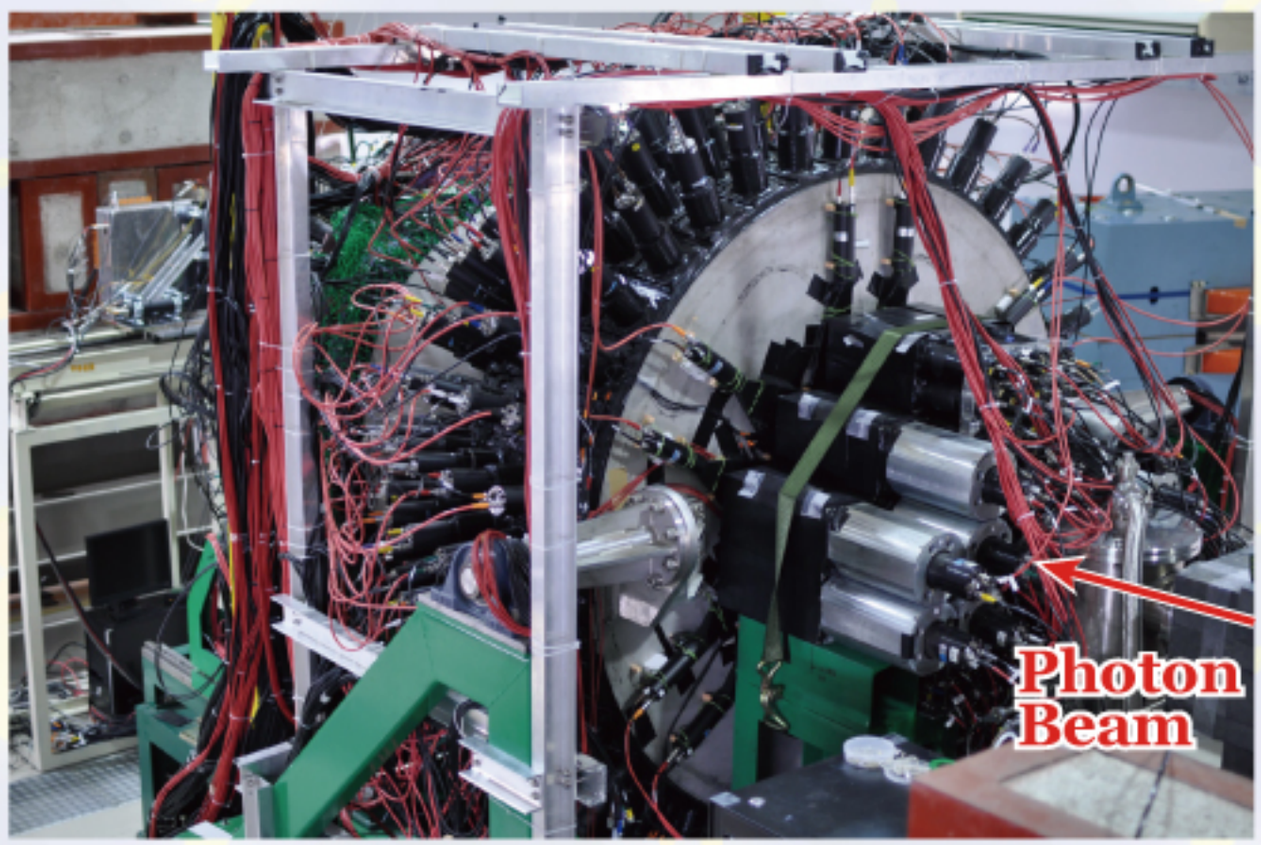
T. Ishikawa et al., Nucl. Instr. Meth. A 622, 1 (2010);
T. Ishikawa et al., Nucl. Instr. Meth. A 811, 124 (2016).

EM calorimeter

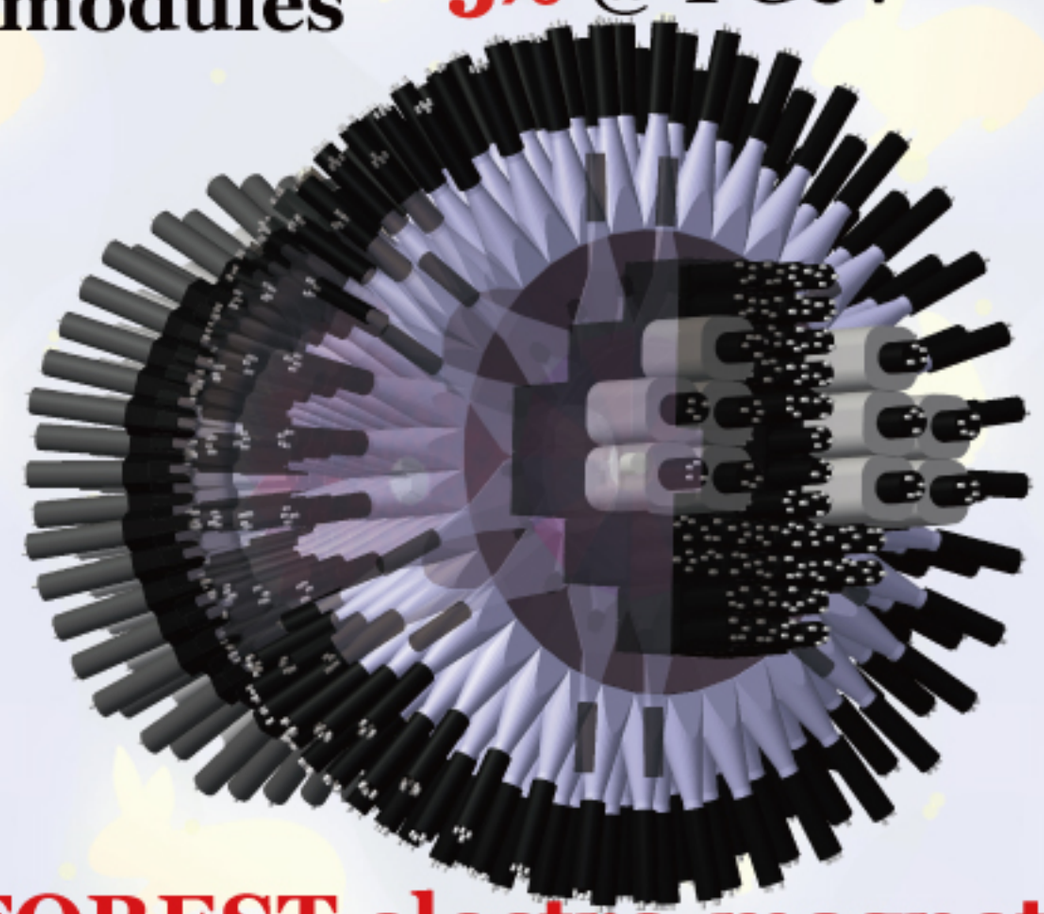
192 CsI crystals
3% @ 1 GeV

252 Lead/SciFi modules
7% @ 1 GeV

62 Lead Glasses
5% @ 1 GeV



Target: 45 mm thick LH2 & LD2



FOREST electro-magnetic calorimeter

T. Ishikawa et al., Nucl. Instr. Meth. A 832, 108 (2016).

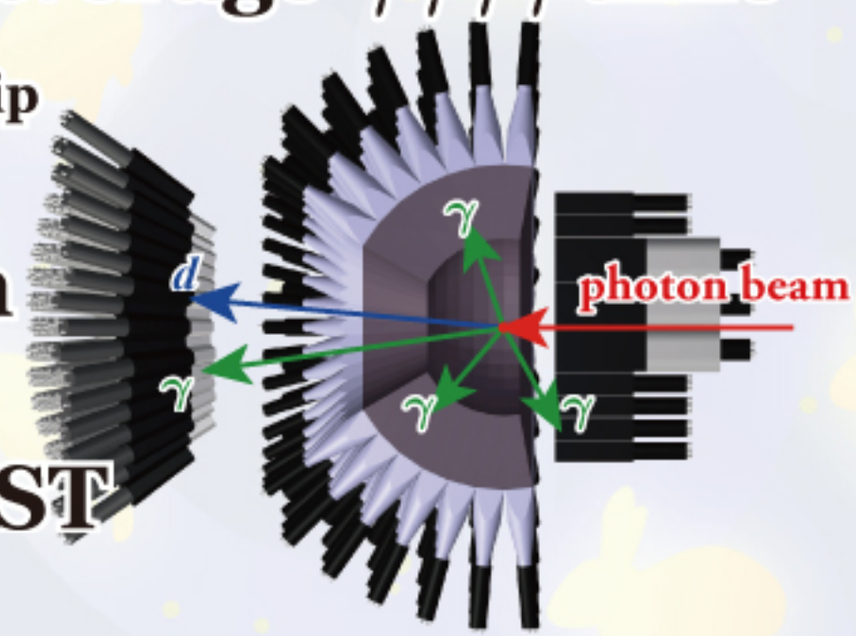
Event selection for $\gamma d \to \pi^0 \pi^0 d$

1. 4 neutral particles and 1 charged particle

2. each neutral pion: $\gamma\gamma$ decay
   time difference is less than $3\sigma_t$
   between every 2 neutral clusters out of 4

3. d is detected with SPIDER
   (response of SCISSORS III is not required)
   time delay is larger than 1 ns wrt average $\gamma\gamma\gamma\gamma$ time
   energy deposit is higher than $2E_{\mathrm{mip}}$

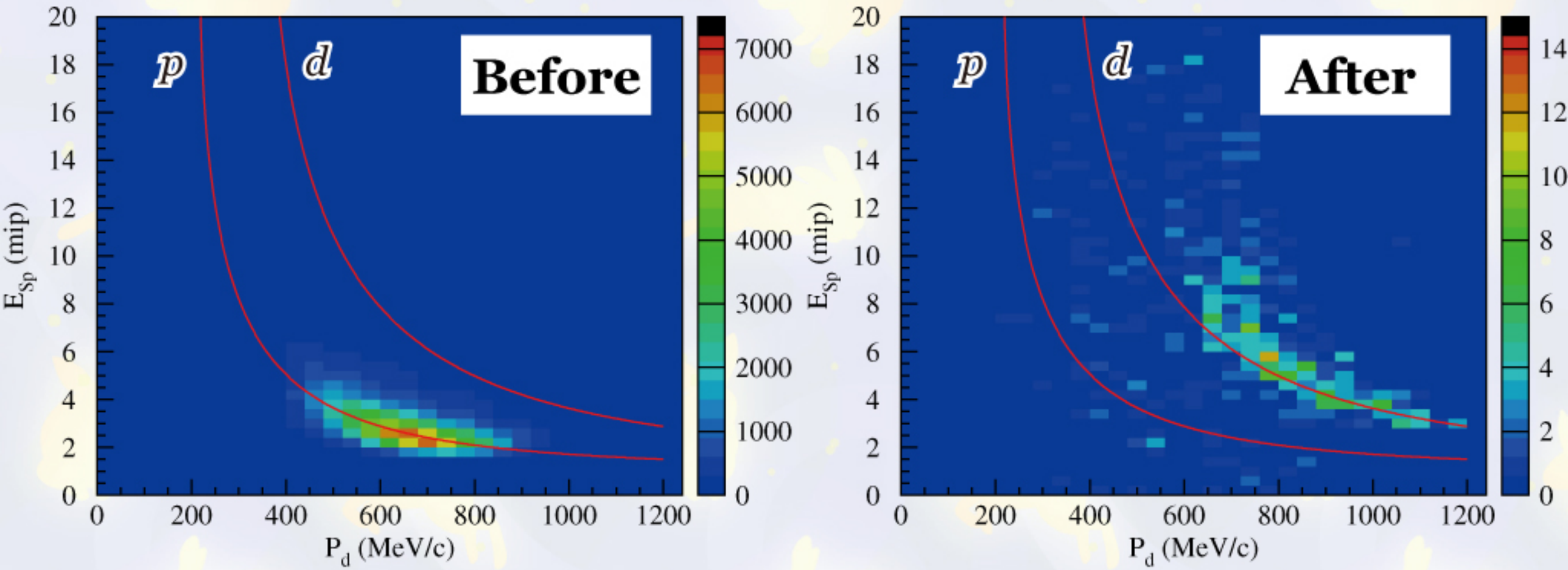
4. sideband background subtraction
   to remove accidental coincidence
   between STB-Tagger II and FOREST



Event selection for $\gamma d \rightarrow \pi^0 \pi^0 d$

Further event selection:

- **a kinematic fit with 6 constraints is applied**
  - **energy and momentum conservation (4)**
  - **each $\gamma\gamma$ invariant mass is m_{π^0} (2)**
  - **χ^2 probability is higher than 0.4**



missing momentum is given for the deuteron in these plots

Event selection for $\gamma d \to \pi^0 \pi^0 d$

Further event selection:

- **a kinematic fit with 6 constraints is applied**
  - **energy and momentum conservation (4)**
  - **each $\gamma\gamma$ invariant mass is m_{π^0} (2)**
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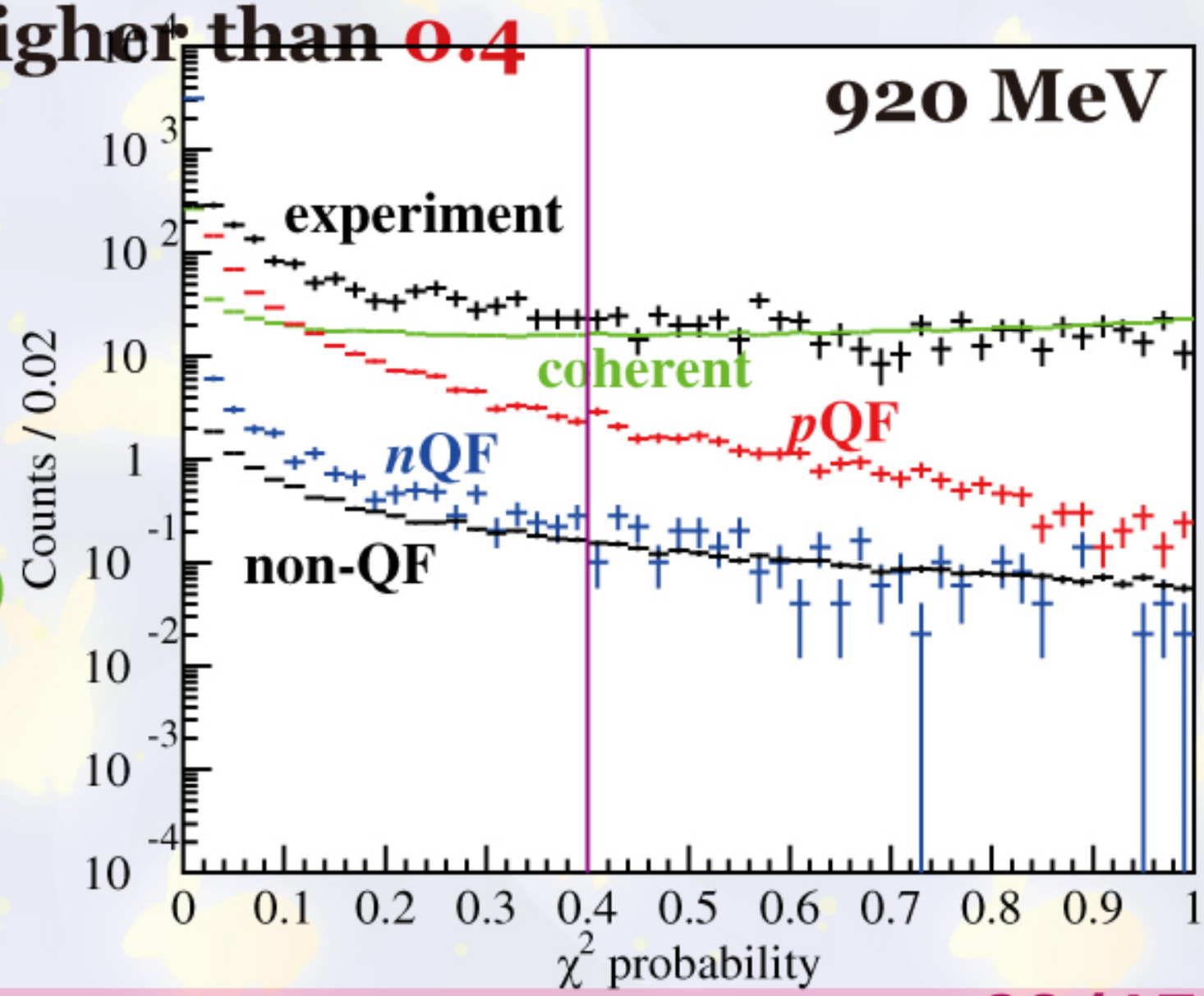


$\gamma d \to \pi^0 \pi^0 d$ (coherent)

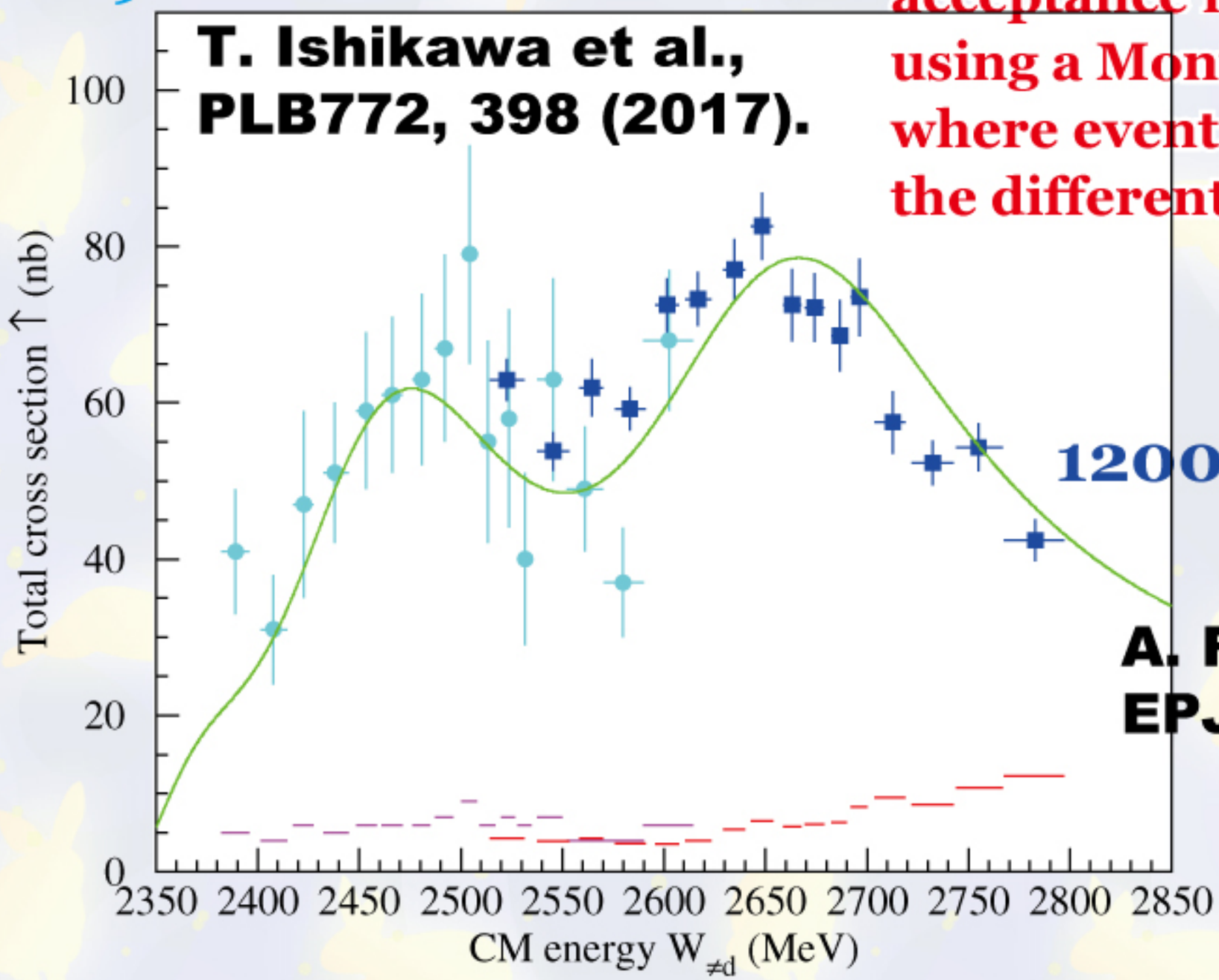
$\gamma p' \to \pi^0 \pi^0 p$ (pQF)

$\gamma n' \to \pi^0 \pi^0 n$ (nQF)

$\gamma d \to \pi^0 \pi^0 pn$ (non QF)

Total cross section

920 MeV



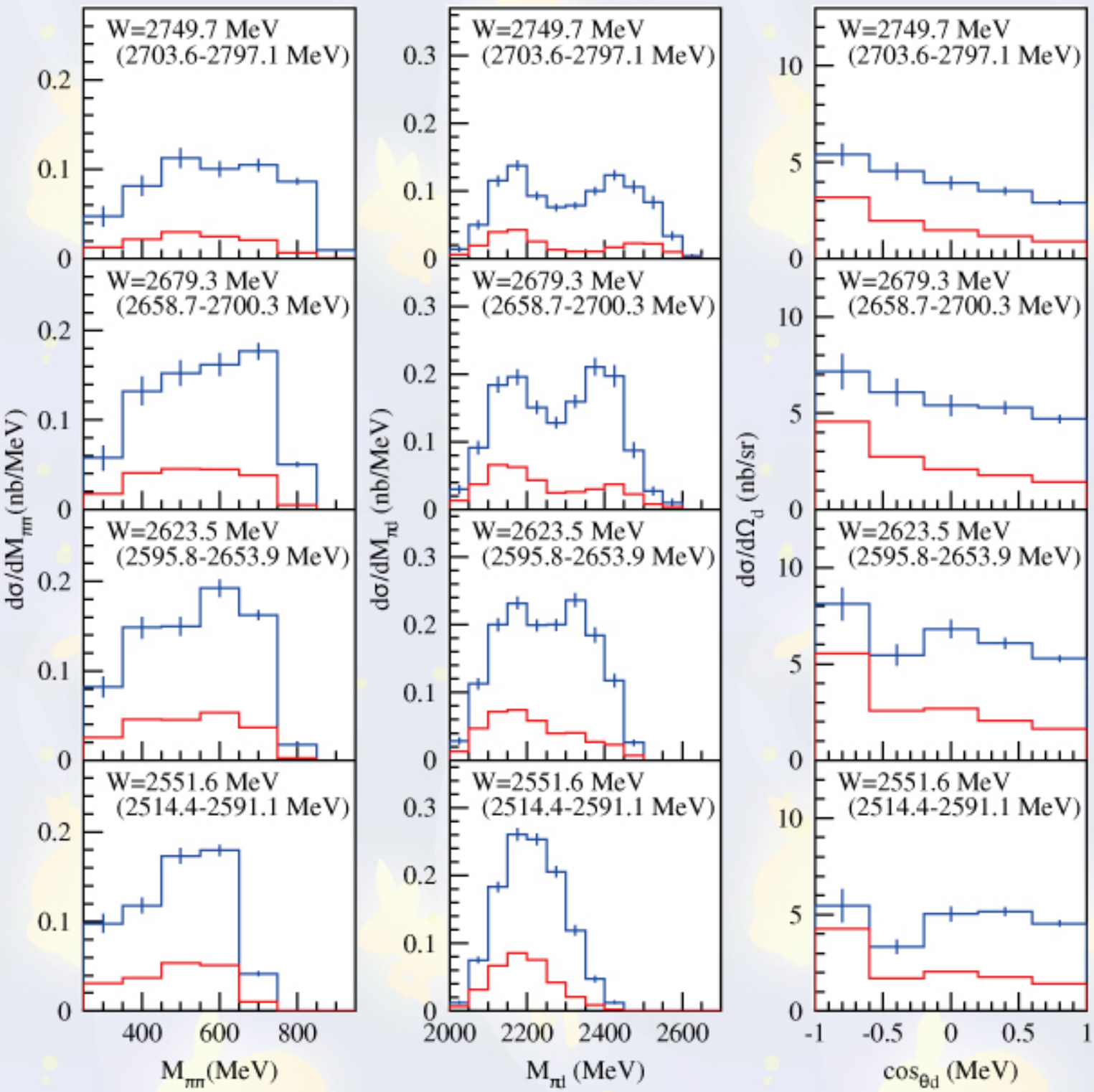
acceptance is estimated using a Monte-Carlo simulation where event generation reproduces the differential cross sections

1200 MeV

A. Fix and H. Arenhövel, EPJA25, 115 (2005).

No clear resonance-like behavior at W=2.37 GeV. consistent with existing theoretical calculations

Differential cross section

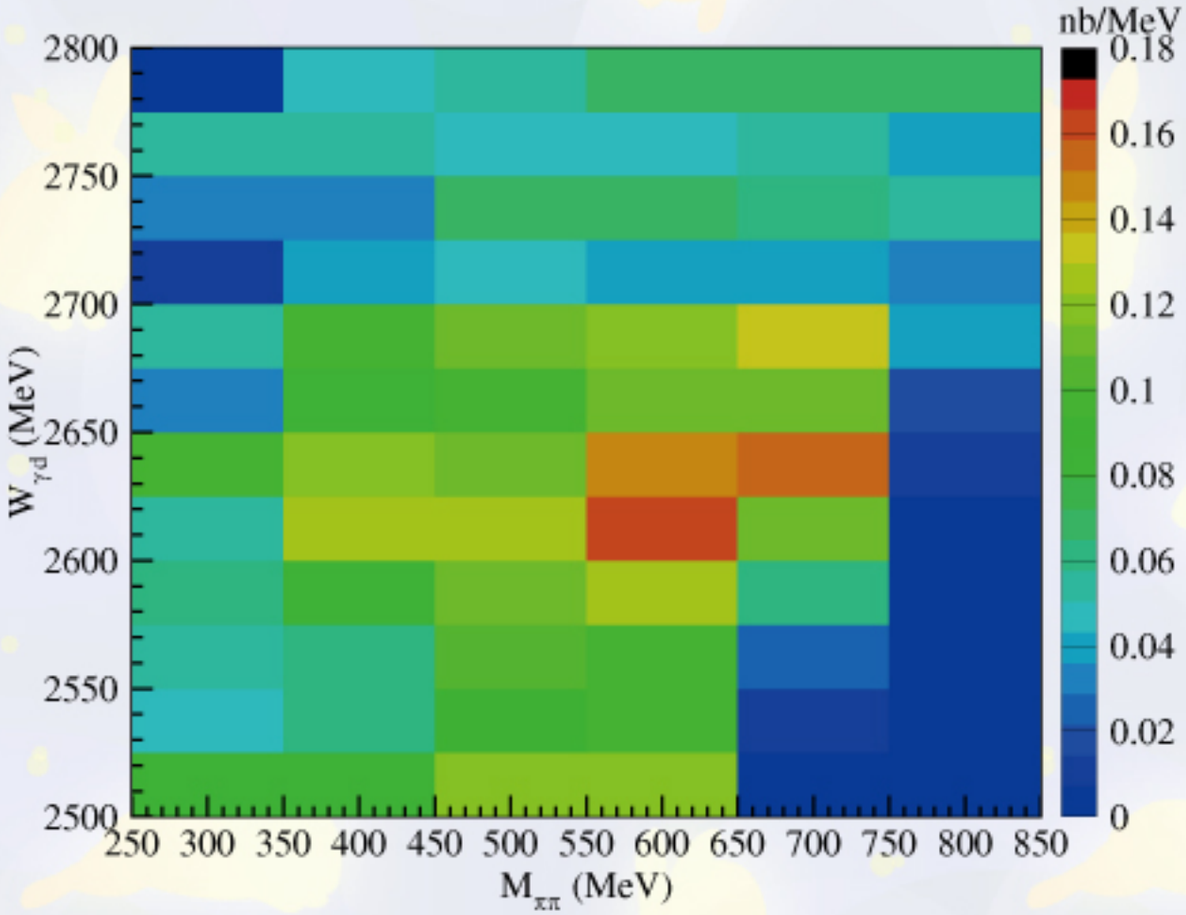


$\pi^o\pi^o$ invariant mass
monotonically increasing
at low energies
convex upward
at high energies

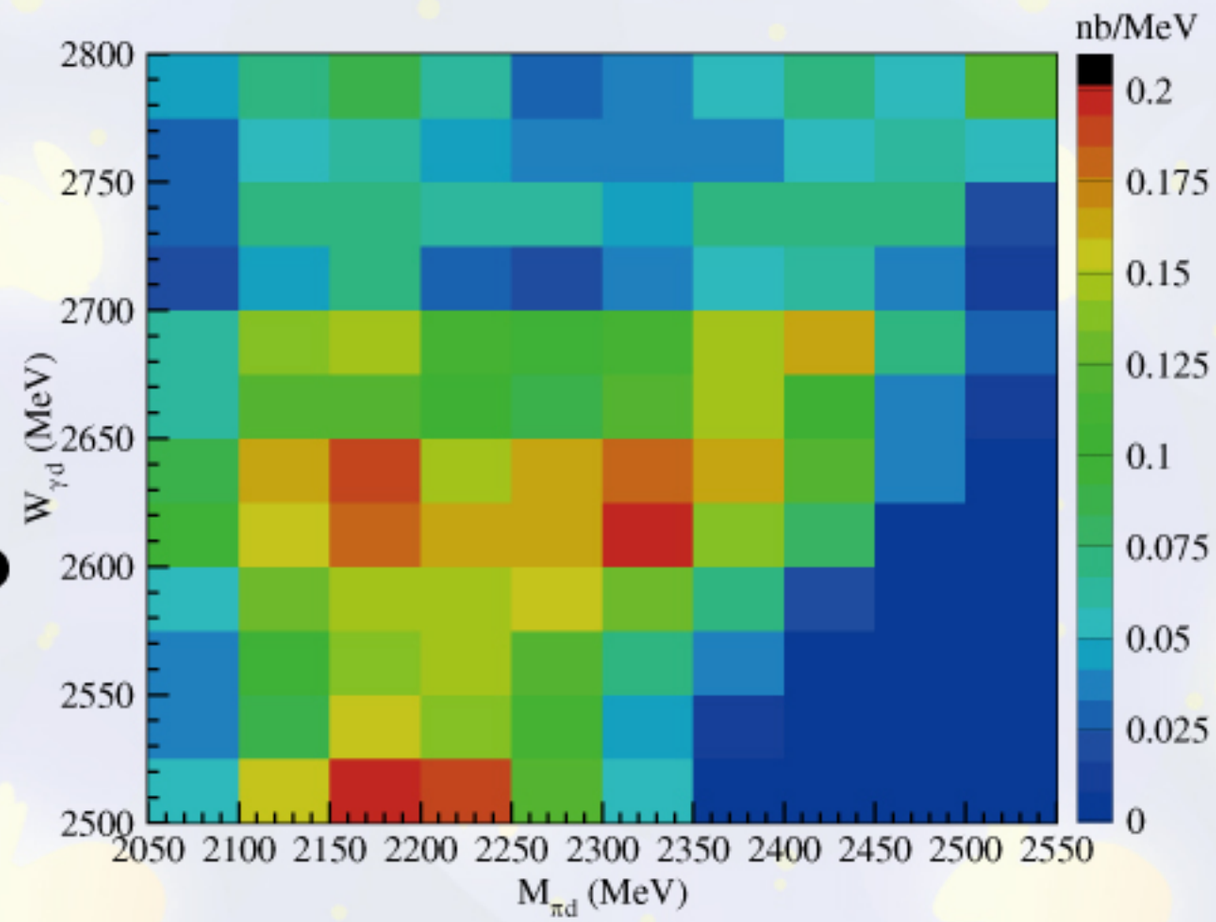
$\pi^o d$ invariant mass
peak at ~2.15 GeV

deuteron emission
backward peaking
at high energies

$\pi^0 d$ resonance?

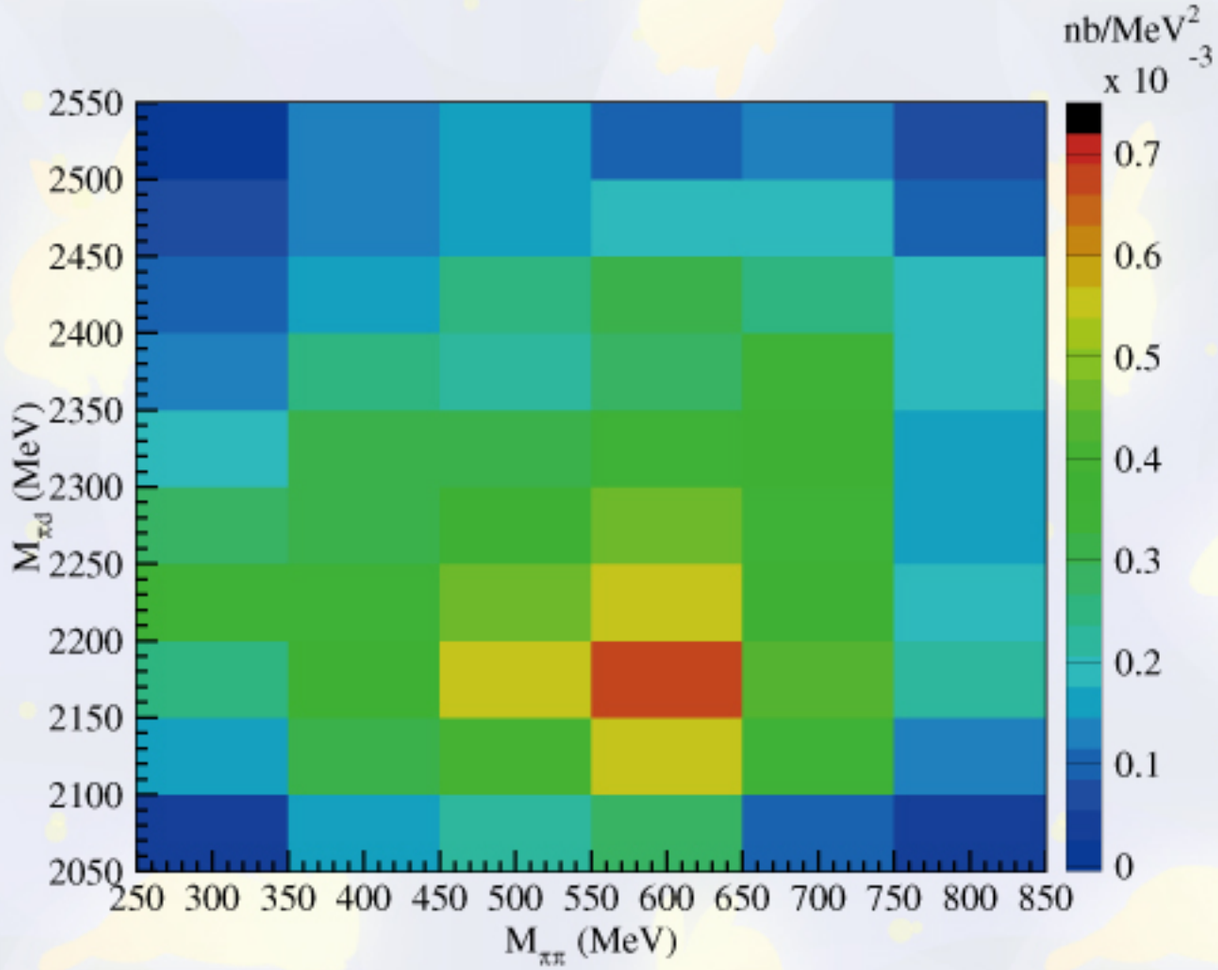


event concentration at $W_{\gamma d}$=2600 MeV & $M_{\pi\pi}$=600 MeV cross section drops above 2700 MeV ($W_{\gamma d}$)

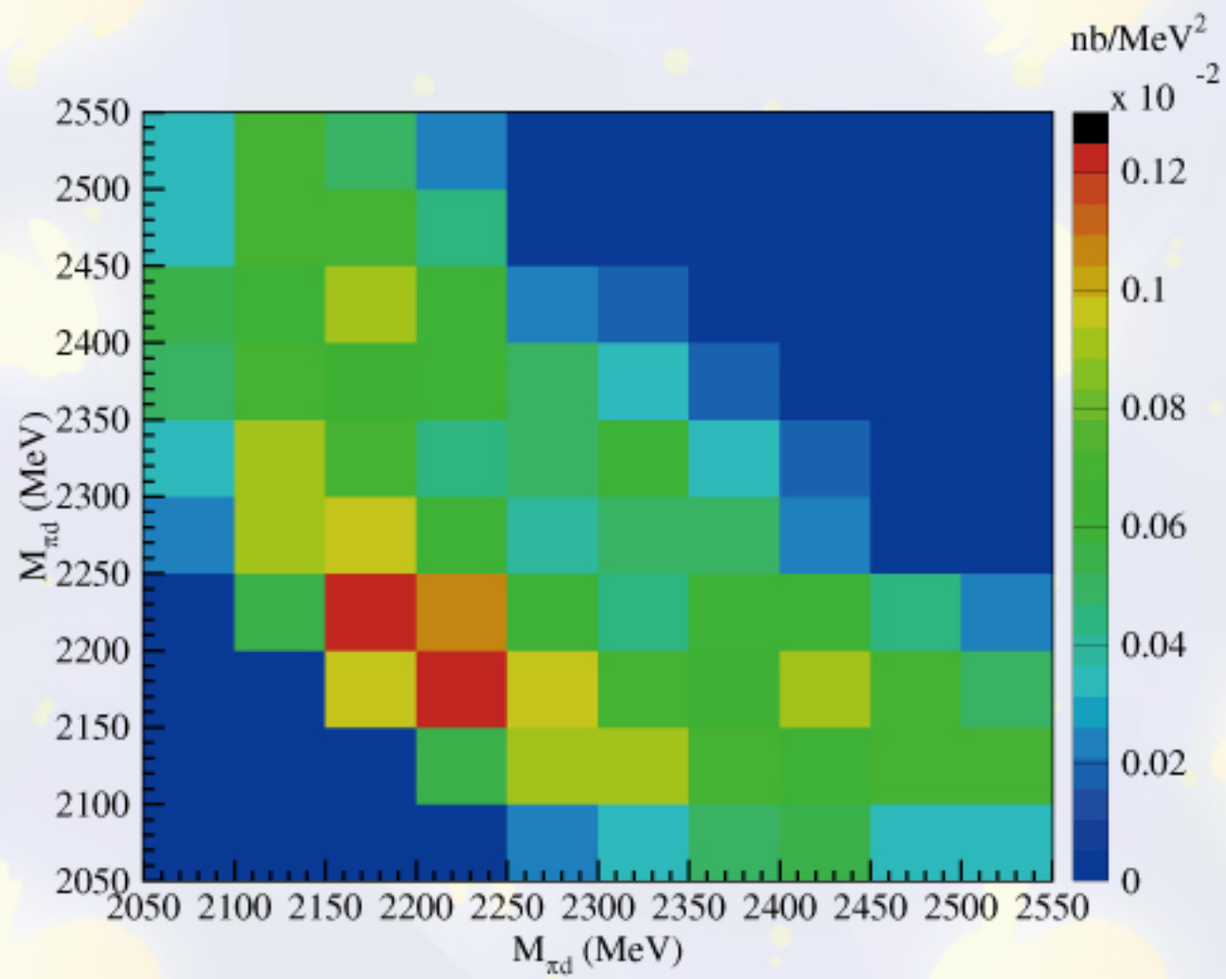


event concentration at $M_{\pi d}$=2150 MeV independently of $W_{\gamma d}$ cross section drops above 2700 MeV ($W_{\gamma d}$)

$\pi^0 d$ resonance?



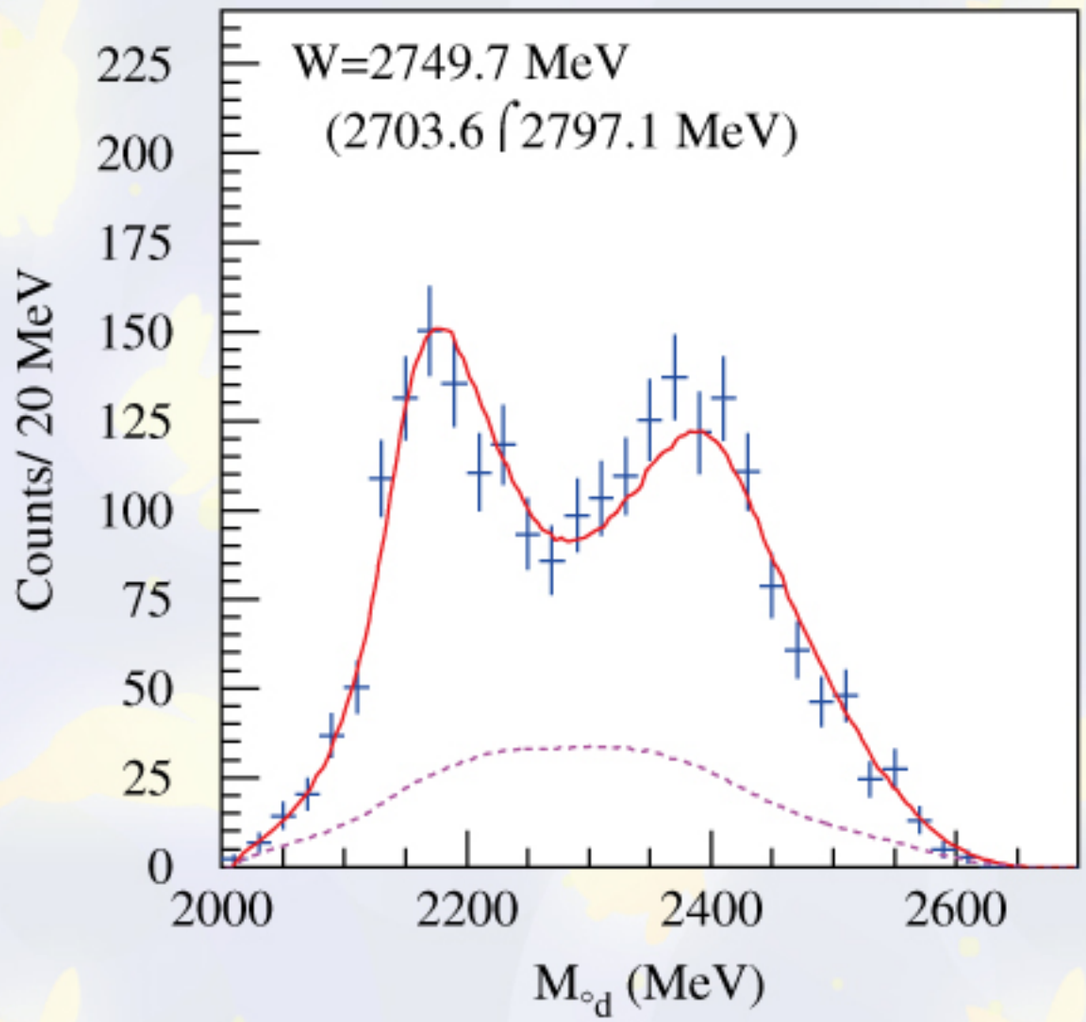
event concentration at $M_{\pi d}$=2150 MeV & $M_{\pi\pi}$=600 MeV suggesting the relative momentum between πd and the other π is large

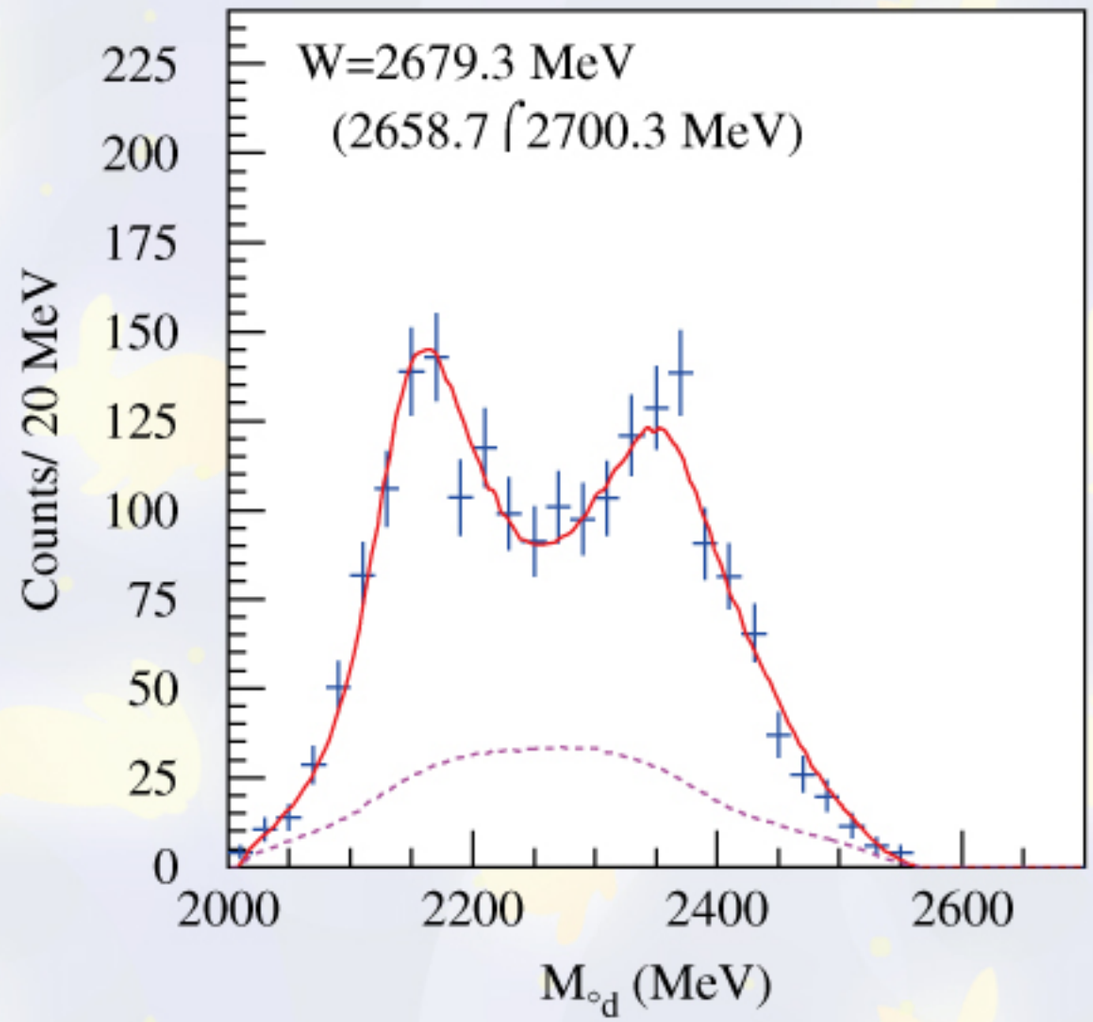


Two loci at $M_{\pi d}$=2150 MeV

$\pi^0 d$ resonance?

I=1 (I=1 for π, I=0 for d)





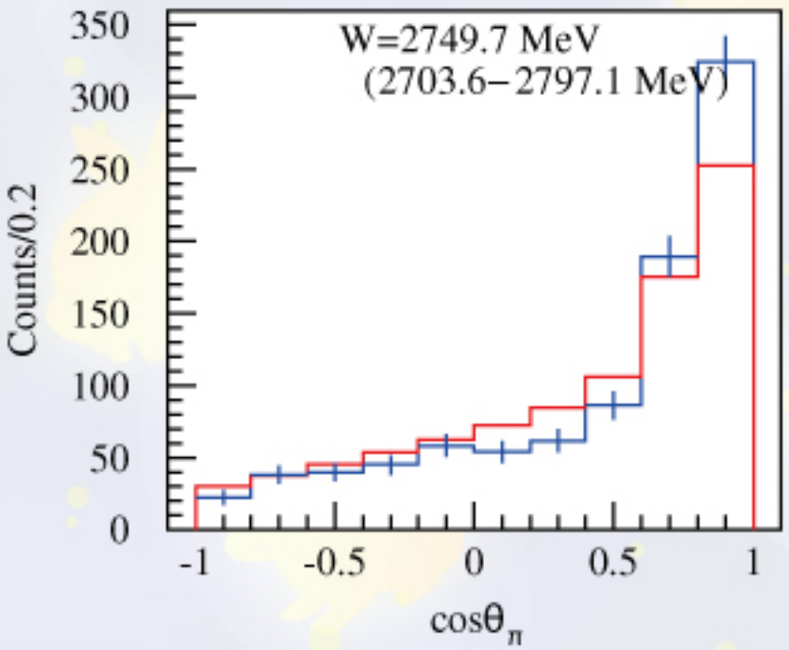
Breit-Wigner convoluted with 11-MeV-σ Gaussian

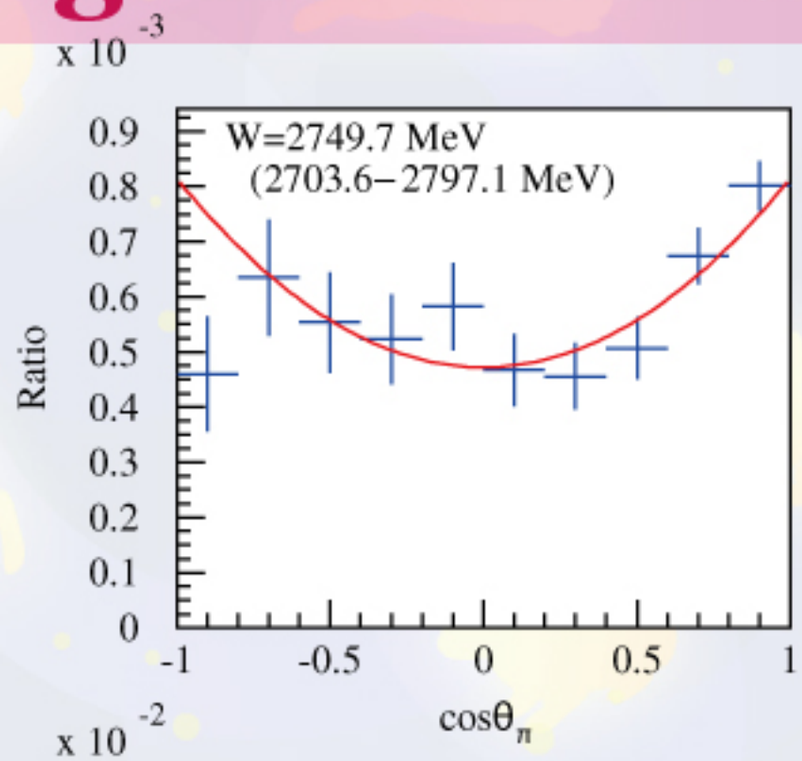
mass 2160±3 MeV **mass 2146±3 MeV**

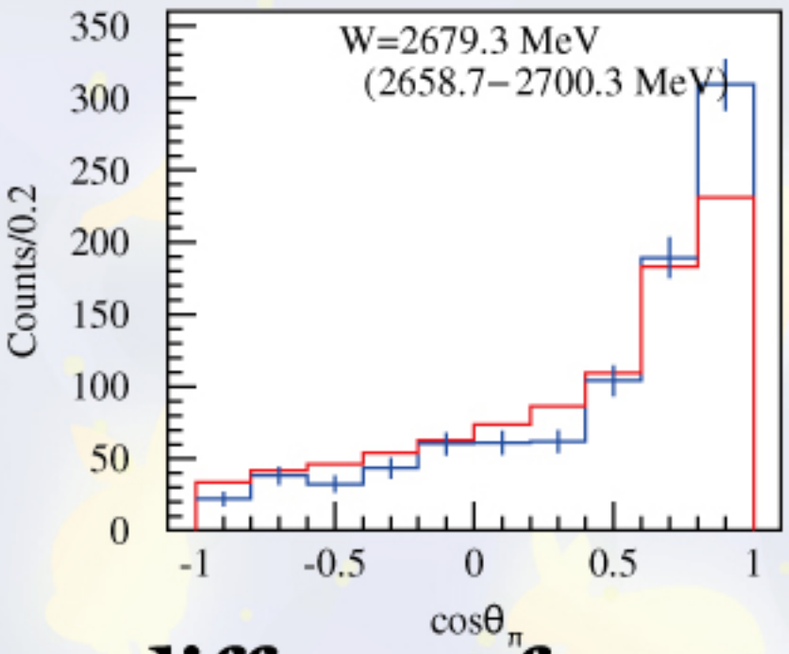
width 119±6 MeV **width 110±3 MeV**

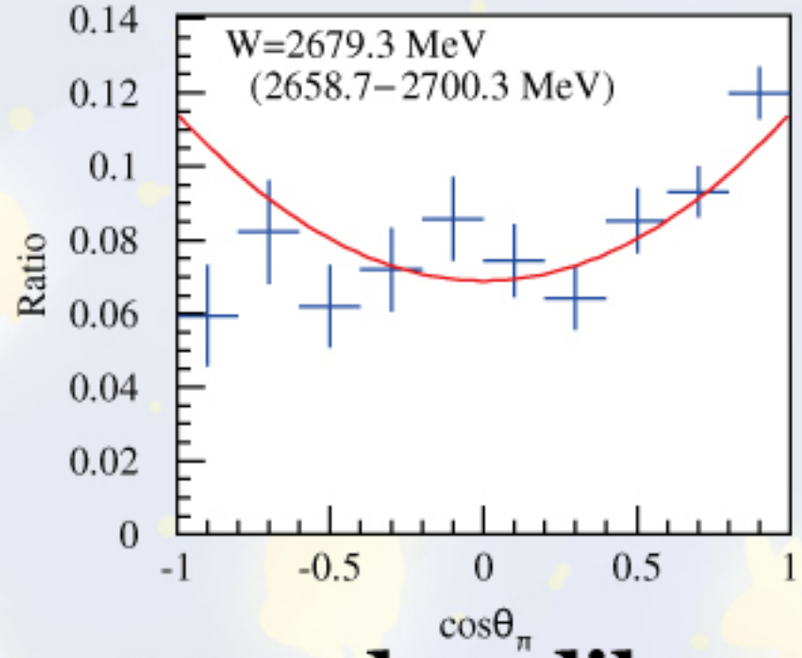
mass 2153±2 MeV & width 112±3 MeV

Decay angular distributions









π^0 emission angle in the $\pi^0 d$ rest frame

$M_{\pi^0 d}$

2.05-2.25 GeV

z axis

opposite direction of the other π^0 momentum

L=1 fits the distributions (m=0 & m=±1)

suggesting 0^+, 1^+ or 2^+

different from two 0^- and 2^- dibaryons reported by the COSY-ANKE collaboration for the $pp \rightarrow \{pp\}_s\pi^0$ reactions

V. Komarov et al., PRC93, 065206 (2016).

Dibaryons

$d^*(2380)$

F.J. Dyson, N.-H. Xuong, Phys. Rev. Lett. 13, 815 (1964).

$\mathcal{D}_{IS}$	$\mathcal{D}_{01}$	$\mathcal{D}_{10}$	$\mathcal{D}_{12}$	$\mathcal{D}_{21}$	$\mathcal{D}_{03}$	$\mathcal{D}_{30}$
BB	NN	NN	ΔN	ΔN	$\Delta\Delta$	$\Delta\Delta$
M	A	A	$A+6B$	$A+6B$	$A+10B$	$A+10B$
	1878	1878	2160	2160	2348	2348

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

A=1878 MeV

B=47 MeV

non-attractive

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

deuteron:

attractive $^3S_1$ state

Summary

Total cross section has been measured at $W_{\gamma d}$=2.38 ~2.61 GeV for the first time.

No clear resonance-like behavior corresponding to $d^*(2380)$ ~$\mathcal{D}_{03}$ candidate~ is observed.

T. Ishikawa *et al.*, PLB772, 398 (2017).

A peak at M~2.16 GeV ~$\mathcal{D}_{12}$ candidate~ is observed in the $\pi^0 d$ invariant mass distribution for the $\gamma d \to \pi^0 \pi^0 d$ reaction at $W_{\gamma d}$=2.50~2.80 GeV.

- M=2153±2 MeV
- Γ=112±3 MeV
- L=1 for the $\pi^0 d$ decay (0^+, 1^+ or 2^+)

Similar peaks seem to be observed in the $\pi^{\pm} d$ invariant mass at JLAB/CLAS and ELPH/NKS2.