EPJ Web of Conferences **271**, 02007 (2022) https://doi.org/10.1051/epjconf/202227102007
HYP2022

The BGOOD experiment at ELSA

Exotic structures in the strange quark sector?

Thomas Jude[1,*], *Stefan* Alef[1], *Reinhard* Beck[2], *Alessandro* Braghieri[3], *Philip* Cole[4], *Rachele* Di Salvo[5], *Daniel* Elsner[1], *Alessia* Fantini[5,6], *Oliver* Freyermuth[1], *Frank* Fromberger[1], *Francesco* Ghio[7,8], *Johannes* Groß[1], *Katrin* Kohl[1], *Paolo* Levi Sandri[9], *Guiseppe* Mandaglio[10,11], *Paolo* Pedroni[3], *Mariia* Romaniuk[1,12], *Georg* Scheluchin[1], and *Hartmut* Schmieden[1]

[1]Rheinische Friedrich-Wilhelms-Universität Bonn, Physikalisches Institut, Bonn, Germany
[2]Rheinische Friedrich-Wilhelms-Universität Bonn, HISKP, Bonn, Germany
[3]INFN sezione di Pavia, Pavia, Italy
[4]Lamar University, Department of Physics, Beaumont, Texas, USA
[5]INFN Roma "Tor Vergata", Rome, Italy
[6]Università di Roma "Tor Vergata", Dipartimento di Fisica, Rome, Italy
[7]INFN sezione di Roma La Sapienza, Rome, Italy
[8]Istituto Superiore di Sanità, Rome, Italy
[9]INFN - Laboratori Nazionali di Frascati, Frascati, Italy
[10]INFN sezione Catania, Catania, Italy
[11]Università degli Studi di Messina, Dipartimento MIFT, Messina, Italy
[12]Institute for Nuclear Research of NASU, Kyiv, Ukraine

Abstract. The BGOOD photoproduction experiment accesses forward meson angles and low momentum exchange kinematics in the *uds* sector, which may be sensitive to molecular-like hadronic structure. Recent highlights are summarised in these proceedings.

The recent discoveries of the pentaquark, P_C, states [1, 2] and XYZ mesons in the charmed quark sector [3, 4] have initiated a new epoch in hadron physics, where the existence of exotic multi-quark states beyond the conventional three and two quark systems has been realised. Such states could manifest as colour-singlet objects, or evolve from meson-baryon and meson-meson interactions, creating molecular like systems and re-scattering effects near production thresholds. Equivalent structures may be evidenced in the light, *uds* sector. This includes, for example the $\Lambda(1405)$ which is now considered the archetypal molecular state in the strangeness sector [5]. A cusp-like structure was also recently observed in $K^0\Sigma^+$ photoproduction at the $K^*\Sigma$ threshold [6] which was suggested to derive from a vector meson-baryon dynamically generated state, the $N^*(2030)$ [7]. This was considered as the strangeness counterpart to the P_C states, which were predicted by an equivalent model [8].

To experimentally study any potentially loosely bound molecular hadronic structure, access to a low momentum exchange and forward meson production region is mandatory. The BGOOD experiment [9] at the ELSA electron accelerator facility [10] is ideally suited for such photoproduction measurements. A 3 GeV electron beam impinges upon a thin radiator to produce an energy tagged bremsstrahlung photon beam which is subsequently incident

*e-mail: jude@physik.uni-bonn.de

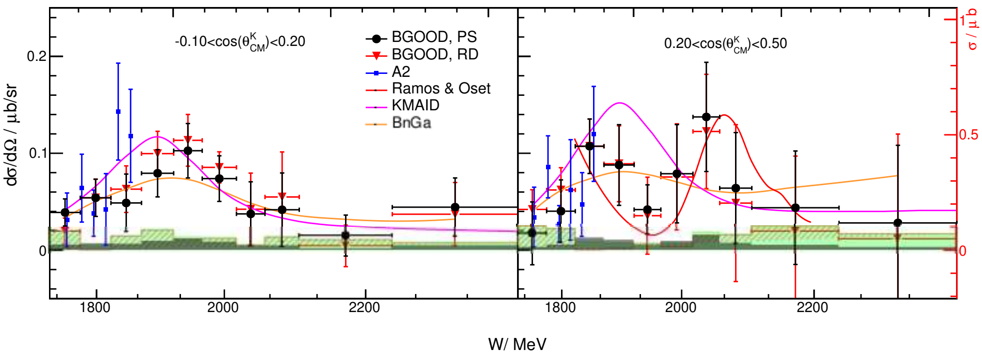

Figure 1. Differential cross section of $\gamma n \to K^0\Sigma^0$ as a function of W for two intervals in $\cos\theta^K_{\mathrm{CM}}$ and two different fitting methods (red triangles, and black circles). Data from the A2 Collaboration and calculations from KMAID and BnGa are labelled in the legend. The predicted total cross section from Ramos and Oset [7] is included in the angular bin $0.2 < \cos\theta^K_{\mathrm{CM}} < 0.5$ (red solid line) at an arbitrary scale denoted by the red axis on the right. Figure (adapted) and references in Ref. [11].

upon the target at the centre of the BGOOD experiment. BGOOD is comprised of two main parts, a central calorimeter region ideal for the reconstruction of neutral mesons via their decays, and a forward spectrometer used for charged particle identification and momentum reconstruction at forward angles.

BGOOD has an extensive strangeness photoproduction physics programme, recent of results of which are highlighted below. Due to space constraints, previous data or calculations that are not cited above are referenced in the corresponding BGOOD publication.

Measurement of the $\gamma n \to K^0\Sigma^0$ differential cross section over the K^* threshold [11]

The calculation of Ramos and Oset, which suggested the dynamically generated $N^*(2030)$ amplified the cusp in the $K^0\Sigma^+$ channel, predicted constructive interference in $K^0\Sigma^0$ photoproduction resulting in a peak [7]. Observing this experimentally would therefore be direct evidence of such a molecular state in the *uds* sector.

Using a deuterium target, the reaction $\gamma n(p) \to K^0\Sigma^0$ was identified via the decays $K^0\pi^0\pi^0$ and $\Sigma^0 \to \gamma(\Lambda \to p\pi^-)$. After numerous selection criteria, the $\pi^0\pi^0$ invariant mass was fitted to separate signal and background events from other channels, and reactions off the proton were subtracted by an equivalent analysis using a hydrogen target.

Two intervals in the cosine centre-of-mass polar angle of the kaon, $\cos\theta^K_{\mathrm{CM}}$ are shown in fig. 1. The data are in reasonable agreement with the previous data from the A2 collaboration, calculations from the KaonMAID isobar model and the Bonn Gatchina partial wave analysis (BnGa). In the more forward interval, a peak is observed which is consistent with the predicted peak from the model of Ramos and Oset. Further data has now been taken to improve the statistical precision and enable a firm interpretation.

Photoproduction of $K^+\Lambda(1405) \to K^+\pi^0\Sigma^0$ extending to forward angles and low momentum transfer [12]

The BGOOD setup enables a clean identification of the decay $\Lambda(1405) \to \pi^0\Sigma^0$ over a $\cos\theta^K_{CM}$ range enabling access to previously unattainable low momentum transfer regions. The reaction channel was identified by identifying all final state particles and using a kinematic fit. Subsequent fitting to two-dimensional $\Sigma^0\pi^0$ and $\gamma\Lambda$ invariant mass spectra enabled a clean separation of signal to background.

Fig. 2 shows the cross section versus photon beam energy, E_γ, integrated over all $\cos\theta^K_{CM}$, with good agreement to previous CLAS data however much improved E_γ resolution. The purple line is a calculation by Wang et al., of a triangle singularity being driven by the $N^*(2030)$ resonance. The excellent agreement supports the $N^*(2030)$ as being a molecular $K^*\Sigma$ system.

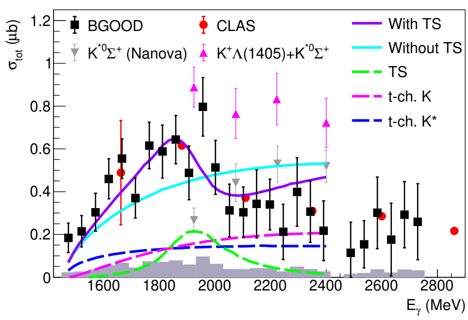

Figure 2. Integrated $\gamma p \to K^+\Lambda(1405)$ cross section. The purple and cyan line is the model of Wang *et al.* with and without the triangle singularity, the $K^{*0}\Sigma^+$ data from CBELSA/TAPS are the grey triangles and the sum of the $K^{*0}\Sigma^+$ and the BGOOD $K^+\Lambda(1405)$ data are the magenta triangles. Red circles are CLAS data. Figure and references in Ref. [12].

$K^+\Lambda$ and $K^+\Sigma^0$ photoproduction at forward angles and low momentum transfer [13, 14]

Forward $K^+\Lambda$ photoproduction provides low-t data which is an important constraint on the electroproduction of hypernuclei, where the Q^2 is required to be small. It is also particularly sensitive to intermediate high spin N^*. Fig. 3 shows the differential cross section data for $\cos\theta^K_{CM} > 0.9$. The statistical precision is markedly improved and enables a discrimination between previous conflicting datasets.

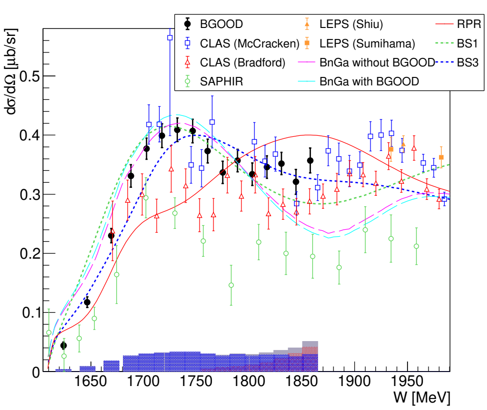

Figure 3. $\gamma p \to K^+\Lambda$ differential cross section for $\cos\theta^K_{CM} > 0.90$ (black filled circles). The systematic uncertainties on the abscissa are in three components, where the grey bars are the total. Previous data (only including statistical errors) is indicated in the legend. The CLAS data are at the more backward angle of 0.85 $< \cos\theta^K_{CM} < 0.95$. The RPR, BS1, and BS3 are the Regge plus resonant model and isobar models BS1 and BS3 of Skoupil and Bydžovský. The Bonn-Gatchina PWA solutions are shown with and without the inclusion of the new data. Figure and references in Ref. [13].

The $K^+\Sigma^0$ differential cross section for $\cos\theta^K_{CM} > 0.9$ is shown in fig. 4. Similarly for $K^+\Lambda$, the statistical precision of the data is able to discriminate between differences in previous datasets. A cusp-like structure is resolved close to the pK^+K^- threshold at $W \sim 1900$ MeV. Fig. 5 shows the data extrapolated to minimum momentum transfer, $t_{\min}$ and $\cos\theta^K_{CM} = 1$, where the cross section drops by 75 %. No firm interpretations have been made, but it is interesting to note the proximity of multiple thresholds and predicted bound states

https://doi.org/10.1051/epjconf/202227102007

immediately at this centre-of-mass energy. The extent of this cusp-like structure changes quickly over $\cos\theta^K_{\mathrm{CM}}$ at forward angles, demonstrating the importance of accessing these forward kinematics.

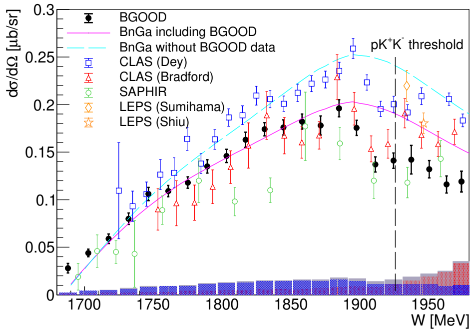

Figure 4. $\gamma p \to K^+\Sigma^0$ differential cross section for $\cos\theta^K_{\mathrm{CM}} > 0.90$ (black circles). The systematic uncertainties on the abscissa are in three components, where the grey bars are the total. Previous data (only including statistical errors) is indicated in the legend. The CLAS data are at the more backward angle of $0.85 < \cos\theta^K_{CM} < 0.95$. The Bonn-Gatchina PWA solutions with and without the inclusion of the new data are the solid magenta and dashed cyan lines respectively. The pK^+K^- threshold is indicated by the dashed black line. Figure and references in Ref. [14].

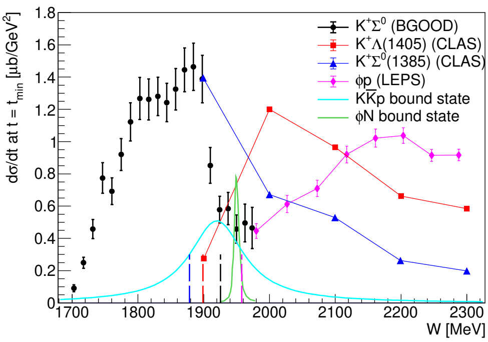

Figure 5. $\gamma p \to K^+\Sigma^0$ differential cross section, $d\sigma/dt$ extrapolated to t_{min} versus W (filled black circles). Previous data of other final statesis indicated in the legend. The vertical dashed lines indicate the respective thresholds, with the addition of the K^+K^-p threshold indicated by the black dashed line. Predictions of $K\bar{K}N$ and ϕN bound states are shown. Figure and references in Ref. [14].

This work is supported by the Deutsche Forschungsgemeinschaft Project Numbers 388979758 and 405882627, the Third Scientific Committee of the INFN and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement STRONG–2020 No. 824093.

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