Strangeness photoproduction at the BGOOD experiment

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THEIA, 7th Oct 2020

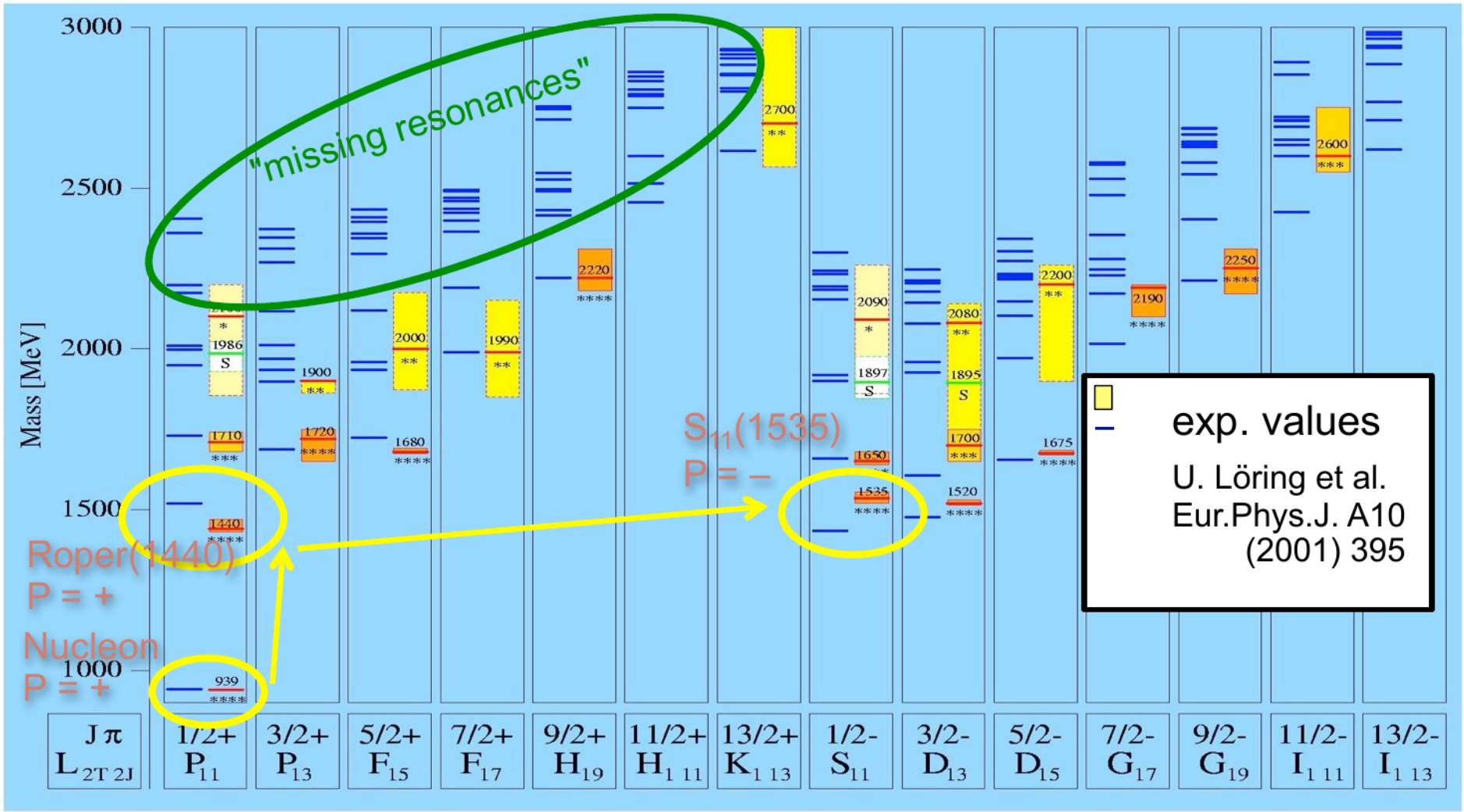
Supported by the DFG PN 388979758 & 405882627 & the EU Horizon 2020 research and innovation programme, grant agreement no. 824093

Strangeness photoproduction at the BGOOD experiment

1. Introduction & motivation - parallels in strange & charmed quark sectors?
2. The BGOOD experiment at ELSA, Bonn
3. Strangeness photoproduction:
   - K^0 photoproduction off neutron (deuterium) targets
   - Extreme forward cross sections for K^+Y and excited hyperons
   - New projects in strangeness photoproduction

Supported by the DFG PN 388979758 & 405882627 & the EU Horizon 2020 research and innovation programme, grant agreement no. 824093

1. Introduction - N^* spectrum: CQM vs. experiment



1. Introduction - Status of N^* spectroscopy

state	J^P	PDG status in 2010	PDG status in 2020(Nγ)
N(1860)	$5/2^+$	*	*
N(1875)	$3/2^-$		**
N(1880)	$1/2^+$		**
N(1895)	$1/2^-$		****
N(1900)	$3/2^+$	****	****
N(1990)	$7/2^+$	**	**
N(2000)	$5/2^+$	**	**
N(2060)	$5/2^-$		***
N(2100)	$1/2^+$	*	**
N(2120)	$3/2^-$		***
N(2190)	$7/2^-$	****	**
N(2220)	$9/2^+$	****	**
N(2250)	$9/2^-$	****	**

- Wealth of data from ELSA, MAMI, GRAAL & CLAS facilities
- Interpretation via sophisticated PWA, eg Bonn-Gatchina

- Much improved understanding of known resonances, but few new states observed
- Hadronic structure & relevant degrees of freedom -
  - 3 quark states only?
  - Molecule-like states, meson-baryon degrees of freedom?

Glozman & Riska, Phys. Rep. 268 (1996) 263, Garcia-Recio et al., PLB 582 (2004) 49, Lutz & Kolomeitsev, PLB 585 (2004) 243

- How would this manifest in reaction mechanisms & excitation spectra?

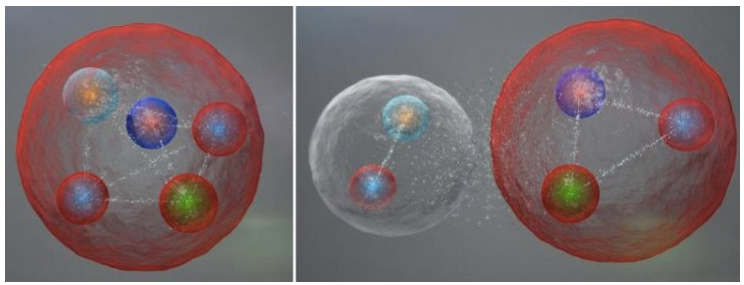
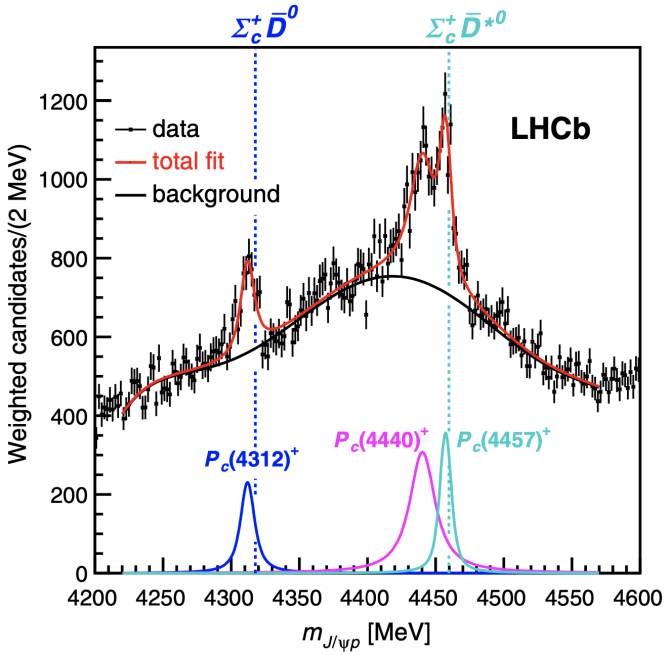


Fig from Nature 523, 267 (2015)

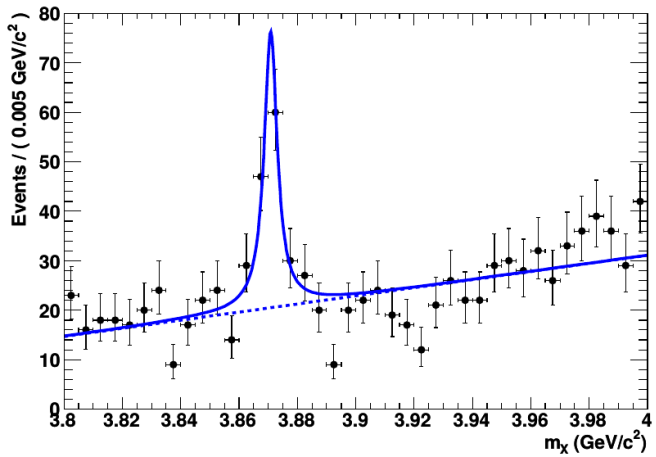
1. Motivation - Exotic phenomena in the charmed sector

- Pentaquark candidates at LHCb: $P_c(4312)^+$ $P_c(4380)^+ P_c(4440)^+$ $P_c(4457)^+$ R. Aaij et al, PRL 115, 072001 (2015) & PRL 112, 222001 (2019)



- Meson-baryon dynamically generated states in the charmed sector? eg J.-J. Wu, R. Molina, E. Oset, and B.S. Zou, PRL 105, 232001 (2010)

$X(3872) \to \pi^+\pi^- J/\psi$ - most cited paper from Belle, PRL91, 262001 (2003)



B. Aubert et al (BARBAR), PRD 77 111101 (2008)

- Very close to $D^0 \bar{D}^{0*}$ threshold
- J^{PC} verified: 1^{++} R. Aaij *et al.* (LHCb), PRL 110, 222001 (2013)
- $X(3872)$ - molecular $D^0 \bar{D}^{0*}$? eg, N.A. Törnqvist, PLB 590, 209 (2004)

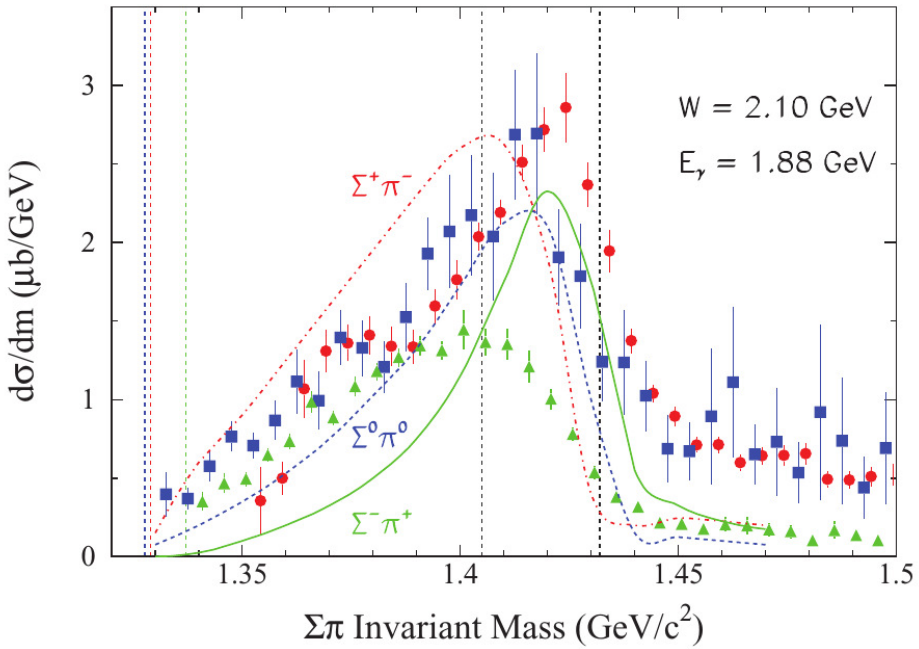
1. Motivation - Similarities in the *uds* sector?

Moving back to the “light” strange quark sector!

1. Motivation - Structure of the $\Lambda(1405)$

- Well established since the 1960's but peculiar features!
- Difficult to reconcile within a CQM
  - Mass too low compared to $N^*(1535)$
  - Large spin orbit splitting to $\Lambda(1520)$
- Lies between the $\pi\Sigma$ & $\bar{K}N$ thresholds
- Line shape (invariant mass) depends upon the decay mode ($\rightarrow \pi^0\Sigma^0$, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$)
- Distorted by interference of Isospin 0 & 1 amplitudes

K. Moriya *et al.* (CLAS) Phys. Rev. **C 87**, 035206 (2013)



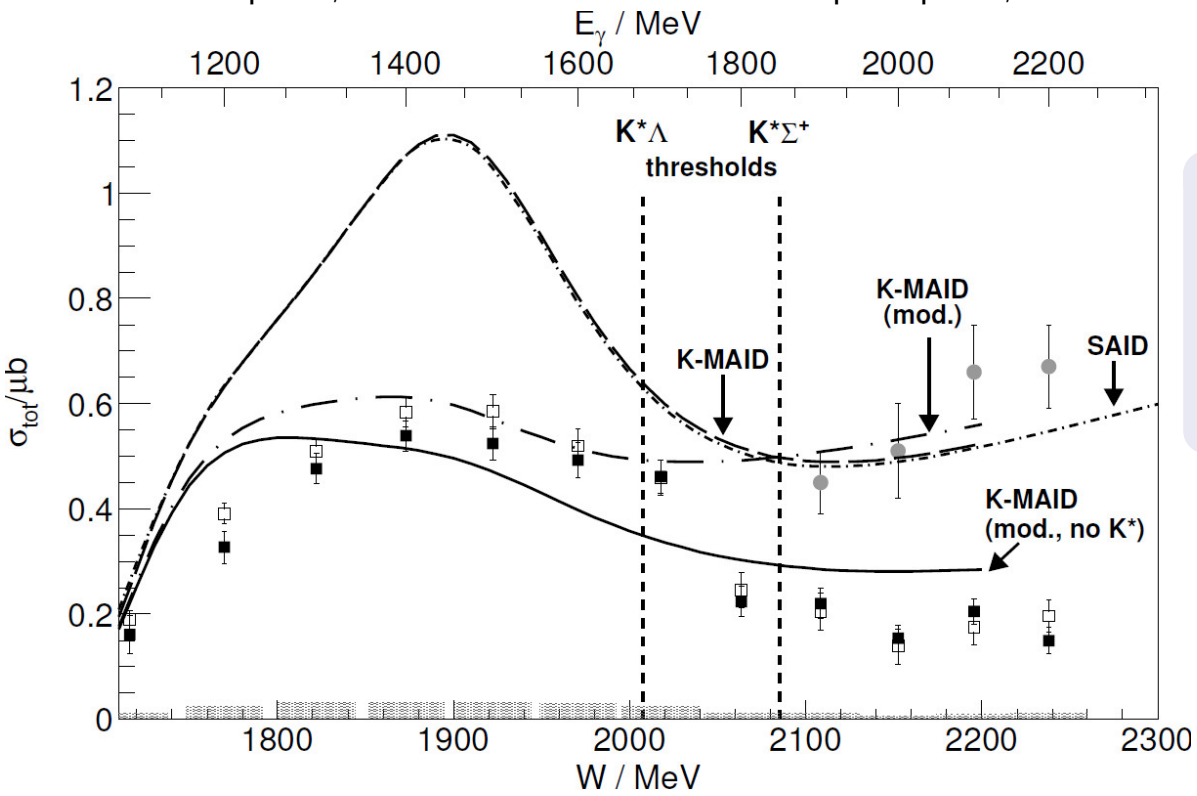
- $\Lambda(1405)$ - dynamically generated by meson-baryon interactions?

  J.C. Nacher, E. Oset, H. Toki, A. Ramos, U.G. Meissner, Nucl. Phys. A 725 (2003) 181
- LQCD: J.M.M Hall et al., PRL 114 (2015) 132002
- UχPT: R. Molina & M. Döring, Phys. Rev. D 94, 056010 & 079901 (2016)

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

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

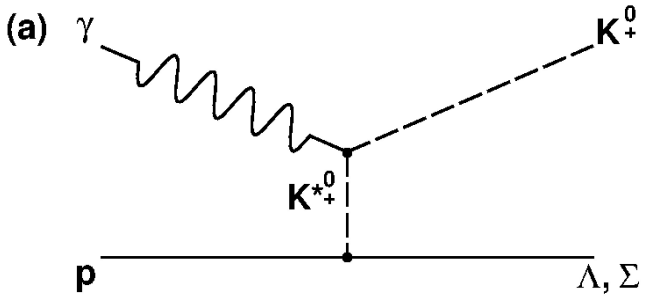
This data: Full squares, Previous CBELSA-TAPS data: open squares, Previous SAPHIR data: triangles (references therein)

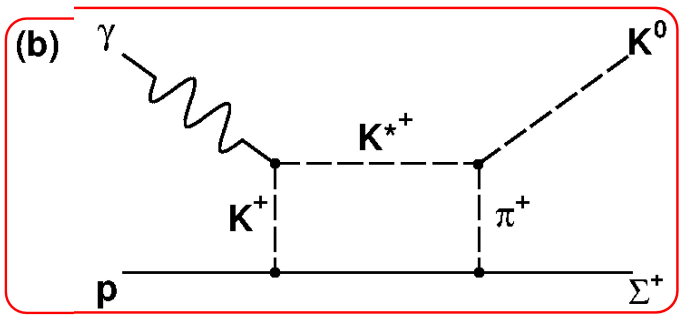


- Cusp-like structure due to K^{*0} subthreshold production rescattering to π^0 & K^0?

Grey points - $K^0\Sigma^+ + K^*\Sigma^+$

M. Nanova et al., EPJ A35, 333 (2008)



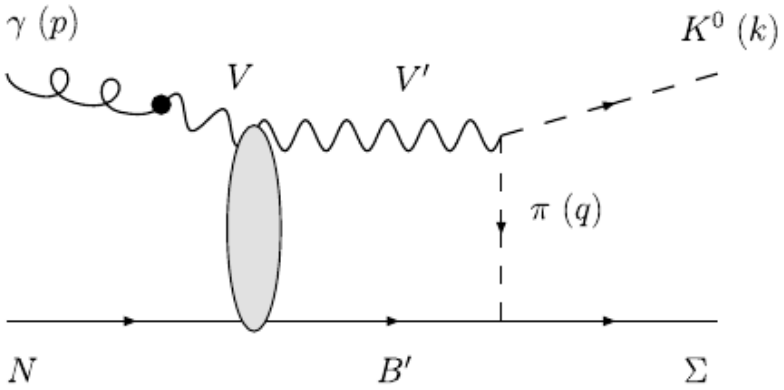


?

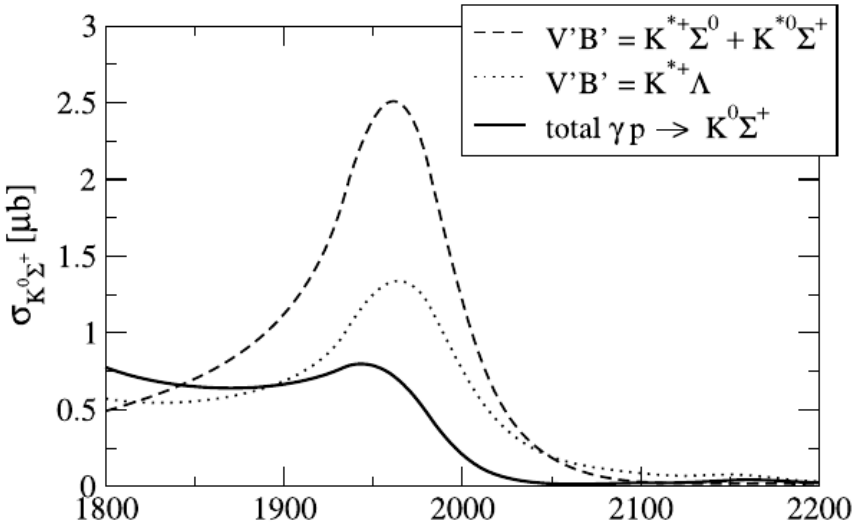
1. Motivation - K^0 photoproduction

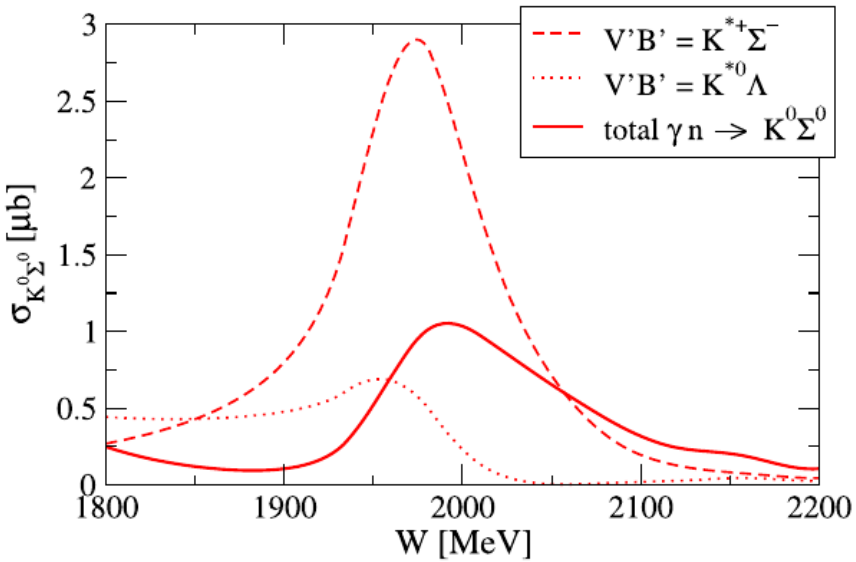
A. Ramos and E. Oset, Phys. Lett. **B 727**, (2013) 287 *The role of vector-baryon channels & resonances in the $\gamma p \to K^0\Sigma^+$ & $\gamma n \to K^0\Sigma^0$ reactions near the $K^*\Lambda$ threshold*

- The same model that predicted P_c states as meson-baryon dynamically generated!
- Cusp - destructive interference of dynamically generated N^* states
- Predict constructive interference & peak in $\gamma n \to K^0\Sigma^0$



Off the proton:



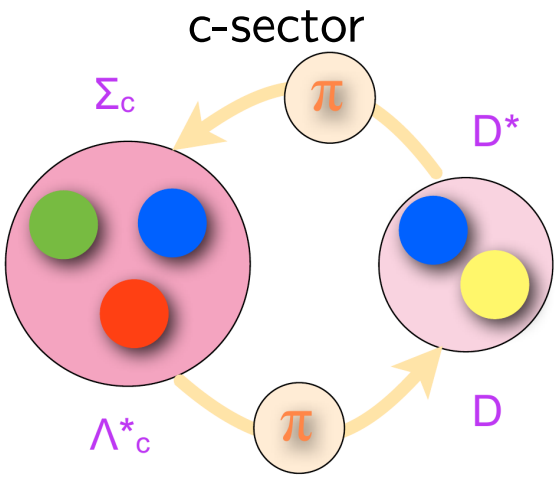


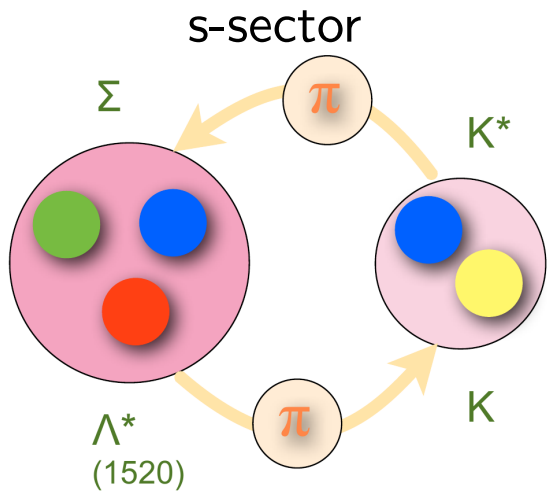
Off the neutron (bottom)

1. Motivation - Parallels between charmed & strange sectors

Table from H. Schmieden, private communication (2018)

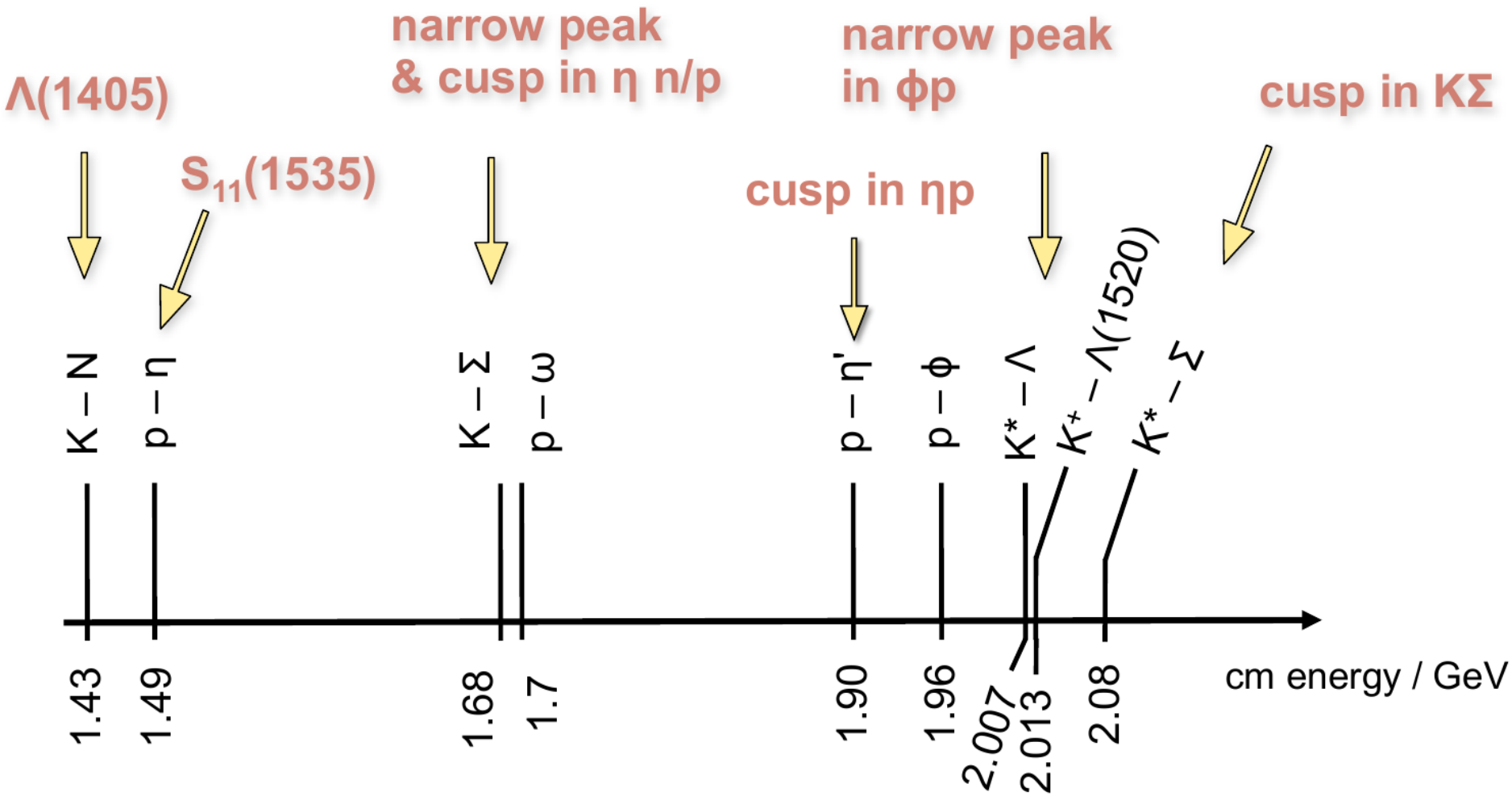
	Charmed-sector		Strange-sector	
	Meson	Baryons	Meson	Baryons
State(s)	$X(3872)$	$P_c^*(4380/4457)$	$f_1(1285)$	$N^*(2030/2080)$
π exchange transition	$D^{*0}\bar{D}^0/D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D}+\Sigma_c\bar{D}^*$	$K^*\bar{K}/K\bar{K}^*$	$\Lambda^*\bar{K}+\Sigma\bar{K}^*$
Quantum numbers	$J^{PC}=1^{++}$	$J^P=3/2^-$	$J^{PC}=1^{++}$	$J^P=3/2^-$
3-body threshold	$D^0\bar{D}^0\pi^0$	$\Sigma_c^+\bar{D}^0\pi^0$	$K\bar{K}\pi$	$\Sigma\bar{K}\pi^0$
Closed flavour thresh.	$J/\psi\omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp





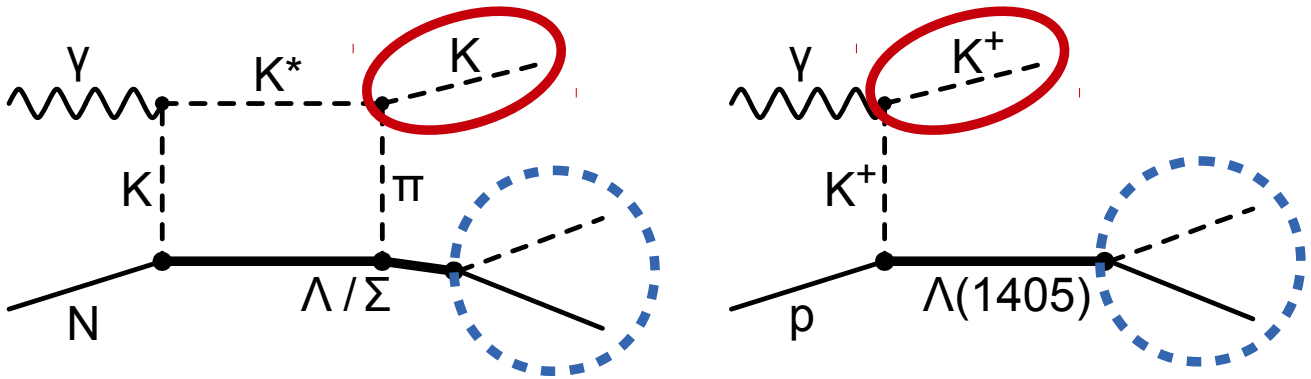
1. Motivation - Threshold dynamics

Figure from H. Schmieden, private communication (2018)



1. Motivation - 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).

BGOOD at the ELSA facility, Bonn

Strangeness photoproduction at the BGOOD experiment

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2. The Electron Stretcher Accelerator (ELSA)

A 3 stage e^- accelerator delivering continuous electron beams up to ~ 3.2 GeV

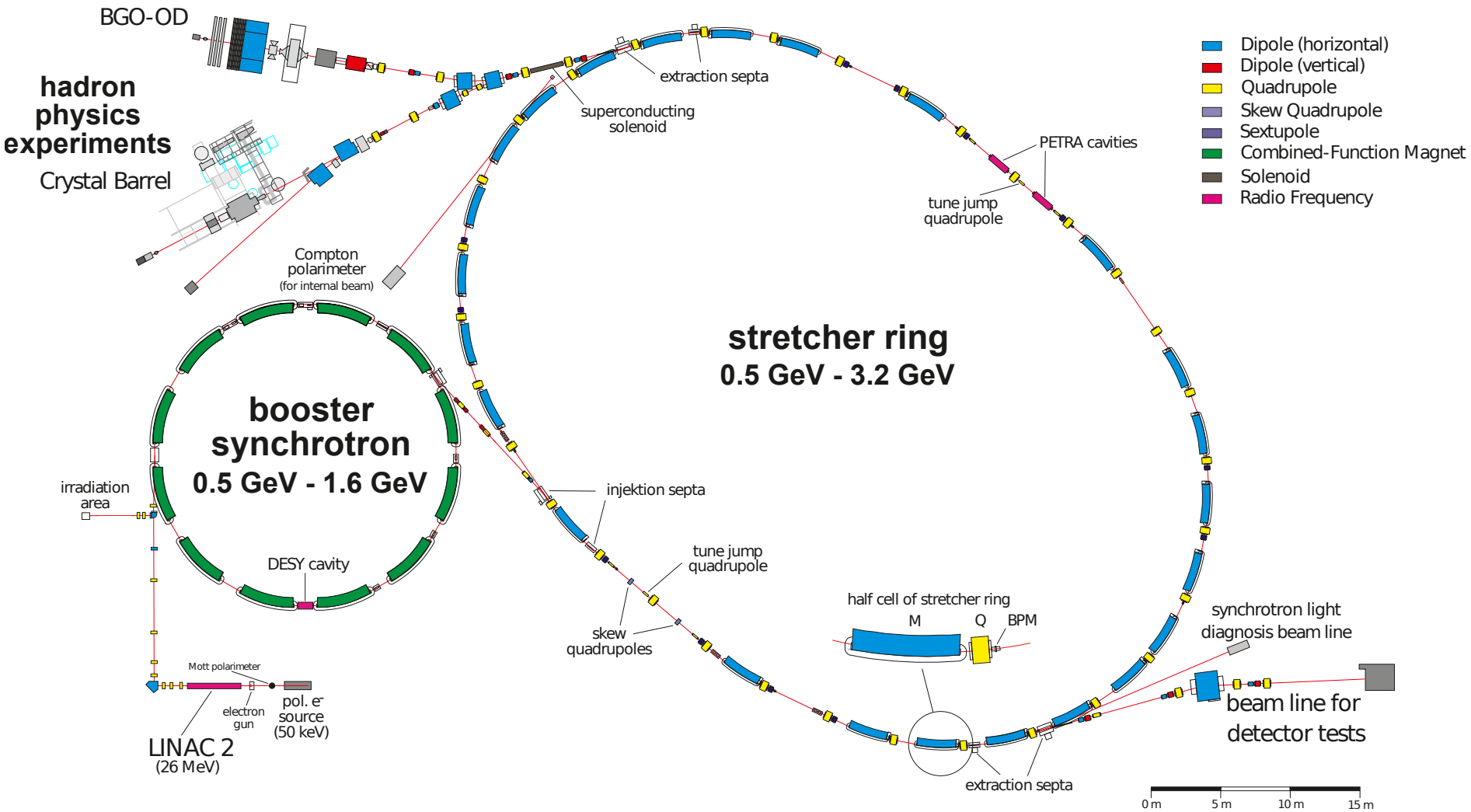

Figure adapted from W. Hillert *et al.*, EPJ Web Conf. 134, 05002 (2017)

2. The BGOOD experiment EPJA 56:104 (2020)

- The BGOOD *Technical Paper* published in EPJA
- And we made the front cover!

Eur. Phys. J. A (2020) 56:104
https://doi.org/10.1140/epja/s10050-020-00107-x

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Experimental Physics

The BGOOD experimental setup at ELSA

S. Alef[1], P. Bauer[1], D. Bayadilov[2,3], R. Beck[2], M. Becker[2], A. Bella[1], J. Bieling[2], S. Böse[2], A. Braghieri[4], K.-Th. Brinkmann[5], P. L. Cole[6], R. Di Salvo[7], D. Elsner[1], A. Fantini[7,8], O. Freyermuth[1], F. Frommberger[1], G. Gervino[9,10], F. Ghio[11,12], S. Goertz[1], A. Gridnev[3], E. Gutz[5], D. Hammann[1], J. Hannappel[1,19], W. Hillert[1,19], O. Jahn[1], R. Jahn[2], J. R. Johnstone[1], R. Joosten[2], T. C. Jude[1,a], H. Kalinowsky[2], V. Kleber[1,20], F. Klein[1], K. Kohl[1], K. Koop[2], N. Kozlenko[3], B. Krusche[13], A. Lapik[14], P. Levi Sandri[15,b], V. Lisin[14], I. Lopatin[3], G. Mandaglio[16,17], M. Manganaro[16,17,21], F. Messi[1,22], R. Messi[7,8], D. Moricciani[7], A. Mushkarenkov[14], V. Nedorezov[14], D. Novinskiy[3], P. Pedroni[4], A. Polonskiy[14], B.-E. Reitz[1], M. Romaniuk[7,18], T. Rostomyan[13], G. Scheluchin[1], H. Schmieden[1], A. Stugelev[3], V. Sumachev[3], V. Tarakanov[3], V. Vegna[1], D. Walther[2], H.-G. Zaunick[2,5], T. Zimmermann[1]

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[17] Dipartimento MIFT, Università degli Studi di Messina, Via F. S. D'Alcontres 31, 98166 Messina, Italy
[18] Institute for Nuclear Research of NASU, 03028 Kiev, Ukraine
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[20] *Present Address:* Forschungszentrum Jülich, Jülich, Germany
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EPJ A

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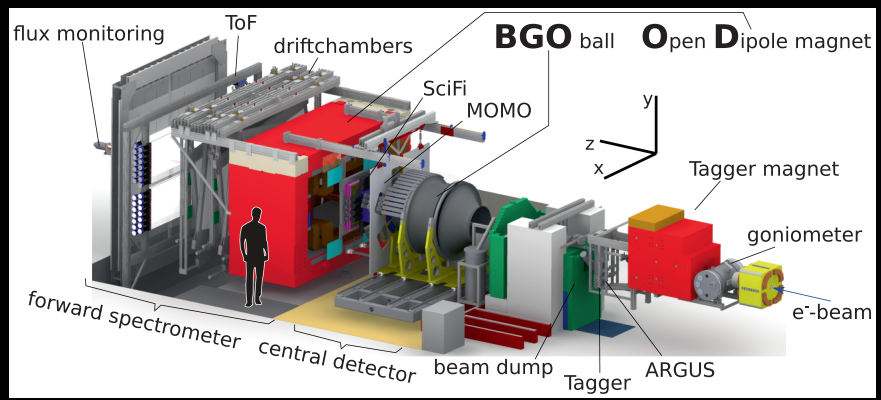
Hadrons and Nuclei



Overview of the BGOOD (BGOball Open Dipole magnet) experiment at the Elsa Facility dedicated to study meson photo-production

From: T. C. Jude and P. Levi Sandri et al. on "The BGOOD experimental setup at ELSA"

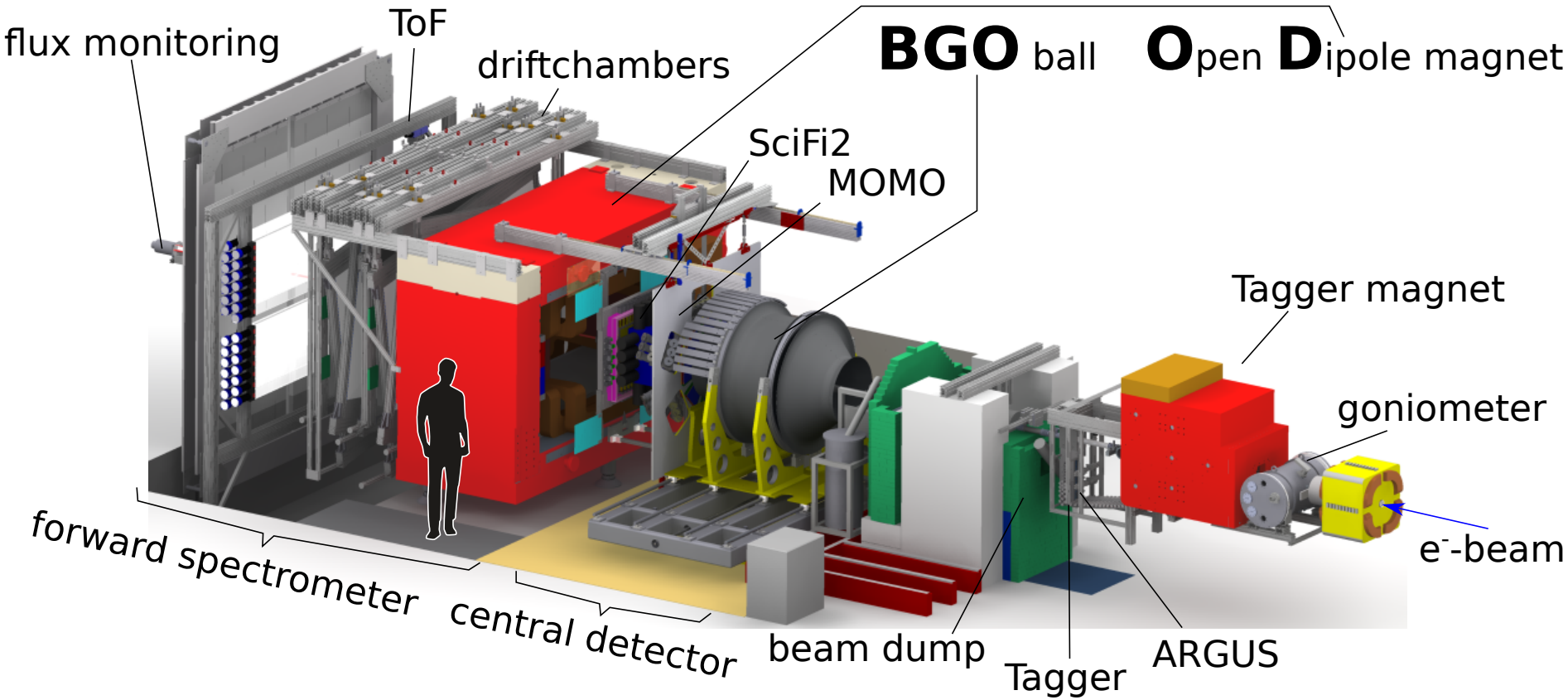
Società Italiana di Fisica

Springer

2. The BGOOD experiment at ELSA EPJA 56:104 (2020)

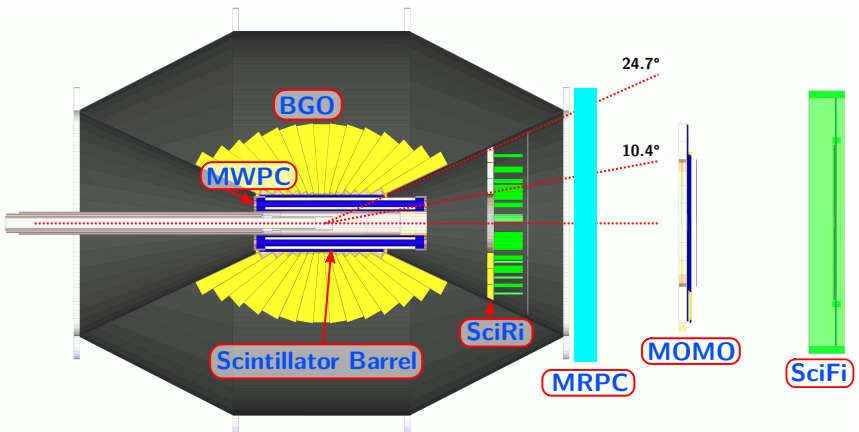
Spokespersons: H. Schmieden (Bonn) & P. Levi Sandri (Frascati)

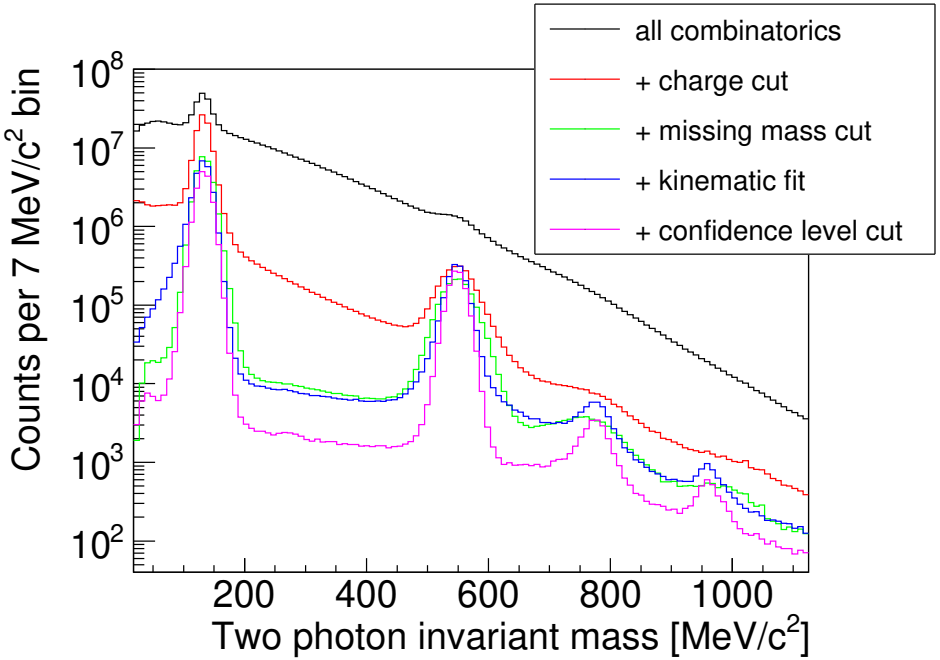
- BGO calorimeter (central region) & Forward Spectrometer combination
- High momentum resolution, excellent charged & neutral particle ID



2. The BGOOD experiment at ELSA - Central region

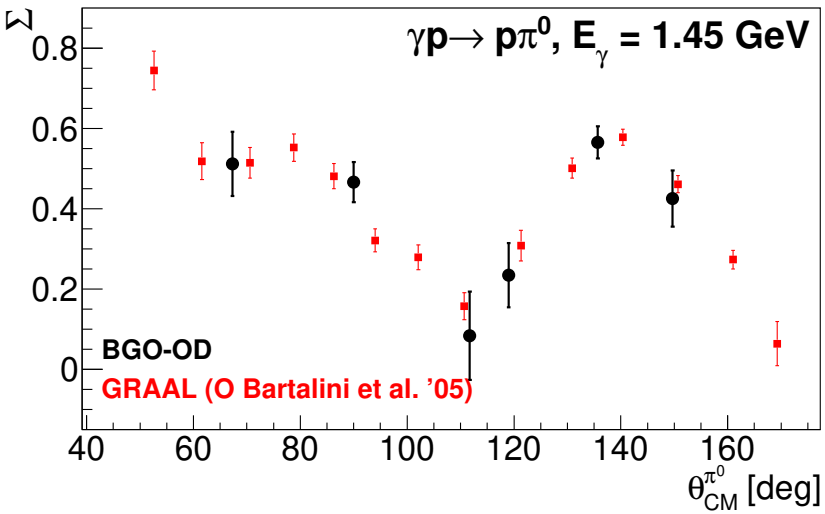
- BGO calorimeter (central region)
- Charged & neutral particle ID
- excellent time resolution ($\sim$ 2 ns) per BGO crystal

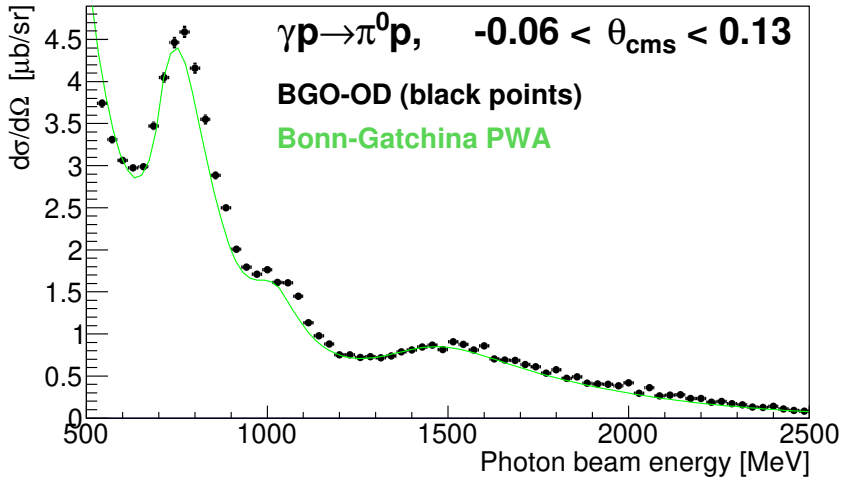


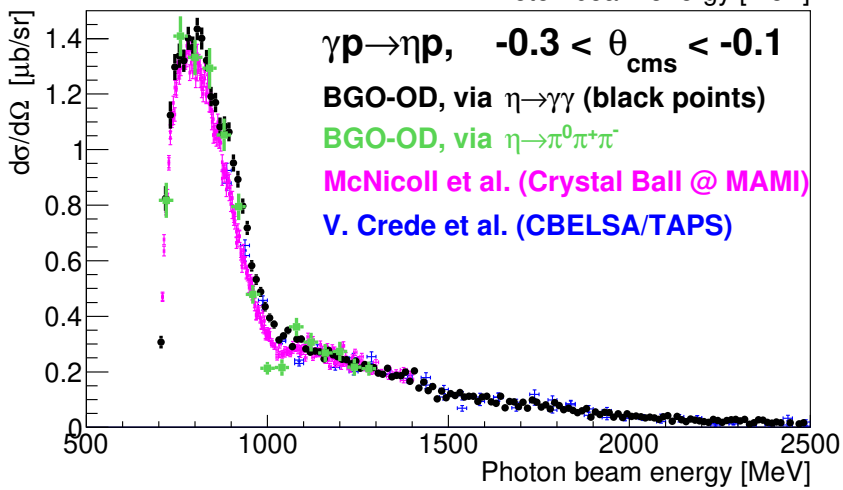


2. The BGOOD experiment at ELSA - Central region

- Accurate neutral meson photoproduction cross sections
- γ flux well understood ($\sim 3\%$)
- BGOOD - both neutral & mixed charged identification!
- Well understood degree of linear polarisation





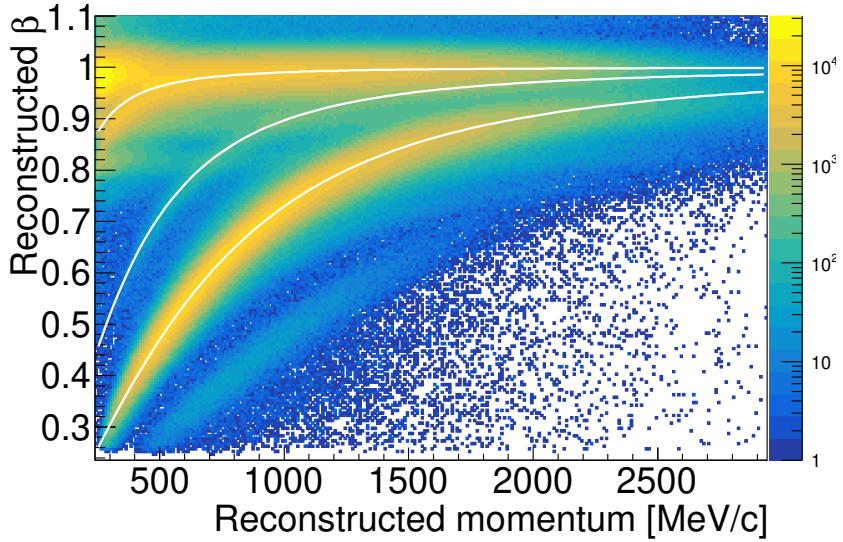


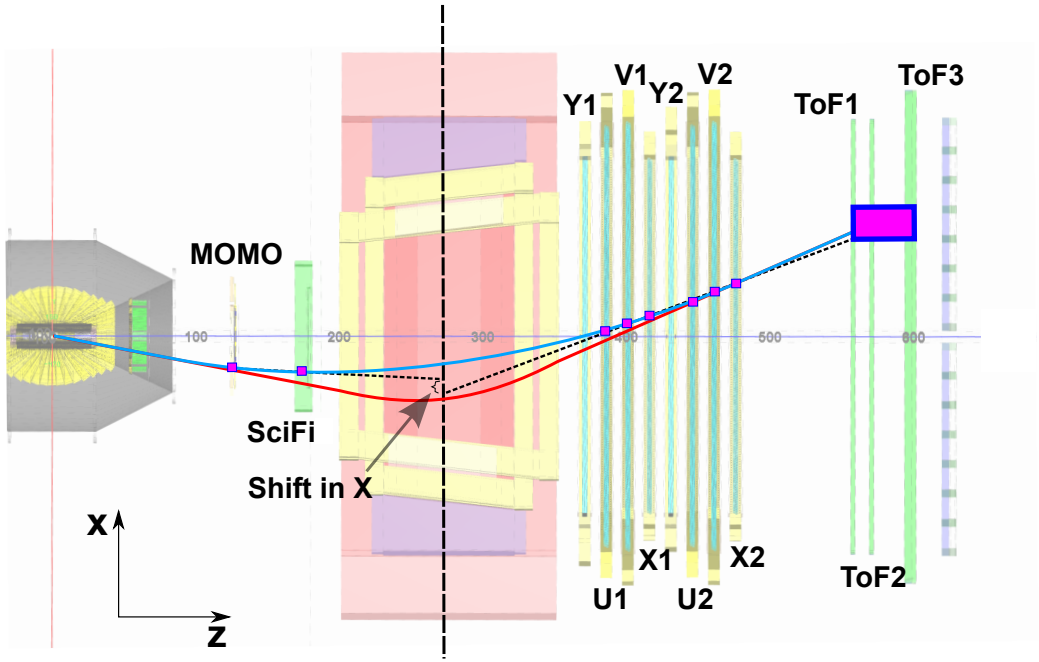
O. Bartalini *et al.*, EPJA **26**, 399 (2005)
Bn-Ga: A. V. Anisovich *et al.*, EPJA **25**, 427 (2005)
E. F. McNicoll *et al.*, PRC **82** 035208 (2010)

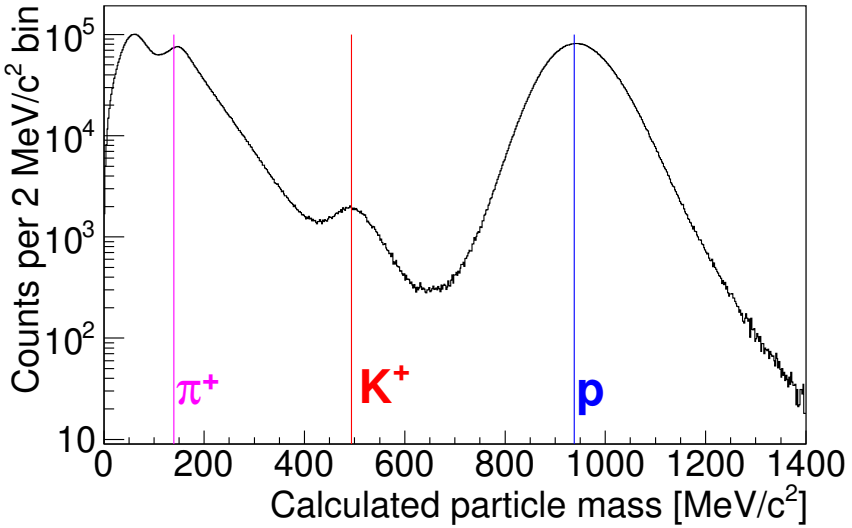
V. Crede *et al.*, PRC **80**, 055202 (2009)

2. BGOOD - Forward region

- Excellent charged particle identification & momentum reconstruction
- $1^\circ < \theta_{\mathrm{Lab}} < 12^\circ$
- $\Delta p/p \sim 3\,\%$
- $\Delta\theta_{\mathrm{lab}} \sim 0.5^\circ$

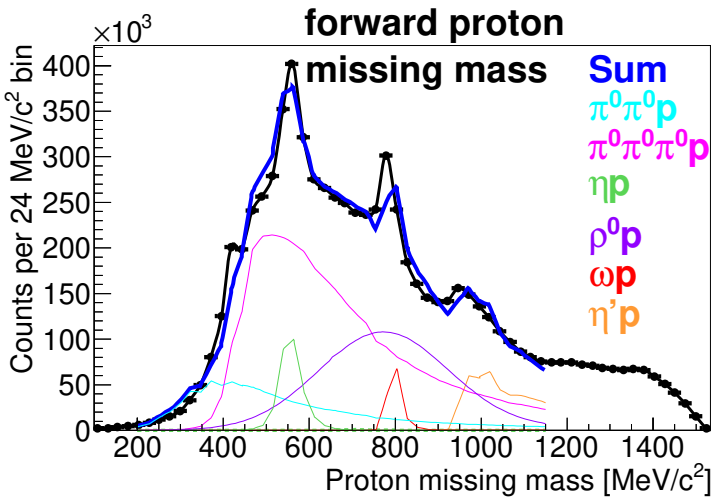


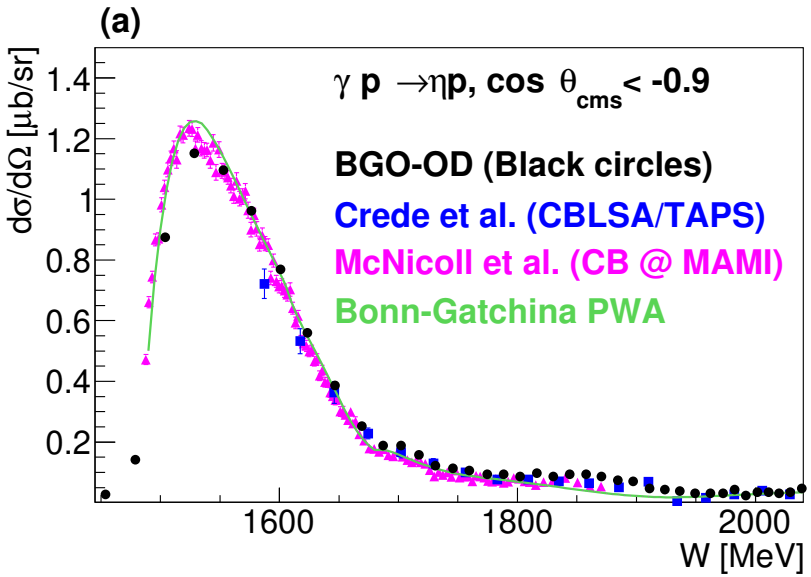


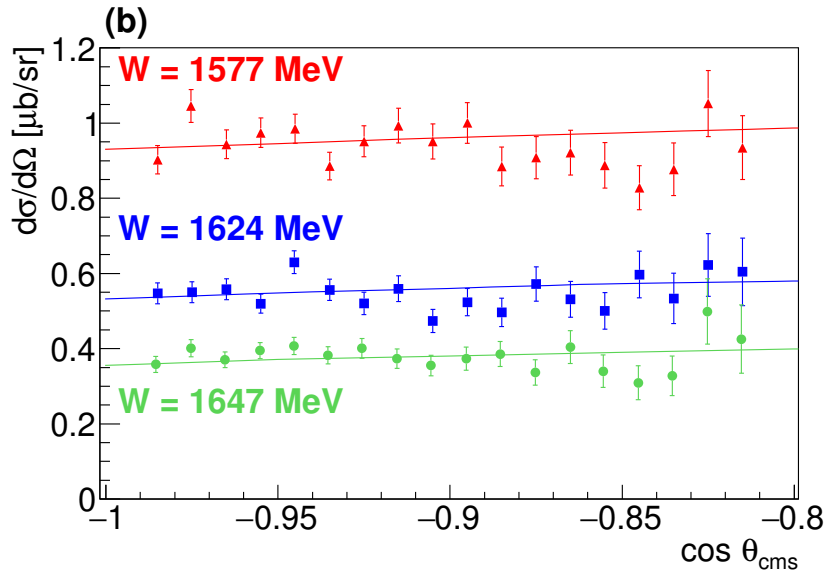


2. BGOOD - Forward region

- Accurate knowledge of detector & trigger efficiencies, momentum & β resolution
- Right: $\gamma p \to \eta p$ (proton in F.S) - excellent agreement with existing data







BnGa: A. V. Anisovich *et al.*, Eur. Phys. J. A**25**, 427 (2005)
E. F. McNicoll *et al.*, Phys. Rev. C**82** 035208 (2010)

V. Crede *et al.*, Phys. Rev. C**80**, 055202 (2009)

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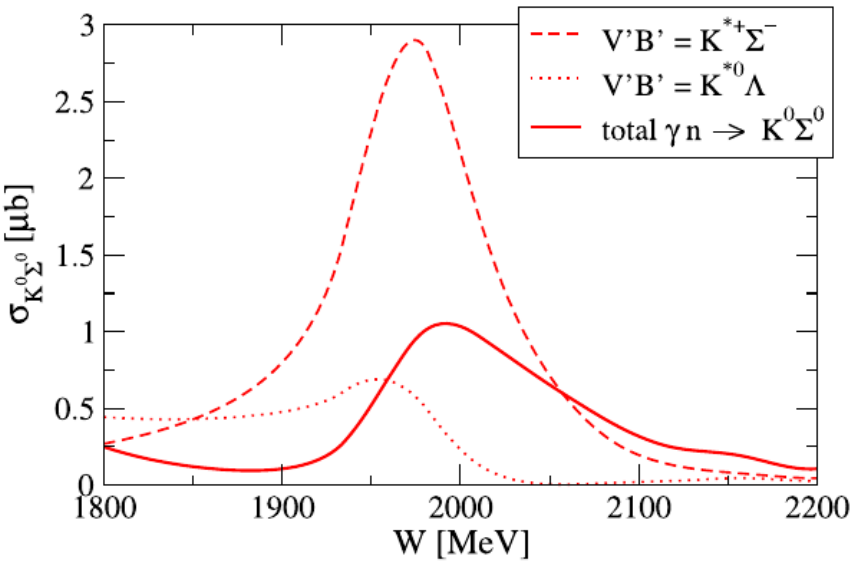
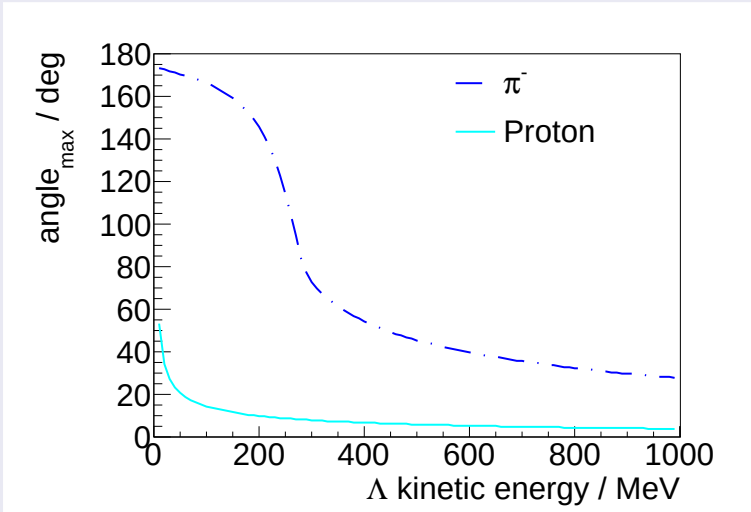
$\gamma n(p) \rightarrow K^0\Sigma^0$ K. Kohl PhD thesis, paper in preparation

- Peak predicted - "smoking gun" for reaction mechanism A. Ramos and E. Oset, Phys. Lett. **B 727**, (2013) 287



$\gamma n(p) \rightarrow K^0\Sigma^0$ at BGOOD

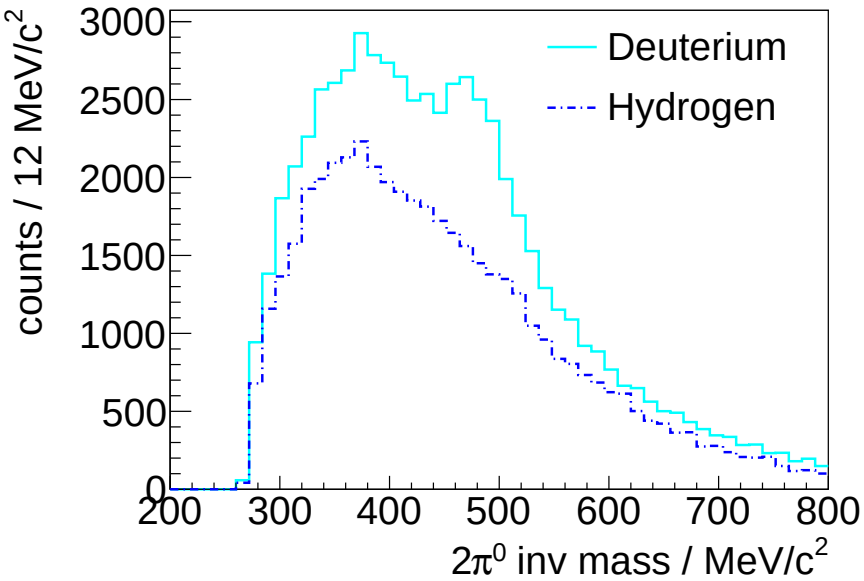
- $K^0 \rightarrow 2\pi^0$ in the BGO Rugby Ball
- γ identification from $\Sigma^0 \rightarrow \gamma\Lambda$
- Angle cut on $\Lambda \rightarrow p\pi^-$:



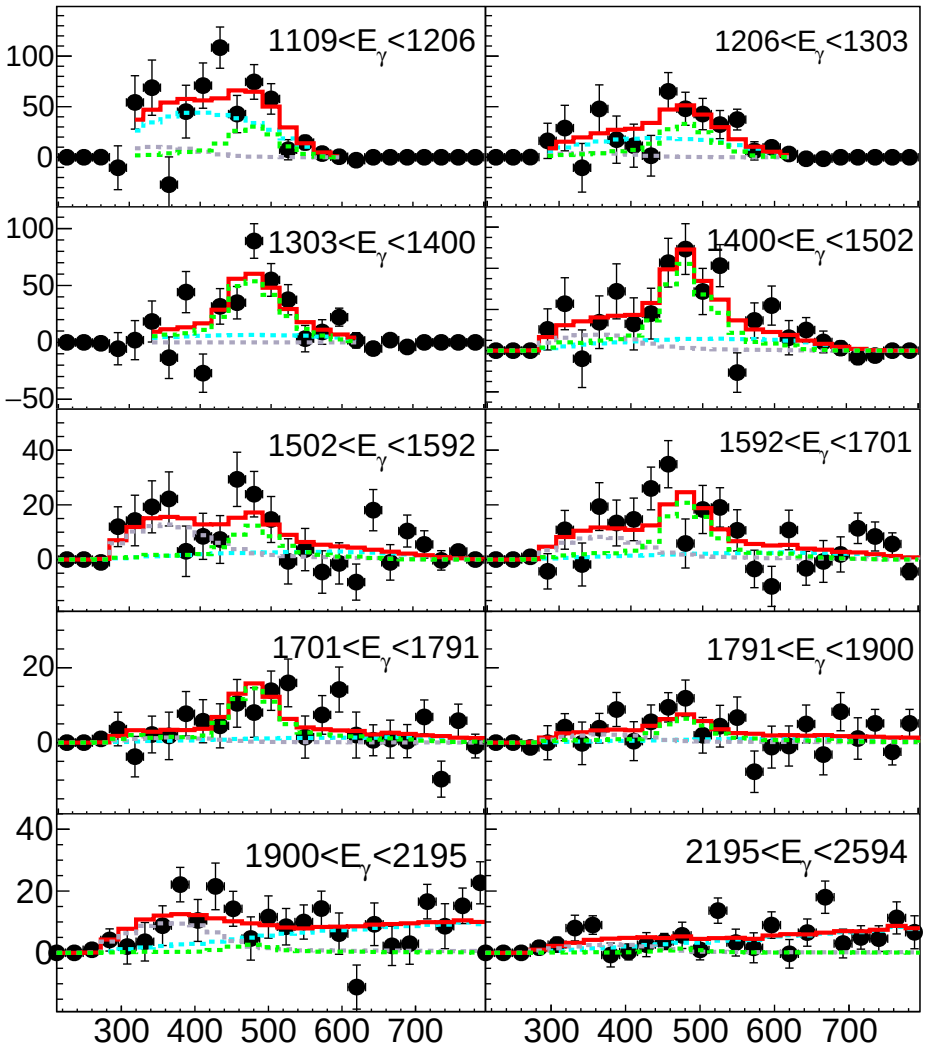
- Select missing mass over Σ^0 mass

$\gamma n(p) \rightarrow K^0\Sigma^0$ K. Kohl PhD thesis, paper in preparation

- Subtract background from reactions off the proton:



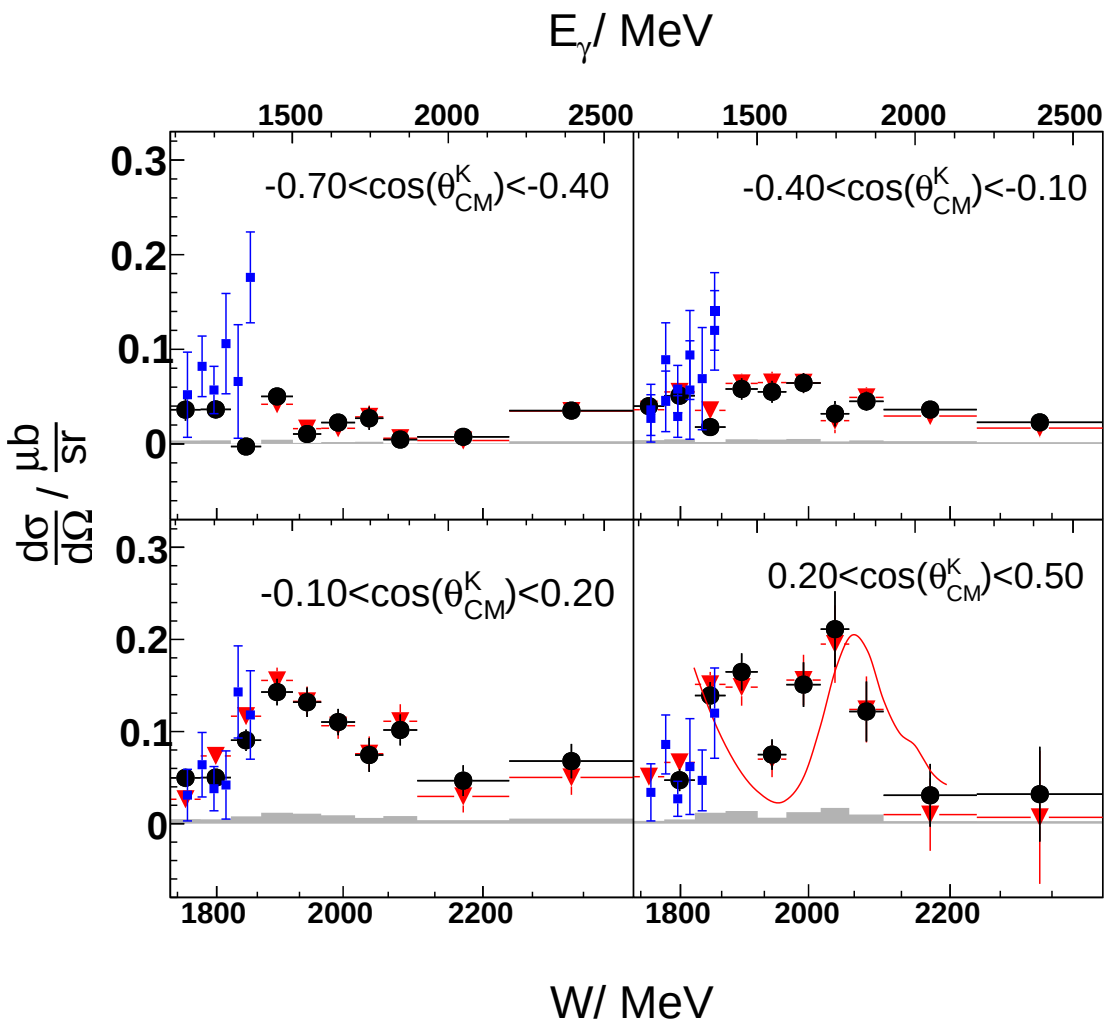
- Fit signal and remaining background off the neutron (mostly $3\pi^0 n$ & ηn)
- 2 background fit methods - sim data or real data with relaxed reaction selection constraints



$\gamma n(p) \rightarrow K^0\Sigma^0$ K. Kohl PhD thesis, paper in preparation

- Data is consistent with model prediction
- More statistics required for definitive statement
- Final steps - Applying Goodness of Fits
- Paper in progress

Triangles - BGOOD, sim. BG fit
Circles - BGOOD, real data BG fit
Line - Total σ prediction (arbitrarily scaled) (A. Ramos & E. Oset)
Squares - C. Akondi et al. (A2) EPJA 55 11, 202 (2019)



More data taking planned

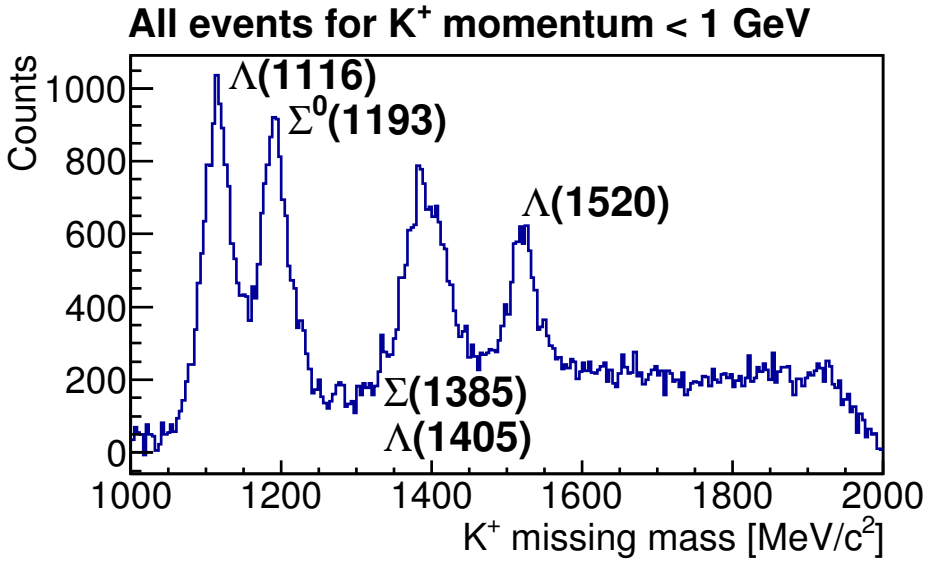
Strangeness photoproduction at the BGOOD experiment

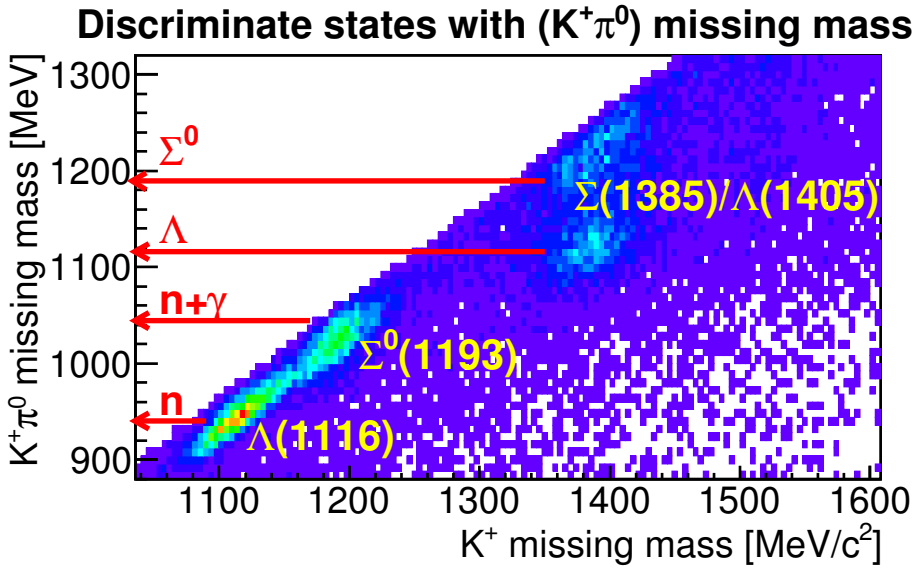
1. Introduction & motivation - parallels in strange & charmed quark sectors?
2. The BGOOD experiment at ELSA, Bonn
3. Strangeness photoproduction:
   - K^0 photoproduction off neutron (deuterium) targets
   - Extreme forward cross sections for K^+Y and excited hyperons
   - New projects in strangeness photoproduction

Supported by the DFG PN 388979758 & 405882627 & the EU Horizon 2020 research and innovation programme, grant agreement no. 824093

3. First results - Mass recoiling from forward K^+

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





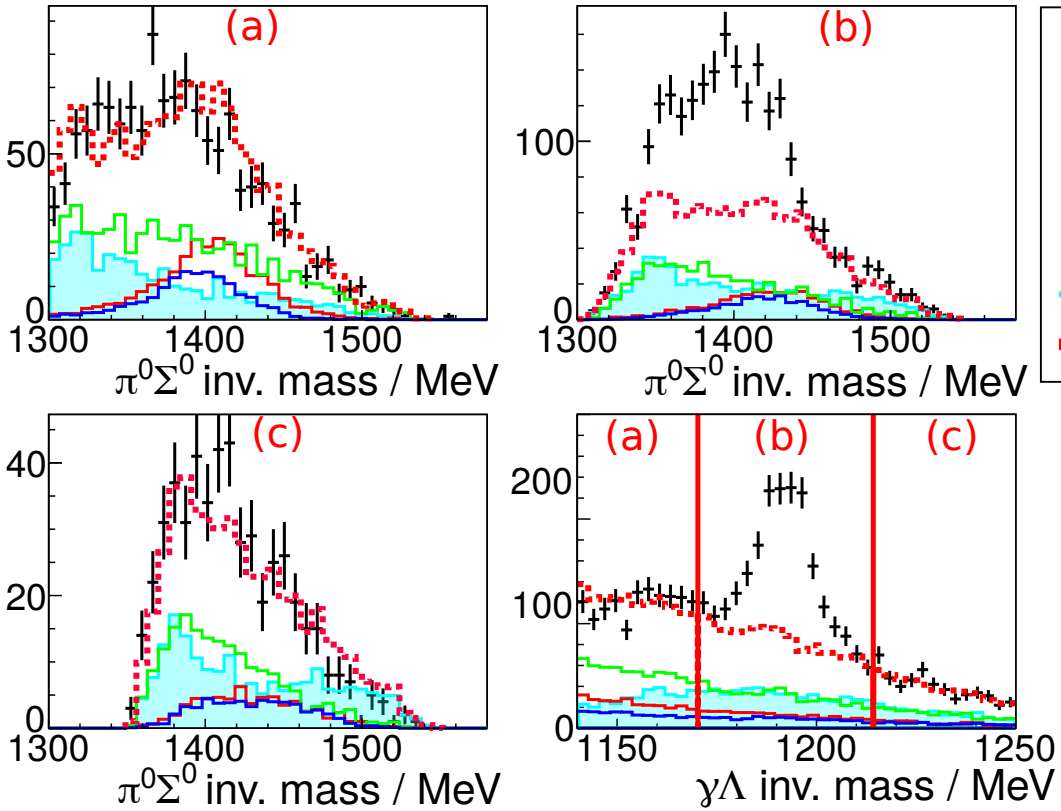
Identify Y^* states from $K^+\pi^0$ recoiling mass

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

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

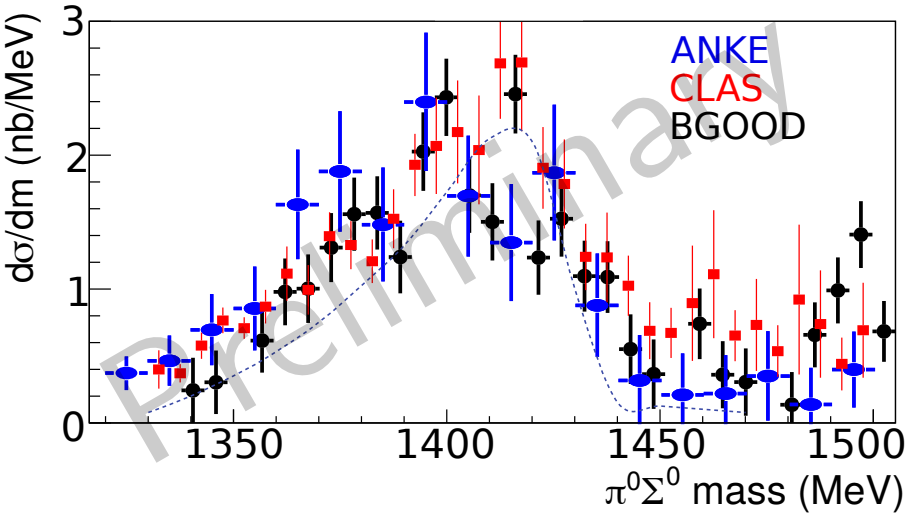
- Line shape & differential cross section for $\gamma p \to K^+(\Lambda(1405) \to \Sigma^0\pi^0)$
- $\gamma p \to K^+(\Lambda(1405) \to \Sigma^0\pi^0) \to K^+(\Lambda\gamma)(\gamma\gamma) \to K^+(p\pi^-\gamma)(\gamma\gamma)$
- Full reconstruction & kinematic fit

- 2D fit to signal & background:
- Other channels (cyan line): $\eta\pi p$, $K^0\Sigma^+$, $K^+\Sigma^0$, $\pi^0\pi^+\pi^- p$



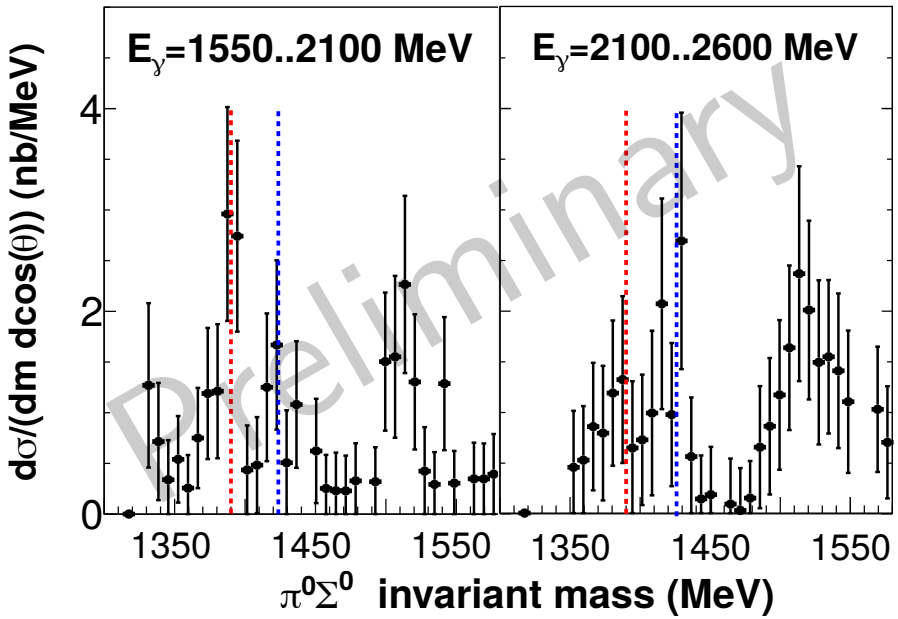
$\gamma p \to K^+\Lambda(1405)$ G. Scheluchin PhD thesis, paper in preparation

- Line shape - good agreement with previous data



- This data & ANKE - 2 peak structure at 1395 & 1425 MeV/c^2?
- Close to the $\Lambda(1405)$ proposed 2-pole structure J.A. Oller & U.-G- Meißner, Phys. Lett. B 500, 263 (2001)

- Cross section of poles appears to change at forward angles
- K^+ in the forward spectrometer ($\sigma_{\mathrm{Mass}} \sim 13\,\mathrm{MeV/c^2}$, $\cos\theta^K_{\mathrm{CM}} > 0.86$):



CLAS: K. Moriya, R. A. Schumacher et al Phys. Rev. C 87, 035206 (2013), ANKE: I. Zychor et al, Phys. Lett. B 660, 167 (2008), dashed line: J.C. Nacher et al. Phys. Lett. B455, 55 (1999)

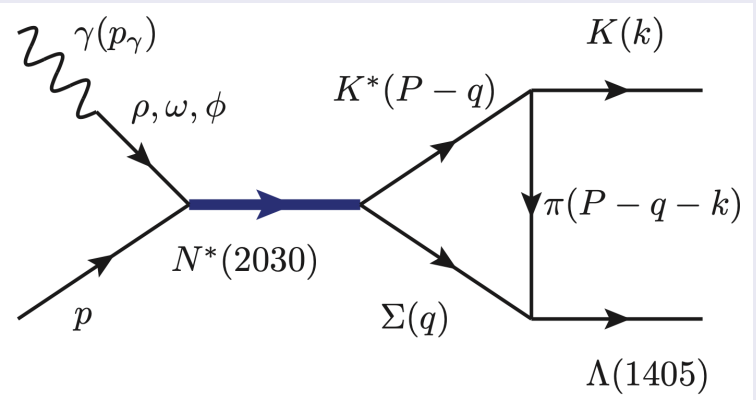
$\gamma p \to K^+\Lambda(1405)$ G. Scheluchin PhD thesis, paper in preparation

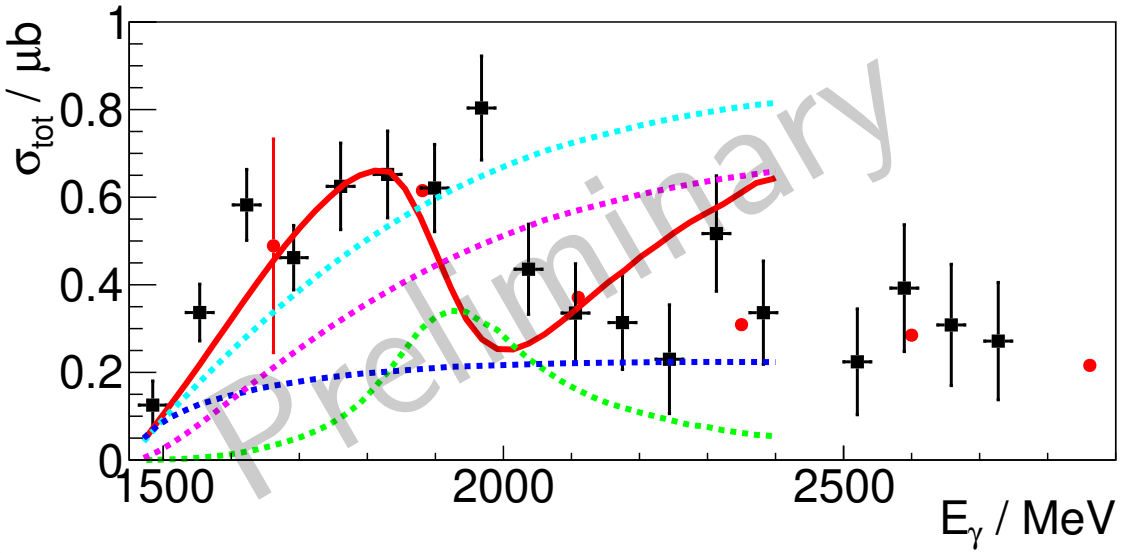
- Total cross section for $\gamma p \to K^+\Lambda(1405) \to \Sigma^0\pi^0$
- $K^+\Lambda(1520)$ channel used as proof of principle (not shown)

Role of the triangle singularity in the $\gamma p \to K^+\Lambda(1405)$ reaction

E. Wang, J. Xie, W. Liang, F. Guo & E. Oset,

Phys Rev. C 95, 015205 (2017)

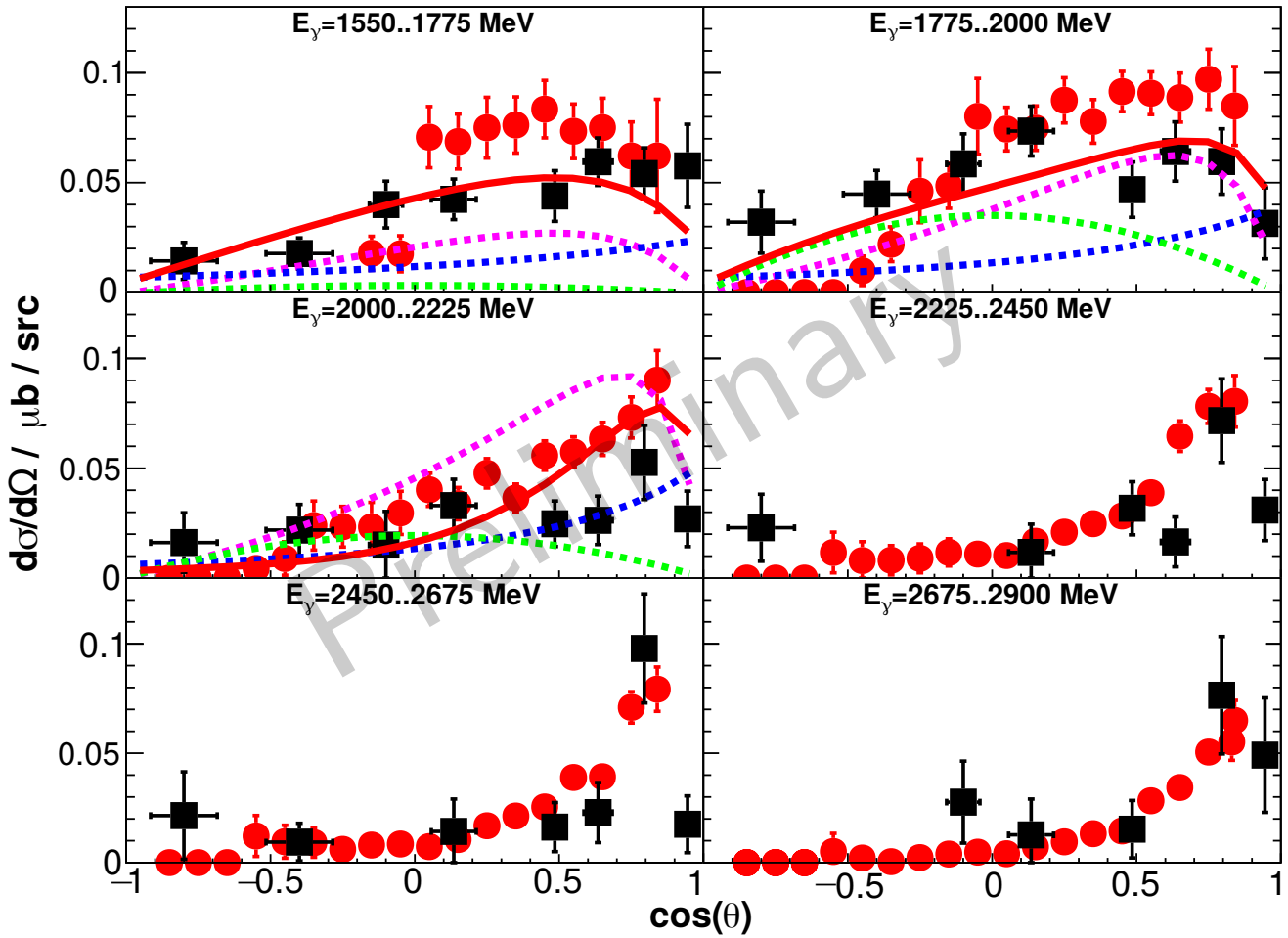




- Black points: BGOOD
- Red points: CLAS
- Solid Red: Total fit
- Dotted cyan: fit without Triangle diagram
- Dotted green: Triangle diagram contribution
- Dotted blue: K^* t-channel exchange
- Dotted magenta: K t-channel exchange

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

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

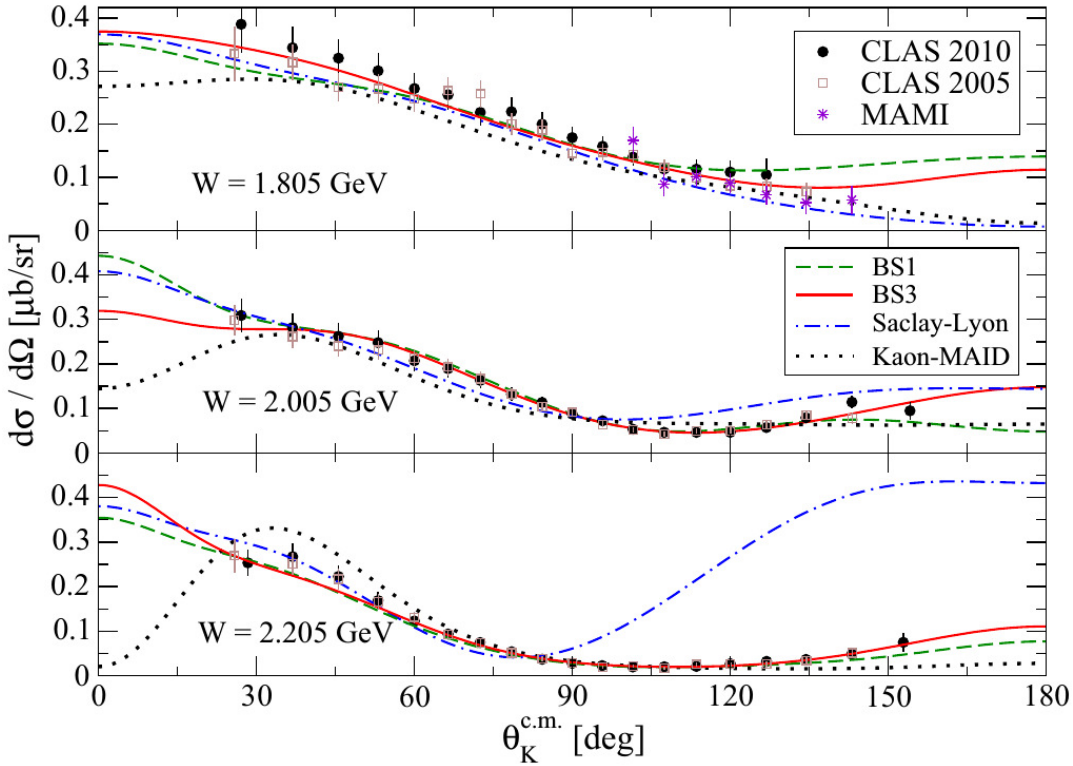


Black points: BGOOD,
Red points: CLAS
Solid Red: Total fit
Dotted cyan: fit without Triangle diagram
Dotted green: Triangle diagram contribution
Dotted blue: K^* t-channel exchange
Dotted magenta: K t-channel

Fits from E. Wang, J. Xie, W. Liang, F. Guo & E. Oset, Phys Rev. C 95, 015205 (2017)

3. Forward $\gamma p \rightarrow K^+\Lambda$ - motivation

Not only Y^* states at forward angles important - photoproduction of ground state hyperons at low t virtually unconstrained by data



- Isobar models - explicitly add $>$ 20 resonances for strangeness photoproduction
- BGOOD - high $\cos^K_{\mathrm{CM}}$ resolution at forward angles - sensitive to high-spin intermediate states

D. Skoupil, P. Bydzovsky, PRC 97, 025202 (2018) (& refs. therein)

T. C. Jude et al. (A2), PLB 735, 112 (2014)

R. Bradford et al. (CLAS), PRC 73, 035202 (2006)

M. E. McCracken et al. (CLAS), PRC 81, 025201 (2010)

Additional models (not shown)

Jülich-Bonn, D. Rönchen, M., Döring, U.G.

Meißner, EPJA (2018) 54

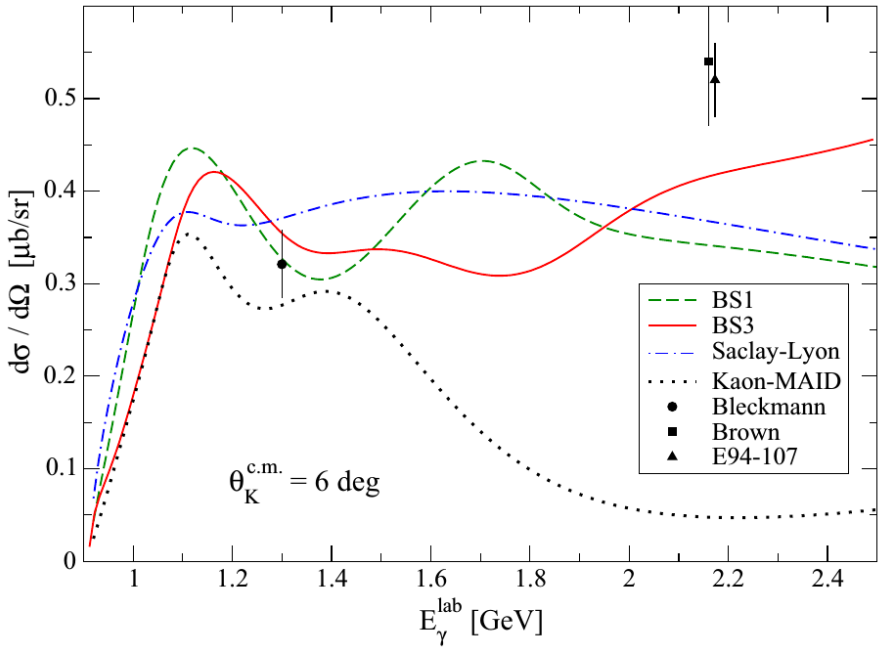
BnGa PWA, E. Klempt, A. Sarantsev, U. Thoma, V. Nikonov

3. Forward $\gamma p \rightarrow K^+\Lambda$ - motivation

Crucial for hypernuclei electroproduction

- eg, $e^- + {}^{12}\mathrm{C} \rightarrow K^+ + {}^{12}_{\Lambda}\mathrm{B}$ at very low Q^2 (Λ remains within nucleus Fermi surface)
- Natural laboratories to probe the $Y - N$ interaction!
- Essential for astrophysical phenomena & $\mathrm{SU}_{\mathrm{flavour}}(3)$ description of baryon interactions
- eg Saclay Leon model for $p(e, e'K^+)\Lambda$

  T. Mizutani, C. Fayard, G.-H. Lamot & B. Saghai, Phys. Rev. **C 58**, 75 (1998)



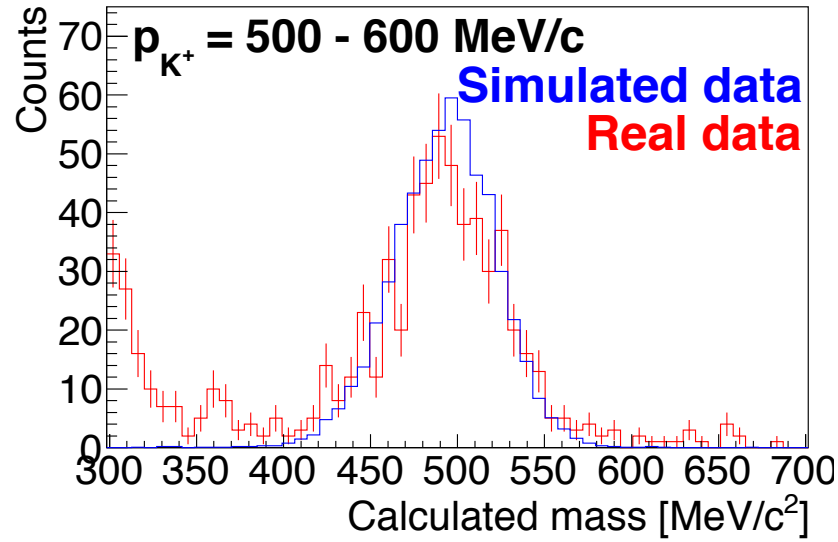
D. Skoupil, P. Bydzovsky, Phys. Rev. **C97**, 025202 (2018)

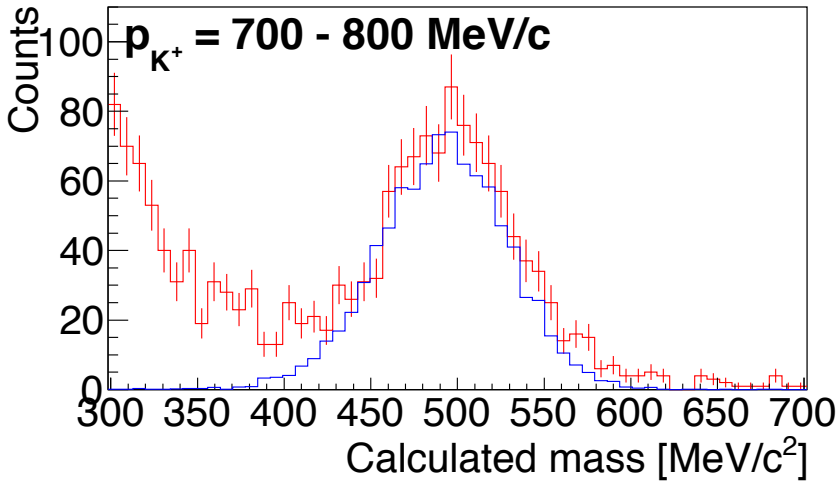
At BGOOD

- Forward CM polar angle range approx. 3-26^0, $0.9 < \cos\theta^{K^+}_{cm} < 1.0$
- $\cos\theta^{K^+}_{cm}$ resolution $\sim 0.015^\circ$

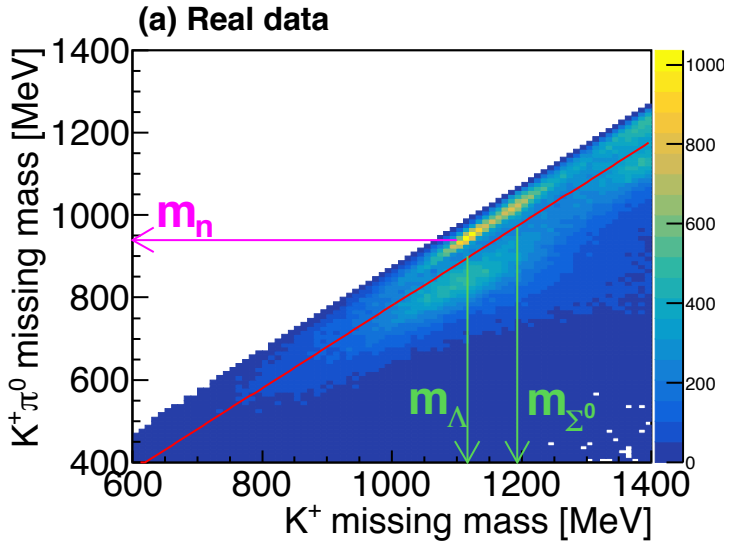
3. Forward $\gamma p \to K^+\Lambda$ arXiv:2006.12350. Submitted to EPJA

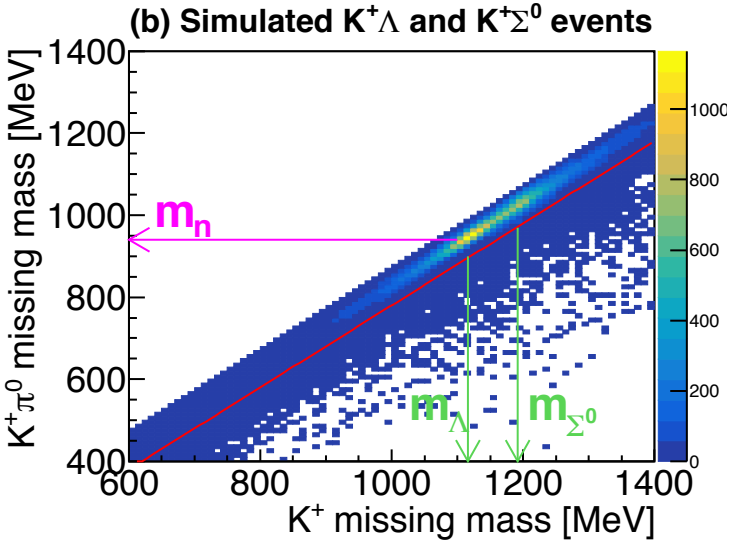
- Selecting forward K^+ by the reconstructed mass:





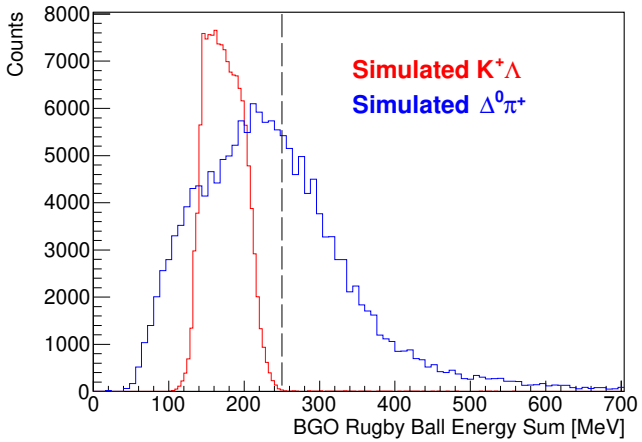
- π^0 identification from $\Lambda \to \pi^0 n$:





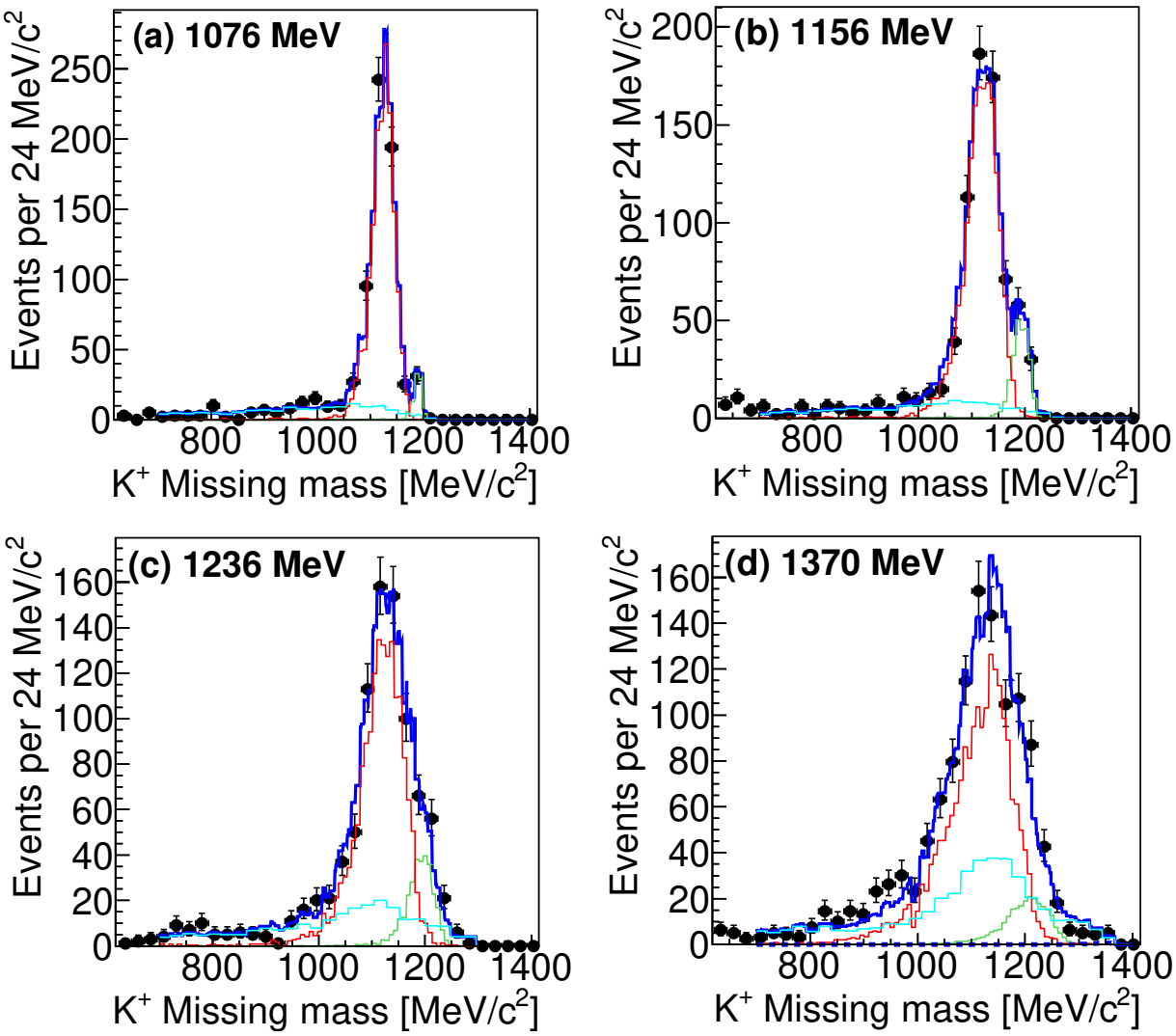
3. Forward $\gamma p \to K^+\Lambda$ arXiv:2006.12350. Submitted to EPJA

- Require $< 250\,\text{MeV}$ deposition in the BGO Rugby Ball
- Removes most $\gamma p \to \Delta^0\pi^+$ background:



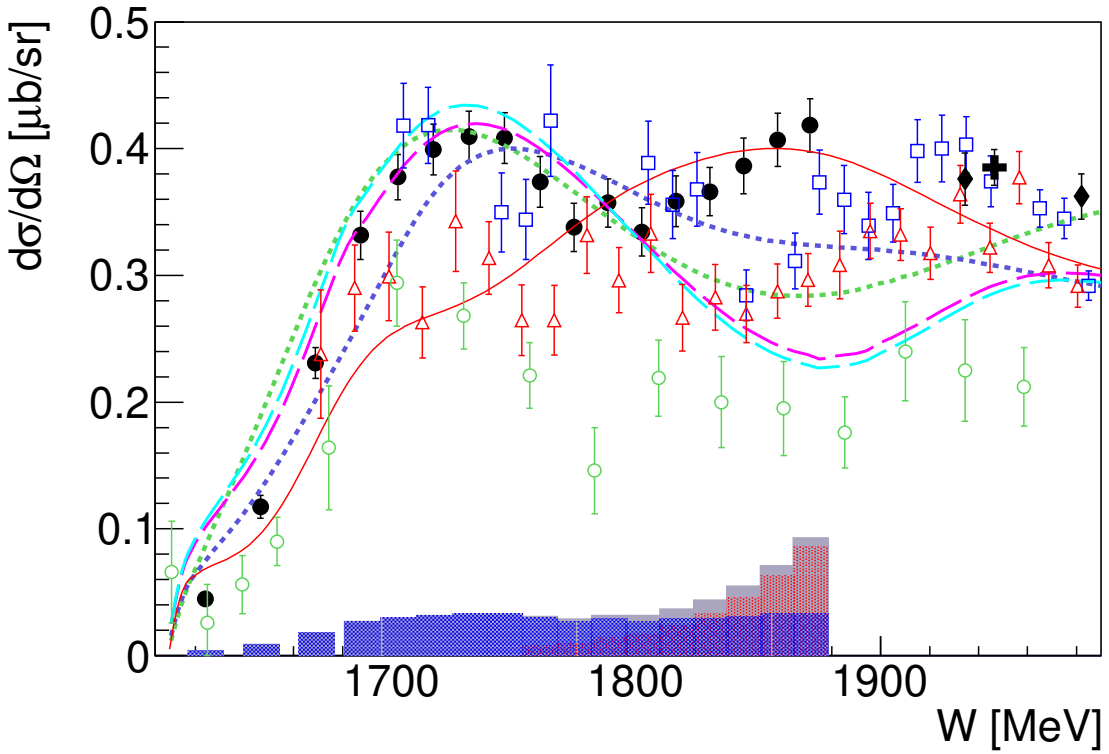
Sim $K^+\Lambda$, Sim $K^+\Sigma^0$, e^+/π^+ background

- Fit to K^+ missing mass spectra:



3. Forward $\gamma p \to K^+\Lambda$ arXiv:2006.12350. Submitted to EPJA

- Differential cross section for $\gamma p \to K^+\Lambda$ for $\cos\theta^K_{CM} > 0.9$
- BGOOD - Black circles
- Systematic errors - Total (grey), "scaling" blue, "fitting" red
- Small statistical error resolves discrepancies in the world data set



Valuable discussions with Dalibor Skoupil & Petr Bydžovský (NPI CAS)!

Data points

R. Bradford *et al.* (CLAS), PRC 73, 035202 (2006)
M.E.McCracken *et al.* (CLAS), PRC 81, 025201 (2010)
CLAS data: $0.85 < \cos\theta^K_{\mathrm{CM}} < 0.95$
K.H. Glander *et al.*(SAPHIR), EPJA 19, 251 (2004)
LEPS (black diamonds & crosses) PRC 73:035214 (2006) & 97:015208 (2018)

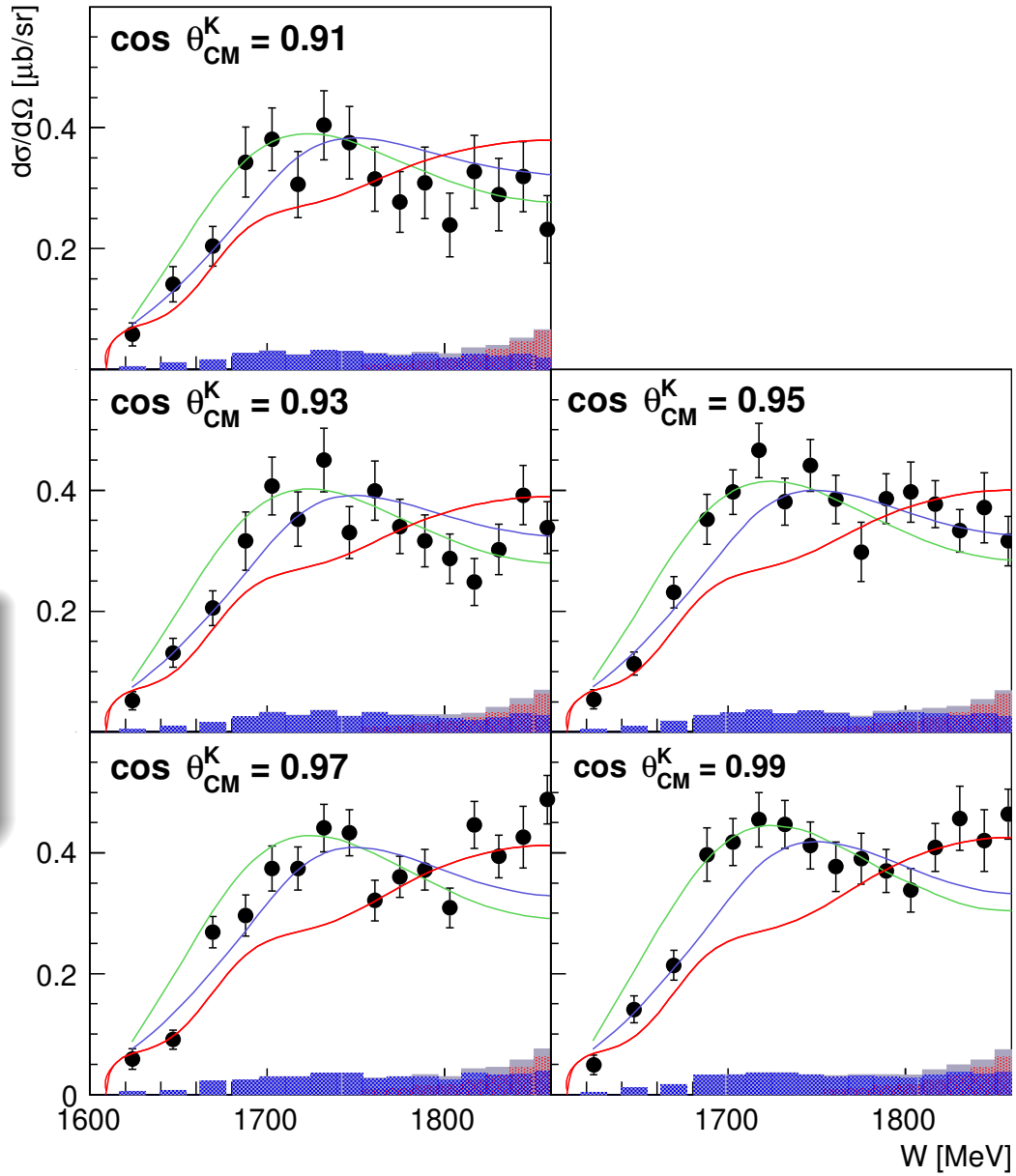
PWA & models

Bonn-Gatchina PWA: Eur.Phys.J. A50 74 (2014)
Bonn-Gatchina PWA including BGOOD
Regge plus resonant model, Skoupil & Bydžovskỳ, PRC, 100:035202, 2019
Isobar models BS1 & s BS3, Skoupil & Bydžovskỳ, PRC, 97:025202, 2018

3. Forward $\gamma p \rightarrow K^+\Lambda$ arXiv:2006.12350. Submitted to EPJA

- Angular resolution ~ 0.015 in $\cos\theta^K_{\mathrm{CM}}$

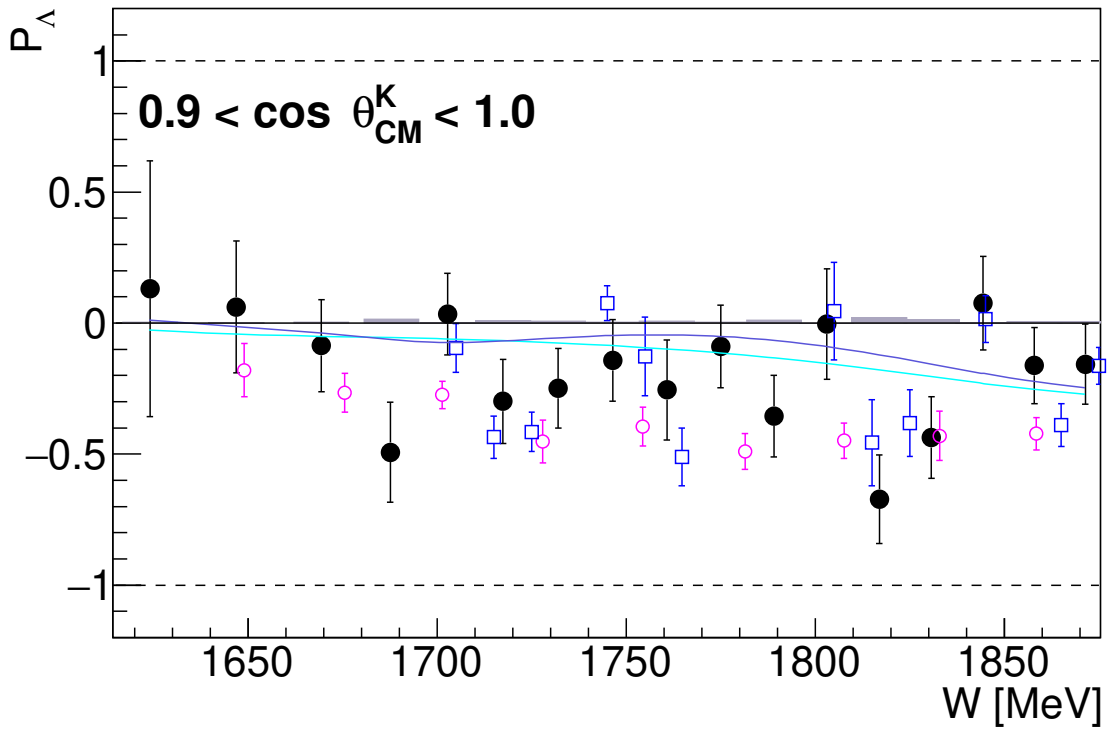
RPR model, Skoupil & Bydžovskỳ, PRC, 100:035202, 2019
Isobar models BS1 & s BS3, Skoupil & Bydžovskỳ, PRC, 97:025202, 2018



3. Forward $\gamma p \to K^+\Lambda$ arXiv:2006.12350. Submitted to EPJA

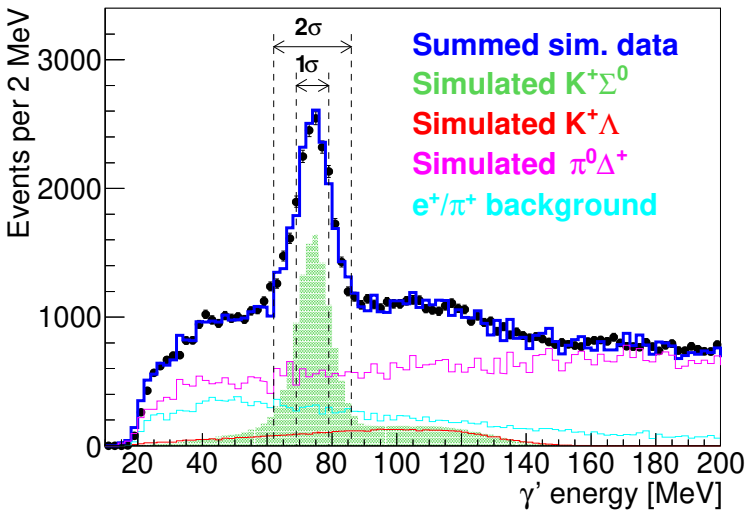
Recoil polarisation - 1st data set for $\cos^K_{\rm CM} > 0.9$

- Access via the self-analysing weak decay of the Λ
- Up-down asymmetry between Λ decay & the reaction plane
- $\Lambda \to \pi^0 n$ identified in the BGO
- $P_\Lambda = \frac{2}{\alpha} \frac{N_{\rm up} - N_{\rm down}}{N_{\rm up} + N_{\rm down}}$
- P_Λ: zero near threshold, negative & agreeing with BS1 & BS2 at higher energies

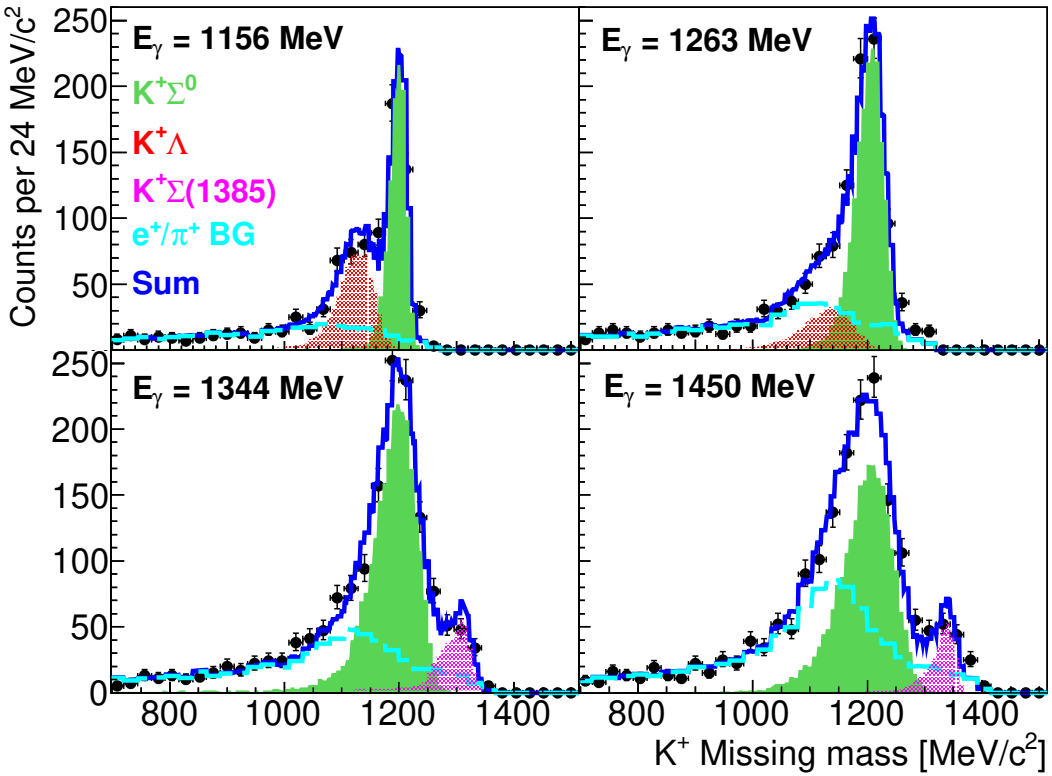


McCracken *et al.* (CLAS), PRC 81, 025201 (2010) $0.85 < \cos^K_{\rm CM} < 0.95$
Lleres *et al.* (GRAAL), EPJA **A 31**, 79 (2007) $0.77 < \cos^K_{\rm CM} < 0.94$
Isobar models BS1 & s BS3, Skoupil & Bydžovskỳ, PRC, 97:025202, 2018

- After identifying forward K^+, boost all γ in the BGO into the Σ^0 rest frame
- 74 MeV decay energy, select 1σ or 2σ events:

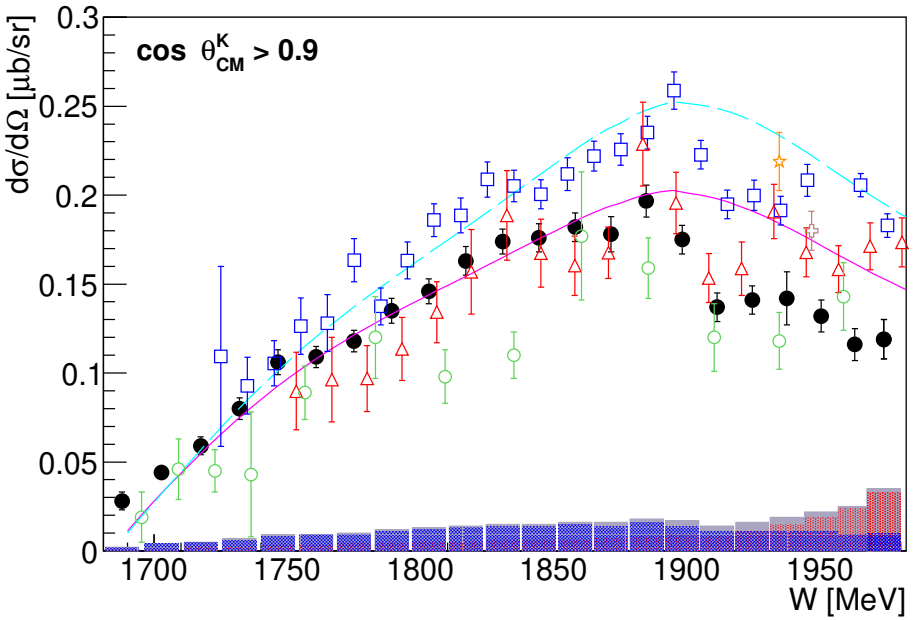


- Missing mass recoiling from forward K^+ after Σ^0 decay photon identification



$\gamma p \to K^+\Sigma^0$ T. C. Jude et al. arXiv:2006.12437 (2020). To be submitted to PLB

- Black circles - BGOOD
- Systematic errors; scaling systematic, fitting systematic, total systematic
- Highest statistics to date for $\cos\theta^K_{\mathrm{CM}} > 0.9$
- Resolve discrepancies in world data set & reveals "cusp" at $W \sim 1900$



- "cusp" regarded as a peak before - PWA have attributed $D_13(1895)$, $S_{31}(1900)$, $P_{31}(1910)$ & $P_{13}(1900)$
- BnGa - A $\Delta(1917)$ with $J^\pi = 5/2$ & $\Gamma = 59$ MeV gave the most improved fit (only for forward data points) - BUT ABSOLUTELY NOT SETTLED

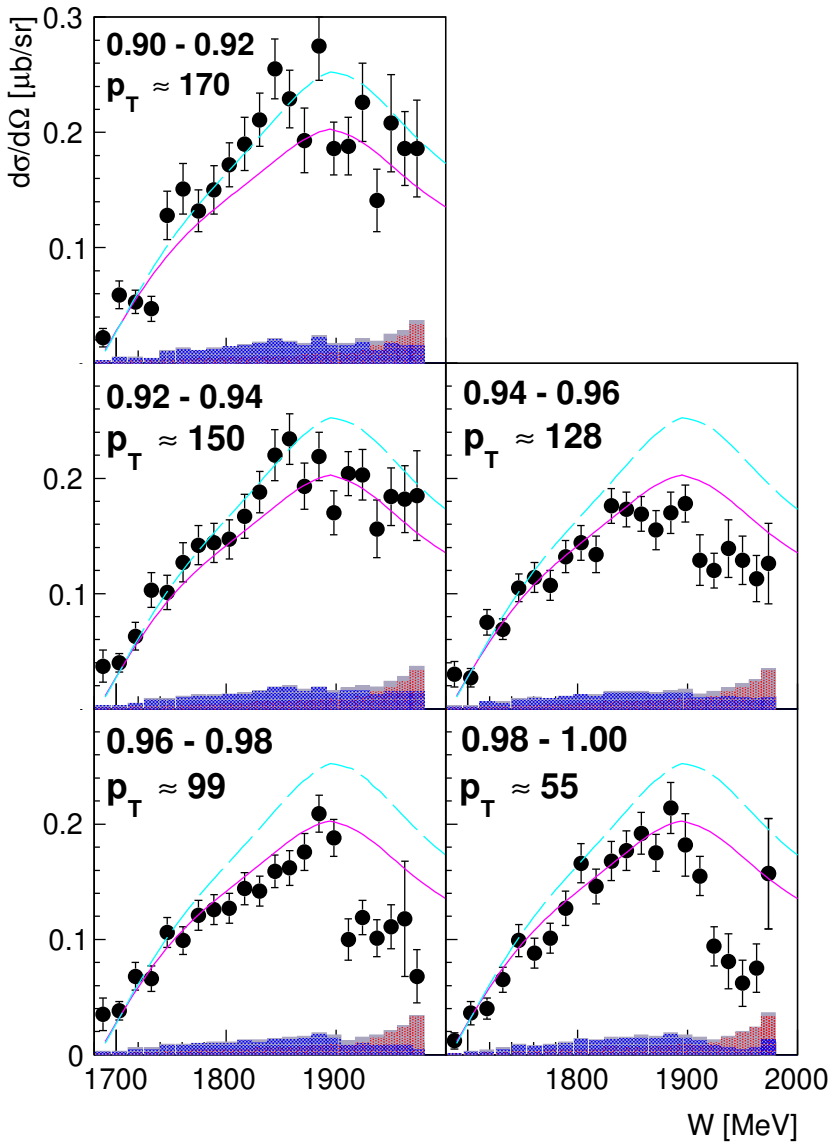
R. Bradford *et al.* (CLAS), PRC 73, 035202 (2006), B.Dey *et al.* (CLAS), PRC 82, 025202 (2010), K.H. Glander *et al.*, EPJA 19, 251 (2004), CLAS data in $\cos\theta^K_{\mathrm{CM}}$ 0.85 to 0.95 interval, BnGa PWA - without BGOOD/with BGOOD

- BGOOD resolves 0.02 $\cos^K_{\mathrm{CM}}$ intervals:
- "Cusp" - most pronounced at most forward angles
- Corresponds to minimal transverse momentum (P_T) (and recoiling momentum to the residual baryon)
- Threshold effects at low momentum transfer? close to thresholds: $K^+\Lambda(1405)$,$K\Sigma(1385)$, $pf_0(980)$, $p\phi$ $p\eta'$

S. Sarkar, E. Oset & M. Vicente Vacas,

Nucl. Phys. A **750** (2005), 294

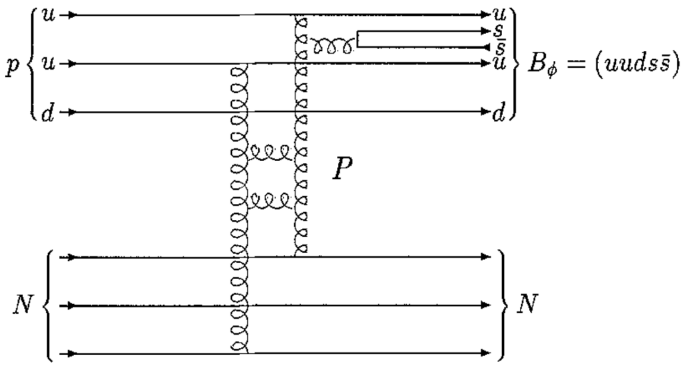
Threshold cusp predicted at 1877 MeV due to the opening of the $K\Sigma(1385)$ channel



$\gamma p \to K^+\Sigma^0$ - Parallels to previous SPHINX data

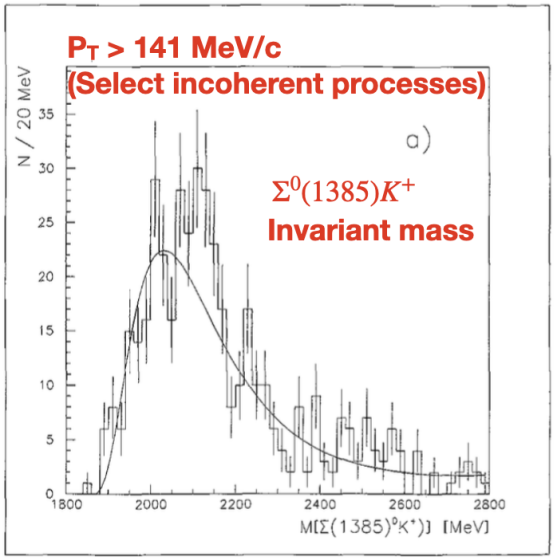
Study of coherent diffractive production reactions of $P + C \to [Y^0 K^+] + C$ type and observation of narrow structures in $\Sigma(1385)^0 K^+$ and $\Sigma^0 K^+$ effective mass spectra S. V. Golovkin et al (SPHINX Collaboration). Z. Phys. C, 68:585 (1995)

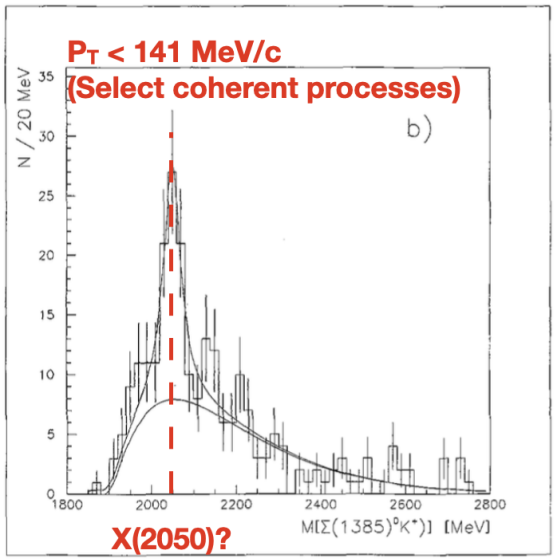
- A search for crypto exotic baryons, $B_\phi^+ = |uuds\bar{s}\rangle$
- Gluon rich, Pomeron exchange in diffractive coherent production mechanisms
- Selected small momentum transfer, P_T to remove non-coherent background



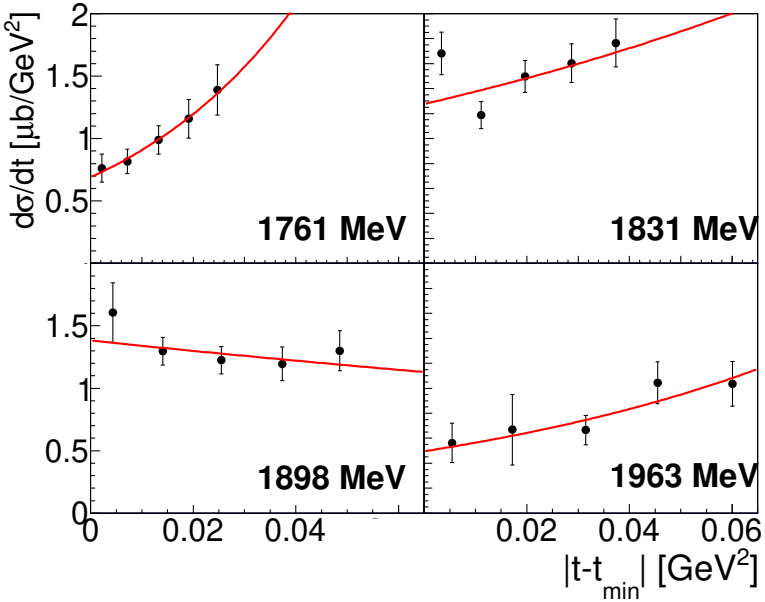
Preliminary reporting
$X(2050) \to \Sigma(1385)^0 K^+$
$X(2000) \to \Sigma^0 K^+$

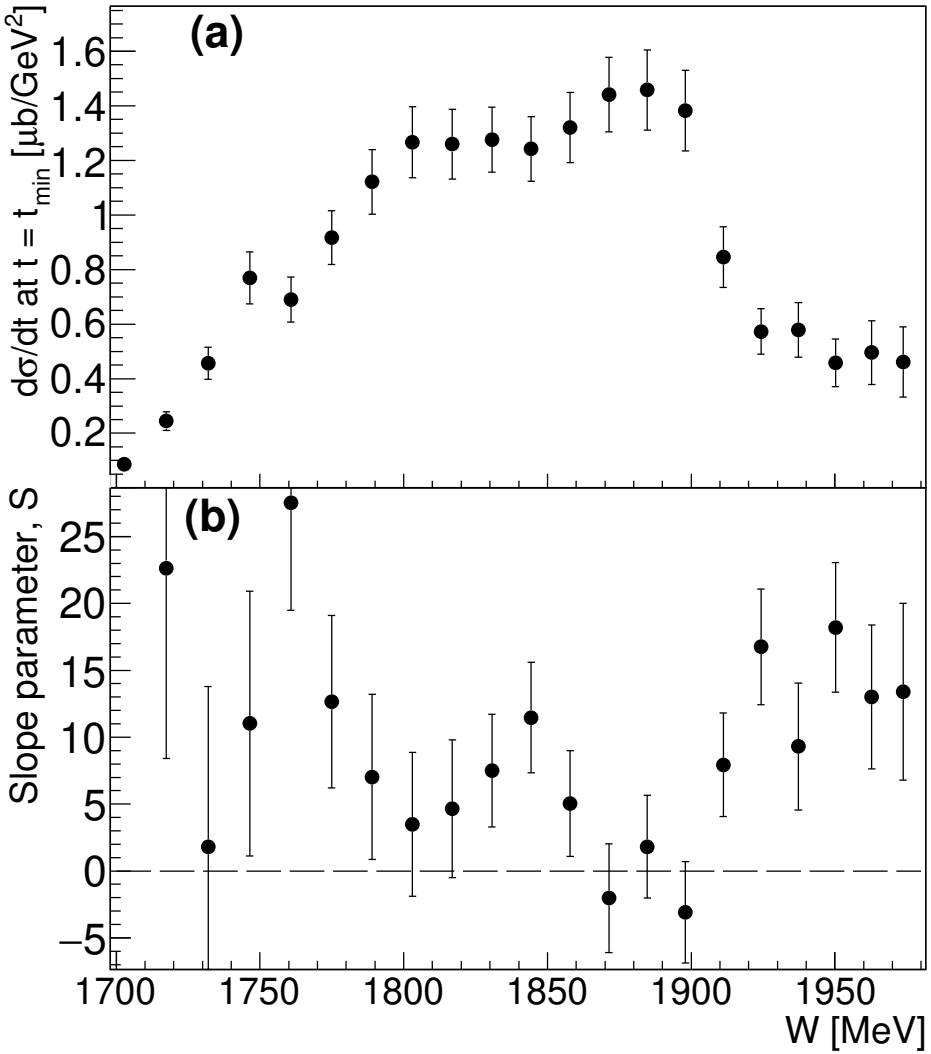
All figures from referenced paper





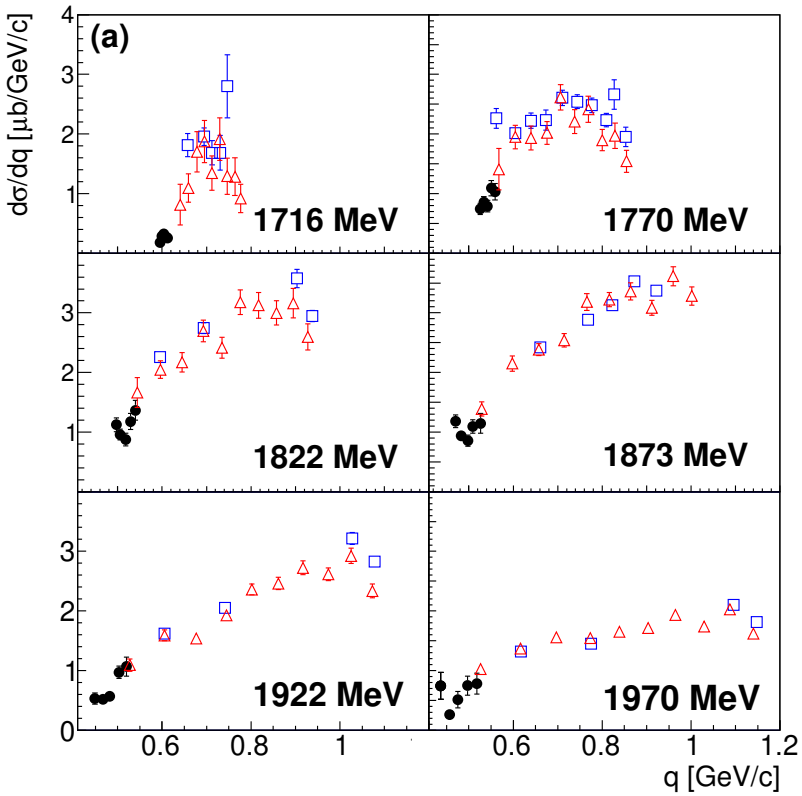
- "Cusp" derived from loosely bound systems, eg meson-baryon multiquark configuration?
- Expect strong dependence on momentum transfer, t
- $\frac{d\sigma}{dt} = \frac{d\sigma}{dt}\Big|_{t=t_{min}} e^{S|t-t_{min}|}$





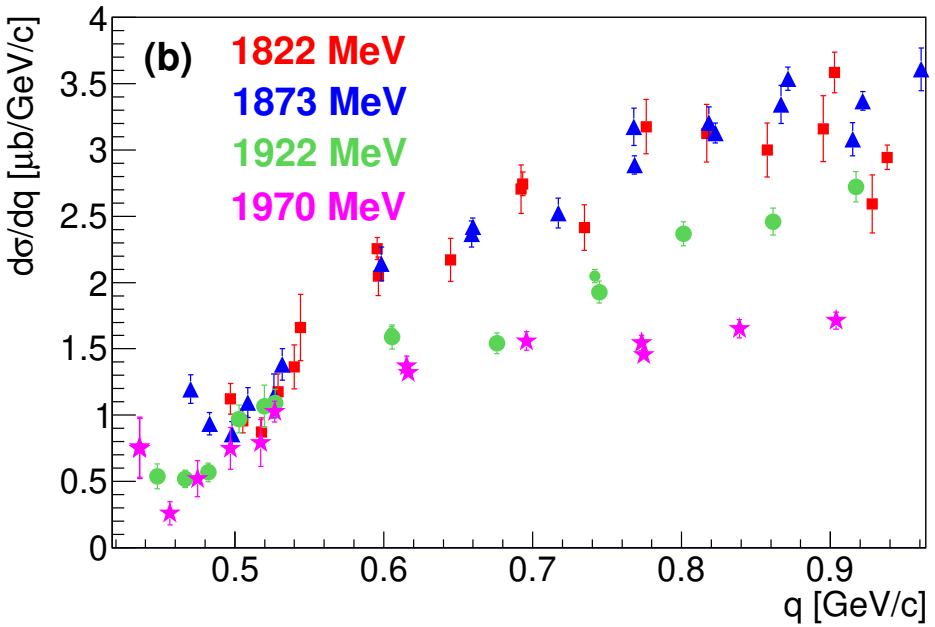
- Change in S at 1900 MeV - a change in t channel contributions?

- Cross section as a function of 3-momentum to the recoiling baryon system, q
- If dominated by the momentum the recoiling baryon can "take" - anticipate scaling with q & weak W dependence



BGOOD - black, CLAS - red & blue

- The data sets plotted in the same colour for each W bin:
- "scaling" does appear to occur at $q \sim 0.5$ GeV/c (at the "cusp")



Strangeness photoproduction at the BGOOD experiment

1. Introduction & motivation - parallels in strange & charmed quark sectors?
2. The BGOOD experiment at ELSA, Bonn
3. Strangeness photoproduction:
   - K^0 photoproduction off neutron (deuterium) targets
   - Extreme forward cross sections for K^+Y and excited hyperons
   - New projects in strangeness photoproduction

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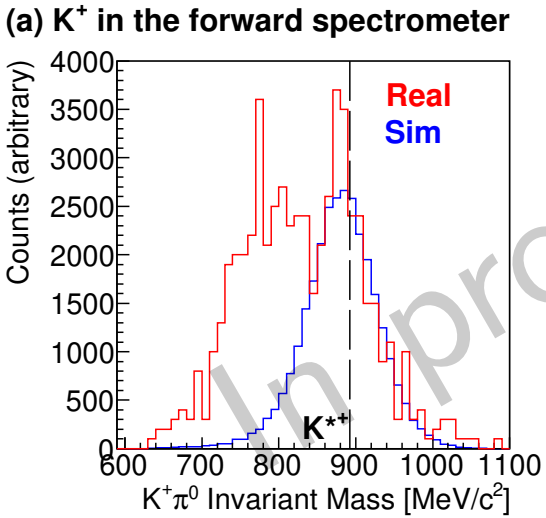
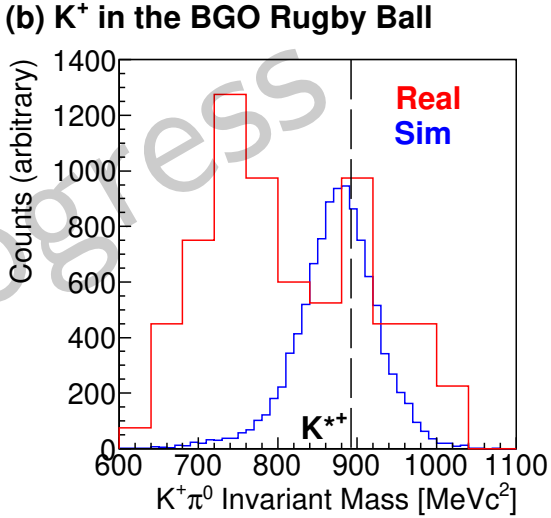
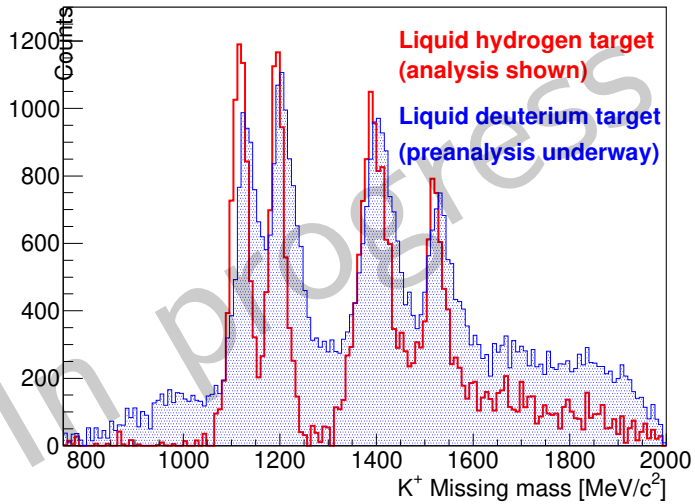
4. New projects in strangeness photoproduction

- $\gamma p \to K^{*+}(892)\Sigma^0$
- Identification via $K^{*+}(892) \to K^+\pi^0$
- Full solid angle coverage
- K^+ identification in the BGO Rugby Ball via time delayed weak decay
- A Figueiredo Master's analysis



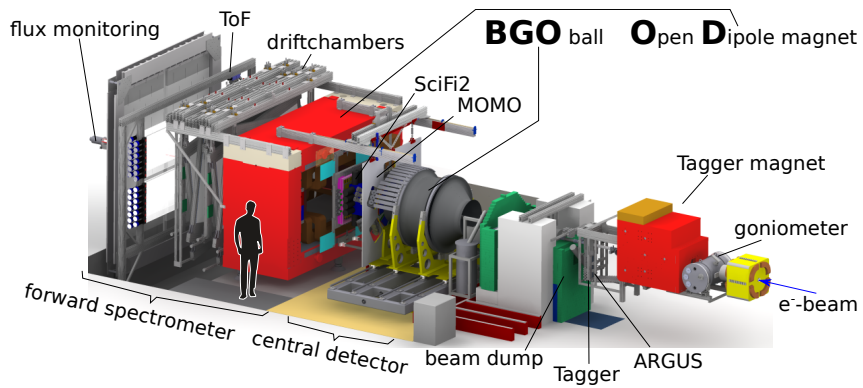


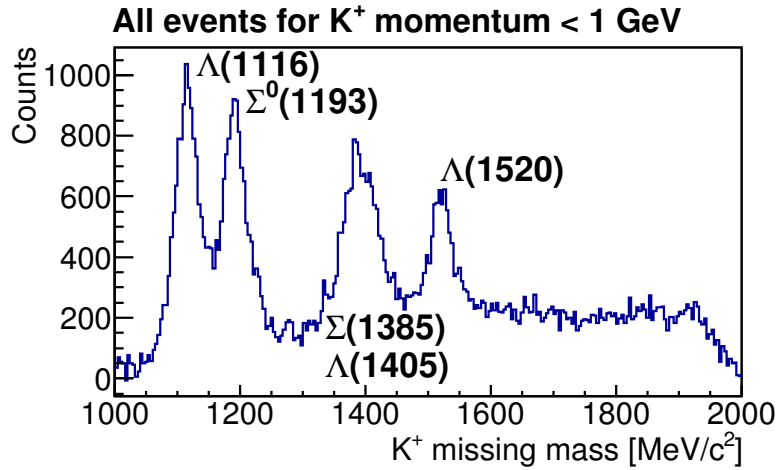
- Deuterium target:
- $\gamma n \to K^+\Sigma^-$
- $\gamma n \to K^+\Sigma^-(1385)$
- Limited data at forward angles - $K\Sigma$ "cusp" a universal $s\bar{s}$, $N\phi$ threshold effect?
- J Groß PhD analysis



Summary

- Molecular-like structure in the light quark system? Parallels between heavy charm and *uds* systems?
- BGOOD - strangeness photoproduction at extremely forward angles & low momentum transfer
- $K^0\Sigma^0$ photoproduction - results consistent with dynamically generated meson-baryon resonance contributions
- $\gamma p \to K^+(\Lambda(1405) \to \Sigma^0\pi^0)$ - 2-pole structure in the line shape? Cross sections maybe support triangle diagram mechanism
- Cusp in $\gamma p \to K^+\Sigma^0$ at $W \sim 1900$ MeV





Extra slides from here

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:

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