Recent Polarization Observable Results in η- and η'-photoproduction off the proton

Master thesis for the CBELSA/TAPS collaboration

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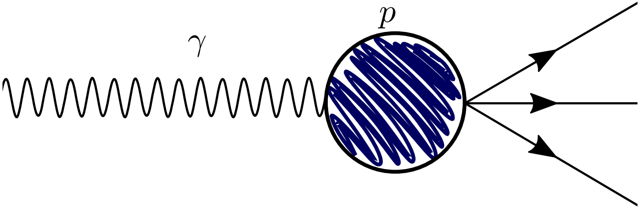
Setting the scene

The Standard Model of Particle Physics

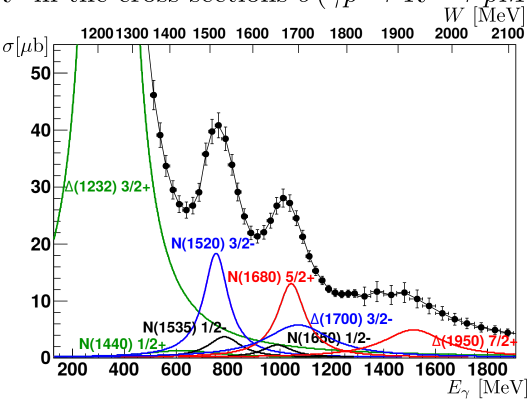
- matter consists of 12 (anti-)*fermions*
- quarks interact via *strong interaction*
- form bound states: mesons ($q\bar{q}$) and baryons (qqq)

baryon spectroscopy (photoproduction) gives insight in strong interaction



Setting the scene

Observe resonances R^* in the cross sections $\sigma(\gamma p \to R^* \to pM)$



Total cross section $\sigma(\gamma p \to R^* \to p\pi^0)$ [Wunderlich et al. 2017]

$\rightarrow$goal: (help to) identify contributing resonances as strong bound states!

1. Theoretical basics

2. Experimental Setup

3. Preliminary results

4. Conclusion

Theoretical basics

- resonances are broad, overlapping, require complicated partial-wave-analysis (PWA)
- constraints for the analysis can be derived from polarization observables
- ultimate goal: "complete experiment"; unambiguous, model-independent PWA solution $\rightarrow$ several single and double polarization observables needed

Beam-target polarization observables

		target polarization		
photon		x	y	z
unpolarized	σ_0	-	T	-
linearly polarized	$-\Sigma$	H	$-P$	$-G$
circularly polarized	-	F	-	$-E$

[Sandorfi et al. 2011]

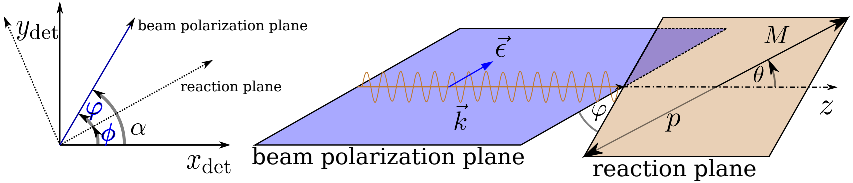
Theoretical basics

Beam asymmetry $\boldsymbol{\Sigma}$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\varphi) = \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}_0 \left[1 - p_\gamma^{\mathrm{lin}} \boldsymbol{\Sigma} \cos(2\varphi)\right]$$

polarization angle φ, polarization degree p_γ^{lin}

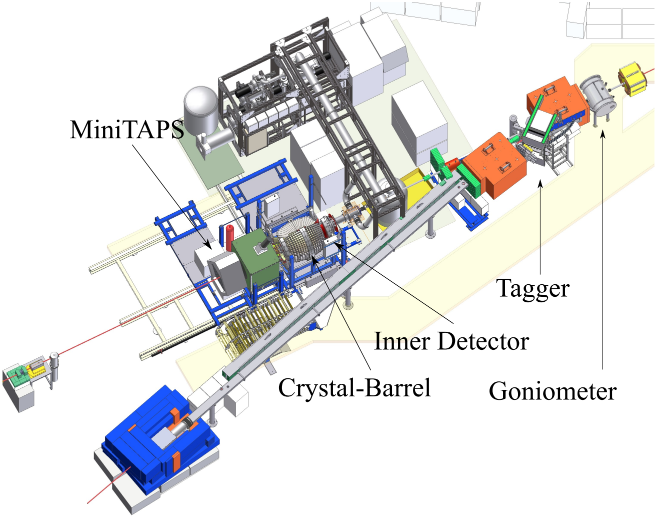
[Sandorfi et al. 2011]



Definition of the polarization angle

Experimental setup

- generate photon beam from accelerated electrons via bremsstrahlung, with $E_\gamma \leq 3.2\,\mathrm{GeV}$
- photon beam impinges on frozen hydrogen target: $\gamma p \to pM \to pX$
- measure decay products X of different final states: $M = \pi^0/\eta/\eta'/\ldots$



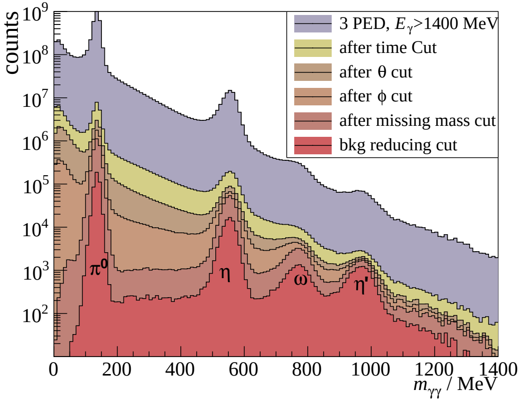
Overview of the experimental area, adapted from [Walther 2022]

Event selection (η')

analysis performed in 2x6 bins of $(E_\gamma, \cos\theta^{\text{CMS}}_{\eta'})$, $E_\gamma \in [1400, 1800]$ MeV

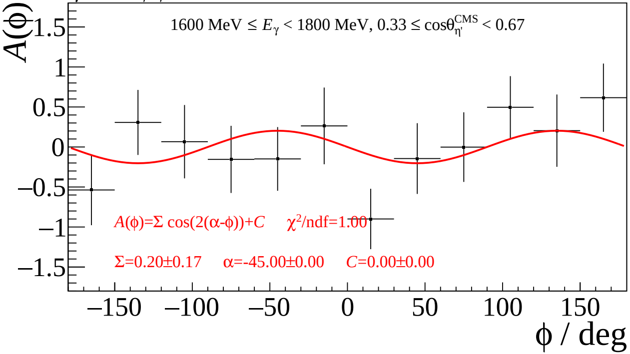
- 3 detector hits, 2 uncharged, 1 charged
- coincident detector hits
- kinematic cuts derived from energy-momentum conservation $p_\gamma + p_p = p'_p + p_{\eta'}$
- additional cuts to reduce background contributions

total: $\sim 11000\ \eta' \to \gamma\gamma$ events

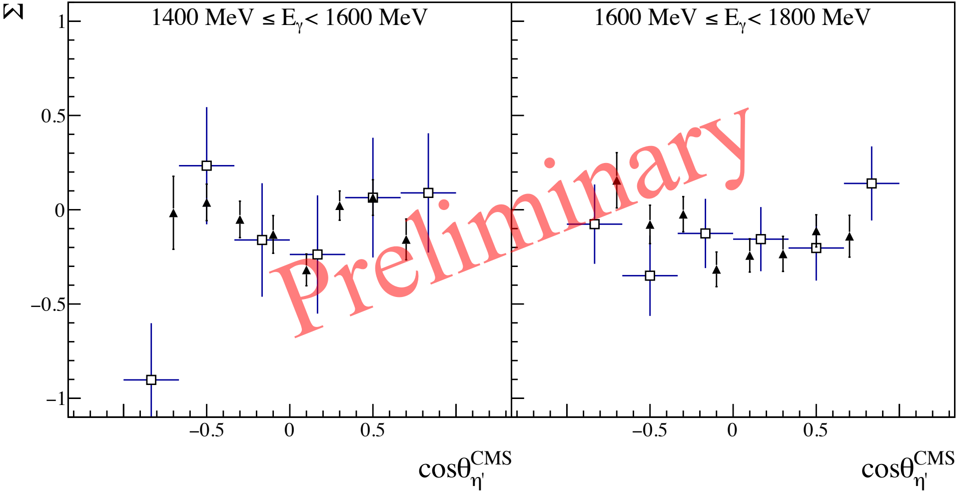


Method (η')

- measure in 2 distinct orthogonal polarization settings $\perp, \parallel$
- χ^2-fit to event yield asymmetries
  $$A(E_\gamma, \theta, \phi) = \frac{N^\perp(E_\gamma,\theta,\phi) - N^\parallel(E_\gamma,\theta,\phi)}{p_\gamma^\parallel N^\perp(E_\gamma,\theta,\phi) + p_\gamma^\perp N^\parallel(E_\gamma,\theta,\phi)} = \Sigma(E_\gamma, \theta) \cos\left(2\left(\alpha^\parallel - \phi\right)\right)$$
- fit from ~ 800 $\eta' \to \gamma\gamma$ events



Preliminary results (η')



Beam asymmetry Σ for all energy and angular bins

Preliminary results (η)

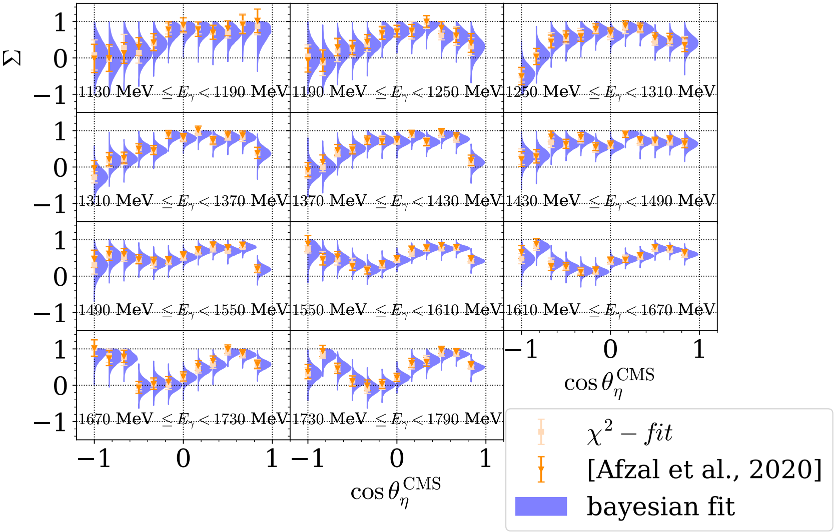
Event selection (η)

analysis performed in 11x12 bins of $(E_\gamma, \cos\theta)$ by [Afzal et al. 2020]

Method

- fit to event yield asymmetries using BAYESIAN inference
- $p(\theta|y) \propto \mathcal{L}(\theta, y) \cdot \pi(\theta)$, obtained using MARKOV-chain-Monte-Carlo (MCMC)

Preliminary results (η)



Beam asymmetry Σ for all energy and angle bins

Conclusion

Summary

- Σ extracted for η and η' final state
- η results obtained with BAYESIAN fit agree with previous results
- η' results agree with previous results

Outlook

- extract Σ using unbinned maximum likelihood fit for η/η'
- apply BAYESIAN approach to above method
- consider bkg contaminations in results of $\Sigma_{\eta'}$

Backup & References

References I

Afzal, F. et al. (Oct. 2020). ‘Observation of the $p\eta'$ Cusp in the New Precise Beam Asymmetry Σ Data for $\gamma p \to p\eta$’. In: *Phys. Rev. Lett.* 125 (15), p. 152002. DOI: 10.1103/PhysRevLett.125.152002. URL: https://link.aps.org/doi/10.1103/PhysRevLett.125.152002.

Chew, G. F. et al. (June 1957). ‘Relativistic Dispersion Relation Approach to Photomeson Production’. In: *Phys. Rev.* 106 (6), pp. 1345–1355. DOI: 10.1103/PhysRev.106.1345. URL: https://link.aps.org/doi/10.1103/PhysRev.106.1345.

Sandorfi, A. M. et al. (Apr. 2011). ‘Determining pseudoscalar meson photoproduction amplitudes from complete experiments’. In: *Journal of Physics G: Nuclear and Particle Physics* 38.5, p. 053001. ISSN: 1361-6471. DOI: 10.1088/0954-3899/38/5/053001. URL: http://dx.doi.org/10.1088/0954-3899/38/5/053001.

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Walther, Dieter (2022). *Crystal Barrel. A 4π photon spectrometer*. URL: https://www.cb.uni-bonn.de (visited on 09/03/2022).

Wunderlich, Y. et al. (May 2017). 'Determining the dominant partial wave contributions from angular distributions of single- and double-polarization observables in pseudoscalar meson photoproduction'. In: *The European Physical Journal A* 53.5. ISSN: 1434-601X. DOI: 10.1140/epja/i2017-12255-0. URL: http://dx.doi.org/10.1140/epja/i2017-12255-0.

Additional theoretical basics

Unpolarized differential cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{1}{4}\rho \sum_{\text{spins}} |\langle f|\mathcal{F}|i\rangle|^2,$$

where

$$\mathcal{F} = i(\vec{\sigma}\cdot\vec{\epsilon})F_1 + (\vec{\sigma}\cdot\hat{q})(\vec{\sigma}\cdot(\hat{k}\times\vec{\epsilon}))F_2 + i(\vec{\sigma}\cdot\hat{k})(\hat{q}\cdot\vec{\epsilon})F_3 + i(\vec{\sigma}\cdot\hat{q})(\hat{q}\cdot\vec{\epsilon})F_4$$

F_i : complex CGLN Amplitudes

[Chew et al. 1957]

$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} \in \mathbb{R}$, not sufficient do determine $\mathcal{F}$ unambiguously
$\rightarrow$ Polarization Observables can be related to F_i