Single and Double Pion Photoproduction off the Deuteron

Manuel Dieterle

Munich, June 13^{th} 2011

XIV International Conference on Hadron Spectroscopy

MAINZER MIKROTRON

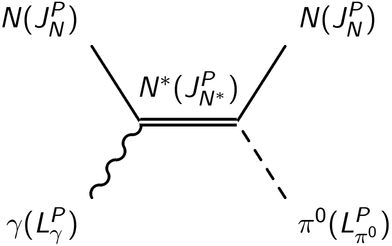
UNI BASEL

A2 Collaboration

Outline

Why Photoproduction of π^0?

- Test modern hadron models by studying nucleon resonances



- Small coupling of photons to neutral mesons

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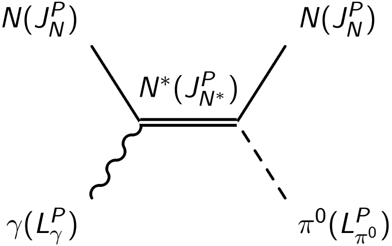
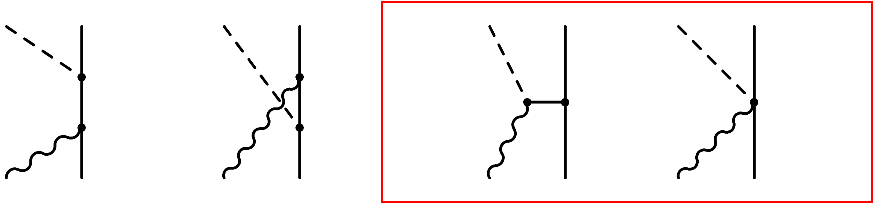


- **Small coupling** of photons to neutral mesons



Why on the Neutron?

- Isospin amplitudes of the elm. transitions depend on reactions on proton and neutron

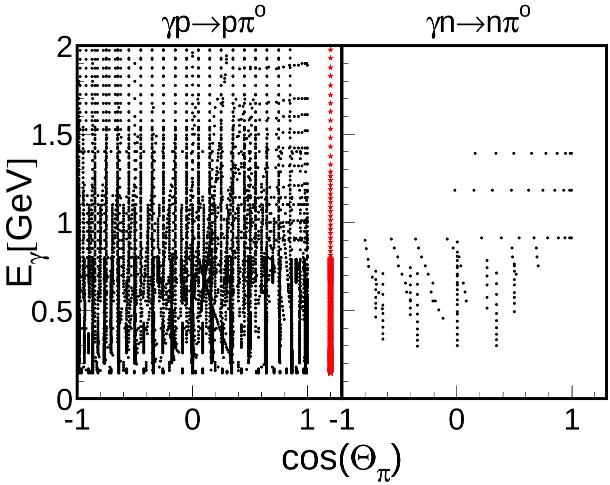
$$A(\gamma p \rightarrow \pi^+ n) = \sqrt{2}(A^{(0)} + A^{(-)})$$
$$A(\gamma n \rightarrow \pi^- p) = \sqrt{2}(A^{(0)} - A^{(-)})$$
$$A(\gamma p \rightarrow \pi^0 p) = (A^{(+)} + A^{(0)})$$
$$A(\gamma n \rightarrow \pi^0 n) = (A^{(+)} - A^{(0)})$$

$A^{(0)}$:= isoscalar

$A^{(+)}, A^{(-)}$:= isovector

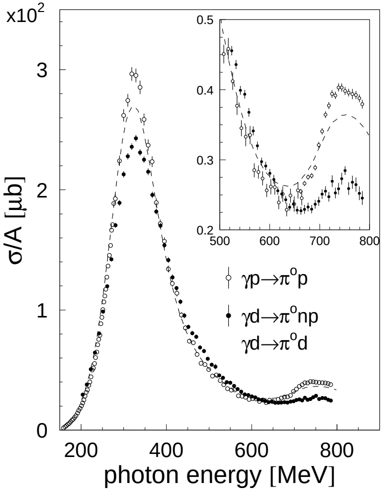
- meson photoproduction from light nuclei, i.e. deuteron
- nuclear effects (rescattering of the mesons, FSI, ...)

World π^0 Data



SAID Data Base - http://gwdac.phys.gwu.edu/

Former Results - MAMI 1999



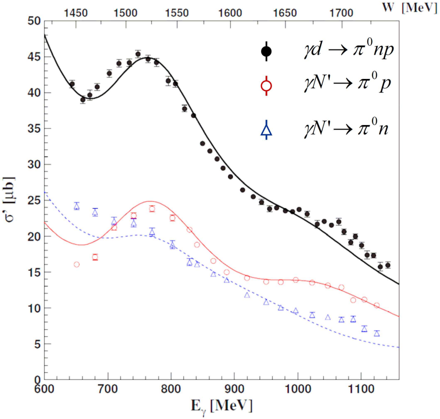
B. Krusche et al., Eur. Phys. J. A 6(1999) 309

- ● $\sigma(\pi^0 np)/A$ $\sigma(\pi^0 d)/A$
- ○ $\sigma(\pi^0 p)$
- — $\sigma(\pi^0 p)$ folded

- significant reduction in σ/A compared to free proton
- can not be explained alone by Fermi motion
- nuclear effect? FSI?

Former Results - LNS Sendai 2009

$\sigma'(-0.7 < \cos\theta^*_{\pi^0} < 0.6)$



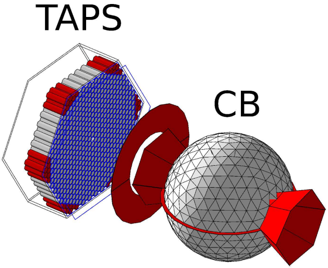
- ● $\sigma(\pi^0 np)$
- ○ $\sigma(\pi^0 p)$
- △ $\sigma(\pi^0 n) = \sigma(\pi^0 np) - \sigma(\pi^0 p)$
- — $0.8 * MAID$ folded

- can not be explained alone by Fermi motion
- nuclear effect? FSI?

H. Shimizu, NNR workshop 2009

Experiment MAinzer MIcrotron, Dec 2007

- Photon beam energies up to $\sim 1.4\ GeV$
- Target: $\sim 5\ cm$ LD_2
- Detectors:
  - Crystal Ball (**CB**):
    - surrounding the target
  - Two Arm Photon Spectrometer (**TAPS**):
    - placed as forward wall
  - $\sim 4\pi$ **steradian**



Identification of the Reaction Channels

Reaction mechanism for π^0 photoproduction on deuterium:

$$\gamma + d \rightarrow \begin{cases} \pi^0 + p(n) & \text{QF on proton} \\ \pi^0 + n(p) & \text{QF on neutron} \\ \pi^0 + d & \text{Coherent } (\xrightarrow{E_\gamma > 500 \text{ MeV}} 0) \end{cases}$$

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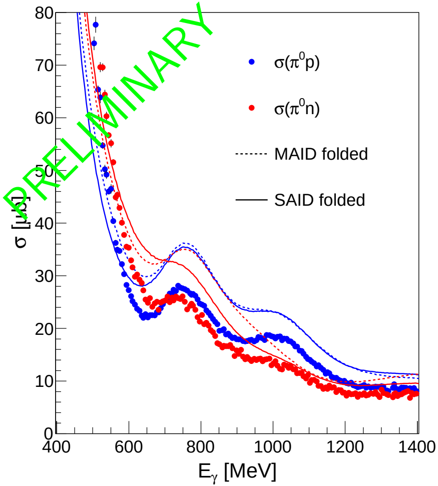
Measurements:

	Exclusive on P:	$\gamma + d \rightarrow \pi^0 + p$
$+$	**Exclusive on N:**	$\gamma + d \rightarrow \pi^0 + n$
$\approx$	**QF-Inclusive:**	$\gamma + d \rightarrow \pi^0 + (N)$

π^0 Total Cross Sections



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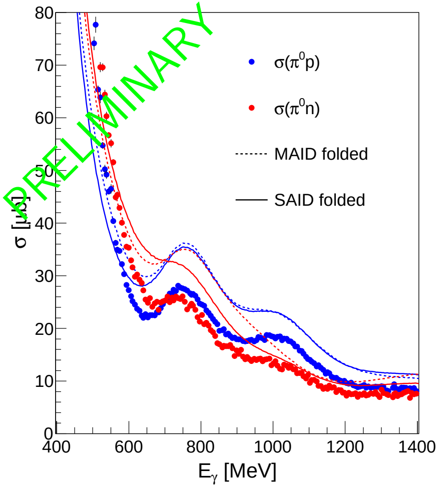
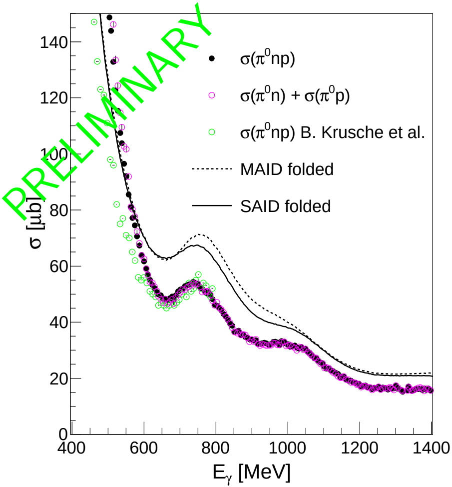
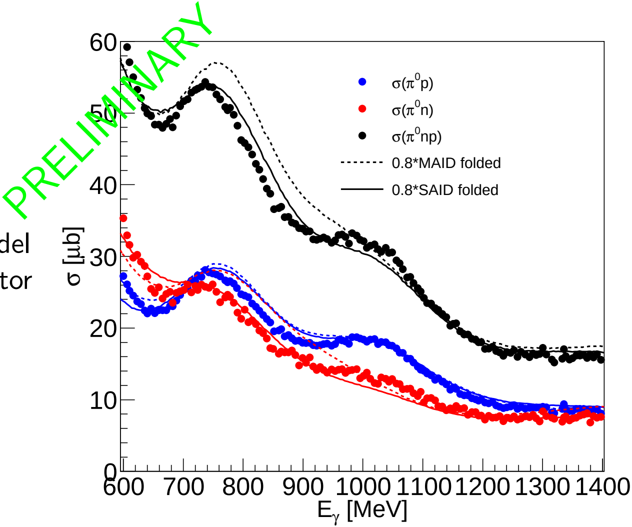


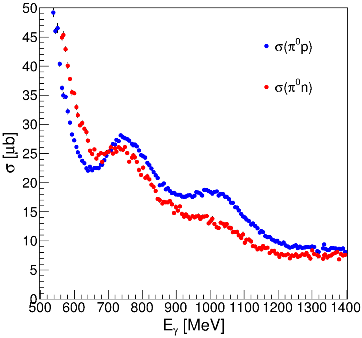


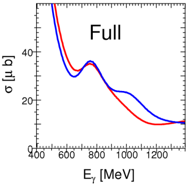
Comparison to Models

MAID and SAID model scaled down with factor 0.8



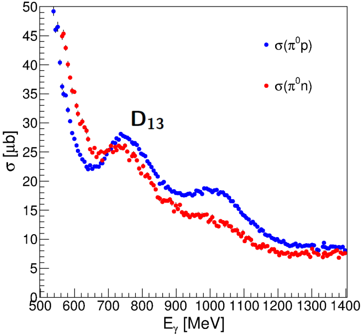
Resonance Contributions

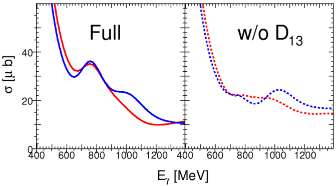




Contributions	

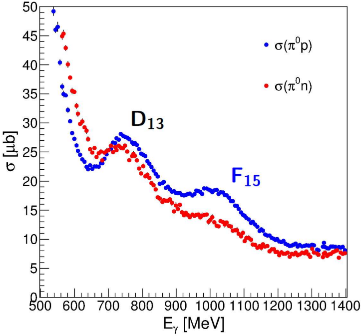
Resonance Contributions

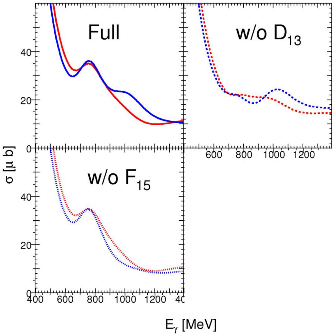




Contributions	D_{13} : p,n

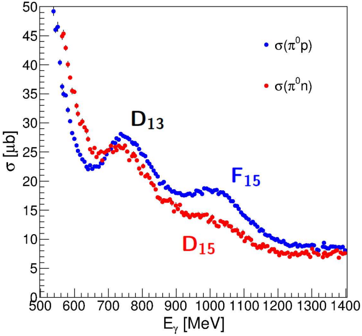
Resonance Contributions

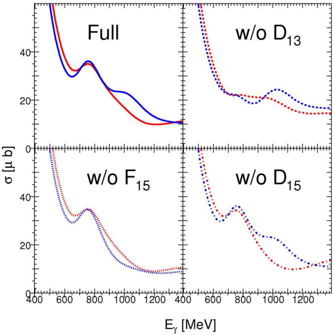




Contributions	D_{13} : **p**,**n** F_{15} : **p**

Resonance Contributions

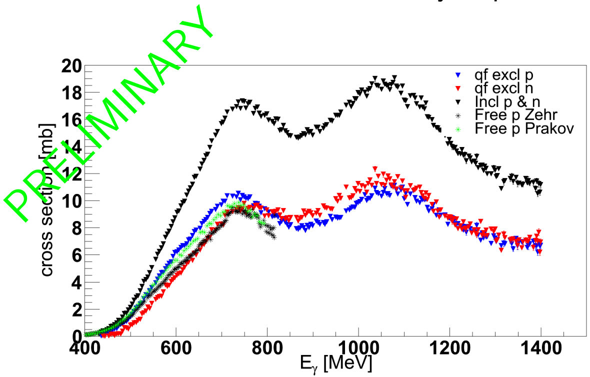


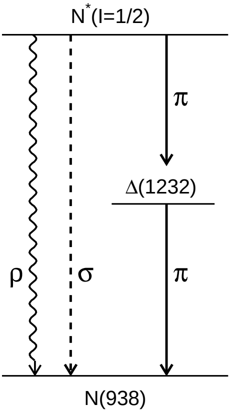


Contributions	D_{13} : **p**,**n** F_{15} : **p** D_{15} : **n**

$2\pi^0$ Total Cross Sections (M. Oberle et al.)

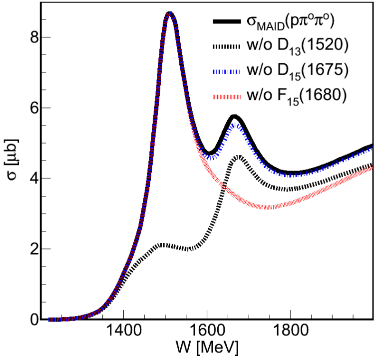
Dominated by sequential decay



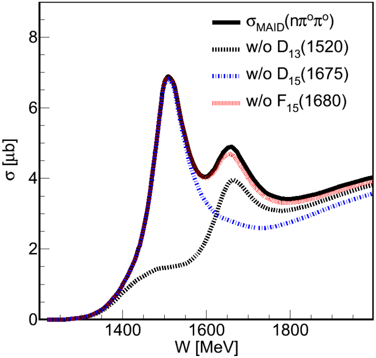


Resonance Contributions

$p(\gamma, 2\pi^0)p$



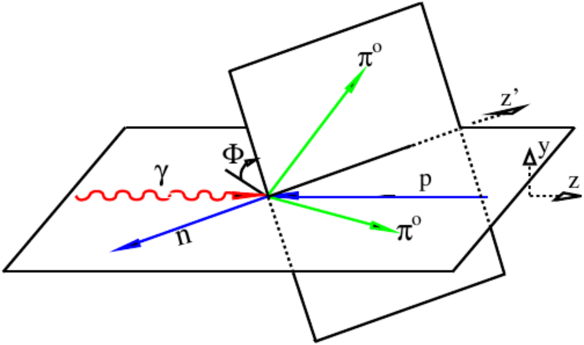
$n(\gamma, 2\pi^0)n$



- Electromagnetic excitation of the **F_{15} stronger on the proton**
- Electromagnetic excitation of the **D_{15} stronger on the neutron**

The Beam-Helicity Asymmetry

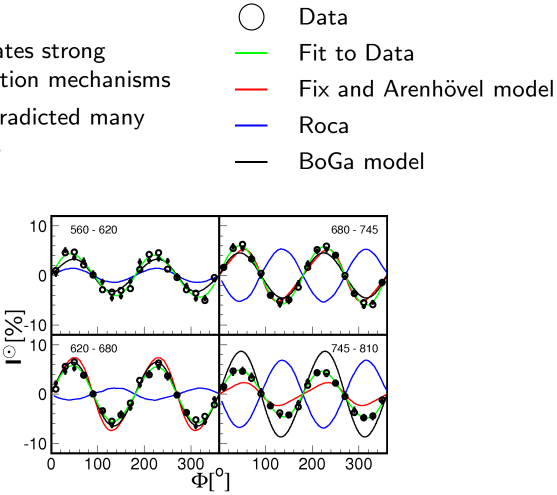
Helicity $h = \vec{S}\hat{P} = -S, ..., S$



$$I^{\odot}(\Phi) = \frac{1}{P_\gamma}\frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{1}{P_\gamma}\frac{N^+ - N^-}{N^+ + N^-}$$

Former Results (D. Krambrich, F. Zehr et al.)

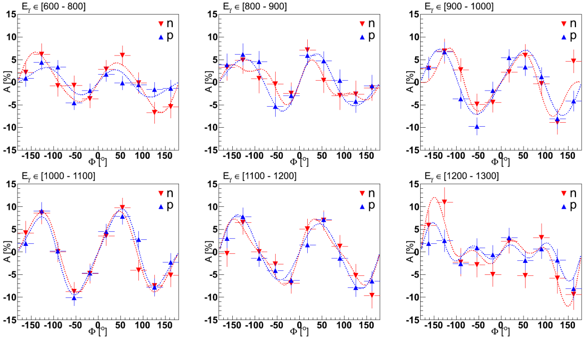
- Asymmetry indicates strong sensitivity to reaction mechanisms
- Early results contradicted many model predictions



D. Krambrich, F. Zehr et al., Phys. Rev. Lett. 103 (2009) 052002

Helicity Asymmetries for $2\pi^0$ (M. Oberle et al.)

PRELIMINARY

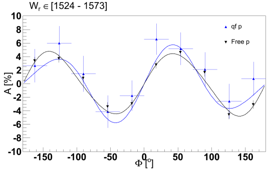


$p(\gamma, 2\pi^0)p$

$n(\gamma, 2\pi^0)n$

$p(\gamma, 2\pi^0)p$

Fermi defolded compared to free p (F.Zehr et al.)



Conclusions

Single π^0 Photoproduction:

- Cross Sections for Single π^0 in good agreement with former results
- MAID/SAID overestimate the cross sections by 25%
- Reduction can not only be explained by Fermi motion

Double π^0 Photoproduction:

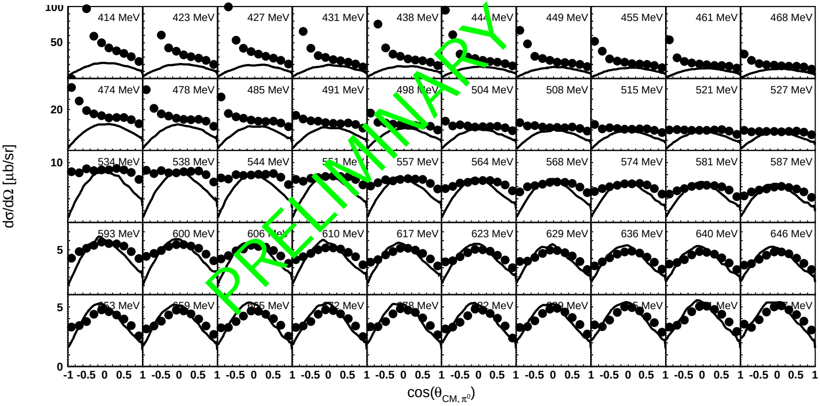
- Same asymmetries for $2\pi^0$ on the proton as on the neutron
- Model predictions not yet in agreement with results, further input needed
- Electromagnetic excitation of the resonances different for proton and neutron. De-excitation of the resonances different for single and double pion production.

Thanks for your attention

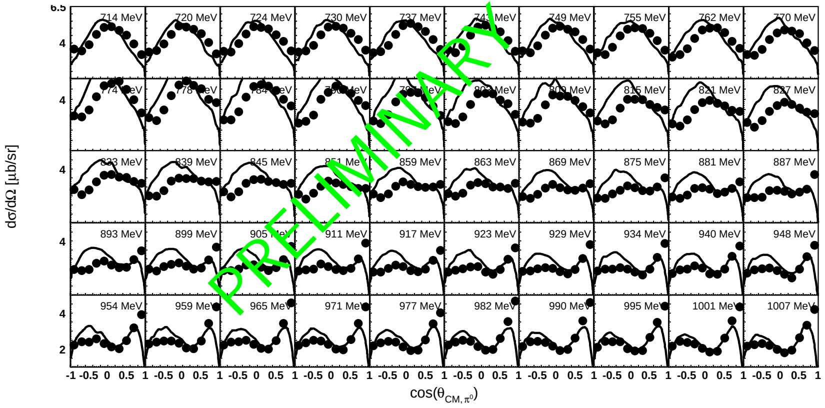
This work is supported by:

Swiss National Fund
Deutsche Forschungsgemeinschaft

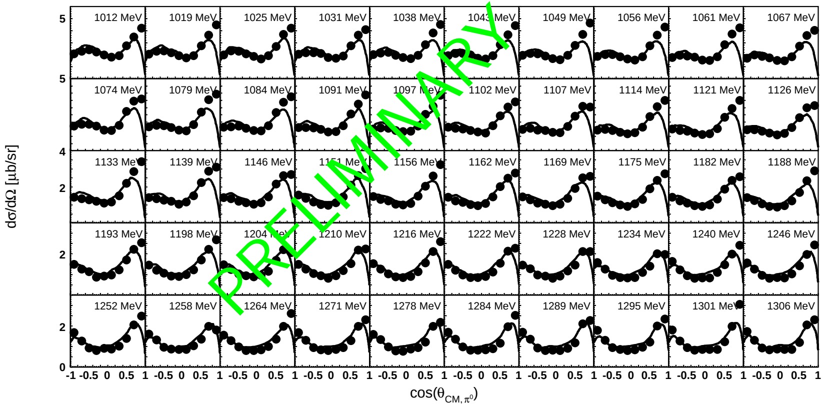
DXS: QF-Inclusive $E_\gamma = [414, 707]$ MeV



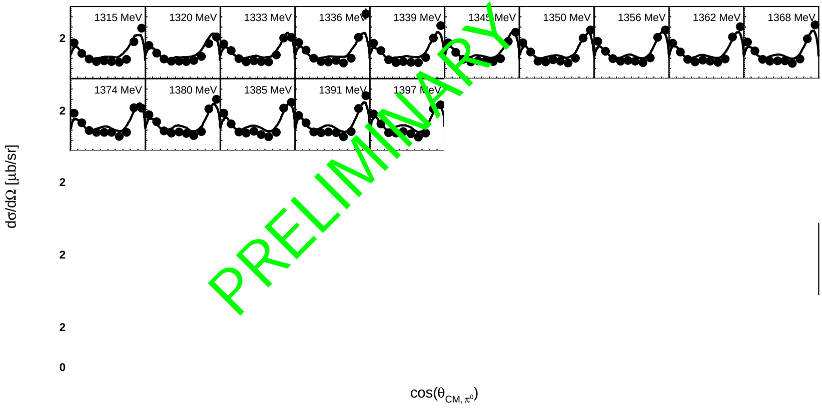
DXS: QF-Inclusive $E_\gamma = [714, 1007]$ MeV



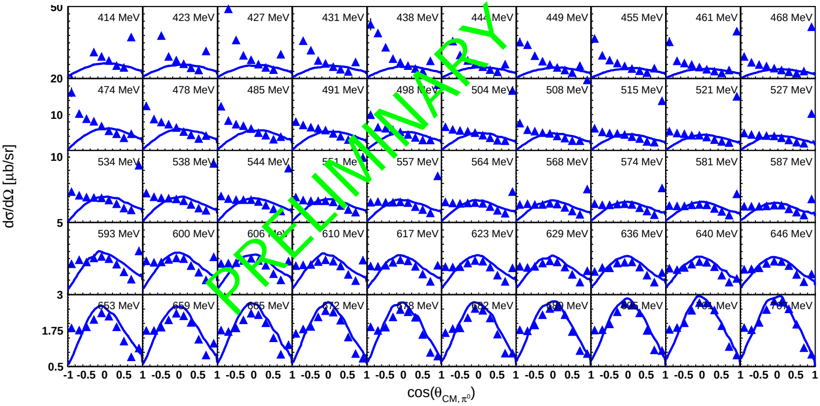
DXS: QF-Inclusive $E_\gamma = [1012, 1306]$ MeV



DXS: QF-Inclusive $E_\gamma = [1315, 1397]$ MeV



DXS: Exclusive Proton $E_\gamma = [414, 707]$ MeV



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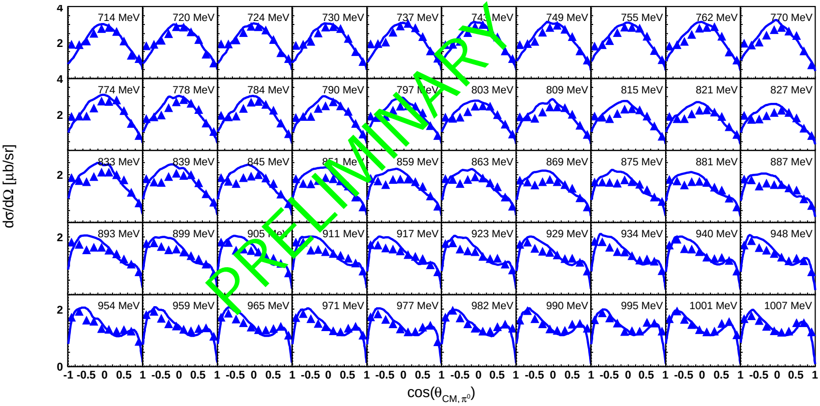

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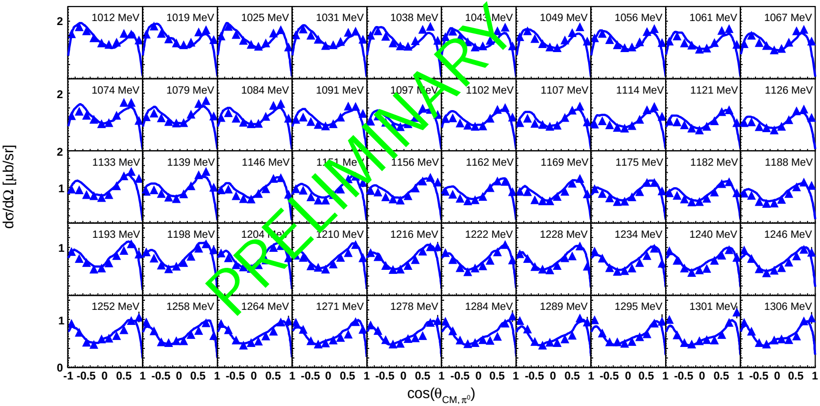

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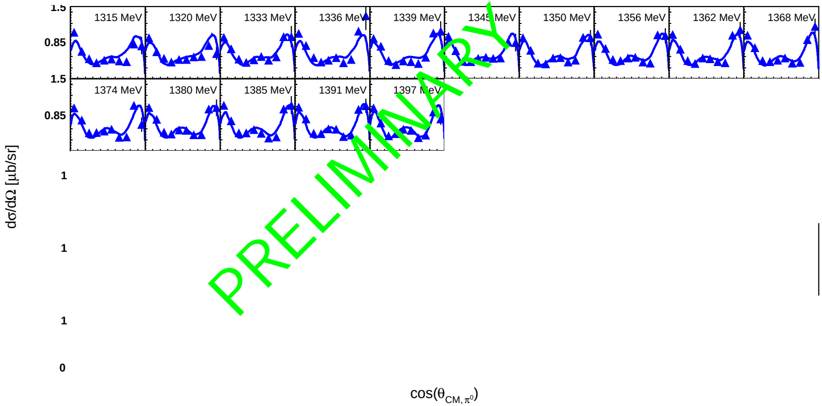
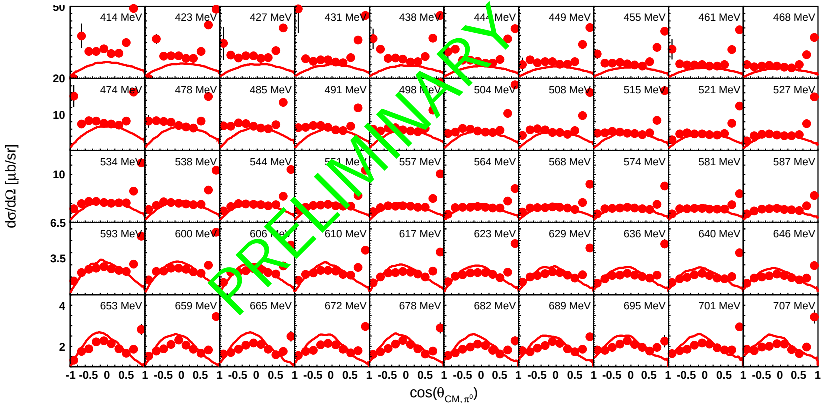


DXS: Exclusive Neutron $E_\gamma = [414, 707]$ MeV



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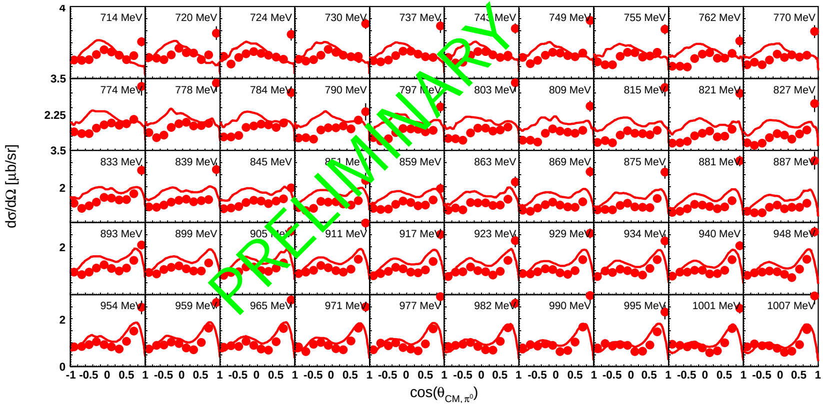

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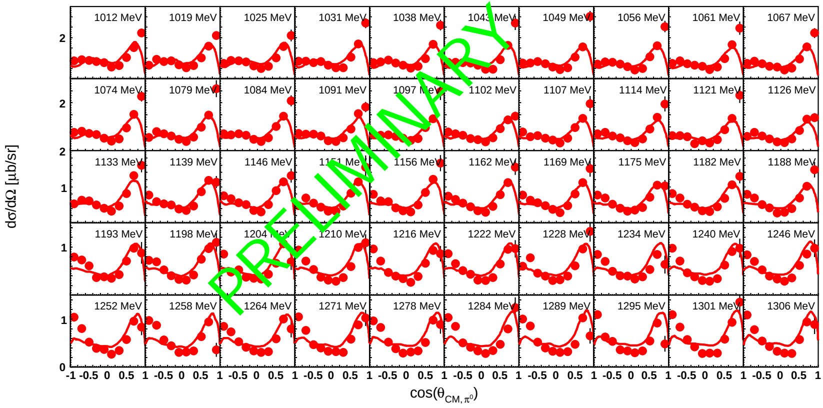

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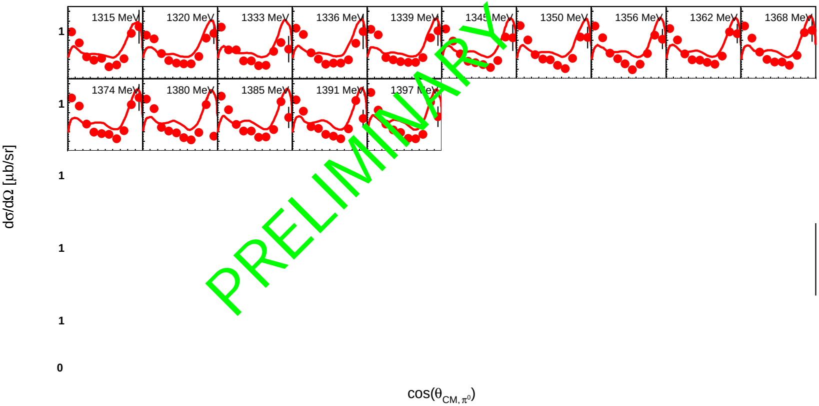

Main Contributing Channels

Initial State	Final State	Threshold [MeV]
$\gamma d \rightarrow$	$\pi^0 d$	~ 140
	$\pi^0 np$	~ 142

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	$\pi^0\pi^0 np$	~ 292
	$\pi^0\pi^- pp$	~ 297
	$\pi^0\pi^+ nn$	~ 297

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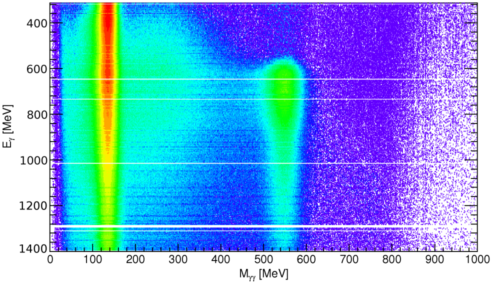
	$\pi^0\pi^0 np$	~ 292
	$\pi^0\pi^- pp$	~ 297
	$\pi^0\pi^+ nn$	~ 297
	$(\eta \rightarrow 3\pi^0)np$	~ 630
	$(\eta \rightarrow \pi^0\pi^+\pi^-)np$	~ 630

Identifications of the π^0-Mesons

$\pi^0 \xrightarrow{99\%} 2\gamma$ ➢Identify π^0: $M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos(\theta_{\gamma_1\gamma_2}))}$



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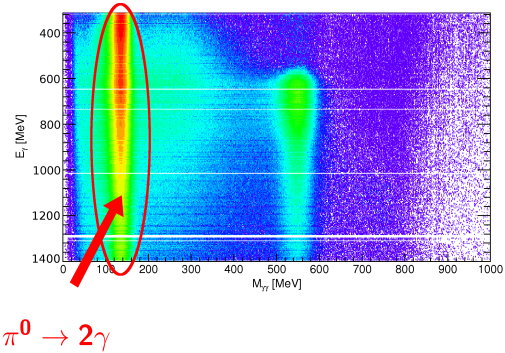

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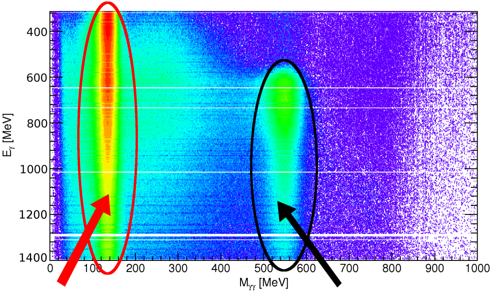


$\pi^0 \rightarrow 2\gamma$

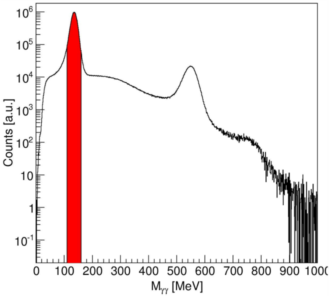
$\eta \rightarrow 2\gamma$

Cut on $M_{\gamma\gamma}$: $110\,MeV < M_{\gamma\gamma} < 160\,MeV$

Missing Mass Analysis

Invariant mass spectrum rather clean

➢ Remove remaining background: Competing channels, π^0 from other channels



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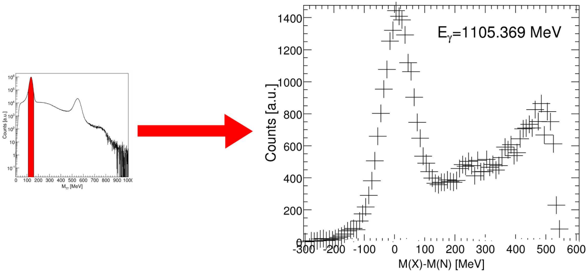
Missing Mass Analysis: $\gamma + N \rightarrow \pi^0 + X$

$$\Rightarrow M(X) = M(\gamma + N - \pi^0)$$



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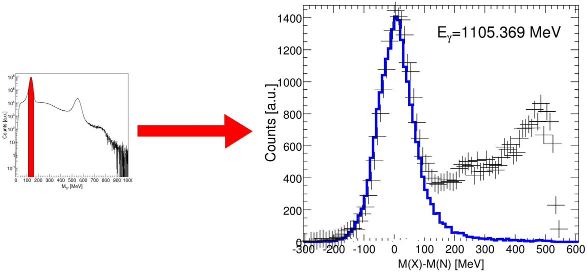

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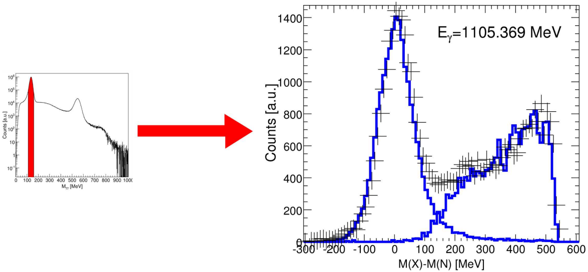

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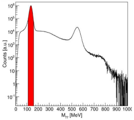

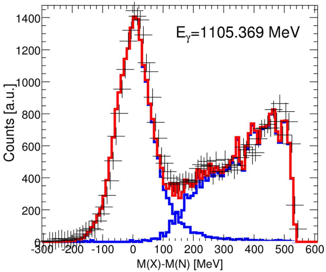

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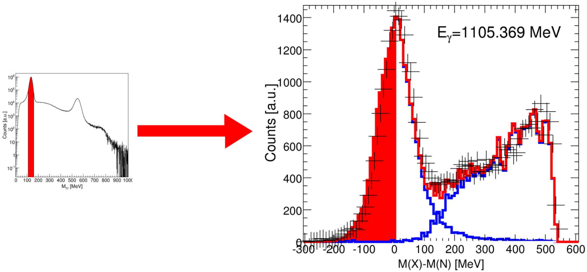

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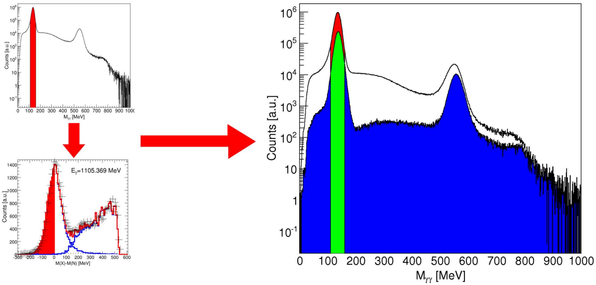
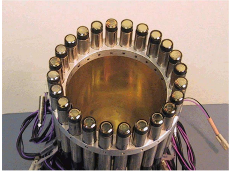
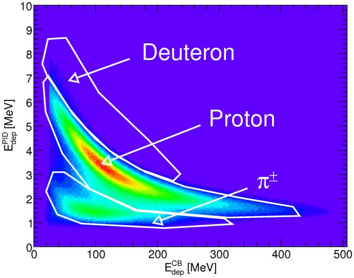


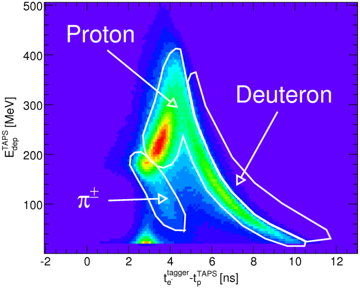
Charged Particle Identification

Crystal Ball:
PID



TAPS:
BaF_2

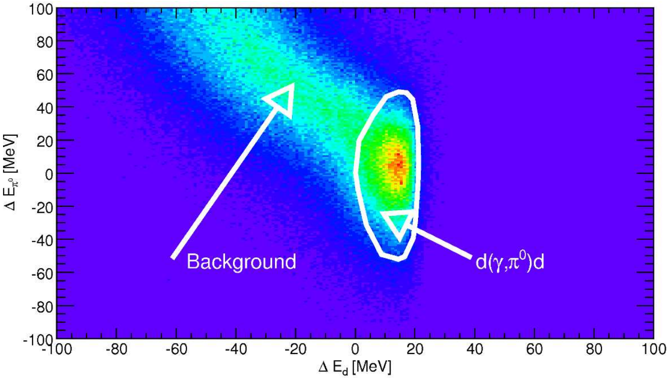




Missing Energy Analysis

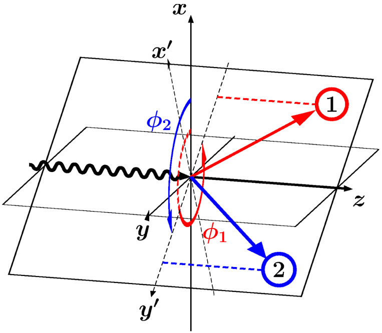
Coherent Reaction: $d(\gamma, \pi^0)d \Leftrightarrow$ two 2-body-decay.

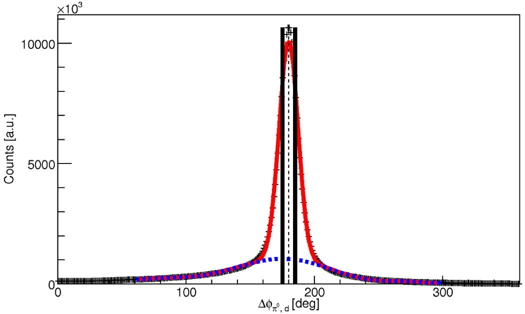
$$\Delta E_i = E^*(i) - E_i^*(E_\gamma) \qquad i = d, \pi^0$$



Coplanarity Cut

Two final state particles always coplanar: $\Delta\phi = \phi_1 - \phi_2 \simeq 180^\circ$

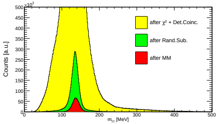


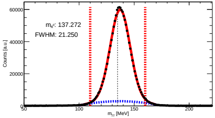


Coherent Reaction: $175^\circ \leq \Delta\phi \leq 185^\circ$

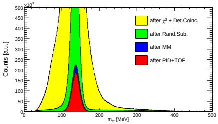
Final Invariant Mass Distributions

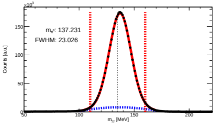
Exclusive on N:



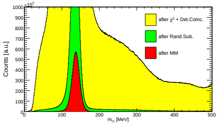


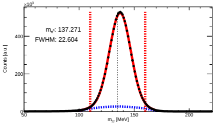
Exclusive on P:



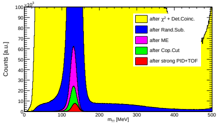


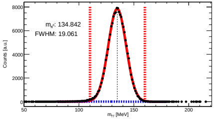
QF-Inclusive:



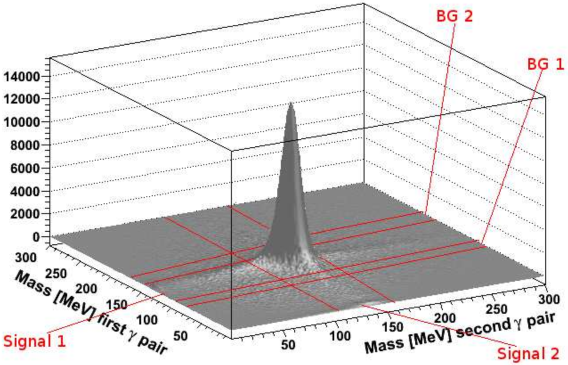


Coherent



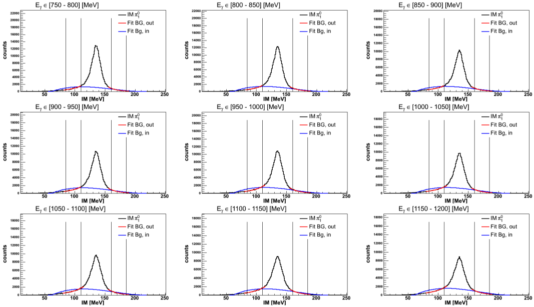


Invariant Mass Cut and Reconstruction

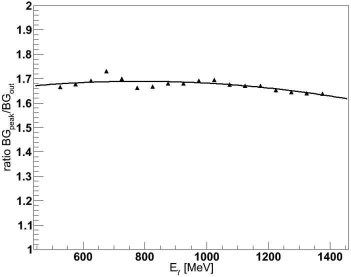


- $\gamma\ p \rightarrow \pi^0\pi^0 p$
- 4 neutral and 1 charged hits
- $\gamma\ n \rightarrow \pi^0\pi^0 n$
- 5 neutral hits
- $\gamma\ D \rightarrow \pi^0\pi^0 X$
- 4 neutral hits or
- 5 neutral hits or
- 4 neutral and 1 charged hits

- Cut on invariant mass: $M_{\gamma\gamma}^{second} \in [110, 160]$ MeV ($M_{\pi 0} \approx 135$ MeV)
- Cut on invariant mass: $M_{\gamma\gamma}^{first} \in [110, 160]$ or

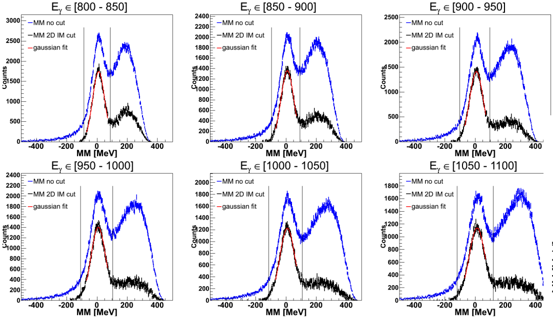


- Ratio (2)/(1) as function of E_γ



- (1) Fit signal in side bins ([85, 110] & [160, 185] MeV)
- (2) Fit background in signal-bins ([110, 160] MeV)
- Calculate ratio (2)/(1)
- Correct online for this background

Missing Mass and Coplanarity Cut

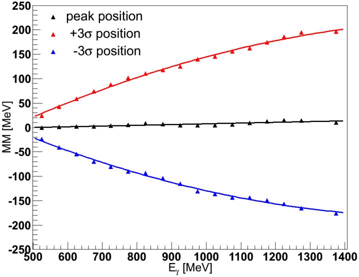


π^0's and nucleon should be coplanar

$$\Phi_{N,2\pi} \in [160^o, 200^o]$$

Background mainly from:

- $\eta \rightarrow \pi^0\pi^0\pi^0$



Fit Peak and plot:

- Peak, Peak $+3\sigma$, Peak -3σ