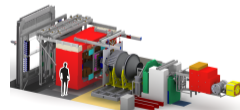# Эксперимент BGO-OD на ускорителе ELSA (Бонн, Германия)

Nikolai Kozlenko, on behalf of the BGOOD collaboration

Петербургский Институт Ядерной Физики
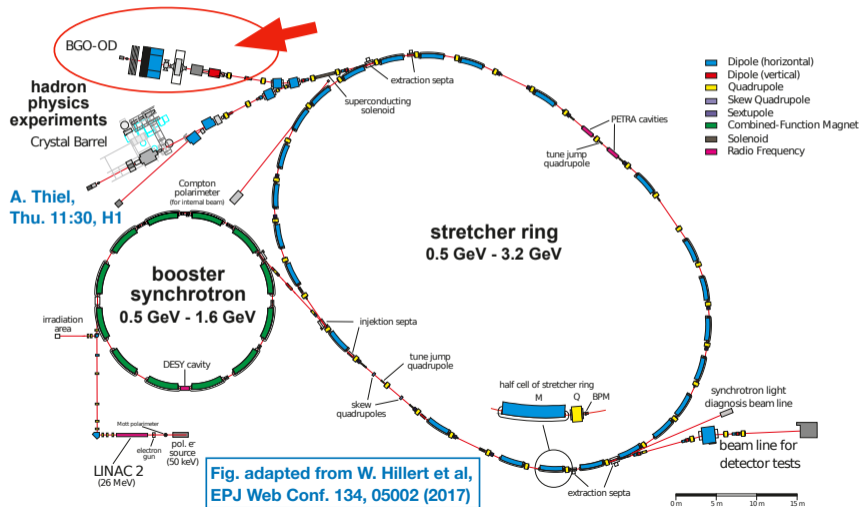
kozlenko_ng@pnpi.nrcki.ru

22 Декабря 2021

The Electron Stretcher Accelerator (ELSA)
A 3 stage e^- accelerator - continuous electron beams up to 3.2 GeV

BGO-OD

hadron physics experiments

Crystal Barrel

A. Thiel,
Thu. 11:30, H1

Compton polarimeter
(for internal beam)

extraction septa

superconducting solenoid

PETRA cavities

tune jump quadrupole

stretcher ring
0.5 GeV - 3.2 GeV

booster synchrotron
0.5 GeV - 1.6 GeV

irradiation area

DESY cavity

injection septa

tune jump quadrupole

skew quadrupoles

half cell of stretcher ring

M   Q   BPM

synchrotron light diagnosis beam line

beam line for detector tests

electron gun

Mott polarimeter

pol. e^- source (50 keV)

LINAC 2
(26 MeV)

extraction septa

| Dipole (horizontal) |
| Dipole (vertical) |
| Quadrupole |
| Skew Quadrupole |
| Sextupole |
| Combined-Function Magnet |
| Solenoid |
| Radio Frequency |

Fig. adapted from W. Hillert et al, EPJ Web Conf. 134, 05002 (2017)

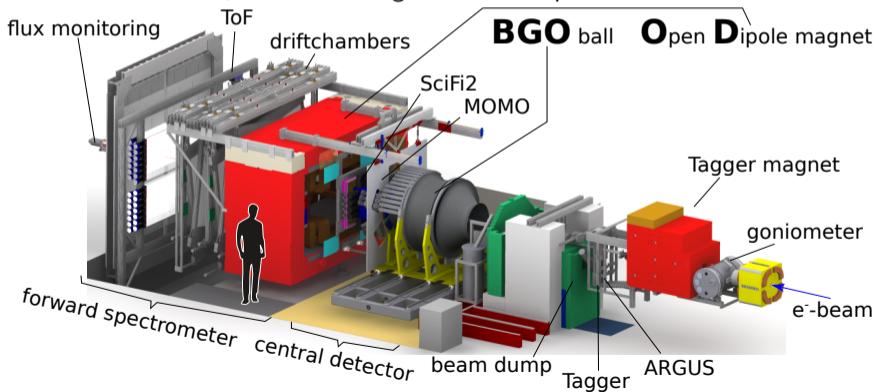0 m   5 m   10 m   15 m

The BGOOD experiment, Eur. Phys. J. A 56:104 (2020)

Spokespersons: H. Schmieden (Bonn) & P. Levi Sandri (Frascati)

- The BGOOD Collaboration - 32 members from universities in Germany, Italy, Russia & USA
- BGO calorimeter (central region) & Forward Spectrometer combination
- High momentum resolution, excellent charged & neutral particle ID

flux monitoring — ToF — driftchambers — **BGO** ball **O**pen **D**ipole magnet — SciFi2 — MOMO — Tagger magnet — goniometer — e⁻-beam — forward spectrometer — central detector — beam dump — Tagger — ARGUS

Experimental requirements

- Charged particle identification at extremely forward angles - reaction dynamics at very low momentum exchange

- High forward momentum resolution

- Reconstruction of complicated, mixed charge final states - eg $K^+\Lambda(1405) \to K^+(\pi^0\Sigma^0) \to K^+\pi^0\gamma p\pi^-$

- Unique & complementary to existing facilities (eg CBELSA-TAPS neutral particle reconstruction, CLAS charged particle reconstruction).
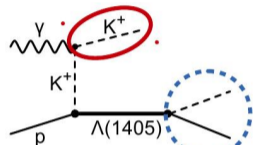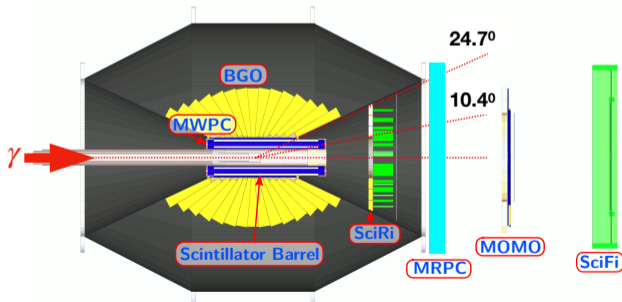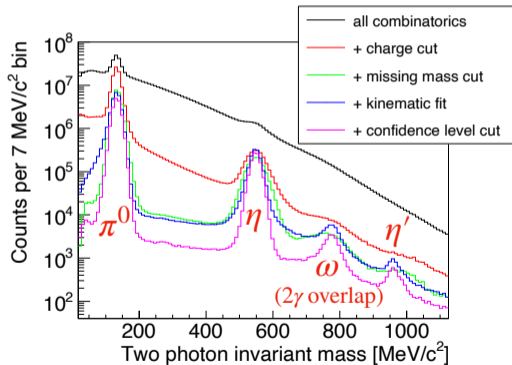
BGOOD at the ELSA facility, Bonn

BGOOD - Central region, Eur. Phys. J. A 56:104 (2020)

- BGO Rugby Ball (central region)
- Charged & neutral particle ID
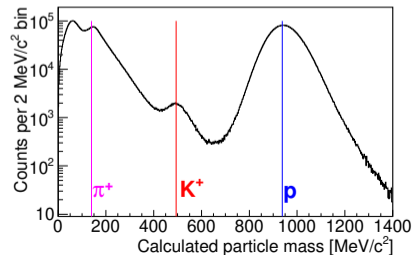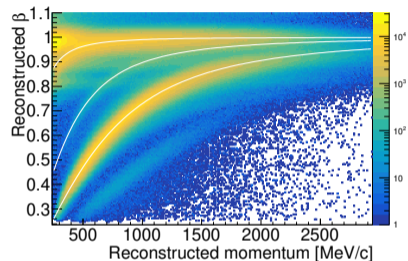- Excellent time resolution (~ 2 ns) per BGO crystal

- Clean reconstruction of neutral meson decays:

BGOOD - Forward region, Eur. Phys. J. A 56:104 (2020)
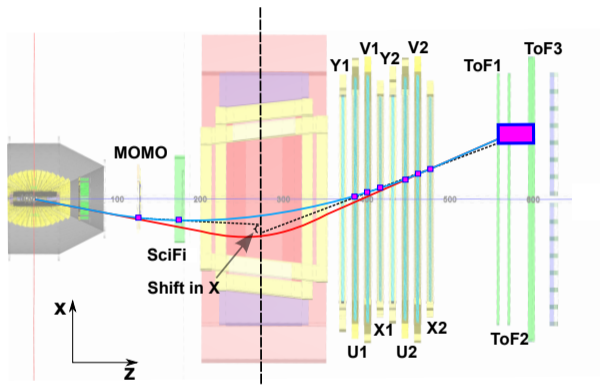
- Charged particle ID & momentum reconstruction
- $1° < \theta_{\mathrm{Lab}} < 12°$, $\Delta\theta_{\mathrm{Lab}} \sim 0.5°$
- $\Delta p/p \sim 3\%$ (at max field strength)

Forward $\gamma p \to K^+\Sigma^0$, Published at PLB 820 (2021) 136559

Observation of a cusp-like structure in the $\gamma p \to K^+\Sigma^0$ cross section at forward angles and low momentum transfer
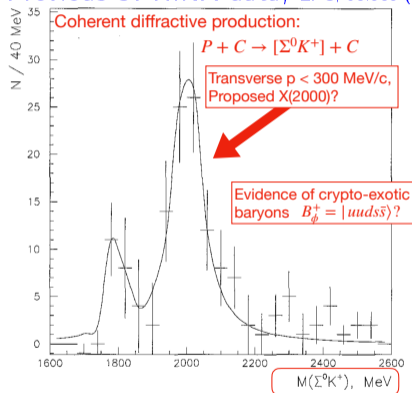
T.C. Jude [a,*], S. Alef [a], P. Bauer [a], D. Bayadilov [b,c], R. Beck [b], A. Bella [a,1], J. Bieling [b,1], A. Braghieri [d], P.L. Cole [e], D. Elsner [a], R. Di Salvo [f], A. Fantini [f,g], O. Freyermuth [a], F. Frommberger [a], F. Ghio [h,i], S. Goertz [a], A. Gridnev [c], D. Hammann [a,1], J. Hannappel [a,2], K. Kohl [a], N. Kozlenko [c], A. Lapik [j], P. Levi Sandri [k], V. Lisin [j], G. Mandaglio [l,m], F. Messi [a,1], R. Messi [f,g], D. Moricciani [k], V. Nedorezov [j], V.A. Nikonov [b,c,3], D. Novinskiy [c], P. Pedroni [d], A. Polonskiy [j], B.-E. Reitz [a,1], M. Romaniuk [f,n], A.V. Sarantsev [b,c], G. Scheluchin [a], H. Schmieden [a], A. Stuglev [c], V. Sumachev [c,3], V. Vegna [a,1], V. Tarakanov [c]

Forward $\gamma p \to K^+ \Sigma^0$ - Motivation

- Limited data at forward K^+ angles

- $W \sim 1900\,\text{MeV}$ at the $K^+ K^- p$ threshold, many predictions:

  - ϕN bound systems Gao, Huang, Liu, Ping, Wang & Z. Zhao, PRC, 95:055202, 2017

  - Molecular $K\Sigma$ states, $J^P = 1/2^-$ & $3/2^-$ consistent with $N^*(1875)$ & $N^*(2100)$ Huang, Zhu & Ping, PRD 97:094019, 2018.

  - A 3-hadron $K\bar{K}N$ molecule with $a_0(980)N$ & $f_0(980)N$ components Martínez Torre, Khemchandani, Meißner & Oset, EPJA 41:361, 2009.

Previous SPHINX data, zPC, 68:585 (1995)

Coherent diffractive production:
$P + C \to [\Sigma^0 K^+] + C$

Transverse p < 300 MeV/c, Proposed X(2000)?

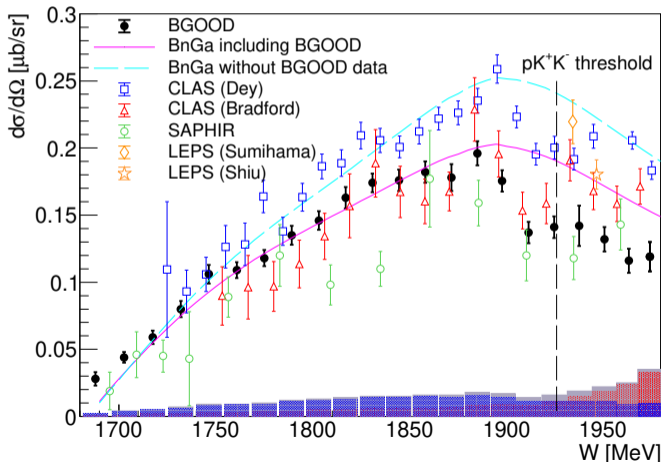Evidence of crypto-exotic baryons $B_\phi^+ = |uuds\bar{s}\rangle$?

$M(\Sigma^0 K^+)$, MeV

Low transverse p requires forward kinematics in photoproduction!

$\gamma p \to K^+ \Sigma^0$ Published at PLB 820 (2021) 136559

- Highest statistics to date for $\cos\theta_{CM}^K > 0.9$ (CLAS data in $\cos\theta_{CM}^K$ 0.85 to 0.95)
- Resolve discrepancies in world data set & reveals "cusp" at $W \sim 1900$ MeV

- Cusp regarded as a peak before - PWA have attributed $D_{13}(1895)$, $S_{31}(1900)$, $P_{31}(1910)$ & $P_{13}(1900)$

R. Bradford *et al.* (CLAS), PRC 73, 035202 (2006),
B. Dey *et al.* (CLAS), PRC 82, 025202 (2010),
CLAS data in $\cos\theta_{CM}^K$ 0.85 to 0.95 interval,
K.H. Glander *et al.* (SAPHIR), EPJA 19, 251 (2004),
BnGa PWA - without BGOOD/with BGOOD

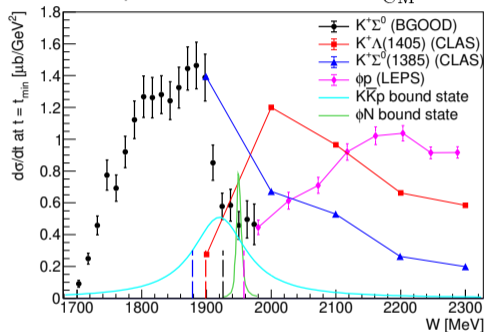$\gamma p \rightarrow K^+ \Sigma^0$ Published at PLB 820 (2021) 136559
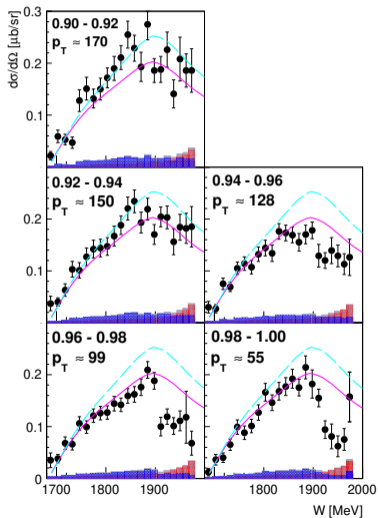
- Cusp increases quickly with $\cos \theta^K_{\mathrm{CM}}$ and K^+ transverse momentum (p_T) (labelled left, inset)

- Consistent with the "extent of cusp" seen at CLAS:
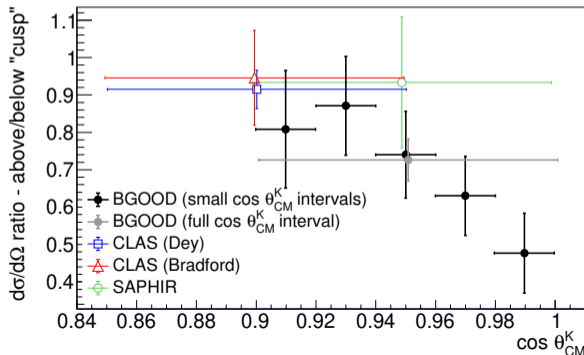
$\gamma p \rightarrow K^+ \Sigma^0$ Published at PLB 820 (2021) 136559

Data extrapolated to $t_{\min}$ & $\cos\theta^K_{\mathrm{CM}} = 1$

CLAS data extrapolated from: K. Moriya. PhD thesis, Carnegie Mellon University, 2010. https://www.jlab.org/Hall-B/general/thesis/Moriya thesis.pdf. LEPS: Mibe et al. PRL.95:182001,2005. $K\bar{K}p$ bound state: Mart et al., EPJA, 41:361, 2009. ϕN bound state: Gao, et al, PRC, 95:055202, 2017.

The Cusp is....

- in the same kinematic regime to the $X(2000)$ proposed by SPHINX
- at predicted $K\bar{K}p$ and ϕp bound states
- 20 MeV above predicted bound $\Sigma(1385)K$ state

Channel thresholds:

- A "smooth" transition between $K^+\Sigma^0$ & $p\phi$
- Similar behaviour of $K^+\Sigma^0(1385)$

Investigating other channels, eg $\gamma n \rightarrow K^+\Sigma^-$
J. Groß, PhD analysis, Uni Bonn

$\gamma p \to K^+\Lambda(1405) \to K^+(\Sigma^0\pi^0)$ G. Scheluchin PhD thesis, paper in preparation

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

Georg Scheluchin,[1, *] Stefan Alef,[1] Patrick Bauer,[1] Reinhard Beck,[2] Alessandro Braghieri,[3] Philip Cole,[4] Rachele Di Salvo,[5] Daniel Elsner,[1] Alessia Fantini,[5, 6] Oliver Freyermuth,[1] Francesco Ghio,[7, 8] Anatoly Gridnev,[9] Daniel Hammann,[1, †] Jürgen Hannappel,[1] Thomas Jude,[1] Katrin Kohl,[1] Nikolay Kozlenko,[9] Alexander Lapik,[10] Paolo Levi Sandri,[11] Valery Lisin,[10] Giuseppe Mandaglio,[12, 13] Roberto Messi,[6, 7, †] Dario Moricciani,[6] Vladimir Nedorezov,[10] Dmitry Novinsky,[9] Paolo Pedroni,[3] Andrei Polonski,[10] Björn-Eric Reitz,[1, †] Mariia Romaniuk,[6] Hartmut Schmieden,[1] Victorin Sumachev,[9, ‡] and Viacheslav Tarakanov[9]

(BGOOD Collaboration)

$\gamma p \to K^+ \Lambda(1405) \to K^+(\Sigma^0 \pi^0)$ G. Scheluchin PhD thesis, paper in preparation

- $\Lambda(1405) \to \pi^0 \Sigma^0$ - Clean identification: $\Sigma(1385) \to \Sigma^0 \pi^0$ isospin forbidden
- Full reconstruction & kinematic fit: $K^+\Lambda(1405) \to K^+\Sigma^0\pi^0 \to K^+\gamma\Lambda\pi^0 \to K^+3\gamma p\pi^-$
- Line shape - good agreement with previous data

- This data & ANKE - 2 peak structure at 1395 & $1425\,\mathrm{MeV}/c^2$?
- Close to the $\Lambda(1405)$ proposed 2-pole structure
  Oller & Meißner, PLB 500, 263 (2001)
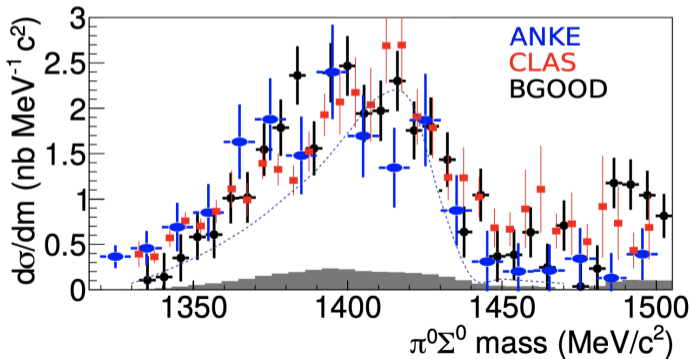
CLAS: Moriya, et al PRC 87, 035206 (2013)
ANKE: Zychor et al, PLB 660, 167 (2008)
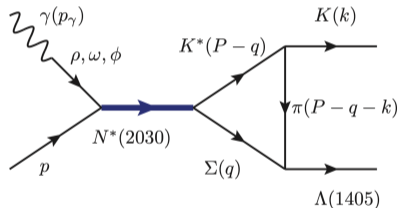Dashed line: Nacher et al, PLB 455, 55 (1999)

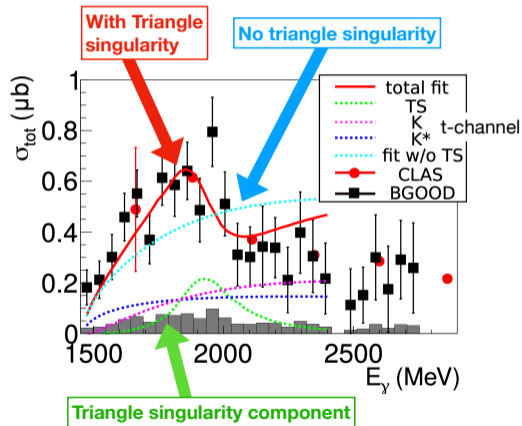$\gamma p \to K^+ \Lambda(1405) \to K^+(\Sigma^0 \pi^0)$ G. Scheluchin PhD thesis, paper in preparation

Total cross section for $\gamma p \to K^+ \Lambda(1405) \to \Sigma^0 \pi^0$

Triangle singularity in $\gamma p \to K^+ \Lambda(1405)$

Wang et al. PRC 95, 015205 (2017)

- $N^*(2030)$ close in mass & strong coupling to $K^*\Sigma$
- $K^*\Sigma$ molecular component?
- $N^*(2030)$ **proposed for the cusp in $K^0\Sigma^+$ photoproduction**

[CLAS: Moriya, PRC 87, 035206 (2013)]

# Forward $\gamma p \to K^+ \Lambda$, Eur. Phys. J. A (2021) 57:80

$K^+\Lambda$ photoproduction at forward angles and low momentum transfer

T.C. Jude[1,a], S. Alef[1], P. Bauer[1], R. Beck[2], A. Bella[1,b], J. Bieling[2,b], A. Braghieri[3], P.L. Cole[4], D. Elsner[1], R. Di Salvo[5], A. Fantini[5,6], O. Freyermuth[1], F. Frommberger[1], F. Ghio[7,8], S. Goertz[1], A. Gridnev[9], D. Hammann[1,b], J. Hannappel[1,c], K. Kohl[1], N. Kozlenko[9], A. Lapik[10], P. Levi Sandri[11], V. Lisin[10], G. Mandaglio[12,13], F. Messi[1,d], R. Messi[5,6], D. Moricciani[5], V. Nedorezov[10], D. Novinskiy[9], P. Pedroni[3], A. Polonskiy[10], B.-E. Reitz[1,b], M. Romaniuk[5,14], G. Scheluchin[1], H. Schmieden[1], A. Stugelev[9], V. Sumachev[9e], V. Tarakanov[9], and T. Zimmermann[1,b]

# Forward $\gamma p \to K^+ \Lambda$, Eur. Phys. J. A (2021) 57:80

- Low t data - constraint on hypernuclei electroproduction
- Forward angles - sensitive to high spin N^*
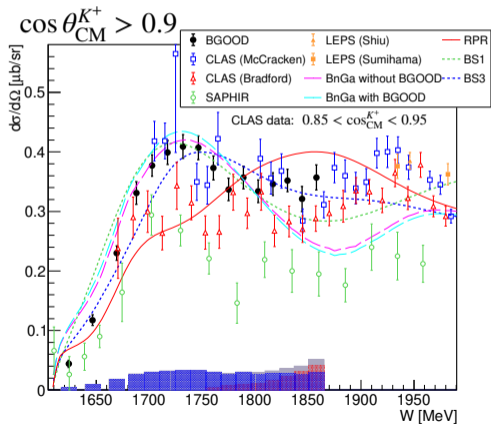
CLAS data:
$0.85 < \cos\theta_{CM}^{K^+} < 0.95$

BnGa: EPJA 50:74 (2014)
RPR: Skoupil & Bydžovský, PRC, 100:035202 (2019)
BS1 & BS3: Skoupil & Bydžovský, PRC, 97:025202 (2018)
Bradford, PRC 73:035202 (2006)
McCracken, PRC 81:025201 (2010)
SAPHIR, EPJA 19:251 (2004)
LEPS: PRC 73:035214 (2006) & 97:015208 (2018)
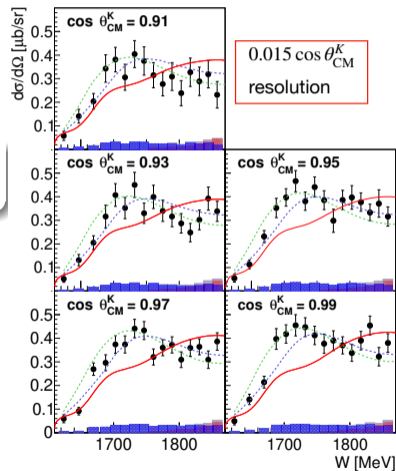
The BGOOD experiment at ELSA
Exotic structures in the light quark sector?

① Motivation - parallels in the strange & charmed quark sectors?

② The BGOOD experiment at ELSA, Bonn

③ Exotic structure in associated strangeness photoproduction?

- K^0 photoproduction - driven by molecular N^* states?

- $K^+\Lambda(1405)$ - evidence of triangle singularity mechanism

- Cusp at forward $K^+\Sigma^0$ photoproduction at the $K\bar{K}p$ threshold

④ Searches for exotic dibaryons at BGOOD

Forward $\gamma D \to \pi^0 \pi^0 D$, Готовится к публикации

Изучение рождения двух π^0 мезонов на дейтроне.

Evidence of a dibaryon spectrum in coherent $\pi^0 \pi^0 d$ photoproduction at forward deuteron angles

T.C. Jude[a,*], S. Alef[a], R. Beck[b], A. Braghieri[d], P.L. Cole[e], D. Elsner[a], R. Di Salvo[f], A. Fantini[f,g], O. Freyermuth[a], F. Frommberger[a], F. Ghio[h,i], S. Goertz[a], A. Gridnev[c], K. Kohl[a], N. Kozlenko[c], A. Lapik[j], P. Levi Sandri[k], V. Lisin[j], G. Mandaglio[l,m], V. Nedorezov[j], D. Novinskiy[c], P. Pedroni[d], A. Polonskiy[j], B.-E. Reitz [a,1], M. Romaniuk[f,n], G. Scheluchin[a], H. Schmieden[a], A. Stuglev[c], V. Sumachev[c,2], V. Tarakanov[c]

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

K. Kohl,[1, *] S. Alef,[1, †] R. Beck,[2] A. Braghieri,[3] P.L. Cole,[4] D. Elsner,[1] R. Di Salvo,[5] A. Fantini,[5, 6]
O. Freyermuth,[1] F. Frommberger,[1] F. Ghio,[7, 8] S. Goertz,[1] A. Gridnev,[9] D. Hammann,[1, †] J. Hannappel,[1]
T.C. Jude,[1, ‡] N. Kozlenko,[9] A. Lapik,[10] P. Levi Sandri,[11] V. Lisin,[10] G. Mandaglio,[12, 13] R. Messi,[5, 6]
D. Moricciani,[11] V. Nedorezov,[10, §] V.A Nikonov,[2, 9] D. Novinskiy,[9] P. Pedroni,[3] A. Polonskiy,[10] B.-E. Reitz,[1, †]
M. Romaniuk,[5, 14] G. Scheluchin,[1, †] H. Schmieden,[1] A. Stuglev,[9] V. Sumachev,[9, §] and V. Tarakanov[9]
(BGOOD Collaboration)

С Наступающим Новым Годом!