Multi-meson photoproduction off the proton - recent results from the CBELSA/TAPS experiment

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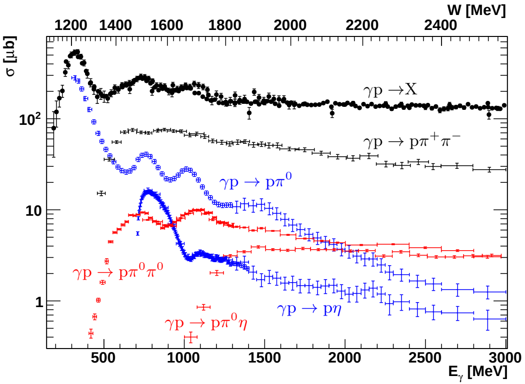
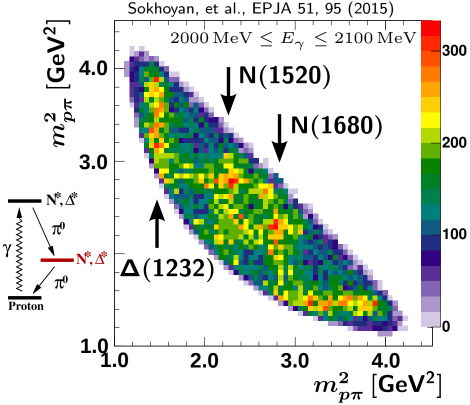
05.06.2023

Introduction

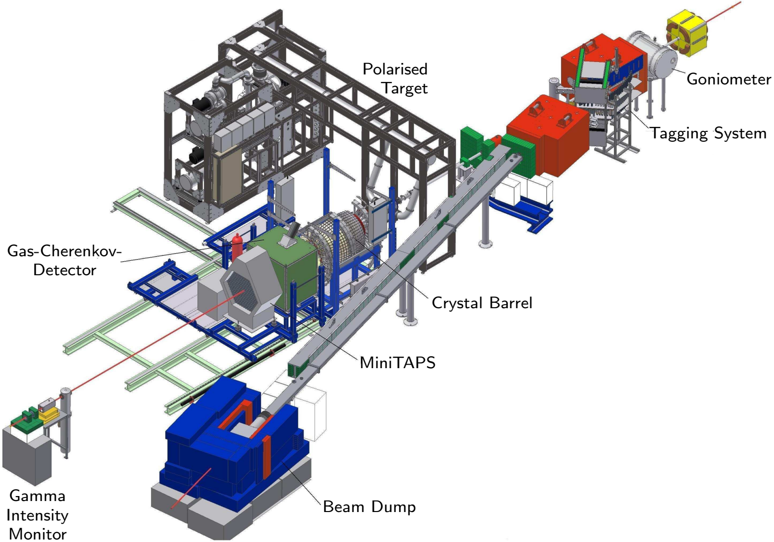




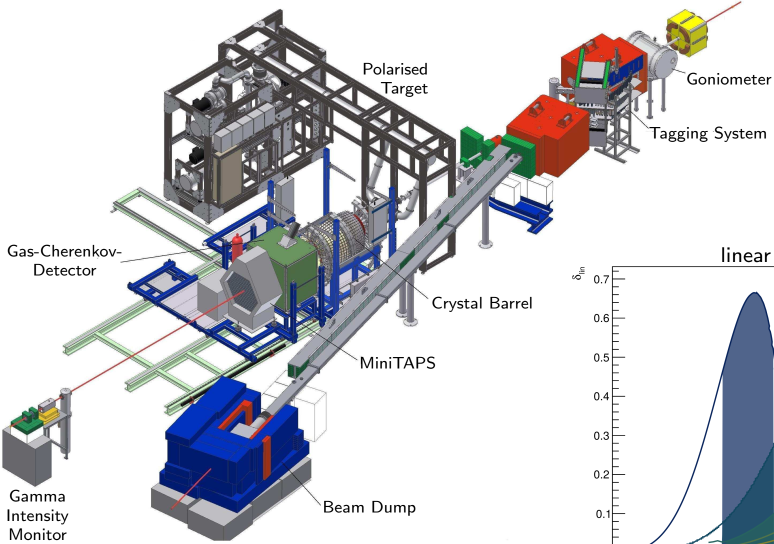
$\gamma p \rightarrow p\pi^0\pi^0$

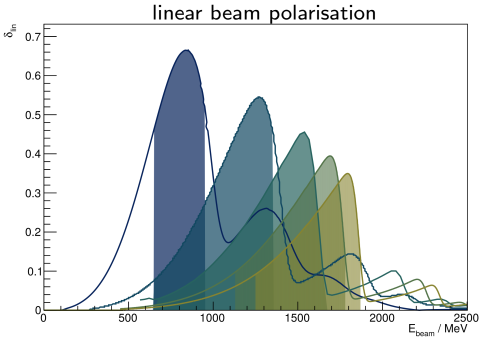
- importance increases with E_γ
- access to sequential decays
- less background amplitudes than $p\pi^+\pi^-$ but cannot discriminate between N^*/Δ^*

The Crystal Barrel/TAPS experiment

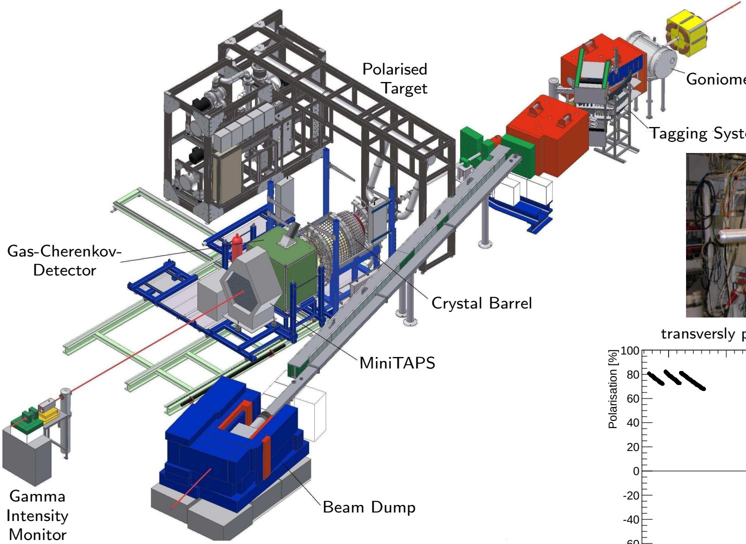


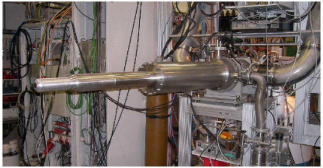
The Crystal Barrel/TAPS experiment



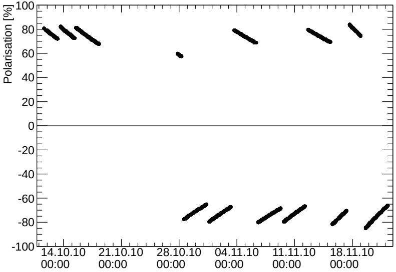


The Crystal Barrel/TAPS experiment





transversly polarised butanol target (C_4H_9OH)



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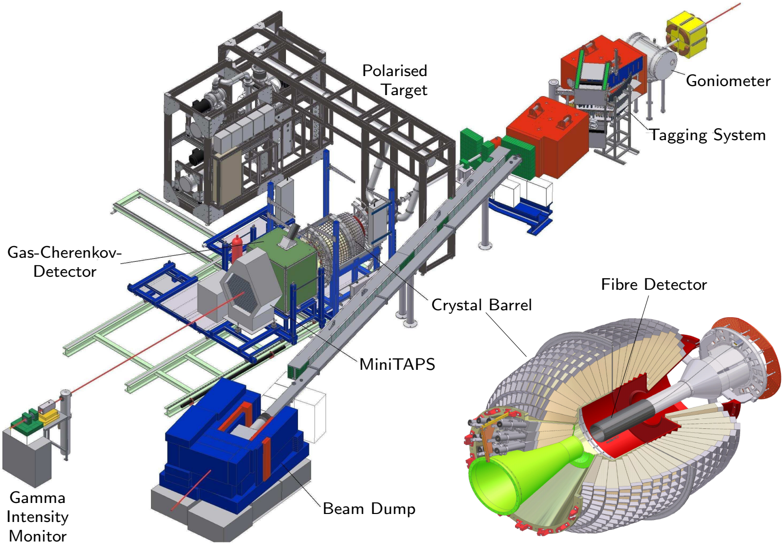
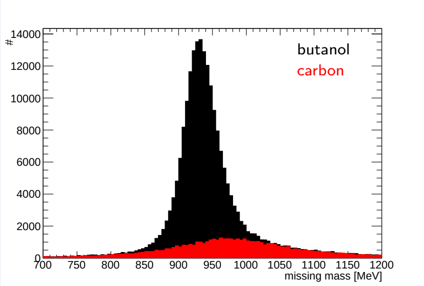


Event selection

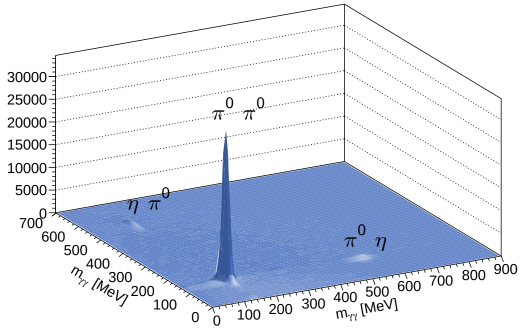
Selection of $\gamma p \to p\pi^0\pi^0 \to p4\gamma$
cuts on

- charge $(1\,\text{charged} + 4\,\text{neutral})$
- ϑ, φ difference of p to 4γ
- mass of calculated proton

missing mass



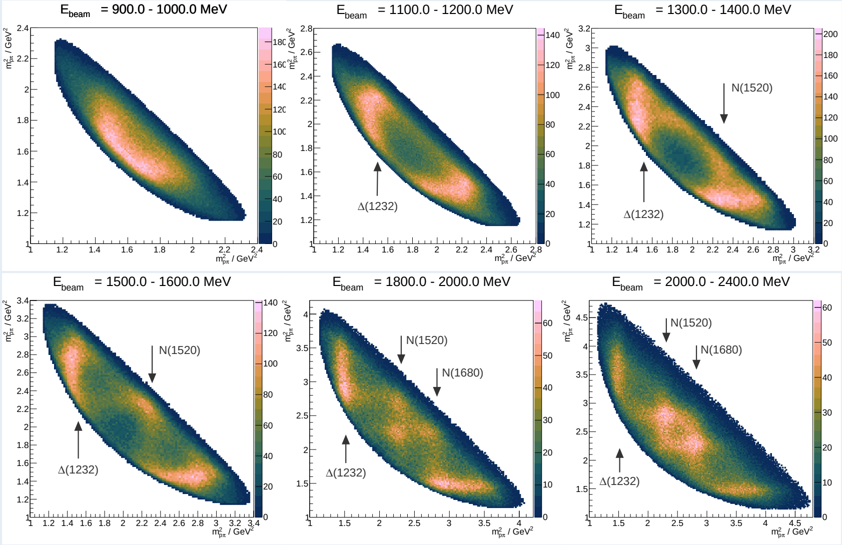
meson mass



after all cuts
global background $\lesssim 1.5\,\%$

Dalitz plots

$\gamma p \to p\pi^0\pi^0$ [Ph. Mahlberg]

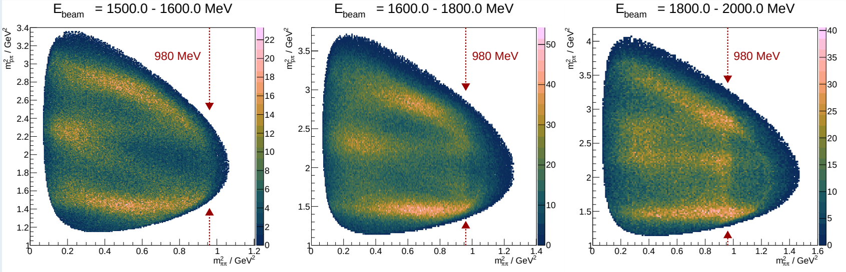


$m^2_{p\pi}$ vs. $m^2_{p\pi}$

only selected bins shown

Dalitz plots

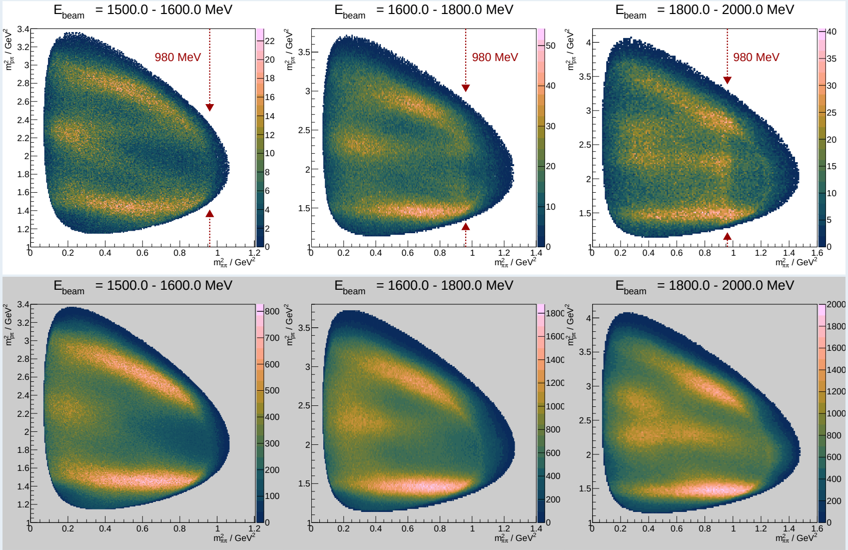
$\gamma p \to p\pi^0\pi^0$ [Ph. Mahlberg]



$m^2_{p\pi}$ vs. $m^2_{\pi\pi}$

Dalitz plots

$\gamma p \rightarrow p\pi^0\pi^0$ [Ph. Mahlberg]



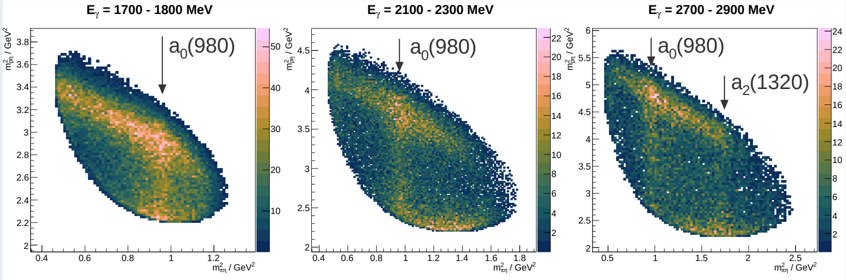
$m^2_{p\pi}$ vs. $m^2_{\pi\pi}$

BnGa PWA

data above not included

Dalitz plots

$\gamma p \rightarrow p\pi^0\eta$ [G. Urff]

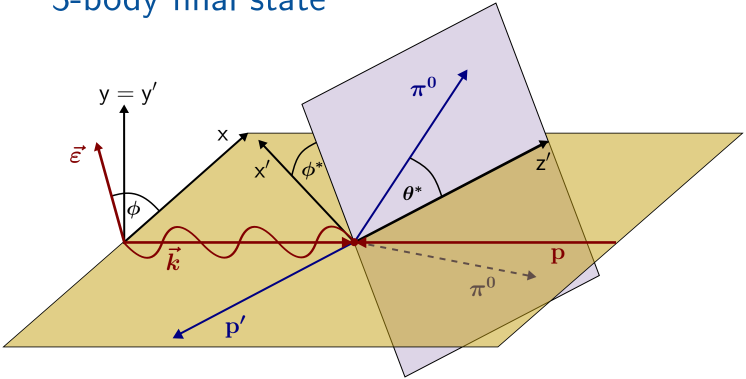


$m^2_{p\eta}$ vs. $m^2_{\pi\eta}$

3-body final state

5 kinematic variables:

- E_γ
- $\cos\vartheta_{\pi^0\pi^0}$
- $m_{\pi^0\pi^0}$
- $\phi^*_{\pi^0\pi^0}$
- $\theta^*_{\pi^0\pi^0}$



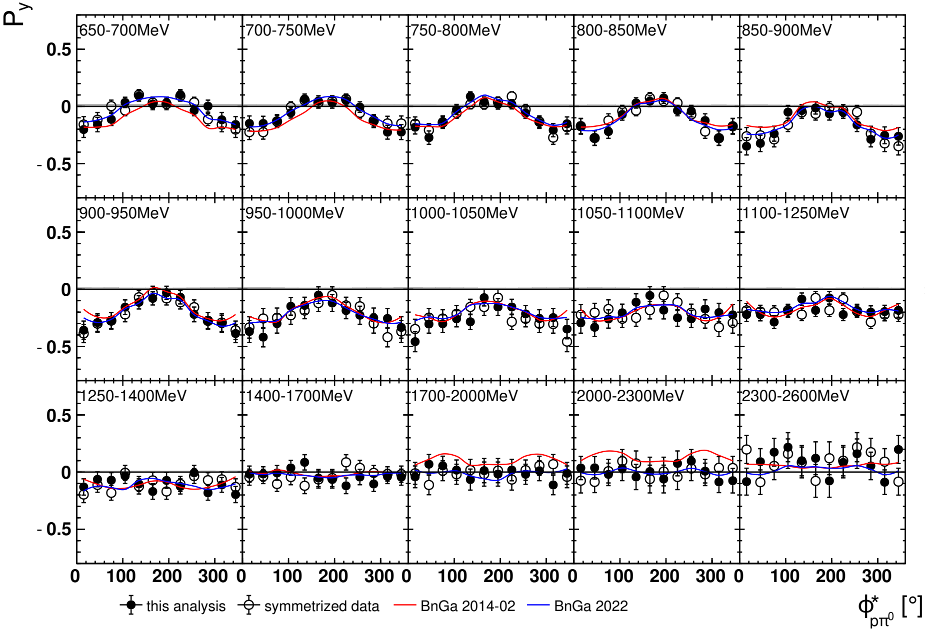
Polarisation Observables

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \Big\{ 1 + \Lambda_x \cdot P_x + \Lambda_y \cdot P_y + \delta_\ell \sin(2\phi) \cdot I^s + \delta_\ell \cos(2\phi) \cdot I^c + \Lambda_y\, \delta_\ell \sin(2\phi) \cdot P_y^s + \Lambda_x\, \delta_\ell \sin(2\phi) \cdot P_x^s + \Lambda_x\, \delta_\ell \cos(2\phi) \cdot P_x^c + \Lambda_y\, \delta_\ell \cos(2\phi) \cdot P_y^c \Big\}$$

W. Roberts, T. Oed, Phys. Rev. C 71 (2005)

Photon Pol.		Target Pol. Axis		
		x	y	z
unpolarised	σ	P_x	P_y	P_z
linear $\sin(2\phi)$	I^s	P_x^s	P_y^s	P_z^s
linear $\cos(2\phi)$	I^c	P_x^c	P_y^c	P_z^c
circular	$I^\odot$	$P_x^\odot$	$P_y^\odot$	$P_z^\odot$

Target asymmetry P_y

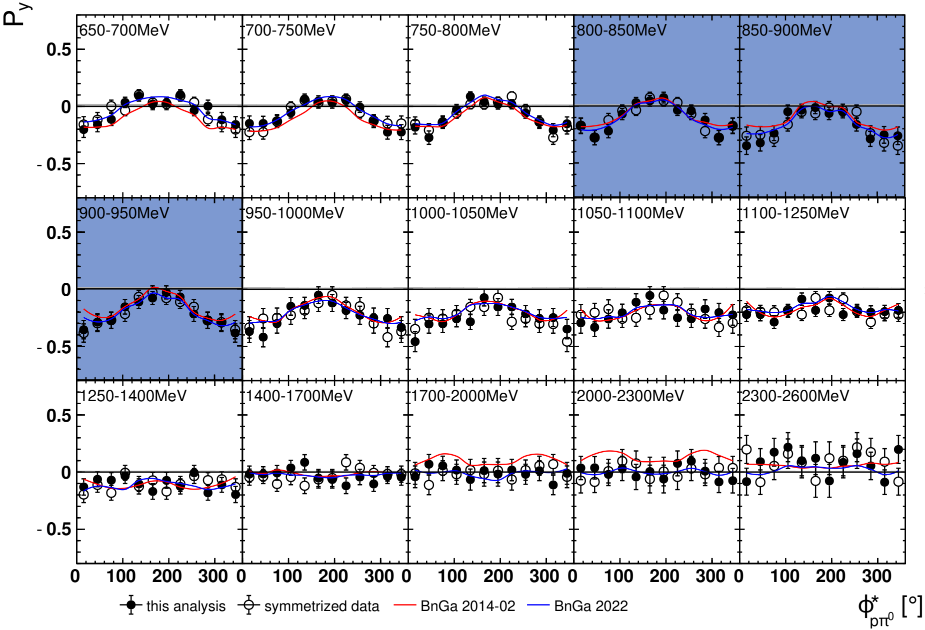


T.S., et al., arXiv:2207.01981

symmetry property

$$P_y(2\pi - \phi^*) = +P_y(\phi^*)$$

Target asymmetry P_y



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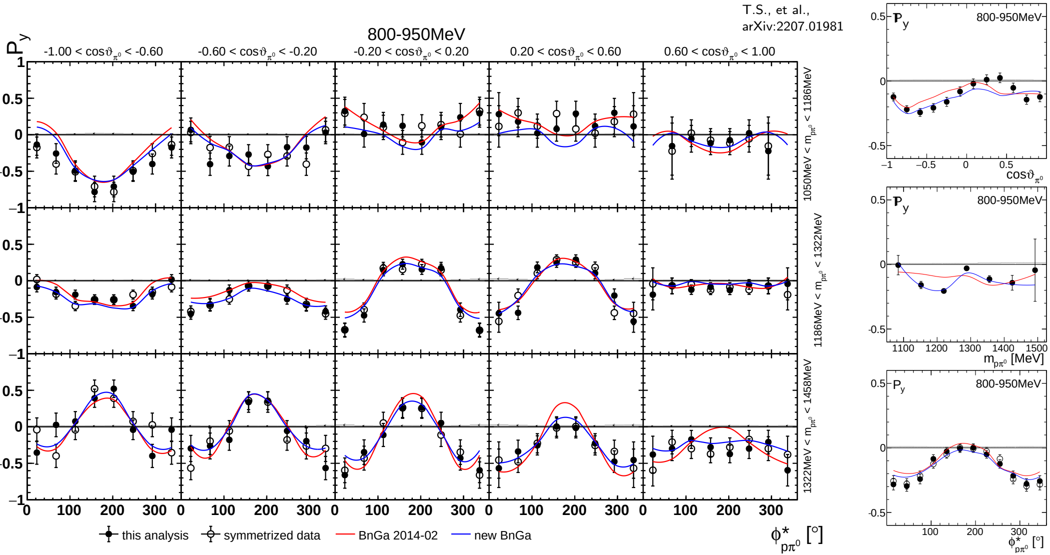
symmetry property
$$P_y(2\pi - \phi^*) = +P_y(\phi^*)$$

Target asymmetry P_y - 4D



Branching ratios

$\Delta(1910)\frac{1}{2}^+$, $\Delta(1920)\frac{3}{2}^+$, $\Delta(1905)\frac{5}{2}^+$, $\Delta(1950)\frac{7}{2}^+$

- BR into $N(938)\pi$ or $\Delta(1232)\pi$ — $(44 \pm 7)\,\%$
- BR into $N(1520)\pi$ or $N(1535)\pi$ — $(\ 5 \pm 2)\,\%$

$N(1880)\frac{1}{2}^+$, $N(1900)\frac{3}{2}^+$, $N(2000)\frac{5}{2}^+$, $N(1990)\frac{7}{2}^+$

- BR into $N(938)\pi$ or $\Delta(1232)\pi$ — $(34 \pm 6)\,\%$
- BR into $N(1520)\pi$, $N(1535)\pi$ or $N\sigma$ — $(21 \pm 5)\,\%$

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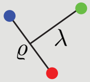
spatial wave function

- $S = \frac{1}{\sqrt{2}}[0s \times 0d] + \frac{1}{\sqrt{2}}[0d \times 0s]$



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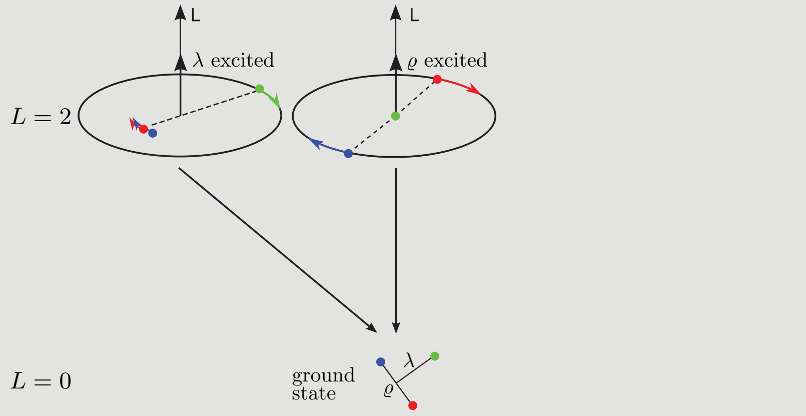
spatial wave function

- $M_S = \frac{1}{\sqrt{2}}[0s \times 0d] - \frac{1}{\sqrt{2}}[0d \times 0s]$
- $M_A = -[0p \times 0p]$

Harmonic oscillator

orbital excitation $L = 2$

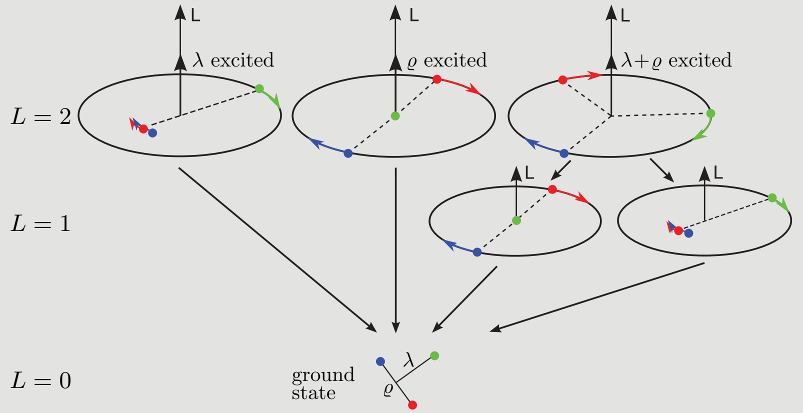


dominant decays:

- single oscillator excitation
  $\rightarrow$ ground state

Harmonic oscillator

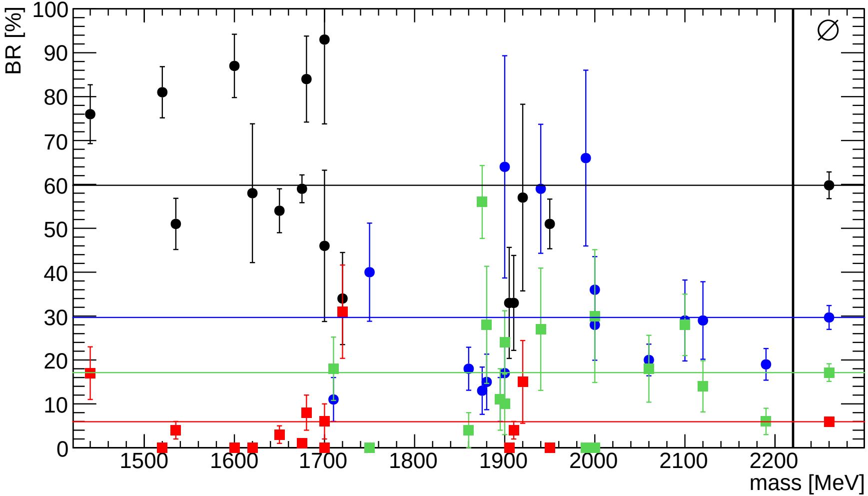
orbital excitation $L = 2$



dominant decays:

- single oscillator excitation
  → ground state
- dual oscillator excitation
  → sequential decay
- mixed oscillator
  → both occur

Branching ratios



T.S., et al., arXiv:2207.01981

single oscillator decays into $N(938)\pi$ or $\Delta(1232)\pi$

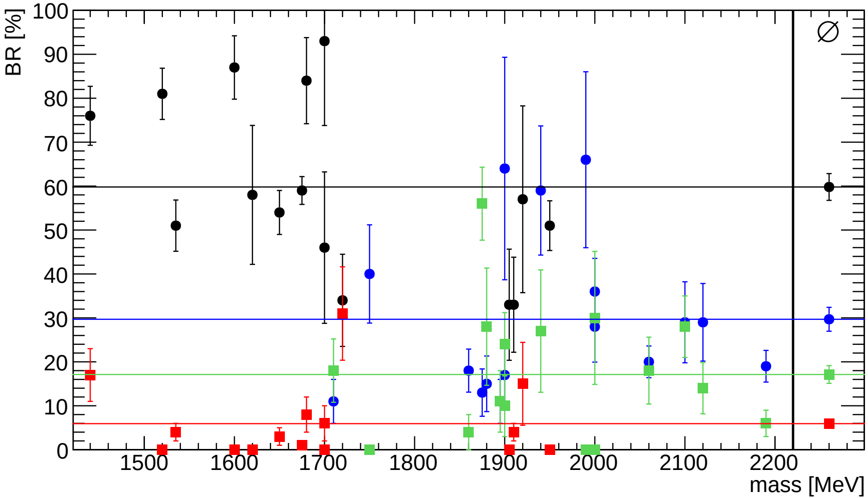
decays into $N(1520)\pi$, $N(1535)\pi$ or $N\sigma$

mixed oscillator decays into $N(938)\pi$ or $\Delta(1232)\pi$

decays into $N(1520)\pi$, $N(1535)\pi$ or $N\sigma$

Branching ratios

T.S., et al., arXiv:2207.01981



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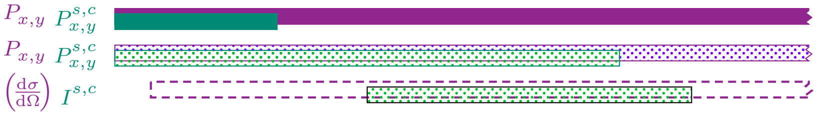
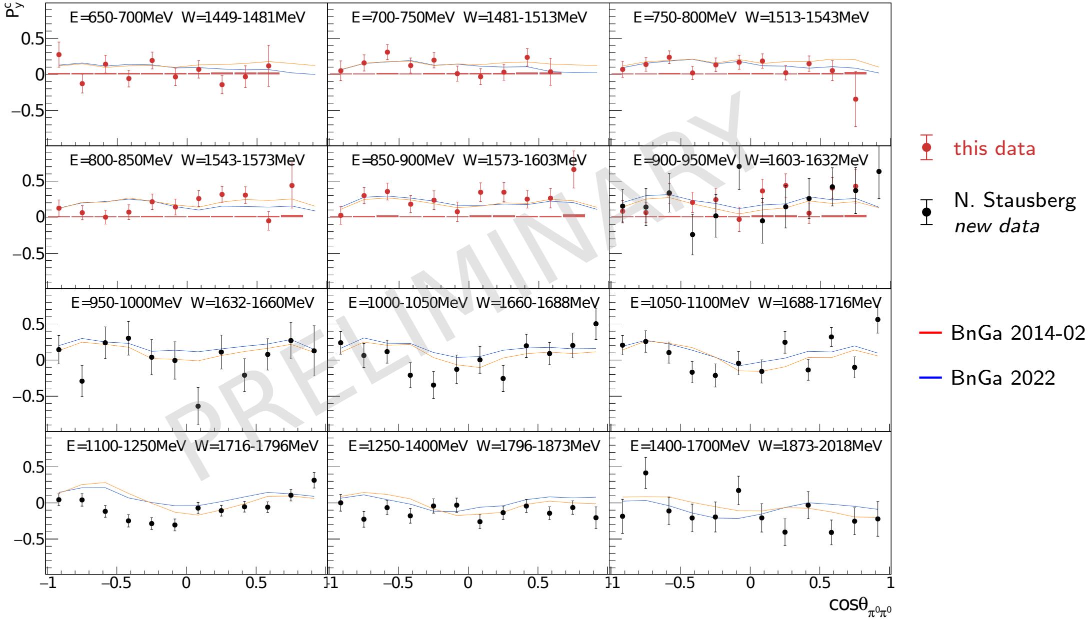


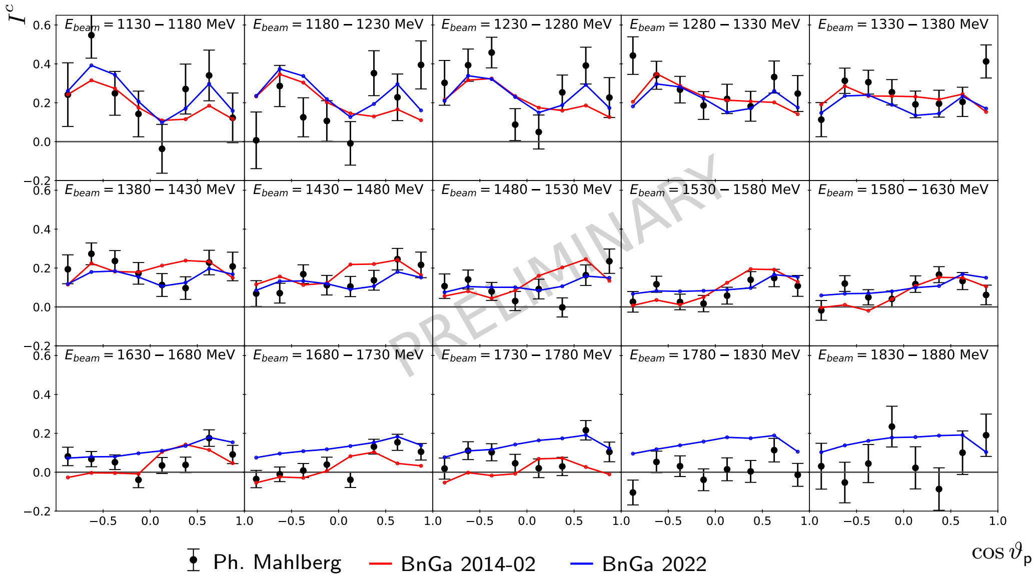
→ included

} new data ⇝ next slide

Double polarization P_y^c – new data



Beam polarization I^c – new data



Summary

CBELSA/TAPS experiment ideally suited for the measurement of neutral meson final states

reaction $\gamma \mathrm{p} \rightarrow \mathrm{p}\pi^0\pi^0$

- intermediate states directly visible in Dalitz plots
- observables $P_x, P_y, P_x^s, P_x^c, P_y^s, P_y^c$ determined in multiple kinematic variables
- for $E_\gamma \leq 1250\,\mathrm{MeV}$ observables determined in 4D

BnGa-PWA $\Rightarrow$ branching ratios of resonances
$\hookrightarrow$ hints for wave function structure of baryon resonances

further analysis of multi-meson final states

- $\mathrm{p}\pi^0\pi^0 + \mathrm{p}\pi^0\eta$: beam polarisation observables I^s, I^c at high energies
- $\mathrm{p}\pi^0\pi^0$: double polarisation observables $P_x^s, P_x^c, P_y^s, P_y^c$ at higher energies