Strangeness photoproduction at extremely forward angles at the BGO-OD experiment

Tom Jude
On behalf of the BGO-OD Collaboration

Physikalisches Institut
University of Bonn
Supported by the DFG PN 50165297

28th June 2018
Strangeness photoproduction at extremely forward angles at the BGO-OD experiment

- The BGO-OD experiment at ELSA, Bonn
- Motivation: Hadron structure - parallels in strange & charmed quark sectors?
- Strangeness photoproduction - first results:
  1. $\Lambda(1405)$ & access to higher lying hyperons
  2. Extreme forward cross sections for $K^+\Lambda$ & $K^+\Sigma^0$ photoproduction
  3. $K^0$ photoproduction off proton & neutron (deuterium) targets
  4. Future opportunities - Y-N interaction & hypernuclei studies
- Summary
The Electron Stretcher Accelerator (ELSA)
The BGO-OD experiment at ELSA

- BGO calorimeter (central region) & Forward Spectrometer combination
- High momentum resolution, excellent charged & neutral particle ID
The BGO-OD experiment at ELSA

- BGO calorimeter (central region) & Forward Spectrometer combination
- High momentum resolution, excellent charged & neutral particle ID
The BGO-OD experiment at ELSA

- BGO calorimeter (central region) & Forward Spectrometer combination
- High momentum resolution, excellent charged & neutral particle ID
Motivation - Exotic phenomena in the charmed sector

Pentaquark candidates observed at LHCb - $P_c(4450)^+ \& P_c(4380)^+$


Forsaken pentaquark particle spotted at CERN

\[ X(3872) - \text{a molecular } D^0\bar{D}^{0*} \text{ state?} \]

Close to $D^0\bar{D}^{0*}$ threshold, favouring $DD^*$ decay

\[ J^{PC} \text{ verified: } 1^{++} \]
R. Aaij et al. (LHCb Collaboration), PRL 110, 222001 (2013)

\[ X(3872) \text{ discovery - most cited paper from Belle, PRL91, 262001 (2003)} \]
Motivation - Structure of the Λ(1405)

- Between the $\pi \Sigma$ & $\bar{K}N$ thresholds
- Line shape (invariant mass) depends upon the $\pi \Sigma$ decay mode
- Distorted by interference of Isospin 0 & 1 amplitudes


Motivation - Cusp structure in $\gamma p \rightarrow K^0\Sigma^+$ cross section


This data: Full squares, Previous CBELSA-TAPS data: open squares, Previous SAPHIR data: triangles (references therein)

Cusp-like structure due to $K^*0$ subthreshold production rescattering to $\pi^0$ & $K^0$?

Grey points - $K^0\Sigma^++K^*\Sigma^+$ M. Nanova et al., EPJ A35, 333 (2008)
Motivation - $K^0$ photoproduction off the neutron


The role of vector-baryon channels and resonances in the $\gamma p \to K^0 \Sigma^+$ and $\gamma n \to K^0 \Sigma^0$ reactions near the $K^* \Lambda$ threshold

- $K^0 \Lambda$ Complementary to $K^+ \Lambda$ - relate hadronic coupling constants

Motivation - Parallels between charmed and strange sectors

Table and figures from H. Schmieden, private communication

<table>
<thead>
<tr>
<th></th>
<th>c-sector</th>
<th>s-sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>meson</td>
<td>baryon(s)</td>
</tr>
<tr>
<td>state(s)</td>
<td>(X(3872))</td>
<td>(P^*_c(4380/4450))</td>
</tr>
<tr>
<td>(\pi)-exchange transition</td>
<td>(D^<em>0\bar{D}^0 + D^0\bar{D^</em>}^0)</td>
<td>(\Lambda^<em>_c\bar{D} + \Sigma_c\bar{D^</em>})</td>
</tr>
<tr>
<td>quantum nos.</td>
<td>(J^{PC} = 1^{++})</td>
<td>(J^P = (3/2)^-)</td>
</tr>
<tr>
<td>3-body threshold</td>
<td>(D^0\bar{D}^0\pi^0)</td>
<td>(\Sigma^+_c\bar{D^0}\pi^0)</td>
</tr>
<tr>
<td>closed flavour channel</td>
<td>(J/\psi\omega)</td>
<td>(\chi_{c1p})</td>
</tr>
</tbody>
</table>

![c-sector diagram](image1.png)

![s-sector diagram](image2.png)
Motivation - Threshold dynamics

Figure from H. Schmieden, private communication

\[ \Lambda(1405) \]
\[ S_{11}(1535) \]

- narrow peak & cusp in \( \eta \) \( \eta'p \)
- narrow peak in \( \phi p \)
- cusp in \( K\Sigma \)

\begin{align*}
K^- N & \quad p - \eta \\
K^- \Sigma & \quad p - \omega \\
K^- \Sigma & \quad p - \phi \\
K^* - \Lambda & \quad K^* - \Sigma
\end{align*}

cm energy / GeV

1.43 1.49 1.68 1.7 1.90 1.96 2.007 2.013 2.08
\( \Lambda^* \) and \( \Sigma^* \) spectra

- Very limited success with constituent quark models
- Hadronic molecules - predict new \( Y^* \) states, eg \( \Sigma^* \left( J^P = 1/2^- \right) \) close to \( \Sigma(1385) \): Jia-Jun Wu et al., Phys. Rev. D 80 (2009) 017503

\[
K^- p \rightarrow \Lambda \pi^+ \pi^-
\]

- 26 PDG \( \Sigma^* \) states - 16 are listed as existence poor to fair. C. Patrignani et al.
Experimental requirements

- Charged particle identification at extremely forward angles - reaction dynamics at very low momentum exchange ($t$-channel)
- High forward momentum resolution
- Reconstruction of complicated, mixed charge final states - eg $K^+\Lambda(1405) \rightarrow K^+(\pi^0\Sigma^0) \rightarrow K^+\pi^0\gamma p\pi^-$

- Unique & complementary to existing facilities (eg CBELSA-TAPS neutral particle reconstruction, CLAS charged particle reconstruction).

BGO-OD at the ELSA facility, Bonn (Germany)
1st large data set taken in 2017. Neutral meson reconstruction (IH$_2$ target):

- Demonstration (1 of many bench marks) - $\gamma p \rightarrow \omega p \frac{d\sigma}{d\Omega}$ via the mixed charge decay, $\omega \rightarrow \pi^0\pi^+\pi^-$ (G. Scheluchin)

M. Williams et al. (CLAS), Phys. Rev. C 80, 065208 (2009)
Detector performance - forward spectrometer

- Top - Particle identification in the Forward Spectrometer
- Bottom - “Missing mass” from forward proton (raw counts)
Strangeness photoproduction at extremely forward angles at the BGO-OD experiment

- BGO-OD experiment at ELSA, Bonn
- Motivation: Hadron structure - parallels in strange & charmed quark sectors?
- Strangeness photoproduction - first results:
  1. $\Lambda(1405)$ & access to higher lying hyperons
  2. Extreme forward cross sections for $K^+\Lambda$ & $K^+\Sigma^0$ photoproduction
  3. $K^0$ photoproduction off proton & neutron (deuterium) targets
  4. Future opportunities - Y-N interaction & hypernuclei studies
- Outlook and conclusions
Mass recoiling from $K^+$ in the forward spectrometer

- The study of $Y^*$ states in an extremely low momentum transfer region

![Graph showing mass recoiling from $K^+$](image)

Identify $Y^*$ states from $K^+\pi^0$ recoiling mass

- $K^+\Lambda \rightarrow K^+\pi^0 n$ (Missing neutron mass from $K^+\pi^0$ system)
- $K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$ (Missing $\Sigma^0$ mass from $K^+\pi^0$ system)
- $K^+\Sigma(1385) \rightarrow K^+\pi^0\Lambda$ (Missing $\Lambda$ mass from $K^+\pi^0$ system)

Goal - $\Lambda(1405)$ lineshape at low momentum transfer region
Λ(1405) over a broad kinematic range

G. Scheluchin


Triangle singularity can describe peak at $W = 2110 \text{ MeV} \& \cos \theta = 0$:

- Full $K^+\Lambda(1405) \& K^+\Lambda(1520)$ reconstruction

- $K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0 \rightarrow K^+\gamma\gamma\gamma\pi^- p$

$\theta_{K^+}^{c.m.} = 0..45^\circ$

$\theta_{K^+}^{c.m.} = 45..90^\circ$

Strangeness photoproduction at extremely forward angles at the BGO-OD experiment

- BGO-OD experiment at ELSA, Bonn
- Motivation: Hadron structure - parallels in strange & charmed quark sectors?
- Strangeness photoproduction - first results:
  1. Λ(1405) & access to higher lying hyperons
  2. Extreme forward cross sections for $K^+\Lambda$ & $K^+\Sigma^0$ photoproduction
  3. $K^0$ photoproduction off proton & neutron (deuterium) targets
  4. Future opportunities - Y-N interaction & hypernuclei studies
- Outlook and conclusions
Not only $Y^*$ states at forward angles important - ground state hyperon photoproduction at low $t$ virtually unconstrained by data!


Crucial constraint for hypernuclei electroproduction!
- eg Saclay Leon model for $p(e, e'K^+)\Lambda$

$K^+\Lambda$ at forward angles - motivation


At BGO-OD

- Forward CM polar angle range approx. 3-26°, 0.9 < \cos \theta_{cm}^{K^+} < 1.0
- Unprecedented $\theta_{cm}^{K^+}$ resolution ($< 1^0$)
- $P_\Lambda$ - recoil $\Lambda$ polarisation accessed by angular distribution of $\Lambda \rightarrow \pi^0 n \& \pi^- p$
Extracting $K^+\Lambda$ & $K^+\Sigma^0$ signal from background

$W = 1600 - 1700$ MeV

$W = 1800 - 1900$ MeV

$W = 1700 - 1800$ MeV

Fitting with RooFit https://root.cern.ch/roofit

- Signal
- Simulated $K^+\Lambda$ events
- Simulated $K^+\Sigma^0$ events
- Background from pair production in the beam
Preliminary forward $K^+\Sigma^0$ differential cross sections

- Test of systematics for forward $K^+$ detection
- Highest statistics data set (& only 75% of available data)
- Work in progress - binning into fine polar angle intervals (3° centre of mass)

\[ \cos \theta^\text{CM}_{K^+} > 0.9 \]

BGO-OD, preliminary

SAPHIR (Glander '04)
CLAS (Dey '10)
CLAS (Bradford '06)
BnGa PWA

Photon beam energy [MeV]

K.H. Glander et al., Eur. Phys. J. A19, 251 (2004), CLAS data in $\cos \theta^\text{CM}_{K^+}$ 0.85 to 0.95 interval
Preliminary forward $K^+\Lambda$ differential cross sections

- Highest statistics data set - distinguish discrepancies in existing data
- Ongoing analysis - statistical error to be reduced by 1/2

$\cos \theta_{K^+}^{CM} > 0.9$

BGO-OD, preliminary
SAPHIR (Glander '04)
CLAS (McCracken '10)
CLAS (Bradford '06)
BnGa PWA

M.E.McCracken et al., Phys.Rev. C81, 025201 (2010),
CLAS data in $\cos \theta_{K^+}^{CM}$ 0.85 to 0.95 interval
Preliminary forward $K^+\Lambda$ differential cross sections

- X-axis: $E_\gamma$, 900 - 1400 MeV. Y-axis: $d\sigma/d\Omega$, 0 - 0.8 [$\mu$b/sr]
- Unprecedented polar angle resolution
- Ongoing analysis - statistical error to be reduced by 1/2

Very preliminary!!!!

BnGa PWA
BGO-OD, very preliminary
$\theta_{CM}$ labelled inset
BGO-OD experiment at ELSA, Bonn

Motivation: Hadron structure - parallels in strange & charmed quark sectors?

Strangeness photoproduction - first results:
1. $\Lambda(1405)$ & access to higher lying hyperons
2. Extreme forward cross sections for $K^+\Lambda$ & $K^+\Sigma^0$ photoproduction
3. $K^0$ photoproduction off proton & neutron (deuterium) targets
4. Future opportunities - Y-N interaction & hypernuclei studies

Outlook and conclusions
Preliminary identification of $K^0\Sigma^+$ with BGO-OD

- Study the Cusp-like structure in the cross section. $K^*0$ subthreshold production rescattering to $\pi^0$ & $K^0$?
- Access $\gamma p \rightarrow K^0\Sigma^+$ via different decay modes at BGO-OD
- Reduction of background & improved momentum resolution achievable with the MWPC (analysis underway)

Tom Jude (University of Bonn)
Strangeness photoproduction at BGO-OD
28th June 2018 26 / 32
Test beam time data (Deuterium target), 2 days

Peak predicted from coherent interference of dynamically generated resonances


- $K^0 \rightarrow 2\pi^0$ reconstructed in the BGO
- Total neutral particles < 6
- Total charged particles < 3

- $K^0 \rightarrow 2\pi^0$ reconstructed in the BGO
- Proton in the Forward spectrometer & select missing $\pi^0$ mass from $\Sigma^+ \rightarrow p\pi^0$
- Total neutral particles < 6
- Total charged particles < 3

(a) $2\pi^0$ in the BGO, Missing mass between 1000 - 1200 MeV

Mean = 508 MeV
Height = 380
$\sigma = 26$ MeV
Integral over $\pm 2\sigma = 23753$

(b) $2\pi^0$ and proton, Missing mass between 1000 - 1200 MeV

Mean = 512 MeV
Height = 296
$\sigma = 18$ MeV
Integral over $\pm 2\sigma = 5787$
BGO-OD experiment at ELSA, Bonn

Motivation: Hadron structure - parallels in strange & charmed quark sectors?

- Strangeness photoproduction - first results:
  1. $\Lambda(1405)$ & access to higher lying hyperons
  2. Extreme forward cross sections for $K^+\Lambda$ & $K^+\Sigma^0$ photoproduction
  3. $K^0$ photoproduction off proton & neutron (deuterium) targets
  4. Future opportunities - Y-N interaction & hypernuclei studies

Outlook and conclusions
Future opportunities: Hypernuclei production

- Hypernuclei photoproduction, eg
  \[ \gamma + ^{12}C \rightarrow K^+ + ^{12}_{\Lambda}B \] - natural laboratory to probe the \( Y - N \) interaction

- Forward \( K^+ \), coherent production, leaving the \( \Lambda \) within the Fermi surface of the residual nuclei

Opportunities for first real photon beam photoproduction?

- In conversation with P. Achenbach & J. Pochodzalla, 2018

  - Mesic decay \((\Lambda \rightarrow \pi N)\) identification in BGO - favour light nuclei
  
  - Identify specific states, eg \( \gamma + ^{12}C \rightarrow \pi^0 + ^{12}C^* \rightarrow \pi^0 + ^{12}C + \gamma' \) (4.4 MeV)
  
  - Can use “sensitive” targets that are spoiled by intense e\(^-\) beams (eg Li)
  
  - Hypernuclei lifetime measurements, angular \( K^+ \) distributions, differential cross sections
Coherent pion production (“non-strange” example)


\[ \gamma + ^{12}C \rightarrow \pi^0 + ^{12}C^* \rightarrow \pi^0 + ^{12}C + \gamma' \ (4.4 \text{ MeV}) \]

- E2 transition, \( J^{\pi} : 2^+ \rightarrow 0^+ \), \( \sin^2(2\alpha) \) distr. between nuclear recoil & \( \gamma' \)

- \( \sim 2 \) hours of commissing data with BGO-OD:

1. Search for coherent \( \pi^0 \) events

- \( E_\gamma = 297 \text{ MeV} \)
- \( \theta_{\pi^0} < 40^\circ \)

2. Search for additional decay photon

- Exponential + Gaussian fn.
- Mean \( \approx 4.5 \text{ MeV} \)
- \( \sigma \approx 0.6 \text{ MeV} \)

3. Verification - decay \( \gamma \) angular distr.

- \( \sin^2(2\alpha) \) fit
- Not efficiency corrected
Future opportunities: Y-N studies with deuterium targets

Data being taken this very moment!

- Final state interactions for
  \( \gamma d \rightarrow K^+ \Lambda + (n) \)
- \(KN, \; YN\) & pion mediated
- \(\theta_K < 30^0\) - FSI dominated by Y-N

Models of YN forces - cusps at \(\Sigma N\) & \(YN\) thresholds


Cross section & pol. obs. sensitive to \(YN\) interactions at these cusps!
Hadrons - molecular-like structure?

BGO-OD - strangeness photoproduction - extreme forward angles

Low momentum transfer region

1st preliminary results - $K^+ Y$ at forward angles

$\Lambda(1405), K^0$ off protons & neutrons - analyses ongoing

Deuterium target - data being taken now!

$Y-N$ interaction study opportunities - deuterium, hypernuclei...
Previous $\gamma p \rightarrow K^0\Sigma^+$ measurements

- The 1st beam asymmetry measurement
  R. Ewald et.al, PLB 738 (2014) 268
  (CBELSA/TAPS Collaboration)
$K^0$ photoproduction off the neutron

- Complimentary to $\gamma p \rightarrow K^+ \Lambda$ measurements: relate hadronic coupling constant - predictions of $n(\gamma, K^0) \Lambda$ cross section

\[
\begin{align*}
    g_{K^+ \Lambda_p} &= g_{K^0 \Lambda_n} \\
    g_{K^+ \Sigma_p^0} &= -g_{K^0 \Sigma_n^0} \\
    g_{K^{*+} \Lambda_p} &= g_{K^{*0} \Lambda_n} \\
    g_{V, T} &= g_{V, T}
\end{align*}
\]

- BGO-OD - 1st differential cross section measurement to $E_\gamma = 3$ GeV & polarisation observables
- Higher statistics - $K^0$ identification via both main decay modes
Separating $K^0\Lambda$ and $K^0\Sigma^0$ final states

- Simulated data to demonstrate separation of channels
- Identify the decay: $\Sigma^0 \rightarrow \Lambda\gamma$

---

(a) Simulated $K^0\Sigma^0 + K^0\Lambda$

(b) Missing mass recoiling from $K^0$

(c) Simulated $K^0\Sigma^0 + K^0\Lambda$

(d) Simulated $K^0\Sigma^0$

Simulated $K^0\Lambda$

Events with decay $\gamma$

Events with no decay $\gamma$

---

Tom Jude (University of Bonn)  Strangeness photoproduction at BGO-OD  28th June 2018  32 / 32
Tagger timing

RF bunch structure from ELSA \( \sigma \sim 160 \) ps
No $K^0$ t-channel exchange (but still $K^*$) - s channel resonances more prominent

Complementary to $K^+\Lambda$ - relate hadronic coupling constants

Incident photon beam parameters

- Energy tagged $\gamma$ beam $\leq 3$ GeV, 250 ps time resolution
- Current $\leq 2$ nA, 10 nA upgrade planned
- Circularly and linearly polarised $\gamma$ beams available

Coherent bremsstrahlung using a diamond radiator

30% polarisation at 1.8 GeV with an incident electron energy of 3.2 GeV
**K^+** identification in the BGO

- Time delayed, **K^+** weak decay within the crystals of the BGO ball

**Lifetime 12 ns, 2 main decay modes:**

\[ K^+ \rightarrow \mu^+ \nu_\mu \]

\[ K^+ \rightarrow \pi^+ \pi^0 \]

---

**Decay cluster energy [MeV]**

<table>
<thead>
<tr>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>250</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>350</td>
</tr>
<tr>
<td>400</td>
</tr>
</tbody>
</table>

**Counts**

- Real data
- Simulated data

**Fitted lifetime ~ 11 ns**

---

**Decay time [ns]**

<table>
<thead>
<tr>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>

**Counts**

- Real data
- Simulated data

**Fitted lifetime ~ 11 ns**
Identifying the $\Sigma^0 \rightarrow \Lambda\gamma$ decay ($\Gamma = 100\%$)

- Boost all neutral particles in the BGO into missing hyperon rest frame
- If $K^+\Sigma^0$:
  - $\gamma$ energy ($\Sigma^0$ rest frame) = $M_{\Sigma^0} - M_\Lambda = 77$ MeV
- Efficiency scale events with/without ID to separate missing mass spectrum

Photon detection in the BGO to separate different $K^+Y^*$ states!
$K^+\Lambda$ Recoil Polarisation at forward angles

- Up-down asymmetry between decay proton/neutron direction in $\Lambda$ rest frame & normal to the reaction plane
- $\Lambda \rightarrow \pi^0 n$ identified in the BGO
- $P_\Lambda = \frac{2N_{up} - N_{down}}{\alpha N_{up} + N_{down}}$, $\alpha = 0.642$ ($\Lambda$ decay parameter)

```
- BGO-OD (cos $\theta_K$ = 0.95, Preliminary)
- CLAS (cos $\theta_K^{CM}$ = 0.9)
- GRAAL (cos $\theta_K^{CM}$ = 0.85)
- Bonn-Gatchina PWA
```

```
Simulated data - event by event comparison

$\epsilon \sim 0.89$
```

$d^*(2380)$ dibaryon, $\Gamma \approx 70$ MeV, $J^P = 3^+$

- Decay branching ratios determined

- Hexaquark/molecule/dominated by diquark components?
  $M_{d^*} = M_{\Delta\Delta} - 80$ MeV

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

High statistics new dataset

- **April 2017 beam time**
  - $914 < E_\gamma < 1300$ MeV
  - 8200 $K^+\Lambda$ events
  - 3500 $K^+\Lambda$ events with $\pi^0$
  - Entries 28098
  - Mean 961.2
  - RMS 236.9

- **July 2015 beam time**
  - $914 < E_\gamma < 1300$ MeV
  - 2450 $K^+\Lambda$ events
  - 1000 $K^+\Lambda$ events with $\pi^0$
  - Entries 8626
  - Mean 916.8
  - RMS 262.9

- 3 bins in $\theta^{K^+}_{CM}$, 6-7 bins in angle
- 25 bins in energy
- $\sim 10\%$ statistical error - consistent with PAC proposal (& higher than other datasets at more backward angles)
- Small bug found in track-tagger correlations, will increase yield by $\sim 1.5$
\[ \gamma p \rightarrow K^+ \Sigma^0 \] with no initial particle Identification

Preliminary analysis, 25 days data, (G. Scheluchin, PhD thesis work)

- \( K^+ \) & \( \Lambda \rightarrow p\pi^- \) over large acceptance region \( (1^0 < \theta < 155^0) \)
- \( \Sigma^0 \) decay photon in the BGO \( (\Sigma^0 \rightarrow \Lambda\gamma) \)
- Technique used for higher lying \( Y^* \) states (eg \( \Lambda(1405) \rightarrow \pi^0\Sigma^0 \))

Reconstructing the \( \Sigma^0 \) invariant mass

(a) Momentum conservation & \( K^+ \) “missing mass” cut

(b) Kinematic fit & confidence level cut

(c) Neural network to suppress background

Real data
Simulated \( K^+\Sigma^0 \)
\[ \gamma p \rightarrow K^+ \Sigma^0 \] with no initial particle Identification

Preliminary identification of $K^0\Sigma^+$ with BGO-OD

Analysis by S. Alef

---

**Image Description**

- **Graph 1:**
  - Title: All data
  - Description: Graph showing two peaks, one for Signal (red) and one for Background (blue), with a Gaussian fit.

- **Graph 2:**
  - Title: $1250 < E_\gamma < 1550$ MeV
  - Description: Graph showing the two $\pi^0$ invariant mass distributions.

- **Graph 3:**
  - Title: $1250 < E_\gamma < 1550$ MeV
  - Description: Graph highlighting the signal with a Gaussian fit for $-1.0 < \cos \theta_{CM}^{K^0} < -0.6$.

- **Graph 4:**
  - Title: $1250 < E_\gamma < 1550$ MeV
  - Description: Graph showing the signal with a Gaussian fit for $-0.6 < \cos \theta_{CM}^{K^0} < -0.2$. 
Previous $\gamma p \rightarrow K^0\Sigma^+$ measurements


This data: Full squares, Previous CBELSA-TAPS data: open squares, Previous SAPHIR data: triangles (references therein).
Access to rare $\Upsilon^*$ decays

\[ \Lambda(1405) \rightarrow \Lambda \gamma \]

\[ \Gamma_{\Lambda \gamma} \] indication of compositeness:

\[ K^+ \eta \] recoiling mass

eg, $\Lambda(1670)1/2^+$ (PDG ****)

Width 25 - 50 MeV

\[ \Gamma_{\Lambda \eta} = 10 - 25\% \] (never observed)

Many poorly known $\Sigma^*$ and $\Lambda^*$ states

Motivation - $\Lambda$ hyperons in a constituent quark model

- Parity ordering of 3 lowest states agrees with CQM model, but $\Lambda(1405)$ mass too low (compared to $N^*(1535)$)
- $Y^*$ spectrum - limited success with constituent quark models
High statistics new dataset

- Unprecedented angular resolution - $3^0$ bins in $\theta_{CM}^{K^+}$
- Fit to background: $e^+e^-$ from the beam, misidentified $\pi^+$ at higher energy

914 < $E_\gamma$ < 1000 MeV

1000 < $E_\gamma$ < 1100 MeV

1100 < $E_\gamma$ < 1200 MeV

1200 < $E_\gamma$ < 1300 MeV

1300 < $E_\gamma$ < 1400 MeV

1400 < $E_\gamma$ < 1500 MeV

Tom Jude (University of Bonn)  
Strangeness photoproduction at BGO-OD  
28th June 2018
Preliminary forward $K^+\Lambda$ differential cross sections

- $X$-axis: $\theta_{K^+}^{CM}$, 0 - 30°. Y-axis: $d\sigma/d\Omega$, 0 - 0.8 $[\mu b/sr]$
- Magenta line - BnGa PWA, Beam energy labelled inset
- $\pi^0$ identification required - $\times 4$ stats anticipated without this
Future opportunities in $K^+\Lambda$ studies: Y-N interaction

- Forward kinematics ideal for BGO-OD
- Increase OD magnetic field to improve momentum resolution
- Difficult measurement but very important and not possible anywhere else!

Right hand side plots: