Evidence of a Di-baryon spectrum in coherent $\pi^0 \pi^0 d$ photoproduction at the BGOOD experiment

Tom Jude et al. [BGOOD collab.]
Phys. Lett. B 832 (2022) 137277

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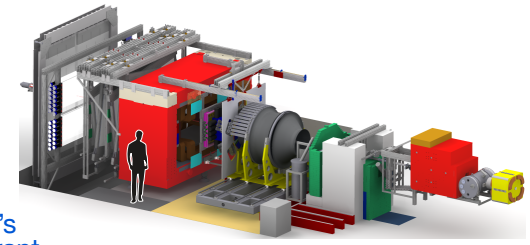
Outline

- motivation
- photoproduction of possible di-baryons
- recent results of BGOOD
- conclusions



Deutsche Forschungsgemeinschaft DFG

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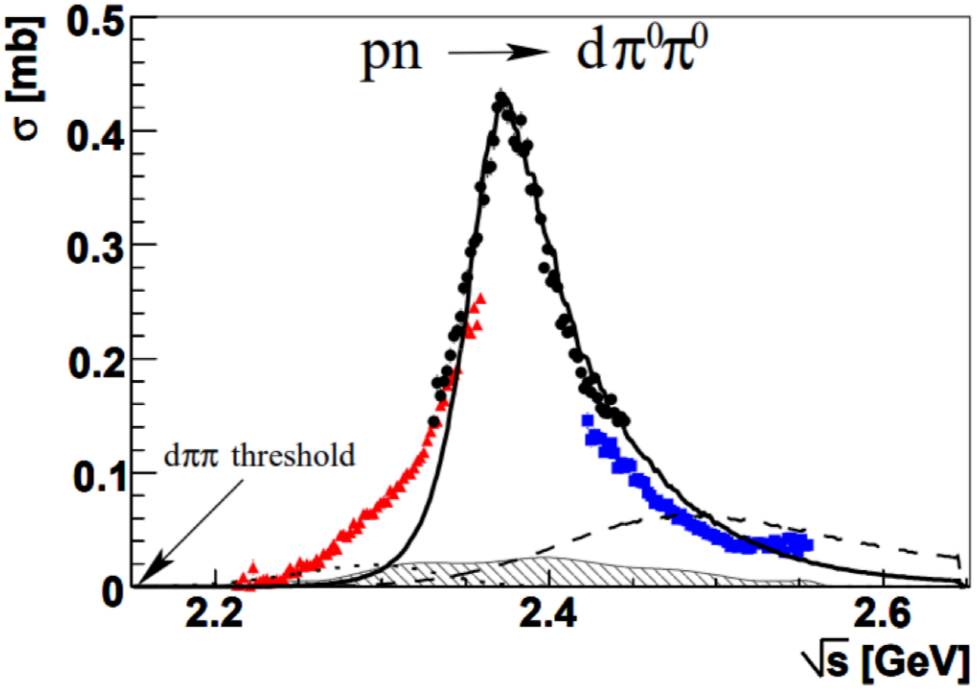
ELSA

from penta to hexa ... → Dibaryons ?

why should we look ?

Dibaryons ?

- early SU(6) predictions – NN, NΔ & ΔΔ type dibaryon candidates
  Dyson & Xuong, PRL 13 (1964) 815
- 3-body calculations NΔ & ΔΔ in good agreement
  Gal & Garcilazo, NPA 928 (2014) 73



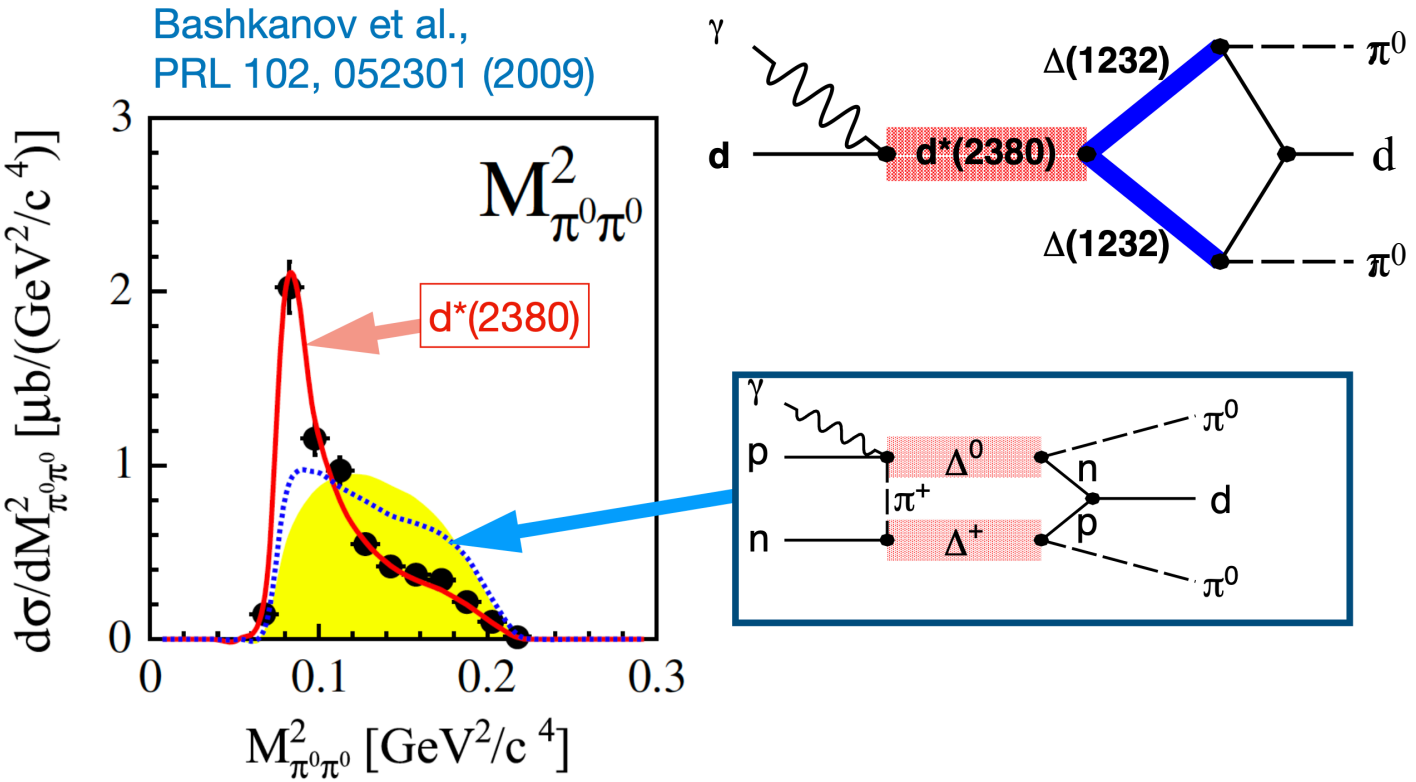
d(2380)*
observed in pn fusion reaction
at WASA experiment at COSY

P. Adlarson et al. [WASA@COSY],
PRL 106 (2011) 242302

- $(I)\ J^P = (0)\ 3^+$
- ΔΔ type object ?
- meanwhile observed in multiple final states in pn reactions

Dibaryons ?

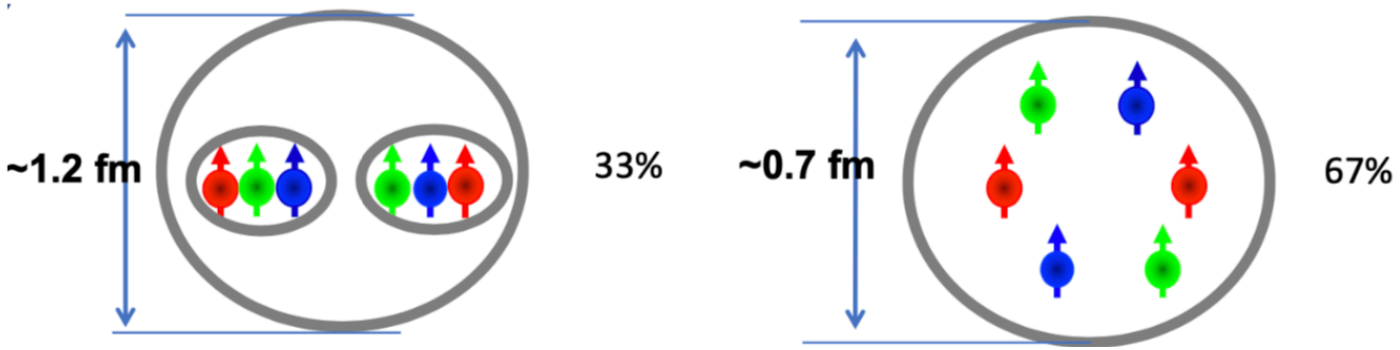
- low mass enhancement in ππ invariant mass in double pionic fusion d + p
  Booth, Abashian & Crowe, PRL 7 (1961) 35 [ABC effect]
- described when including d*(2380)



Dibaryons ?

- Microscopic χ quark models:
  - 2/3 hidden color (compact) configuration
  - 1/3 molecular component

    Huang et al., Chin. Phys. C7 (2015) 071001



- *d*(2380)* in the centre of neutron stars

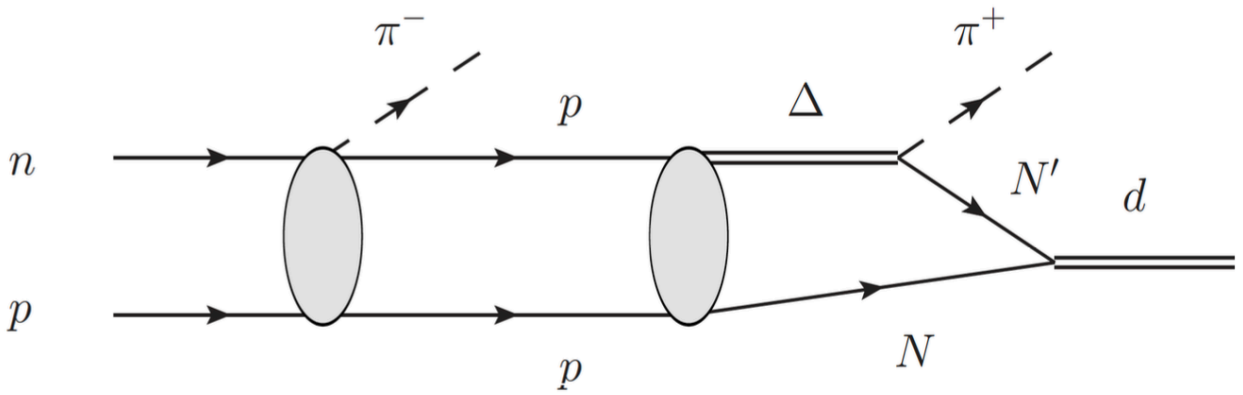
  Vidana et al., PLB 781 (2018) 112

- Dark matter ?? – *d*(2380)* BEC formed in early universe ?

  Bashkanov and Watts, J. Phys. G 47 (2020) 03LT01

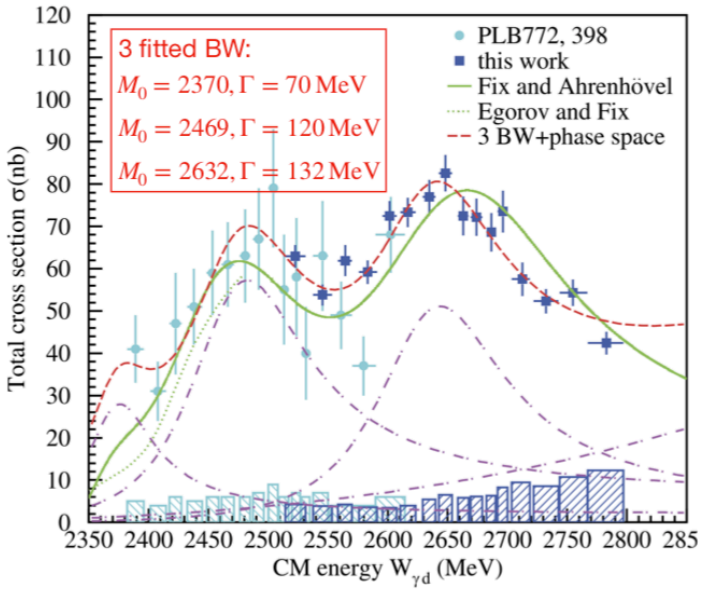
Dibaryons ?

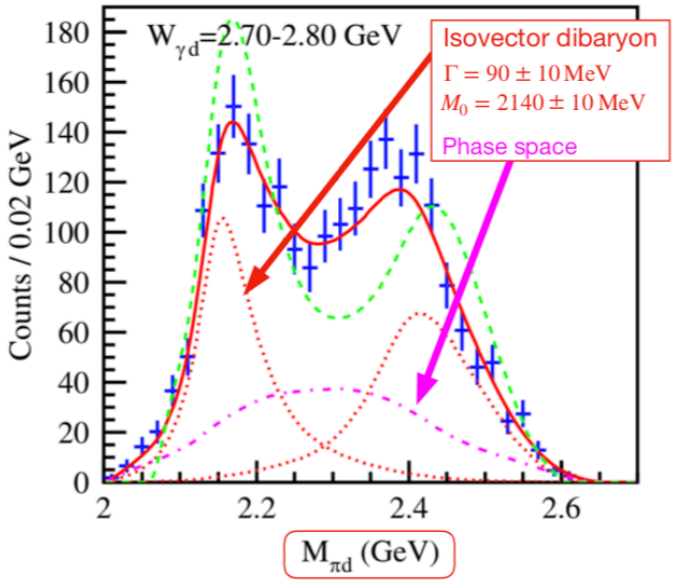
- alternative description $\leftrightarrow$ triangle singularity
- Inspired by: *Analysis of the reaction $np \to np \to d\pi^+\pi^-$ below 3.5 GeV/c* I Bar-Nir et al., Nucl. Phys. B54 (1973) 17
- *Sequential single pion production explaining the dibaryon "d*(2380)" peak* R. Molina, N. Ikeno, and E. Oset, arXiv:2102.05575, PRC 104 (2021) 014614

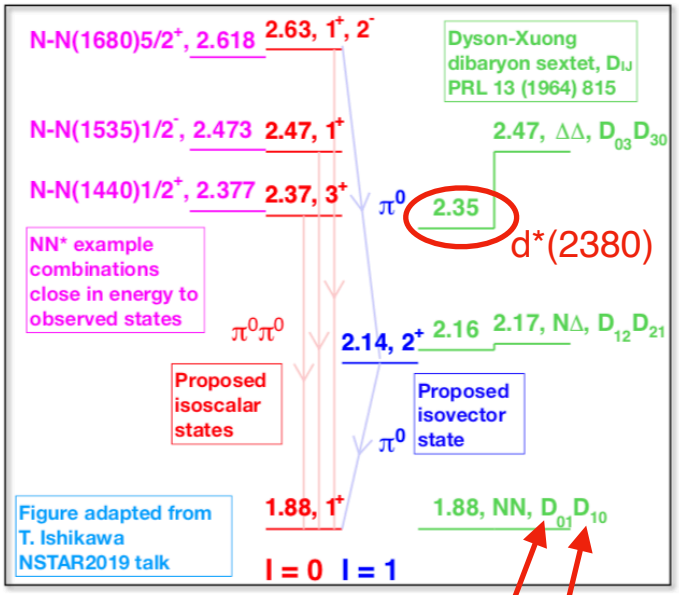


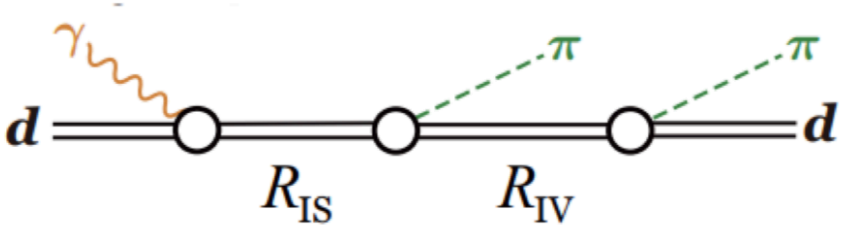
Photoproduction of possible Di-baryons

- coherent photoproduction $\gamma\, d \rightarrow \pi\, \pi\, d$
  challenging: minimal momentum transfer to target deuteron, nbarn x-sec & large qf background
- previous data from ELPH
  Takatsuku Ishikawa et al., PLB 789 (2019) 413







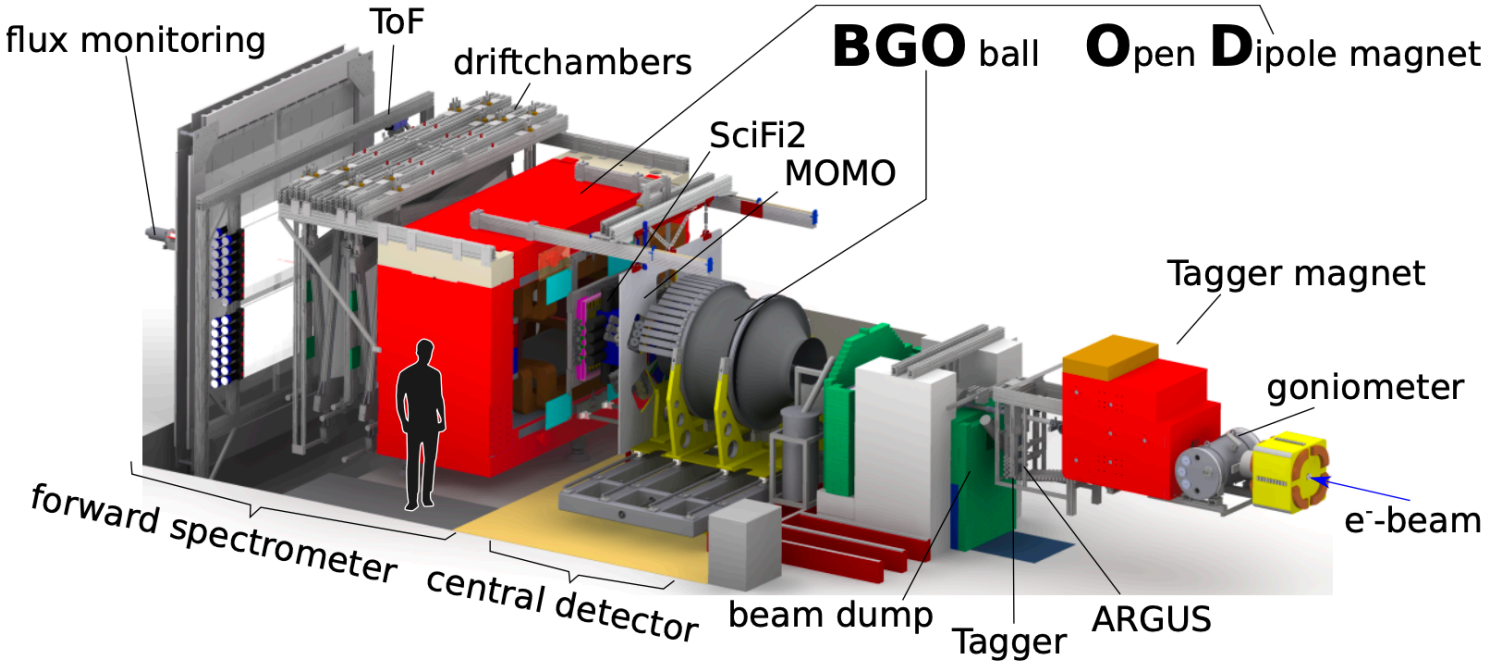


$\gamma\, d \rightarrow d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

experimental setup

S. Alef et al. [BGOOD collab.],
EPJ A 56 (2020) 104

- ELSA - a 3 stage accelerator - continuous e^- beams up to 3.2 GeV
- BGOOD - BGO calorimeter (central region) & Forward Spectrometer combination
- High momentum resolution, excellent charged & neutral particle ID

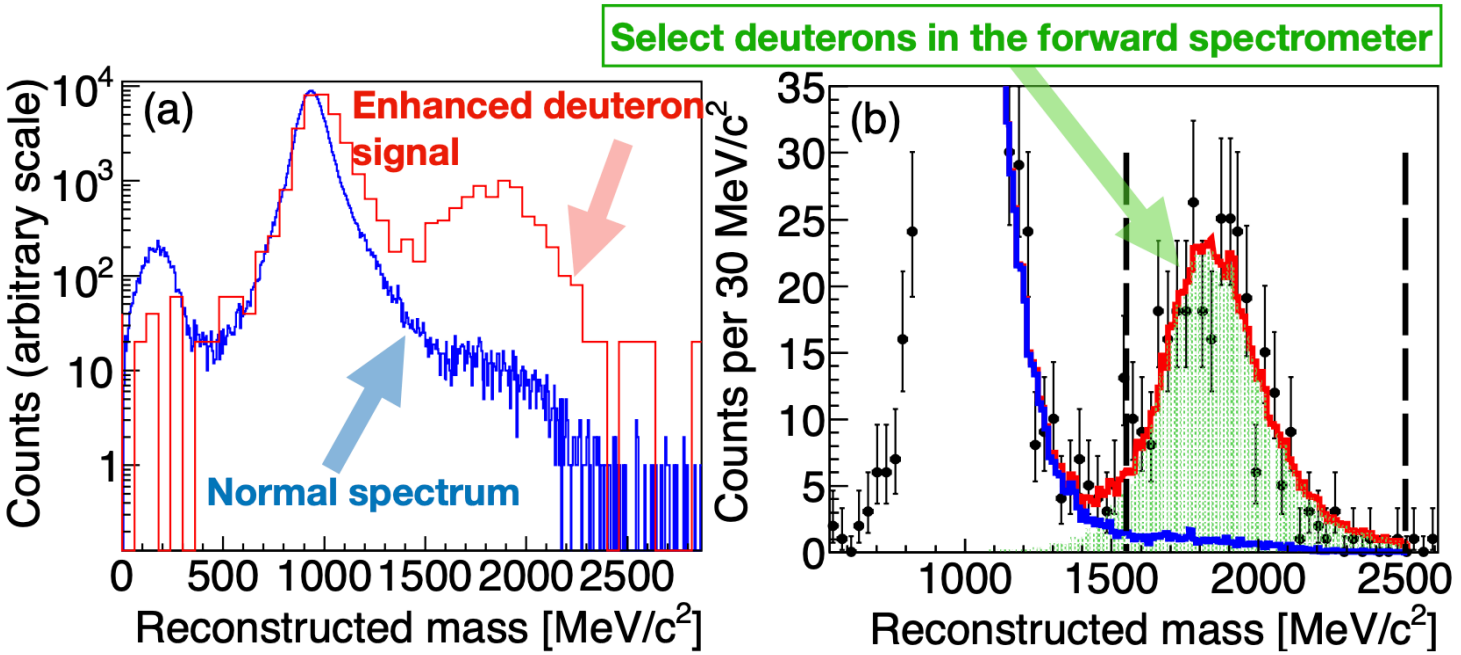


$\gamma\, d \rightarrow d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

T.C. Jude et al. [BGOOD],
PLB 832 (2022) 137277
arXiv:2202.08594

analysis steps

- Coherent reaction - $\gamma d \rightarrow \pi^0\pi^0 d$, deuterons in the forward spectrometer
- Unexpected! $p_d > 400\,\mathrm{MeV/c}$ & deuteron Fermi momentum $\sim 80\,\mathrm{MeV/c}$



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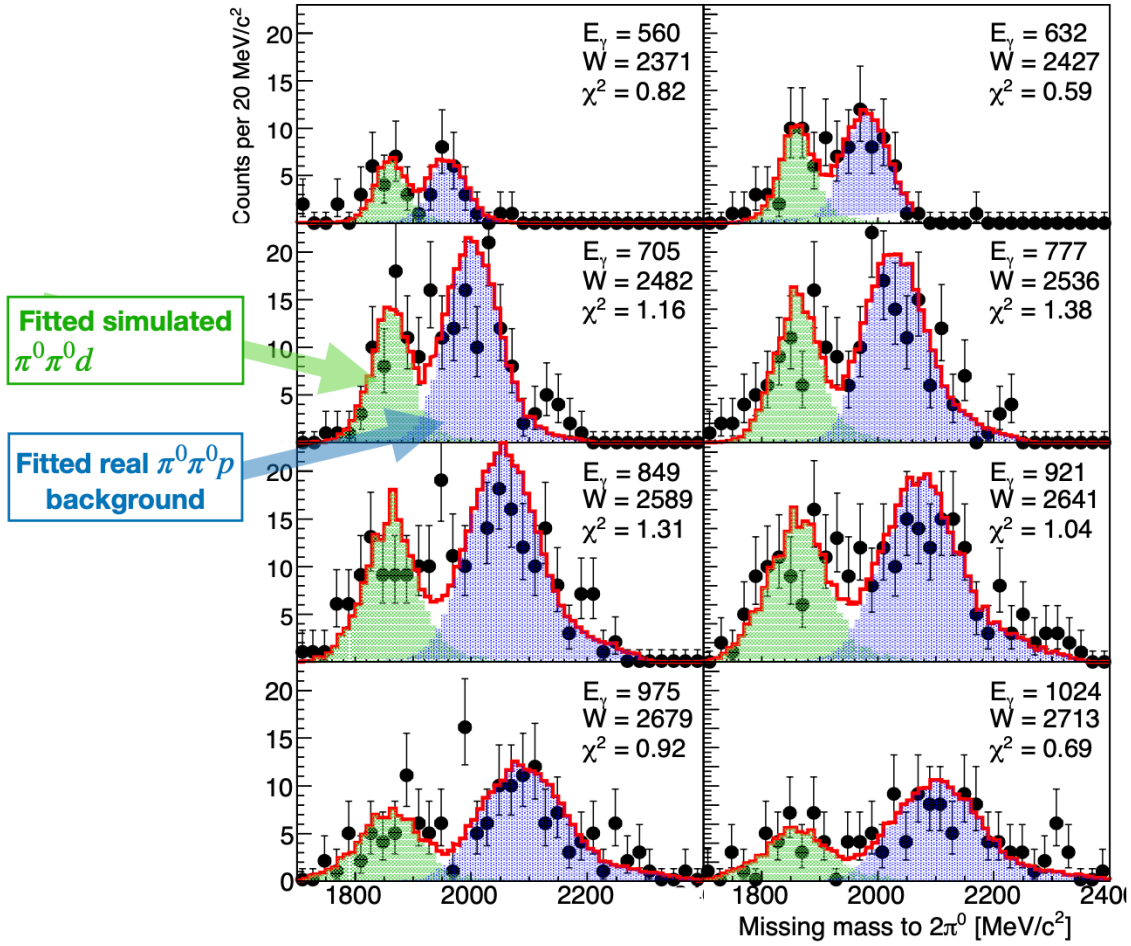
analysis steps

- Forward deuterons
- $\pi^0 \to \gamma\gamma$ in the BGO Rugby Ball
- Reconstructed - measured deuteron direction $< 7.5°$
- Fit to the "$2\pi^0$ Missing mass" ($\gamma d \to \pi^0\pi^0 X$)



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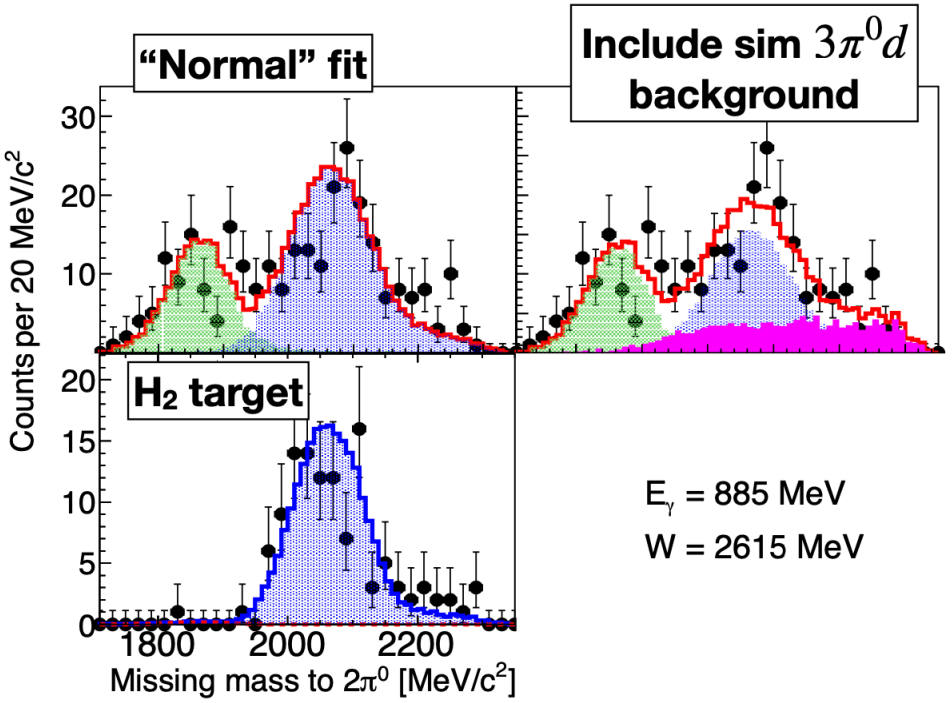
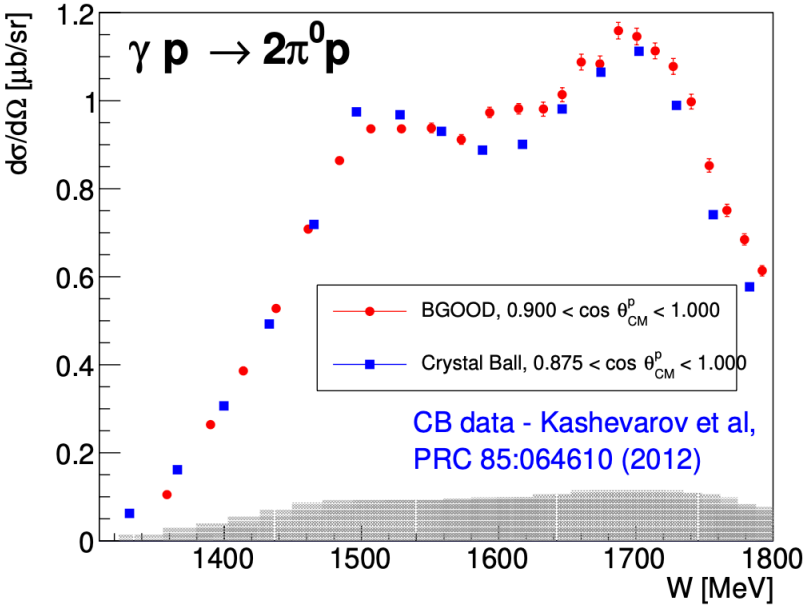
analysis steps

- Systematic studies using hydrogen data & fitting with other background channels



- Good agreement for a "Similar reaction", $\gamma p \to \pi^0 \pi^0 p$
- Small difference at $W \sim 1600$ MeV understood - background from $\gamma p \to \eta p$



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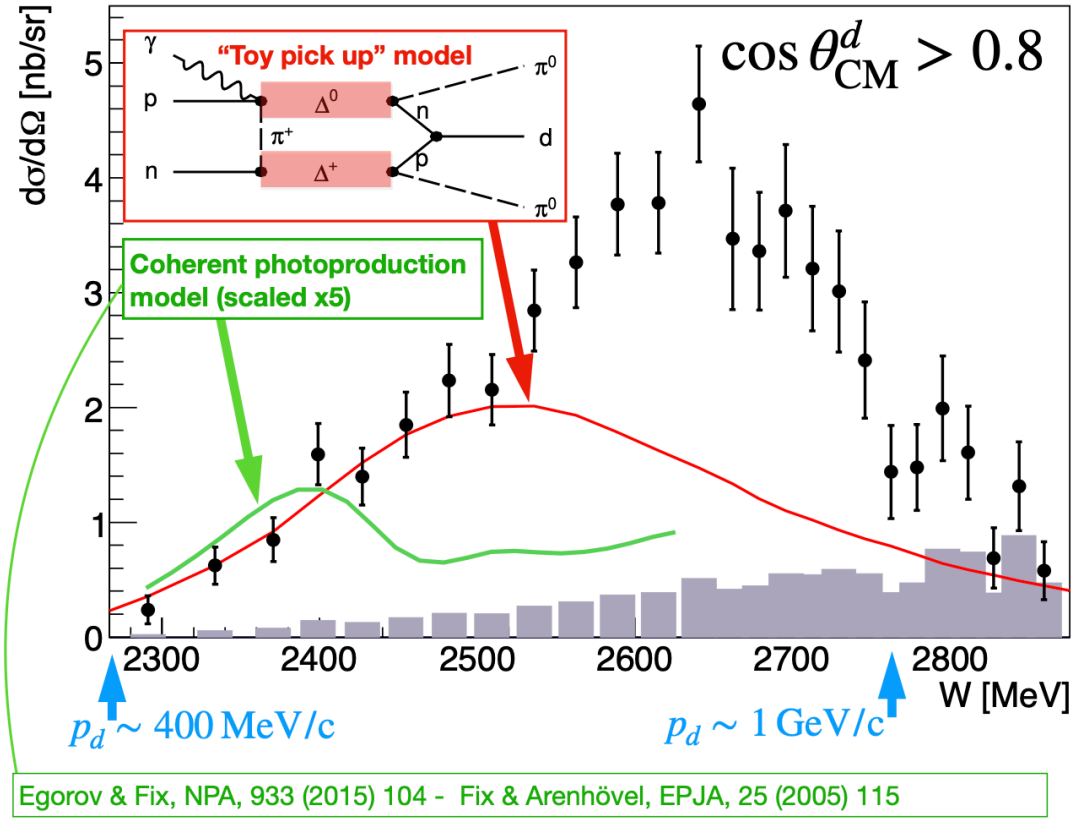
results



The Toy pick up model

- Arbitrary scale
- On-shell momentum & energy conservation
- Nucleons coalesce to form the deuteron if their relative momentum is sufficiently small

$\gamma\, d \rightarrow d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

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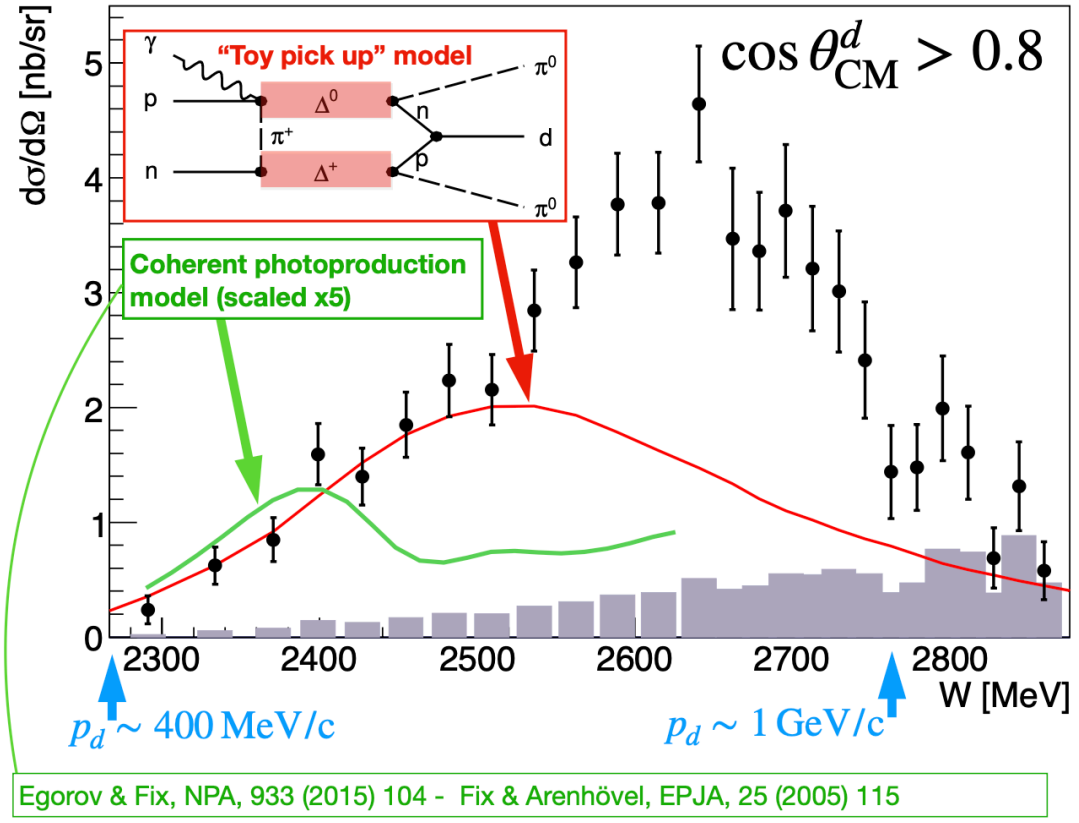
results



Egorov & Fix, NPA, 933 (2015) 104 - Fix & Arenhövel, EPJA, 25 (2005) 115

The Toy pick up model

- Arbitrary scale
- On-shell momentum & energy conservation
- Nucleons coalesce to form the deuteron if their relative momentum is sufficiently small

→ conventional models unable to explain yield of high-momentum deuterons

$\gamma\, d \to d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

T.C. Jude et al. [BGOOD],
PLB 832 (2022) 137277
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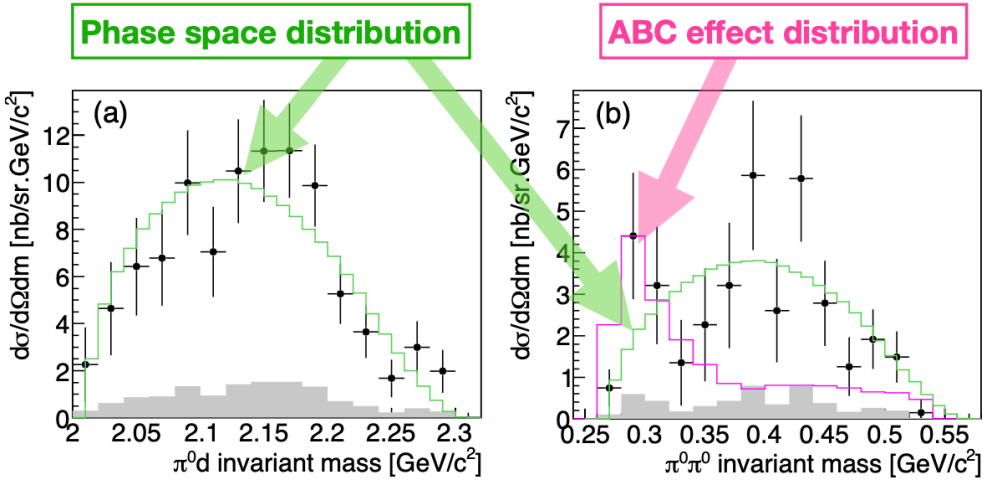
results

- $\pi^0 d$ and $\pi^0\pi^0$ invariant mass distributions over the $d^*(2380)$ range
- appears to be consistent with ABC effect (distribution from P. Adlarson et al. PRC, 86:032201, 2012.)



- differential cross section for $\gamma d \to d^*(2380) \to \pi^0\pi^0 d$: $(22 \pm 6_{\mathrm{stat}} \pm 4_{\mathrm{sys}})$ nb/sr
- angular distribution of $d^*(2380)$ already well determined in fusion reactions
  – total cross section extrapolated to $(11.3 \pm 3.2_{\mathrm{stat}} \pm 2.7_{\mathrm{sys}})$ nb

$\gamma\, d \rightarrow d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

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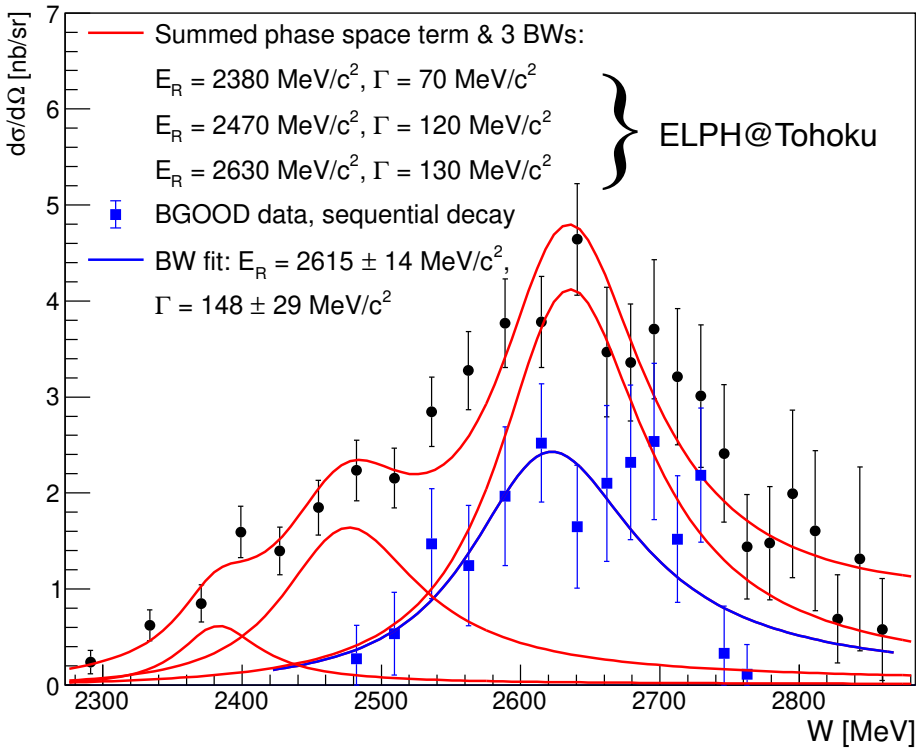
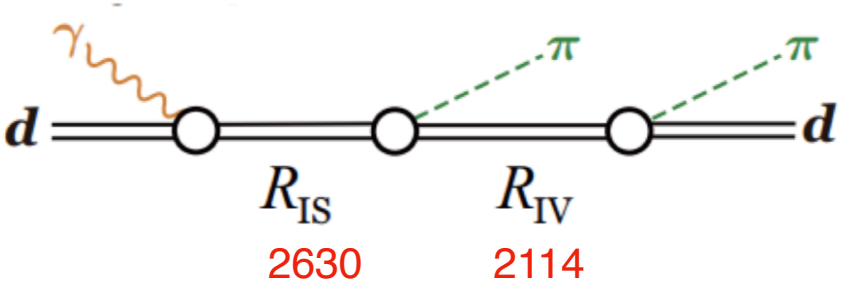
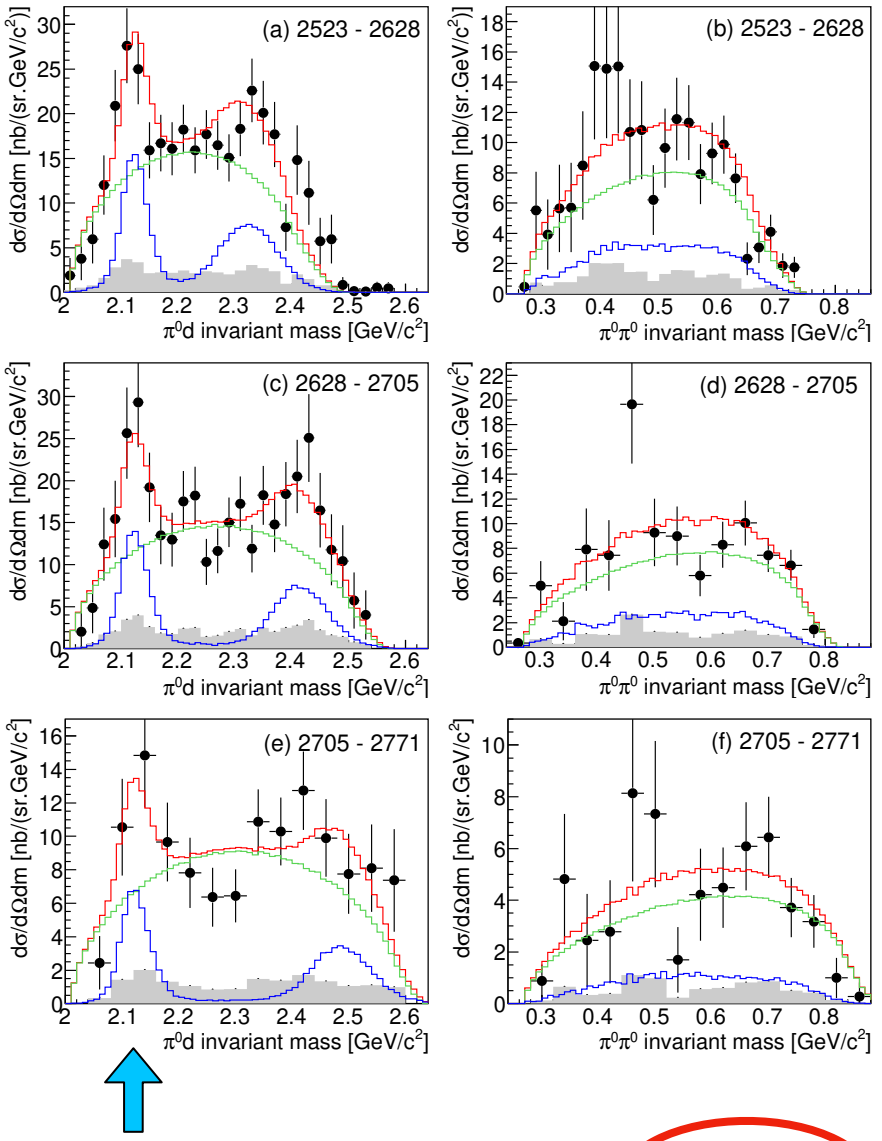






$\pi^0 d$ isovector state: 2114 MeV, Γ≃ 20 MeV

ELPH: 2140 MeV, Γ≃ 90 MeV

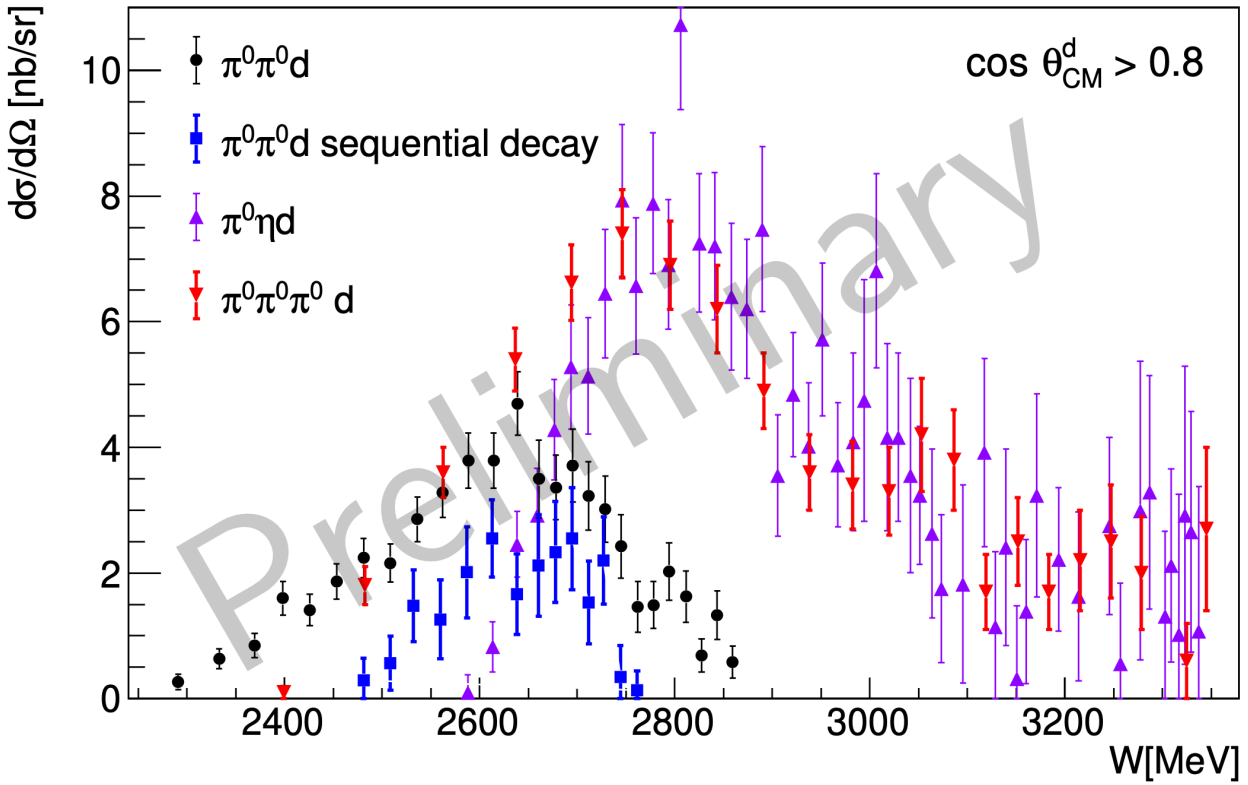
γd coherent photoproduction @BGOOD

new preliminary results

- 2x data now available
- improved W resolution
- other coherent final states
  - ➡ constrain di-baryon composition ?
  - ➡ access to isovector di-baryon candidate ?

$\pi^0 \eta$: L. Lutter, Bachelors thesis (Bonn 2022)
& A. Figueiredo, Masters thesis (Bonn 2023)

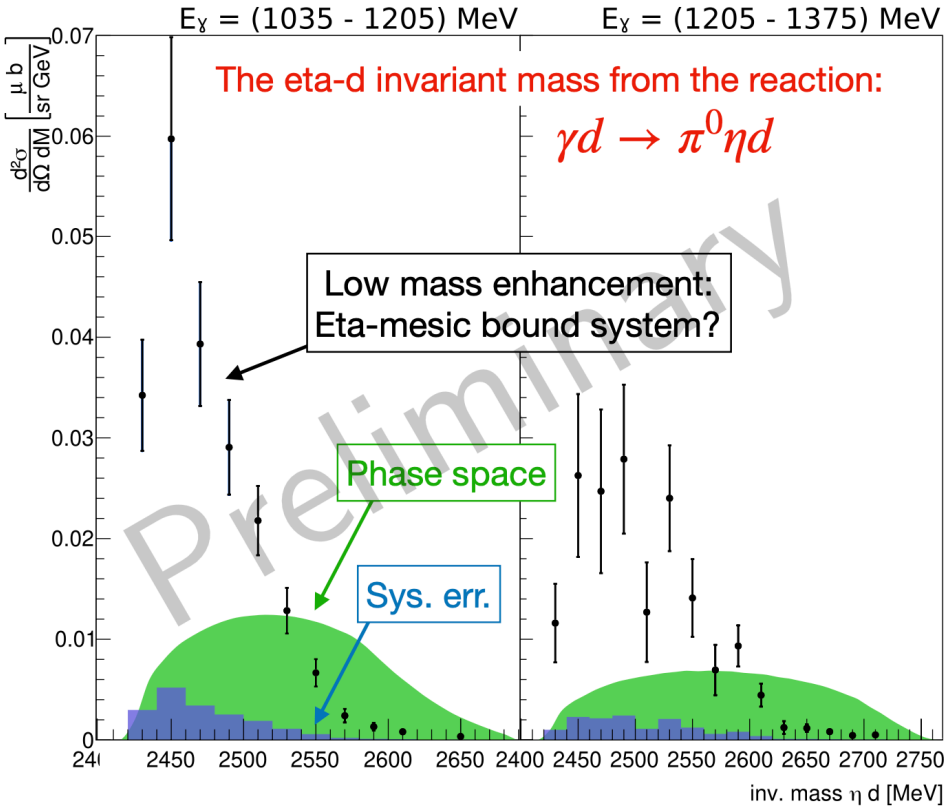
$3\pi^0$: A. Stirner, Masters thesis (Bonn 2021)



$\gamma\, d \rightarrow d\, \eta\, \pi^0$ coherent photoproduction @BGOOD

new preliminary results

A. Figueiredo, Masters thesis (Bonn 2023)



- x-sec $\pi^0\,\eta = 3\pi^0 = 2\pi^0$ in overlap
- unexpected
  - ➡ strong low mass enhancment in (ηd) system composition ?
  - ➡ η-mesic bound system ??
  - ➡ [S_{11}(1535) N] bound system?

$\gamma\, d \rightarrow d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

conclusions

- clean separation of coherent process → d in forward spectrometer
- high-momentum deuteron yield hard to reconcile w/ conventional descriptions
- γd "excitation function" consistent with isoscalar di-baryon states at 2380, 2470 & 2630 MeV (as earlier suggested by ELPH)
- ($\pi^0\, \pi^0$) invariant mass distribution consistent with ABC effect at W in d*(2380) region
- very narrow peak in (π^0 d) invariant mass at 2114 MeV – isovector di-baryon ?
- width $\Gamma \sim 20$ MeV ↔ experimental resolution!

tension w/ ELPH

- further studies in coherent $3\pi^0$ and $\pi\,\eta$ channels underway