

# Investigation of open and hidden strangeness at ELSA

Tom Jude  
On behalf of the BGO-OD Collaboration

Physikalisches Institut  
University of Bonn  
Supported by the DFG / tr-16

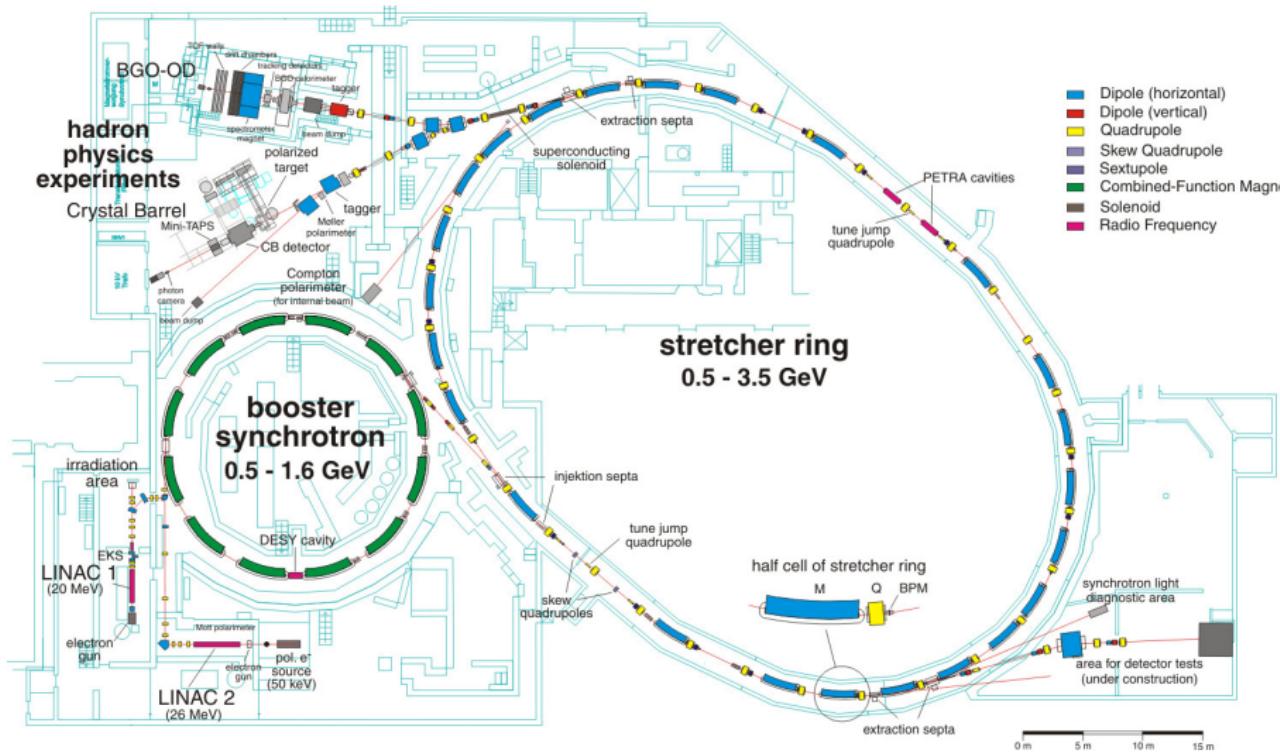
26.09.16 - 27.09.16



- BGO-OD at ELSA, Bonn University
- Exotic hadron evidence in the strangeness sector
- $\gamma p \rightarrow K^0 \Sigma^+$  data from CBELSA/TAPS
- Ongoing analysis at BGO-OD

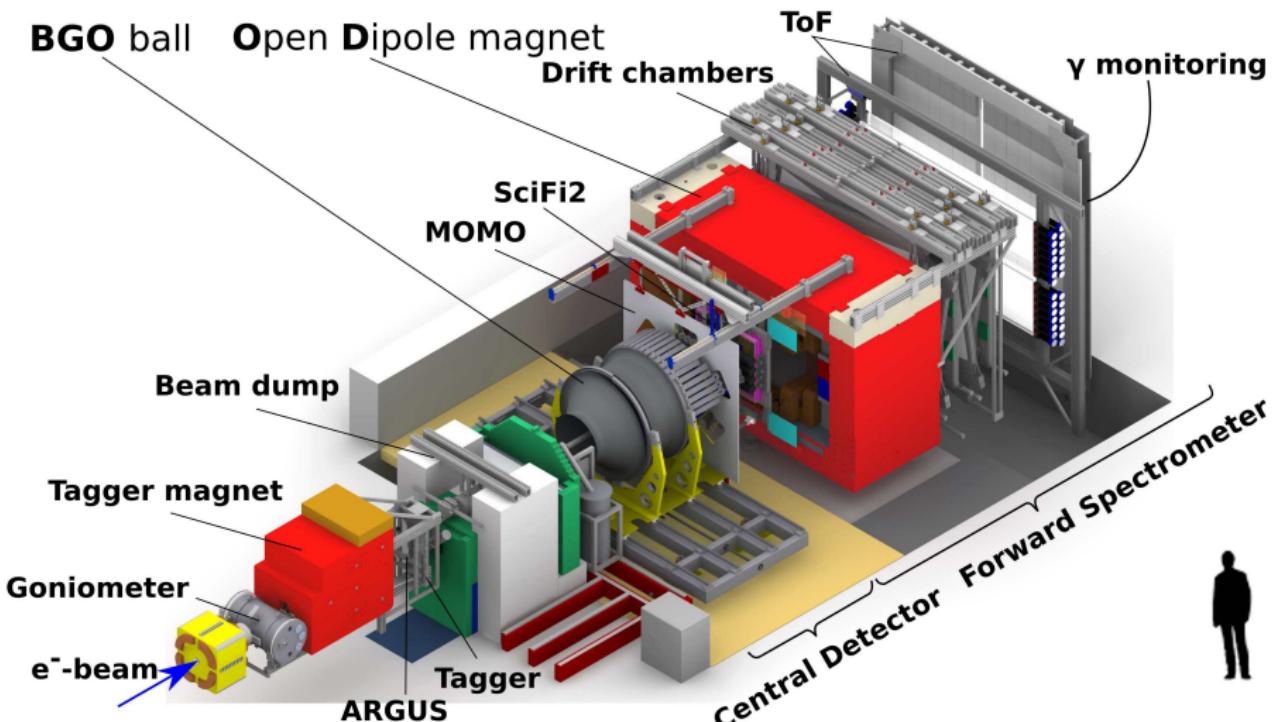


# The Electron Stretcher Accelerator (ELSA)



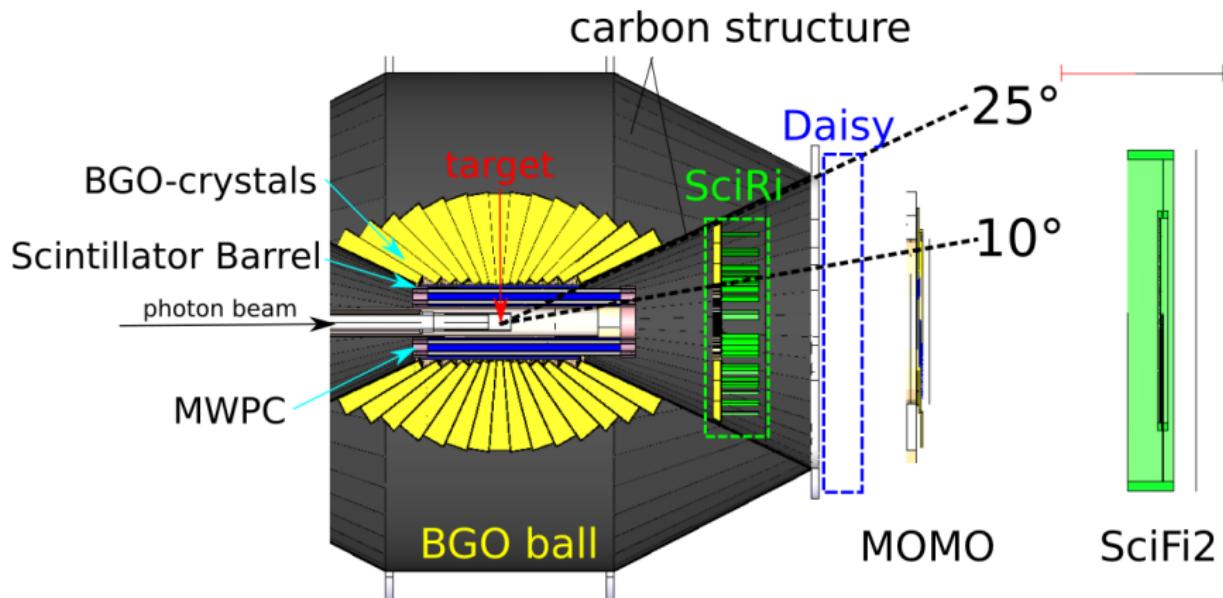
# The BGO-OD experiment at ELSA

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



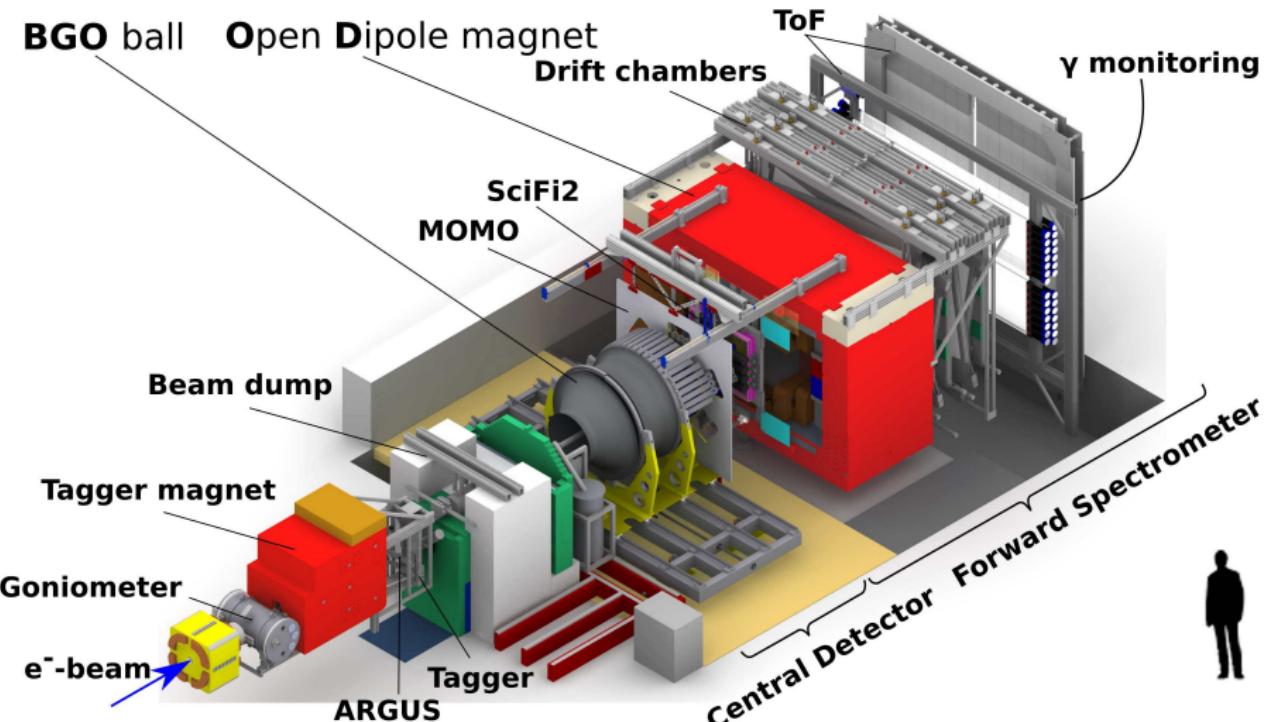
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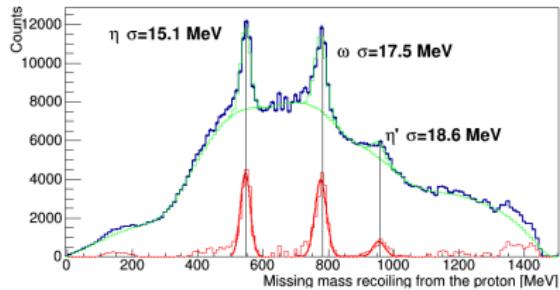
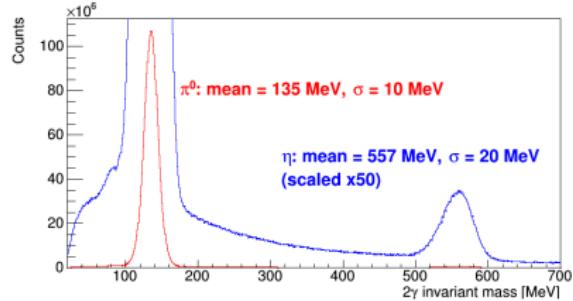
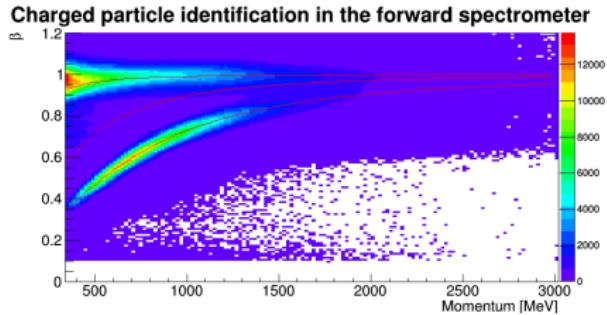
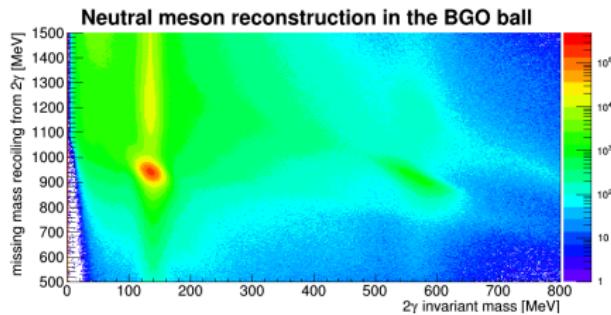
# The BGO-OD experiment at ELSA

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



# Analysis overview

- So far: 25 days lin. pol. data ( $\text{IH}_2$  target), 2 days C target, 2 days  $\text{D}_2$  target
- Example of recent data ( $\text{IH}_2$  target, subset of data):



# Strangeness photoproduction - physics motivation

- BGO-OD - Identify final states of mixed charge - investigation of  $Y^*$  resonances, eg  $K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0 \rightarrow K^+\pi^0\gamma\Lambda \rightarrow K^+\gamma\gamma\gamma p\pi^-$
- $Y^*$  spectrum - limited success with constituent quark models
- Models including meson-baryon interactions as degrees of freedom - more successful, [C. Garcia-Recio, M.F.M. Lutz, and J. Nieves, Phys. Lett. B 582 \(2004\) 49](#), [M.F.M. Lutz and E.E. Kolomeitsev, Phys. Lett. B 585 \(2004\) 243](#).

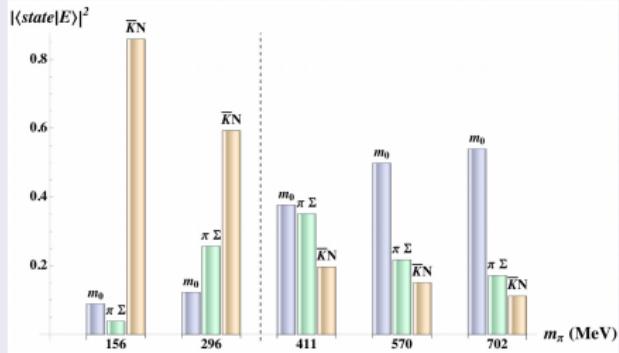
- $\Lambda(1405)$  - dynamically generated by meson-baryon interactions?

[J.C. Nacher, E. Oset, H. Toki, A. Ramos, U.G.](#)

[Meissner, Nucl. Phys. A 725 \(2003\) 181](#)

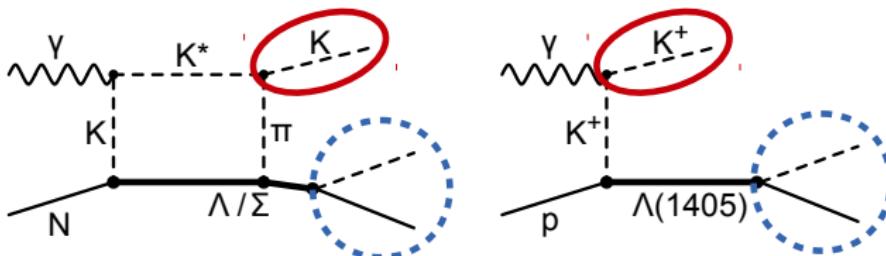
- LQCD calculations: [J.M.M Hall et al., Phys.](#)

[Rev. Lett. 114 \(2015\) 132002](#)



# Strangeness photoproduction - physics motivation

- Hadronic molecules - predict new  $Y^*$  states, eg  $\Sigma^*$  close to  $\Sigma(1385)$  [Jia-Jun Wu, S. Dulat & B. S. Zou, Phys. Rev. D 80 \(2009\) 017503](#)
- BGO-OD measurements at extreme forward angles - reaction dynamics at very low momentum exchange ( $t$ -channel)



# Strangeness photoproduction - physics motivation

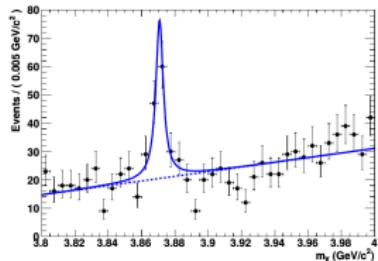
- Hadronic molecules - predict new  $Y^*$  states, eg  $\Sigma^*$  close to  $\Sigma(1385)$  [Jia-Jun Wu, S. Dulat & B. S. Zou, Phys. Rev. D 80 \(2009\) 017503](#)
- BGO-OD measurements at extreme forward angles - reaction dynamics at very low momentum exchange ( $t$ -channel)

## Evidence of hadronic molecules in the charmed sector

Is  $X(3872)$  a molecular  $D^0\bar{D}^{0*}$  state?

N.A. Törnqvist, Phys. Lett. B590, 209 (2004)

Close to  $D^0\bar{D}^{0*}$  threshold



B. Aubert et al (BARBAR Collaboration), Phys. Rev. D77

111101 (2008)

Tom Jude (University of Bonn)

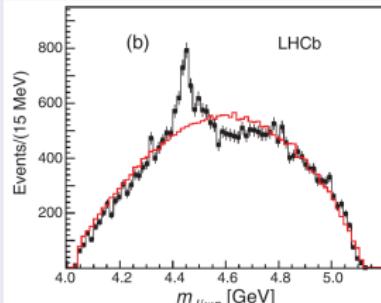
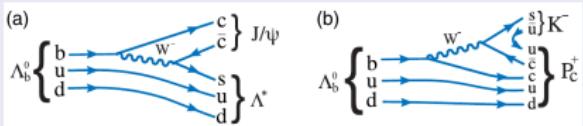
Open and hidden strangeness at ELSA

26.09.16 - 27.09.16

6 / 17

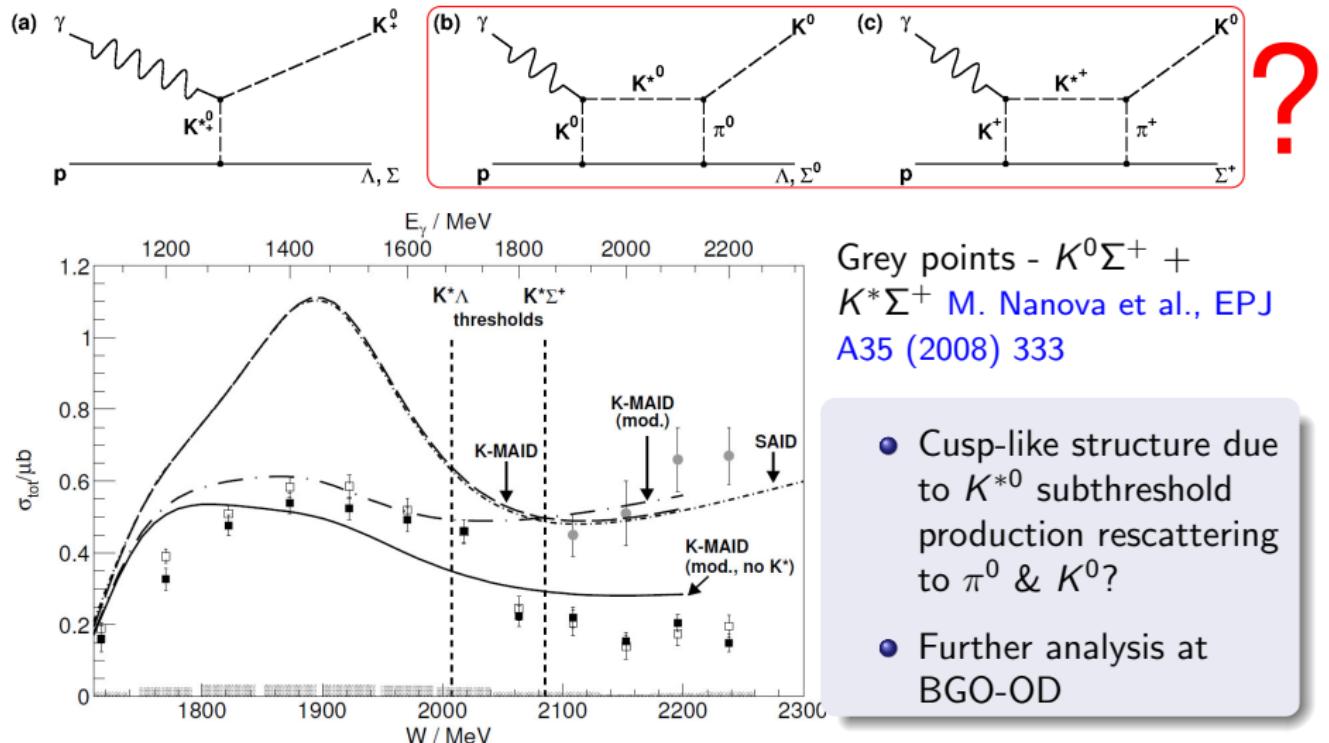
## Pentaquark candidates at LHCb

R. Aaij et al, PRL 115, 072001 (2015)



# $\gamma p \rightarrow K^0 \Sigma^+ d\sigma/d\Omega$ at CBELSA/TAPS

R. Ewald *et al.*, Phys. Lett. B 713 (2012) 180 (CBELSA/TAPS Collaboration)

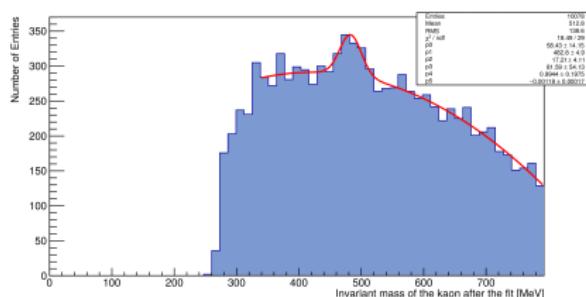


# Preliminary identification of $K^0\Sigma^+$ with BGO-OD

- The 1st beam asymmetry measurement R. Ewald *et.al*, PLB 738 (2014) 268 (CBELSA/TAPS Collaboration)
- Access  $\gamma p \rightarrow K^0\Sigma^+$  via different decay modes at BGO-OD:

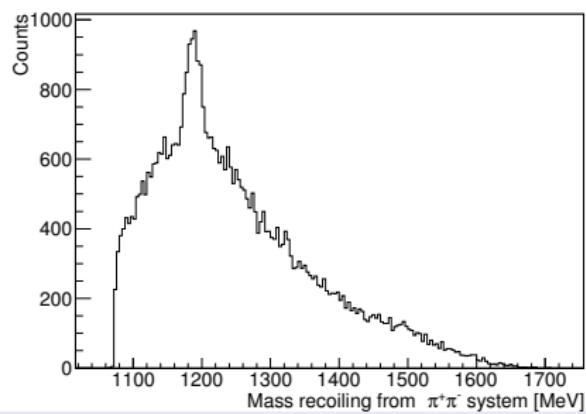
$$K^0 \rightarrow \pi^0\pi^0, \Sigma^+ \rightarrow n\pi^+$$

- S. Alef, preliminary analysis of real data



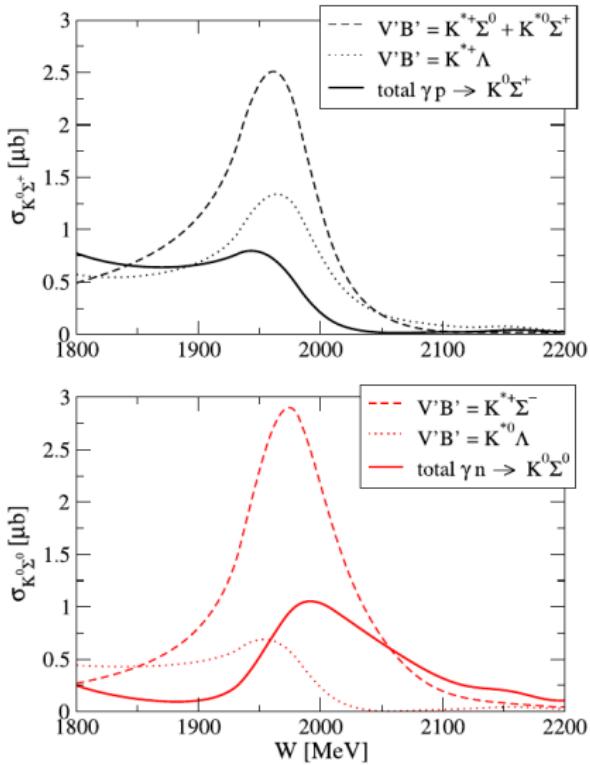
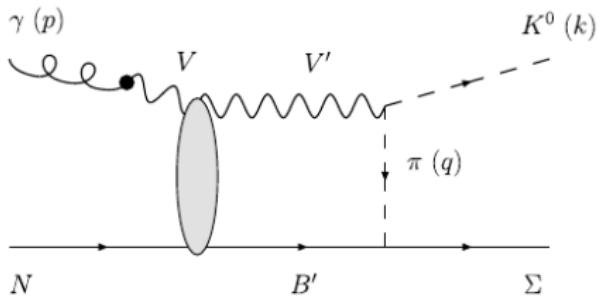
$$K^0 \rightarrow \pi^+\pi^-, \Sigma^+ \rightarrow p\pi^0$$

- B. Reitz, preliminary analysis using simulated data



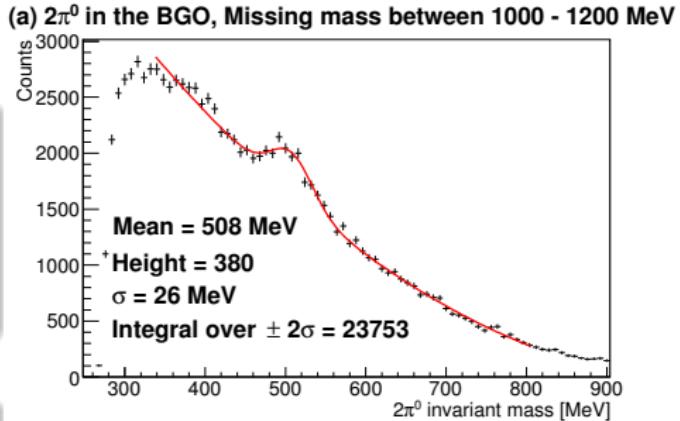
# $K^0$ photoproduction off the neutron

A. Ramos and E. Oset, Phys. Lett.  
**B 727**, (2013) 287 *The role of vector-baryon channels and resonances in the  $\gamma p \rightarrow K^0 \Sigma^+$  and  $\gamma n \rightarrow K^0 \Sigma^0$  reactions near the  $K^* \Lambda$  threshold*

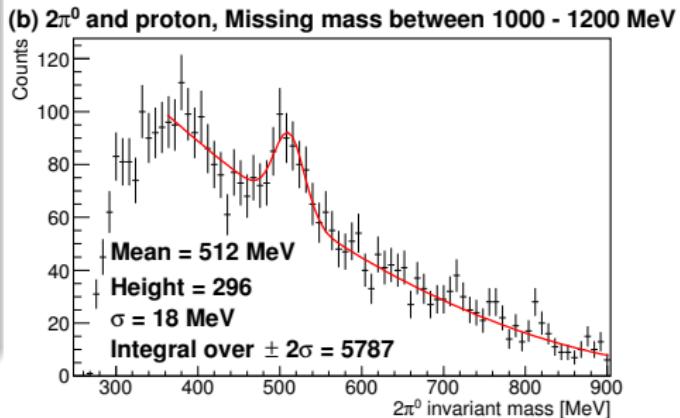


# Test beam time data (Deuterium target), 2 days

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

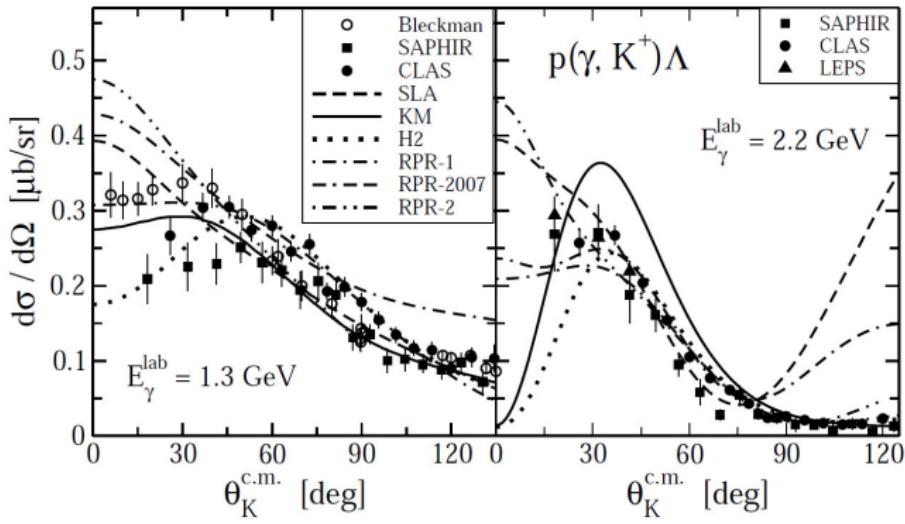


- $K^0 \rightarrow 2\pi^0$  reconstructed in the BGO
- Proton in the Forward spectrometer & select missing  $\pi^0$  mass from  $\Sigma^+ \rightarrow p\pi^0$
- Total neutral particles < 6
- Total charged particles < 3



# $K^+$ at forward angles - motivation

- Higher lying  $Y^*$  states at low  $t$  - complementary to recent  $\Lambda(1405)$  measurements at CLAS (K. Moriya *et al.*, Phys. Rev. **C88**, 045201 (2013))
- $\gamma p \rightarrow K^+ \Lambda$  - Extreme forward angles - Constrain dominant  $t$ -channel mechanisms, & important for hypernuclei electroproduction



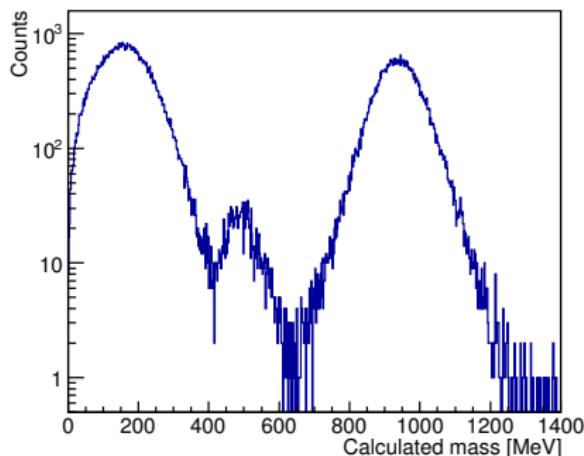
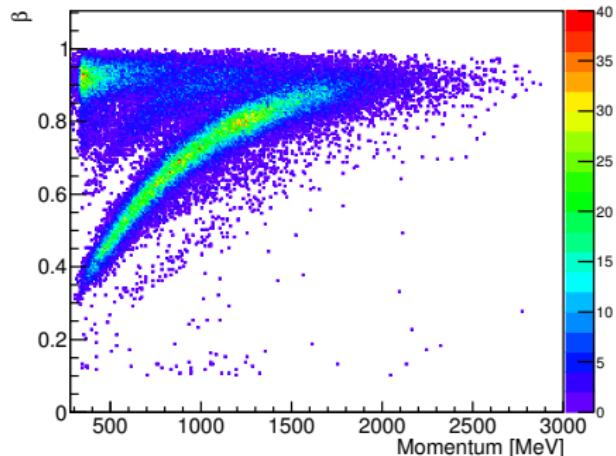
Bydzovsky and D. Skoupil,  
arXiv:1211.2684v1 (2012)  
Proceedings of SNP12

# $K^+$ identification in the forward spectrometer

- $\beta$  & momenta measured in the forward spectrometer

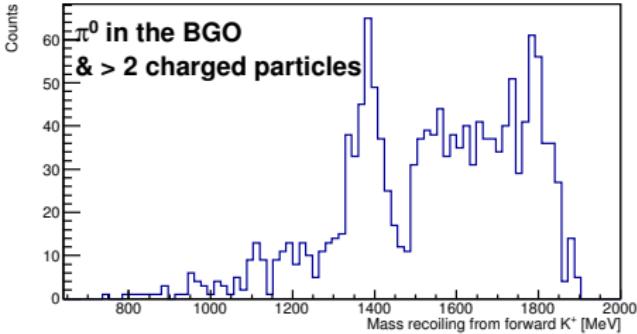
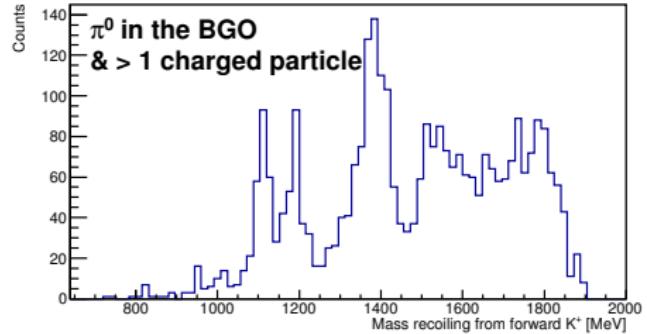
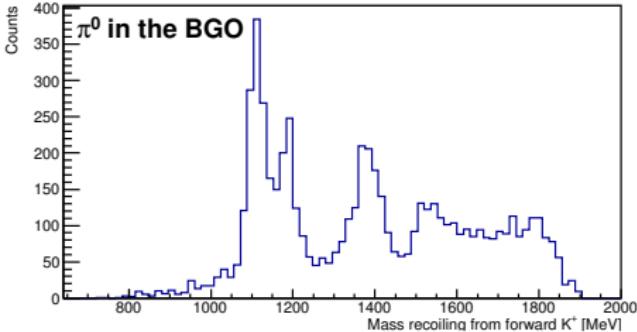
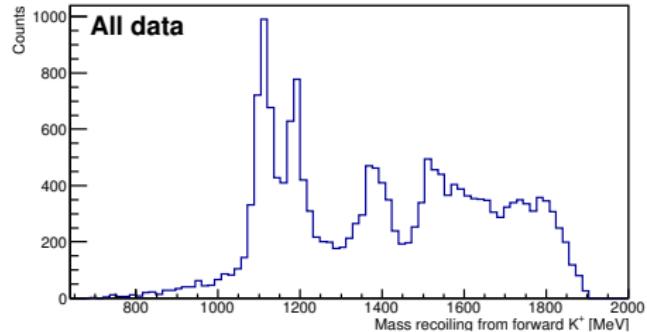
To enhance  $K^+$  signal

- $\pi^0 \rightarrow \gamma\gamma$  mass reconstructed in the BGO
- BGO total energy deposition < 250 MeV
- Beam energies above  $K^+\Lambda$  threshold



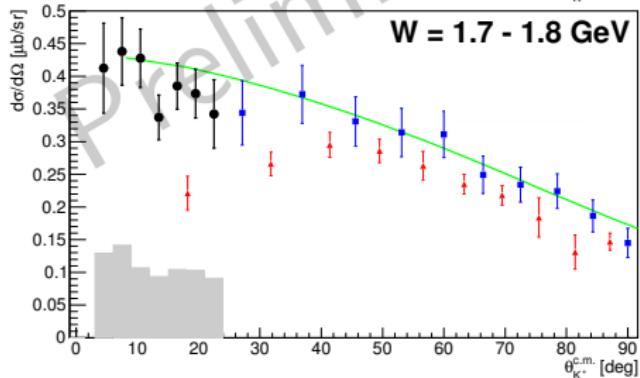
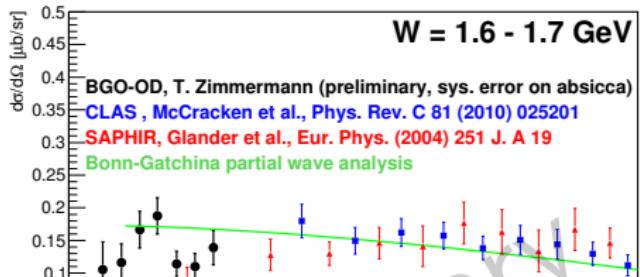
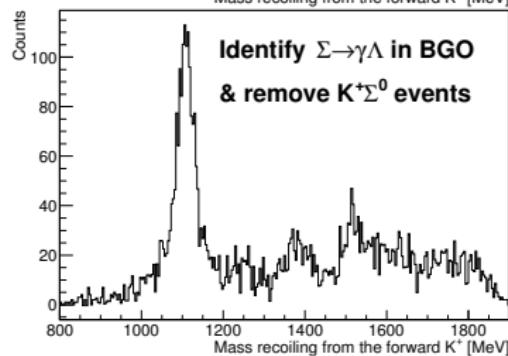
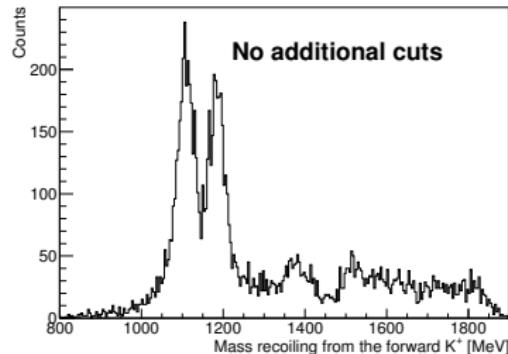
# Mass recoiling from $K^+$ in the forward spectrometer

- 11 days of continuous data (approx. 1/3 of available data)
- Clear peaks of higher lying hyperon states



# Very forward $K^+\Lambda$ $d\sigma/d\Omega$ (preliminary)

T. Zimmermann, preliminary data, PhD thesis work



# $\gamma p \rightarrow K^+ \Sigma^0$ with no initial particle identification

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

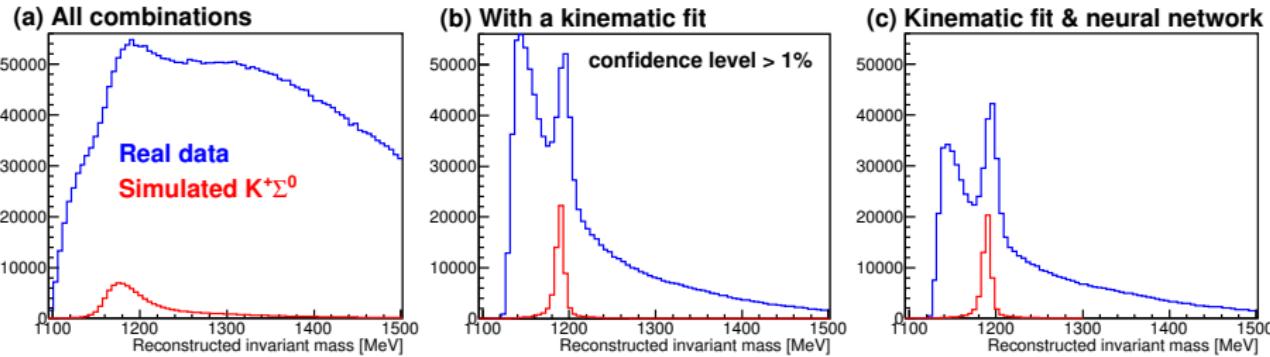
- $K^+ & \Lambda \rightarrow p\pi^-$  over large acceptance region ( $1^0 < \theta < 155^0$ )
- $\Sigma^0$  decay photon in the BGO ( $\Sigma^0 \rightarrow \Lambda\gamma$ )
- Technique used for higher lying  $Y^*$  states (eg  $\Lambda(1405) \rightarrow \pi^0 \Sigma^0$ )

## Reconstructing the $\Sigma^0$ invariant mass

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

(b) Kinematic fit & confidence level cut

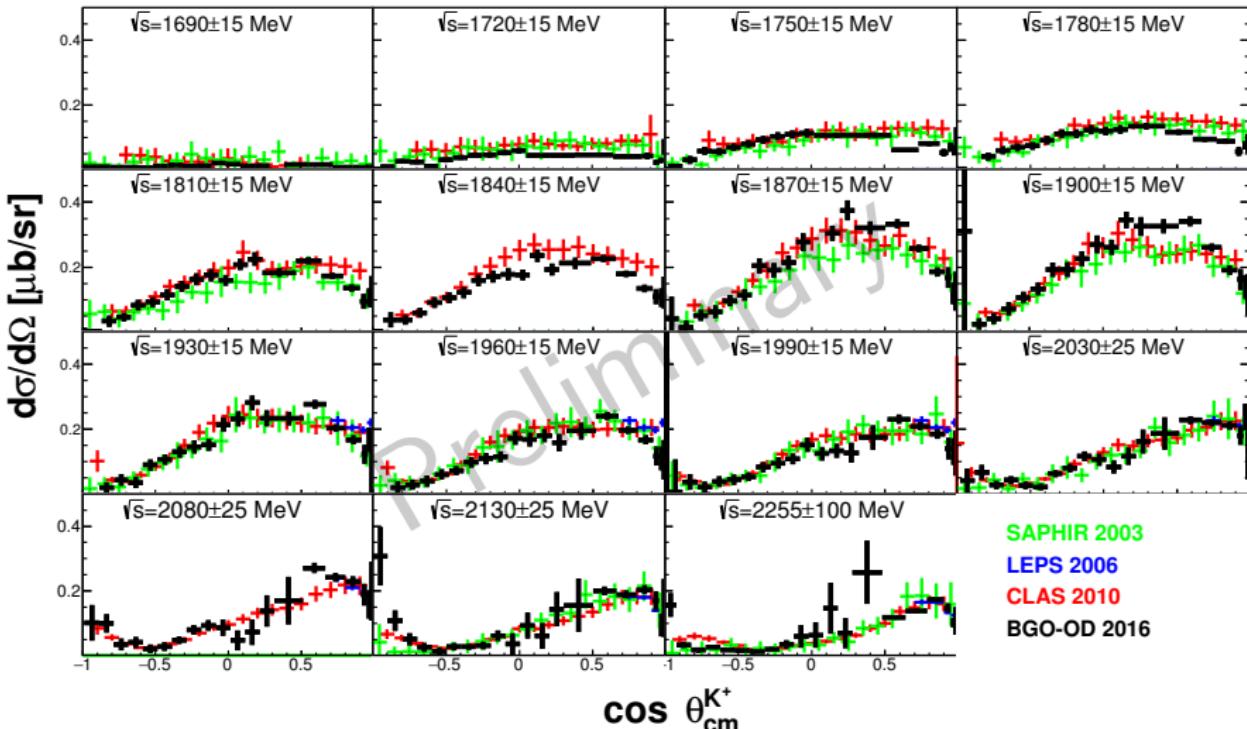
(c) Neural network to suppress background



# $\gamma p \rightarrow K^+ \Sigma^0$ with no initial particle Identification

BGO-OD (preliminary), CLAS: B. Dey, et al., Phys. Rev. C82 025202 (2010)

SAPHIR: K.-H. Glander et al., Eur. Phys. J. A19 251 (2004), LEPS: M. Sumihama et al., Phys. Rev. C73 035214 (2006)



# Summary

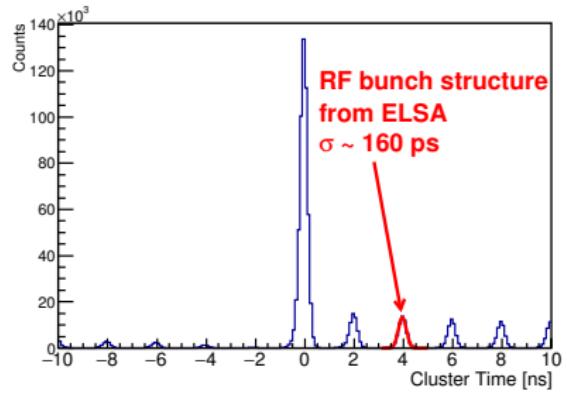
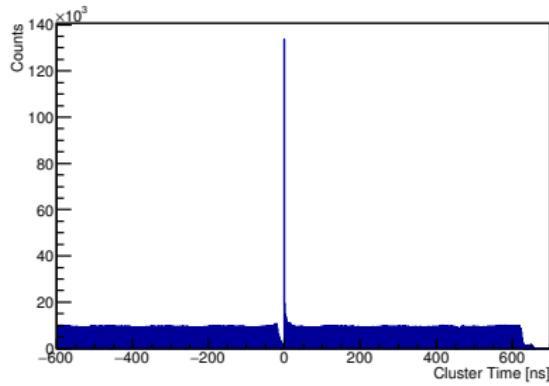
- BGO-OD - Charged particle ID at forward angles & mixed charged final state reconstruction
- Associated strangeness photoproduction & low momentum transfer processes
- $K^0\Sigma^+$  &  $K^0\Lambda$  - study cusp-like structure in  $K^0\Sigma^+$  cross section
- $K^+\Lambda$  &  $K^+\Sigma^0$   $d\sigma/d\Omega$  at extremely forward angles
- Identification of higher lying  $Y^*$  states - analysis on the way!

# Collaborating Institutions

- Physikalisches Institut, Bonn, Germany
- INFN sezione di Pavia, Pavia, Italy
- INFN - ISS, Rome, Italy
- The University of Edinburgh, Edinburgh, UK
- INFN sezione di Roma, Rome, Italy
- INFN Roma Tor Vergata, Rome, Italy
- INFN sezione di Roma, Rome, Italy
- INFN - LNF, Frascati (Rome), Italy
- INFN sezione di Torino, Torino, Italy
- INFN Roma Tor Vergata, Rome, Italy
- The University of Torino, Torino, Italy
- INFN sezione di Catania, Catania, Italy
- Helmholtz-Institut für Strahlen und Kernphysik, Bonn, Germany
- Justus-Liebig-Universität Giessen, Germany
- Institut für Physik, Basel, Switzerland
- The University of Messina,Messina, Italy
- The University of Rome "Tor Vergata", Rome, Italy
- National Science Center Kharkov Institute of Physics and Technology, Kharkov, Ukraine
- Russian Academy of Sciences Institute for Nuclear Research, Moscow, Russia
- Petersburg Nuclear Physics Institute, Gatchina, Russia

# Extra slides...

# Tagger timing

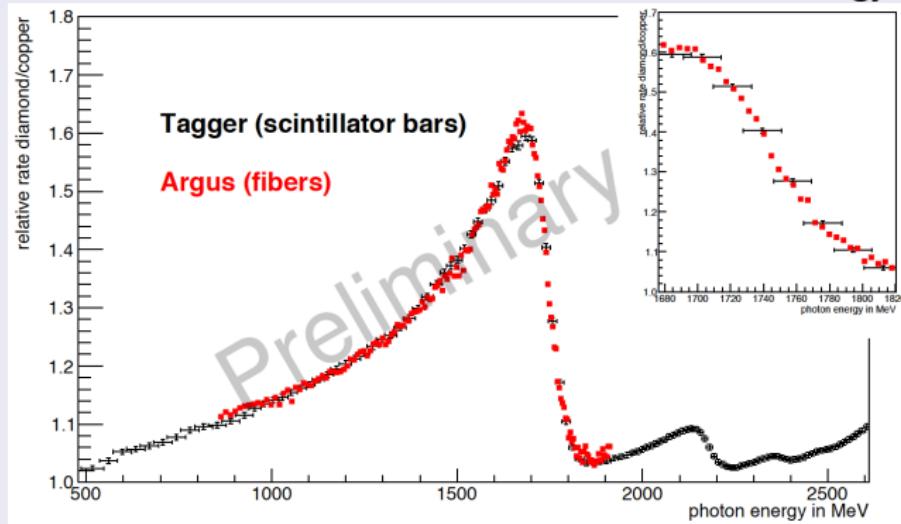


# Incident photon beam parameters

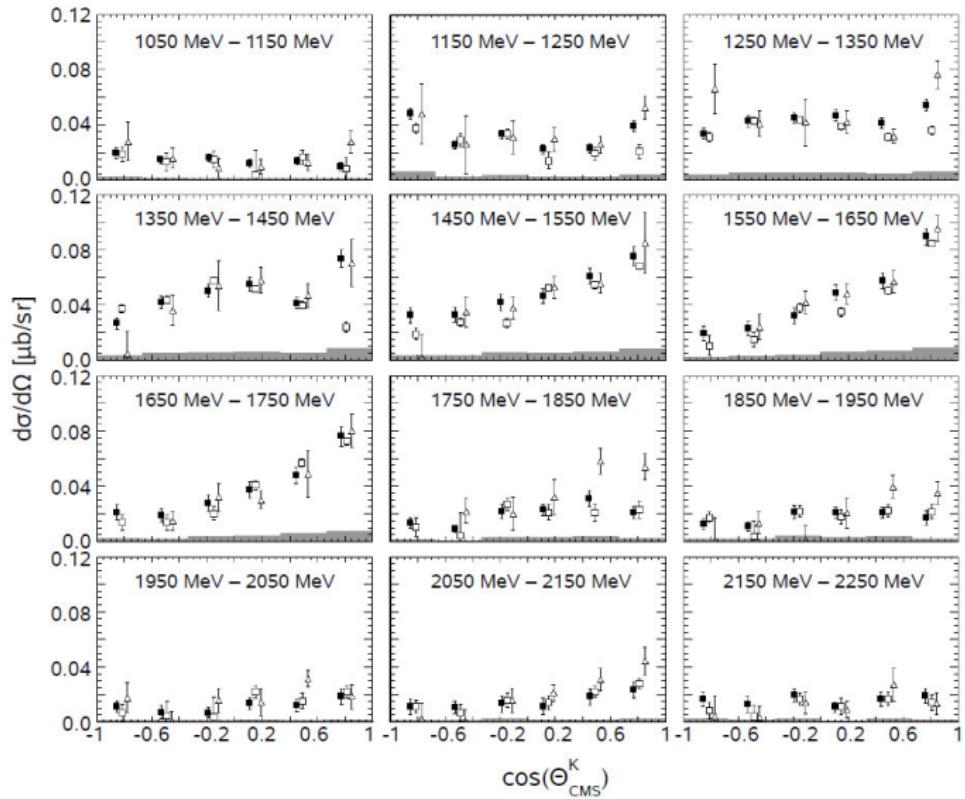
- Energy tagged  $\gamma$  beam  $\leq 3$  GeV, 250 ps time resolution
- Current  $\leq 2$  nA, 10 nA upgrade planned
- Circularly and linearly polarised  $\gamma$  beams available

## Coherent bremsstrahlung using a diamond radiator

30% polarisation at 1.8 GeV with an incident electron energy of 3.2 GeV

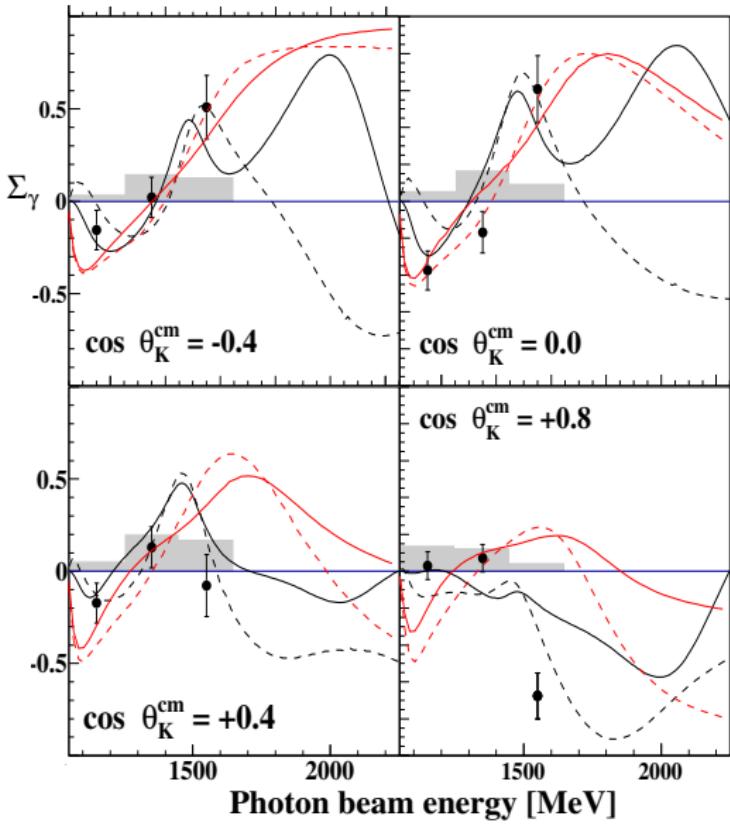


# $\gamma p \rightarrow K^0\Sigma^+ d\sigma/d\Omega$ at CBELSA/TAPS



# First $\gamma p \rightarrow K^0 \Sigma^+$ beam asymmetry, $\Sigma$ , data

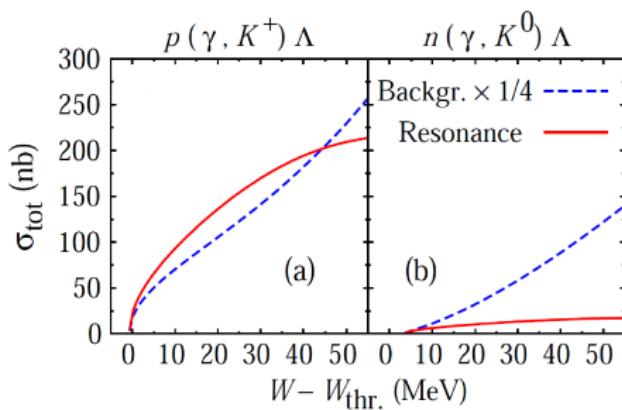
- The 1st beam asymmetry measurement R. Ewald et.al, PLB 738 (2014) 268 (CBELSA/TAPS Collaboration)



# $K^0$ photoproduction off the neutron

- T. Mart, Phys. Rev. C 83, 048203 (2011)
- Complimentary to  $\gamma p \rightarrow K^+ \Lambda$  measurements: relate hadronic coupling constant - predictions of  $n(\gamma, K^0) \Lambda$  cross section

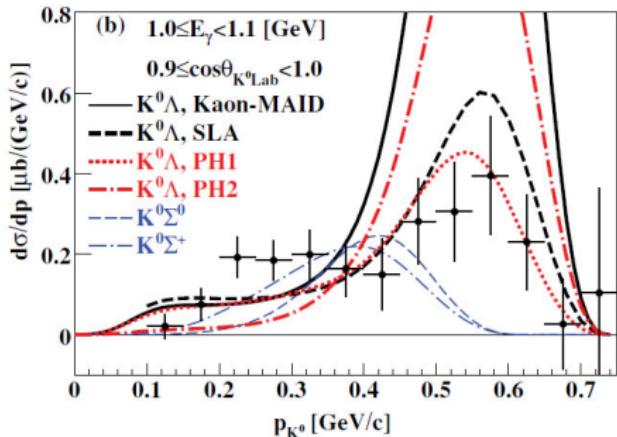
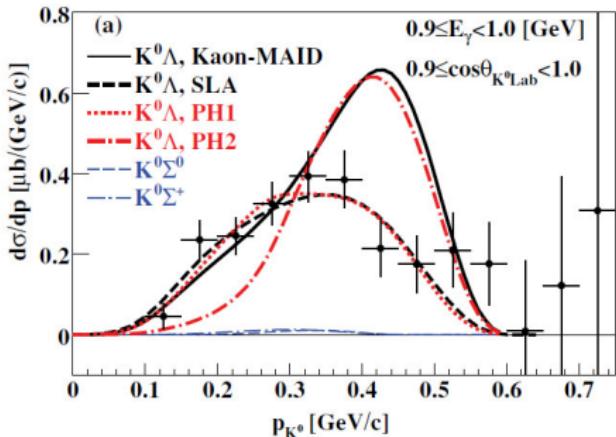
$$\begin{aligned} g_{K^+ \Lambda_p} &= g_{K^0 \Lambda_n} \\ g_{K^+ \Sigma_p^0} &= -g_{K^0 \Sigma_n^0} \\ g_{K^{*+} \Lambda_p}^{V,T} &= g_{K^{*0} \Lambda_n}^{V,T} \end{aligned}$$



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

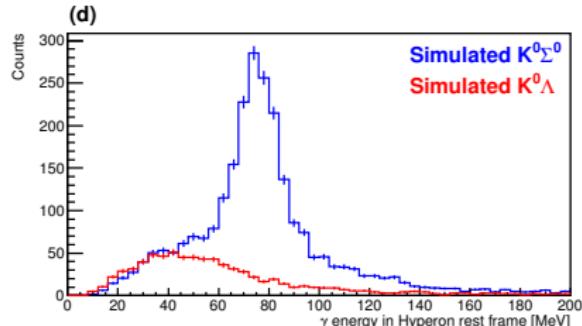
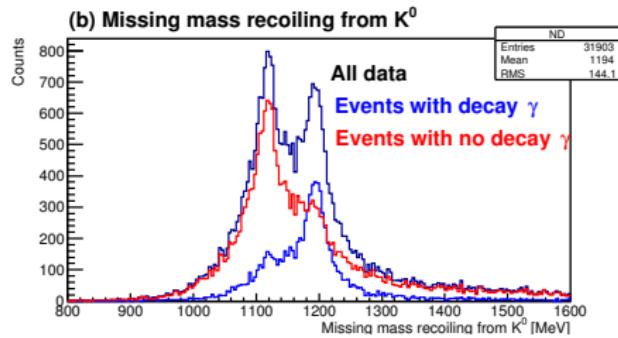
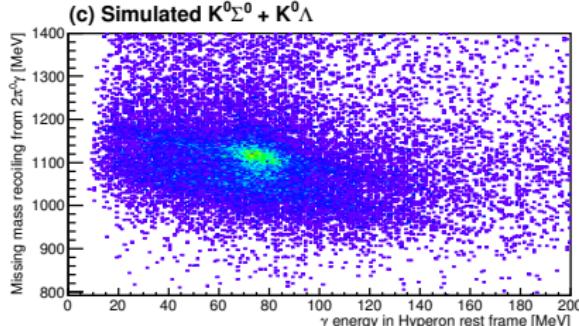
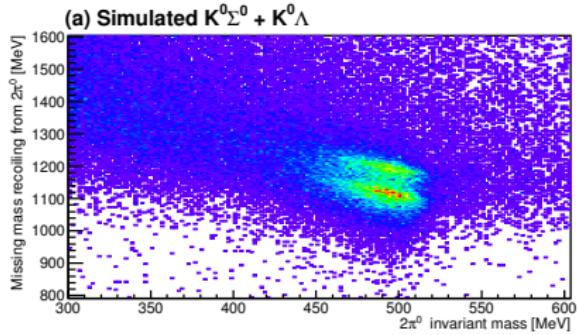
# $K^0$ photoproduction off the neutron

- No  $K^0$  t-channel exchange (but still  $K^*$ ) -  $s$  channel resonances more prominent
- Complementary to  $K^+\Lambda$  - relate hadronic coupling constants
- K. Tsukada et al, Phys. Rev. C 78, 014001 (2008)



# Separating $K^0\Lambda$ and $K^0\Sigma^0$ final states

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

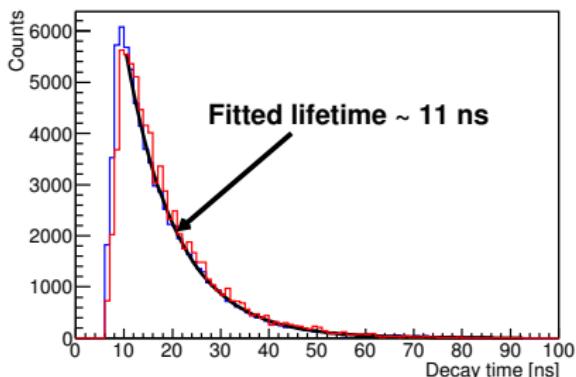
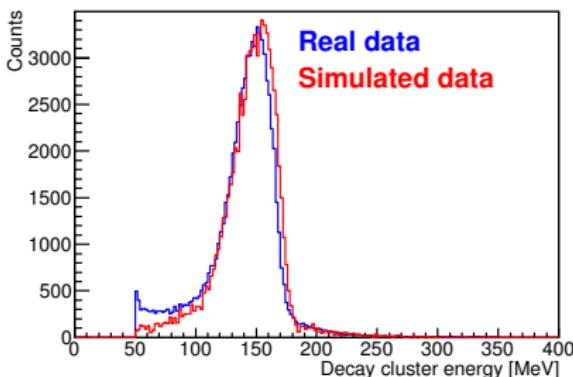
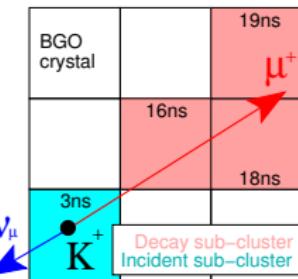


# $K^+$ identification in the BGO

- Time delayed,  $K^+$  weak decay within the crystals of the BGO ball
- T.C Jude, D.I. Glazier, D.P. Watts, et al, PLB, 735 (2014) 112

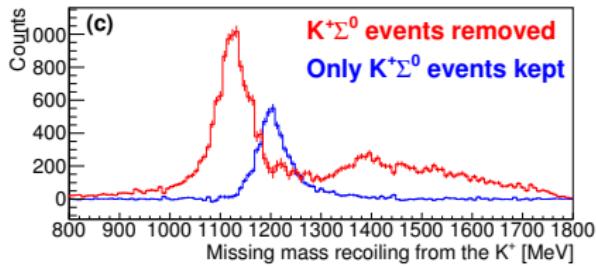
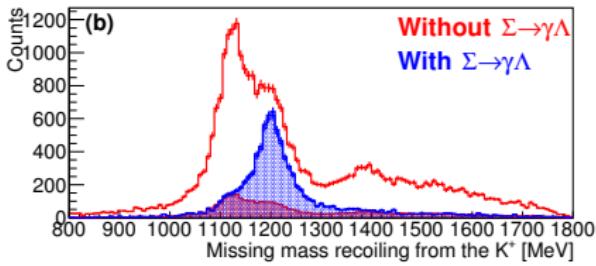
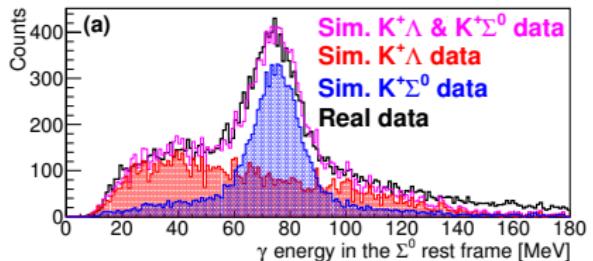
Lifetime 12 ns,  
2 main decay modes:

$$K^+ \rightarrow \mu^+ \nu_\mu$$
$$K^+ \rightarrow \pi^+ \pi^0$$



# $K^+$ identification in the BGO

- Identify photon from  $\Sigma^0 \rightarrow \Lambda\gamma$
- 77 MeV in  $\Sigma^0$  rest frame  
 $(M_{\Sigma^0} - M_\Lambda)$



# Reject $K^+$ punching through BGO crystals

Unreliable signal for energetic  $K^+$  which do decay close or in the PMT

