Strangeness photoproduction at the BGO-OD experiment

Tom Jude, on behalf of the BGO-OD collaboration

Physikalisches Institut
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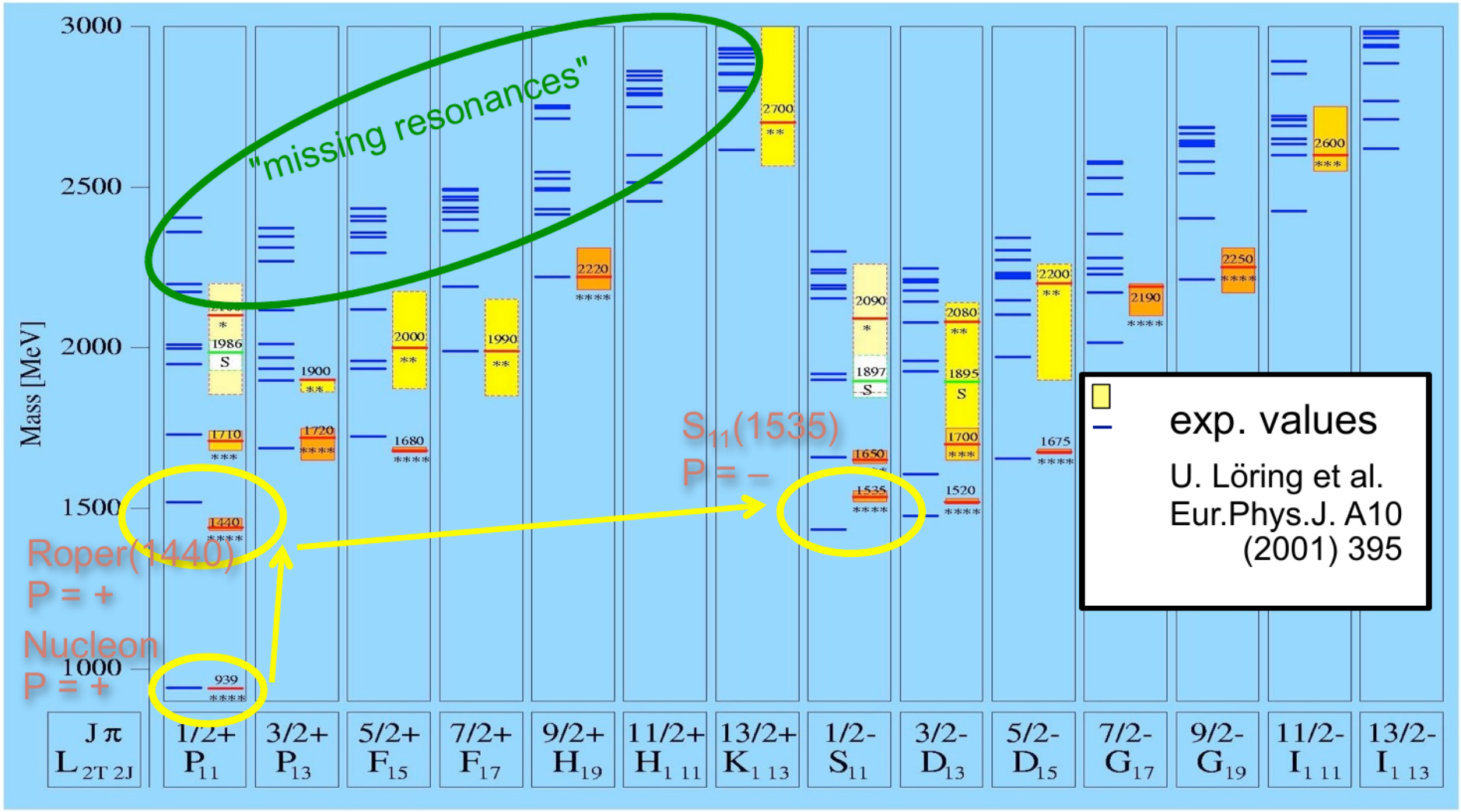
Supported by the DFG PN 50165297

Strangeness photoproduction at the BGO-OD experiment

1. Introduction & motivation - parallels in strange & charmed quark sectors?
2. The BGO-OD experiment at ELSA, Bonn
3. Strangeness photoproduction - first results:
   - K^0 photoproduction off proton & neutron (deuterium) targets
   - Extreme forward cross sections for K^+Y and excited hyperons
   - Future opportunities with BGO-OD

Supported by the DFG PN 50165297

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



1. Introduction - Status of N^* spectroscopy

	PDG (2010)	BnGa PWA	PDG (2018)
N(1860)5/2$^+$		*	**
N(1875)3/2$^-$		***	***
N(1880)1/2$^+$		**	**
N(1895)1/2$^-$		****	****
N(1900)3/2$^+$	**	***	***
N(2060)5/2$^-$		***	**
N(2150)3/2$^-$		**	**
Δ(1900)1/2$^-$	*	*	**
Δ(1940)3/2$^-$	*	**	**

Bonn-Gatchina partial wave analysis

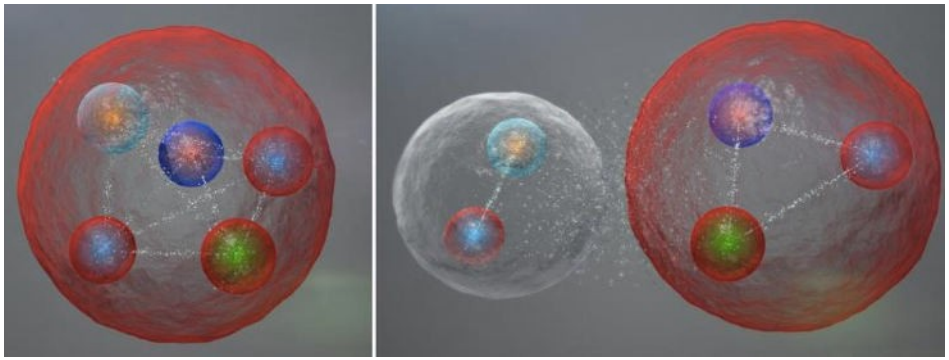
BnGa - E. Klempt, A. Sarantsev, U. Thoma, V. Nikonov

- Wealth of data from ELSA, MAMI, GRAAL & CLAS facilities
- 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?

L.Ya. Glozman and D.O. Riska, Physics Reports 268 (1996) 263, C. Garcia-Recio et al., Phys. Lett. B 582 (2004) 49, M.F.M. Lutz, E.E. Kolomeitsev, Phys. Lett. B 585 (2004) 243.

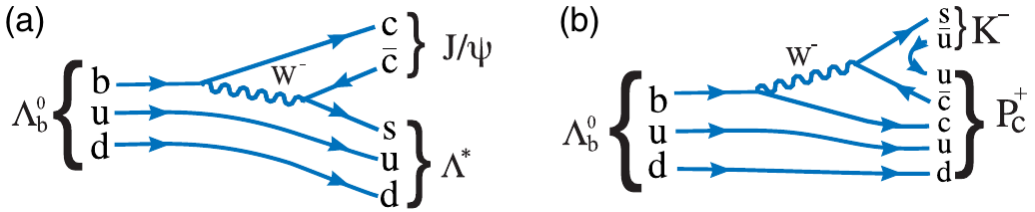
- How would this manifest in reaction mechanisms & excitation spectra?



1. Motivation - Exotic phenomena in the charmed sector

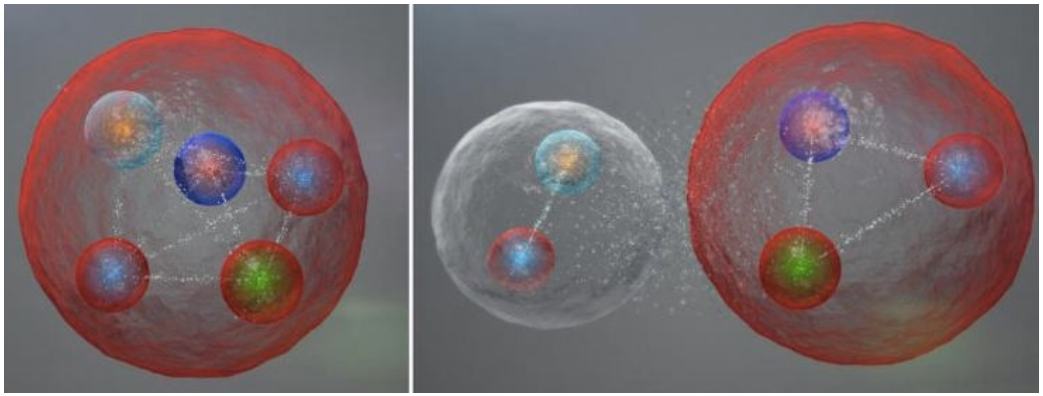
Pentaquark candidates observed at LHCb
$P_c(4450)^+$ & $P_c(4380)^+$ at $\Sigma_c \bar{D}^*$ threshold

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



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

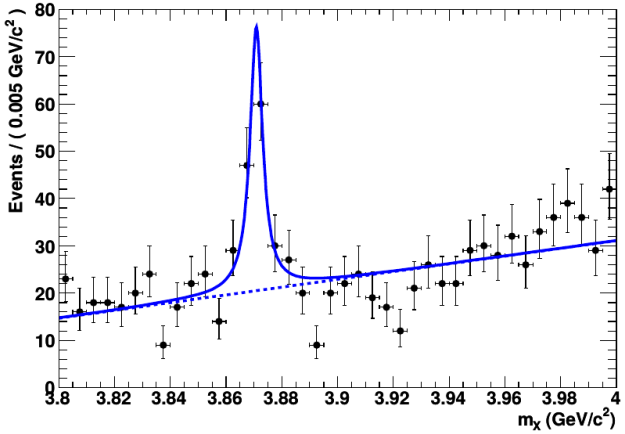
Forsaken pentaquark particle spotted at CERN



Nature 523, 267 (2015)

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

Very close to $D^0\bar{D}^{0*}$ threshold



B. Aubert et al (BARBAR Collaboration), Phys. Rev. D77 111101 (2008)

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

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

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

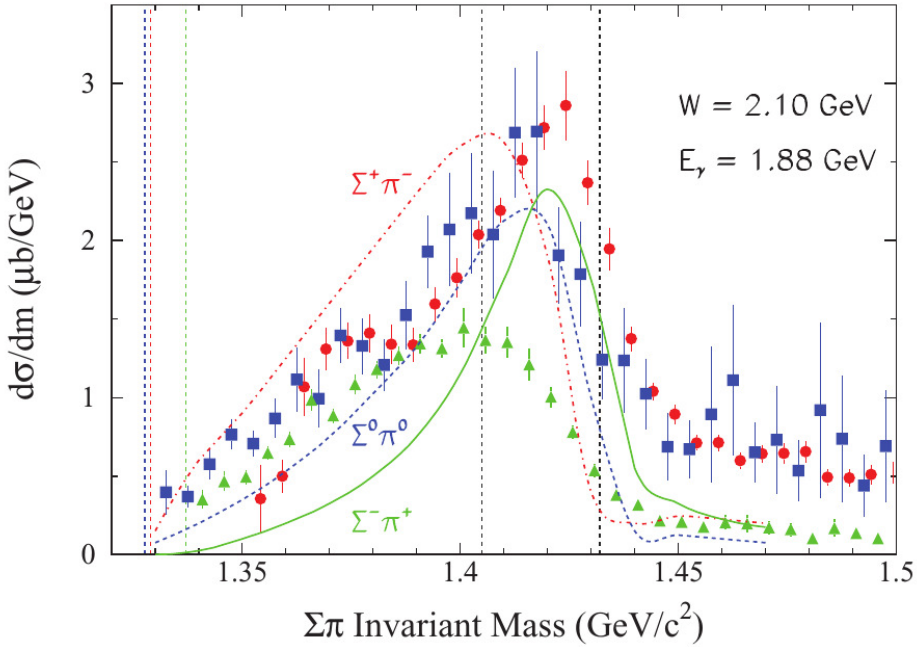
1. Motivation - Similarities in the *uds* sector?

Moving back to the “light” strange quark sector!

1. Motivation - Structure of the Λ(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)



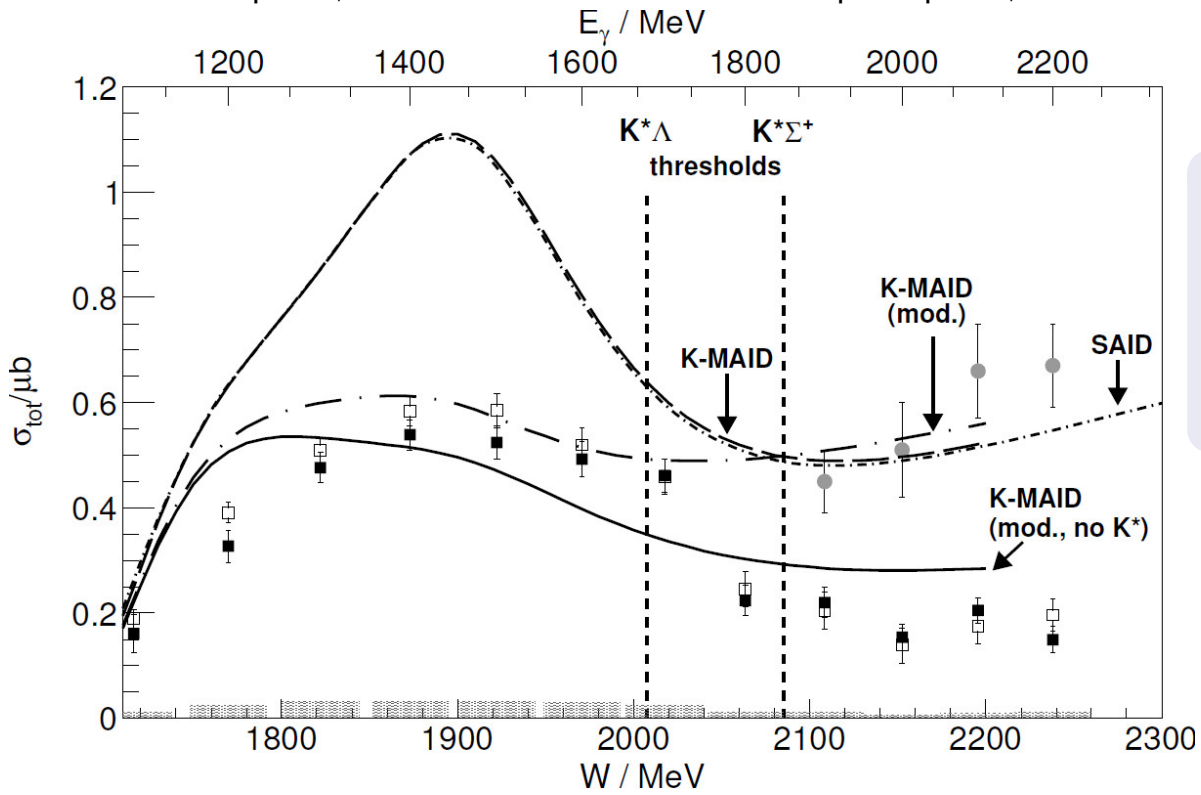
- Λ(1405) - dynamically generated by meson-baryon interactions?

  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 $\gamma p \to K^0\Sigma^+$ cross section

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

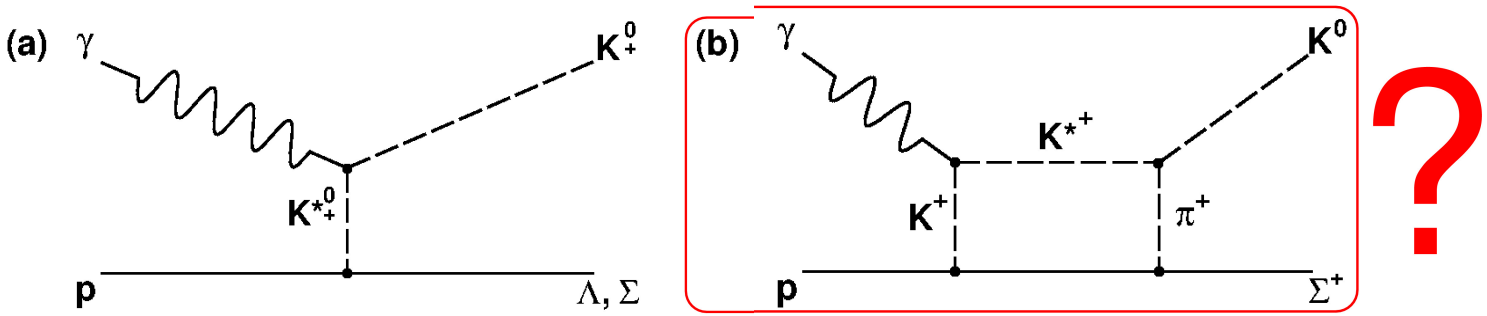
This data: Full squares, Previous CBELSA-TAPS data: open squares, Previous SAPHIR data: triangles (references therein)



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

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

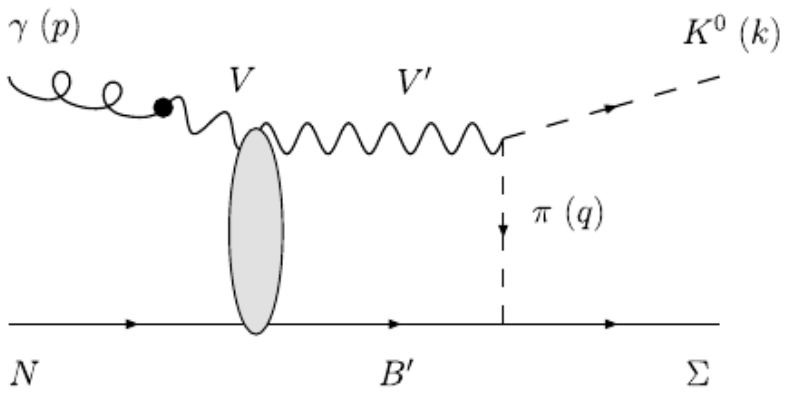
M. Nanova et al., EPJ A35, 333 (2008)



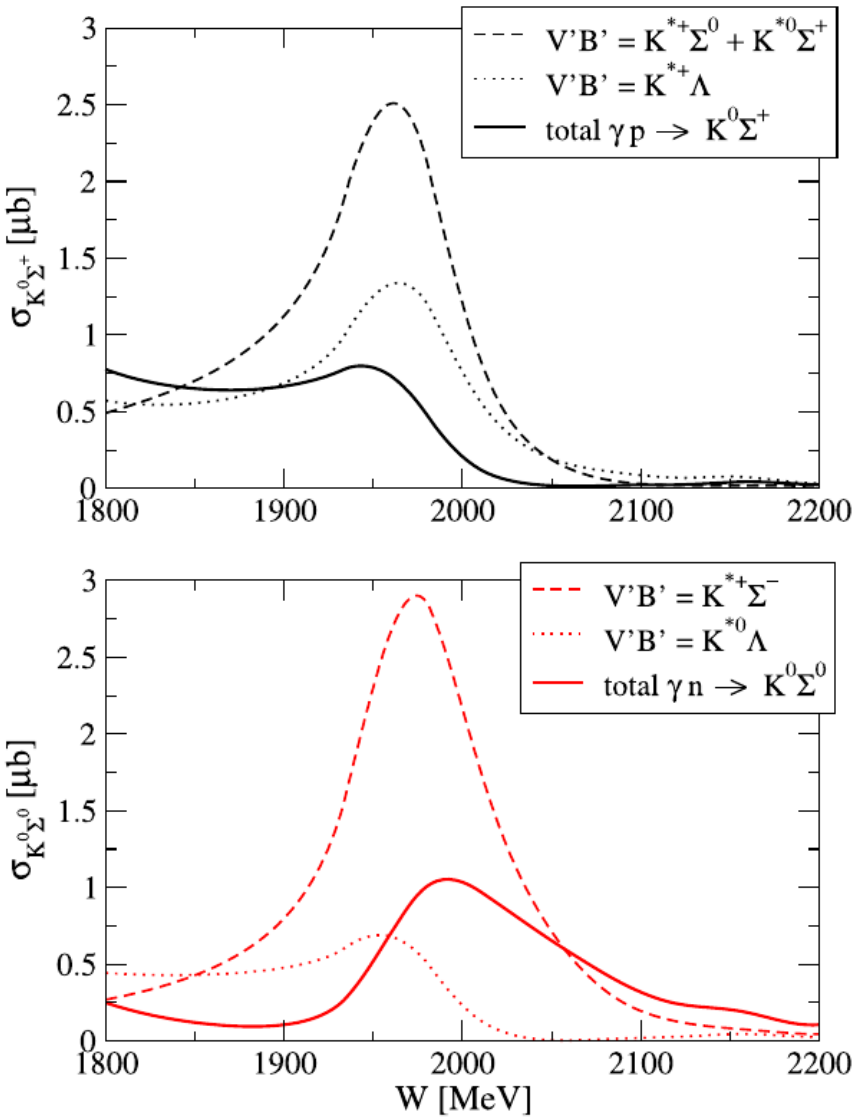
1. Motivation - K^0 photoproduction

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:

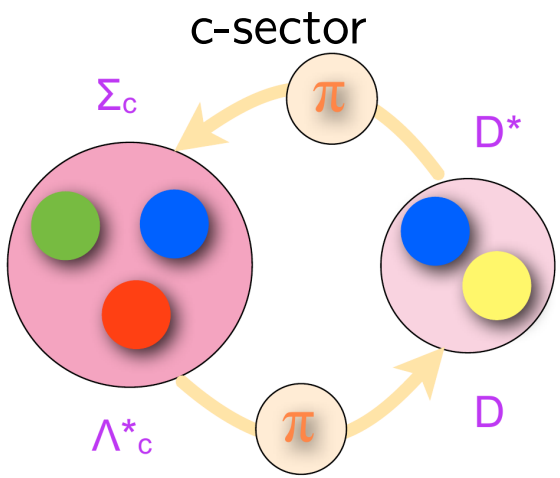


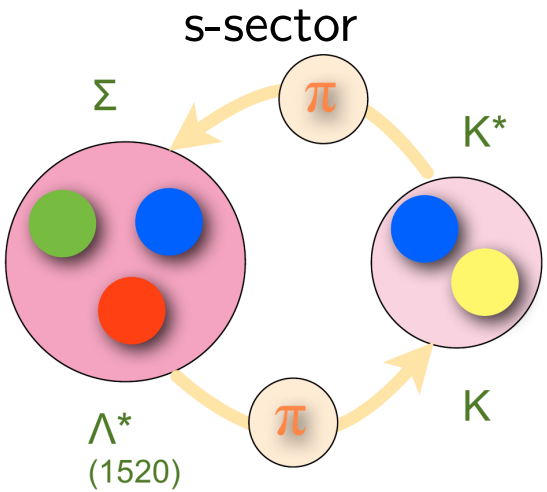
Off the neutron (bottom)

1. Motivation - Parallels between charmed & strange sectors

Table from H. Schmieden, private communication (2018)

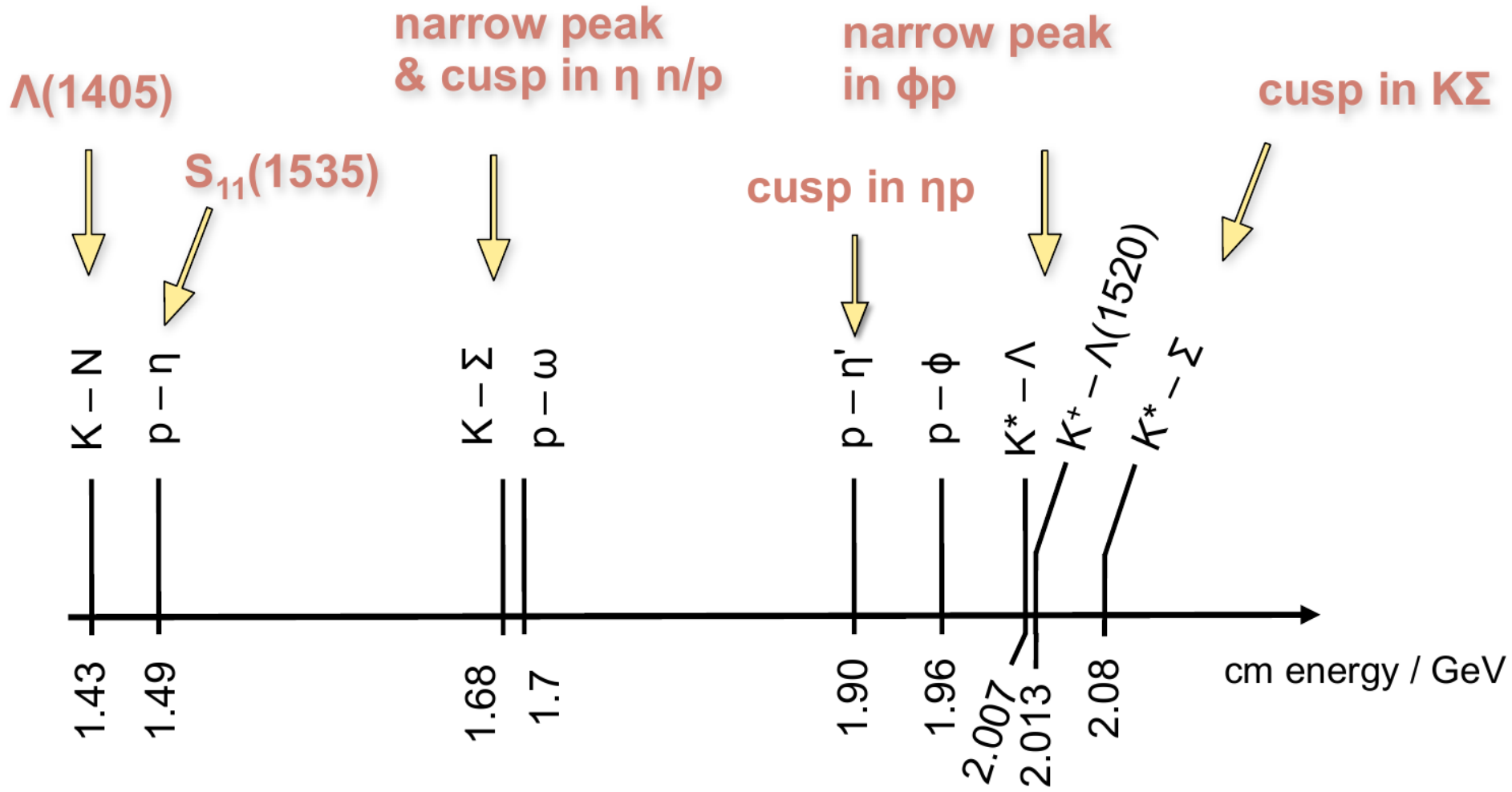
	c-sector		s-sector	
	meson	baryon(s)	meson	baryon(s)
state(s)	$X(3872)$	$P_c^*(4380/4450)$	$f_1(1420)$	$N^*(2030/2080)$
π-exchange transition	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D} + \Sigma_c\bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
quantum nos.	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$
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 channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp





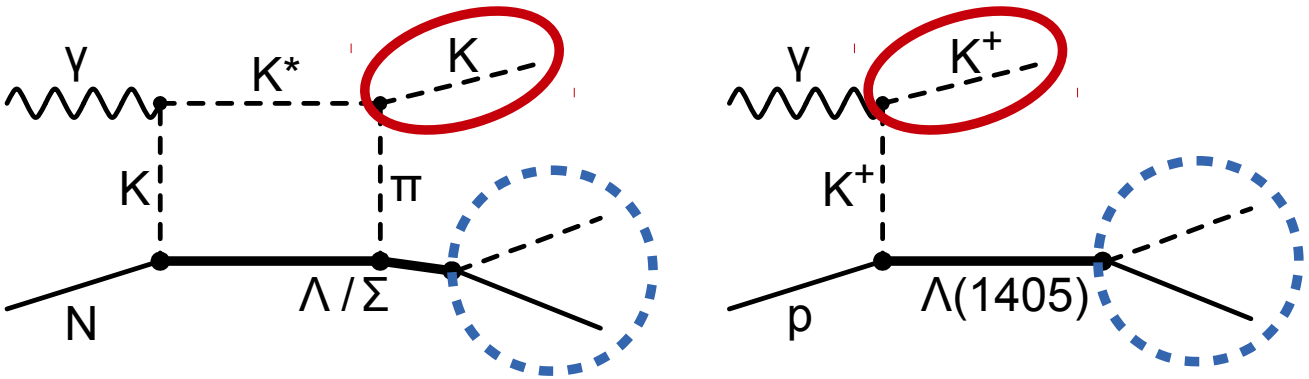
1. Motivation - Threshold dynamics

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).

BGO-OD at the ELSA facility, Bonn

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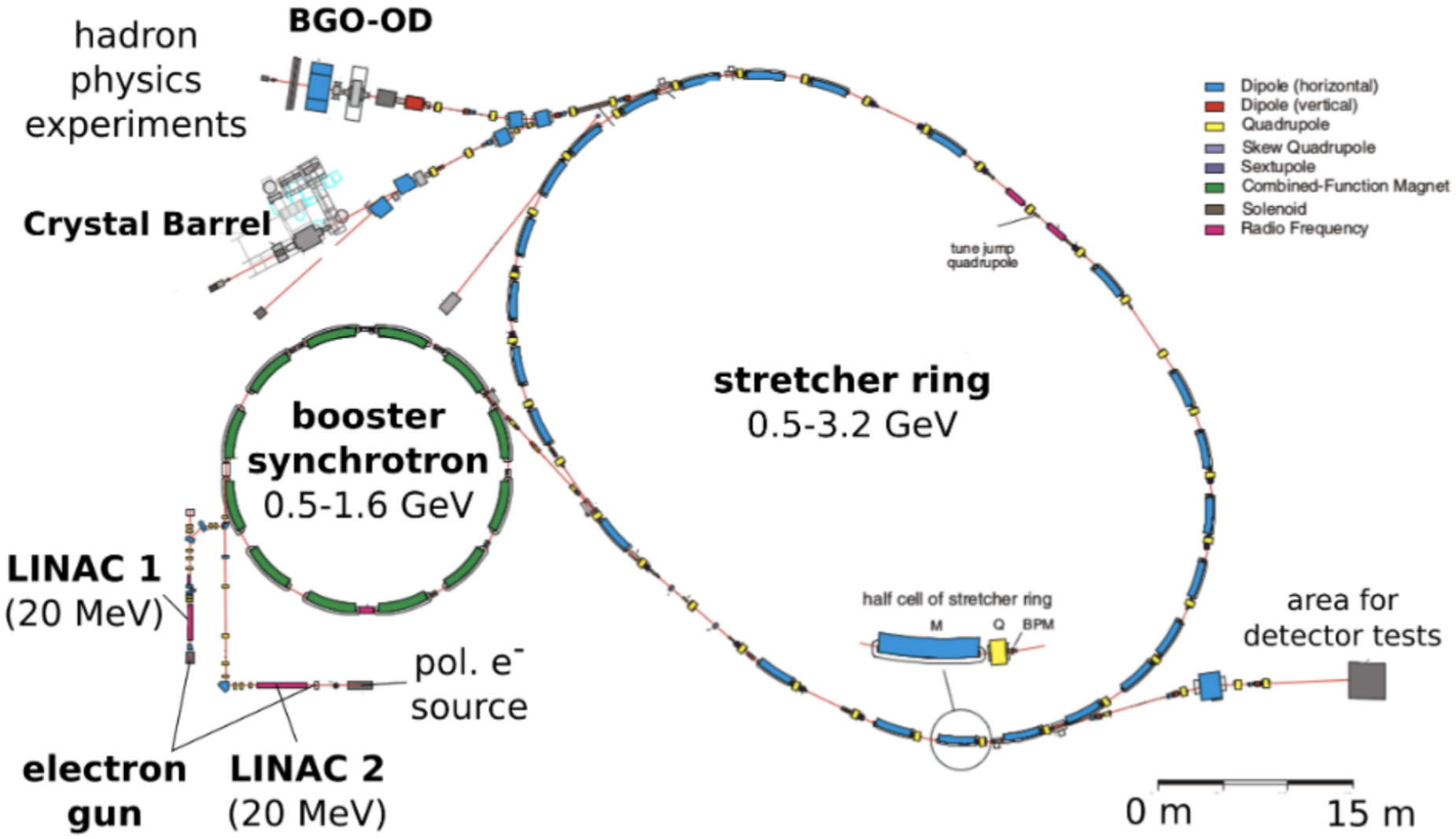
2. The Electron Stretcher Accelerator (ELSA)

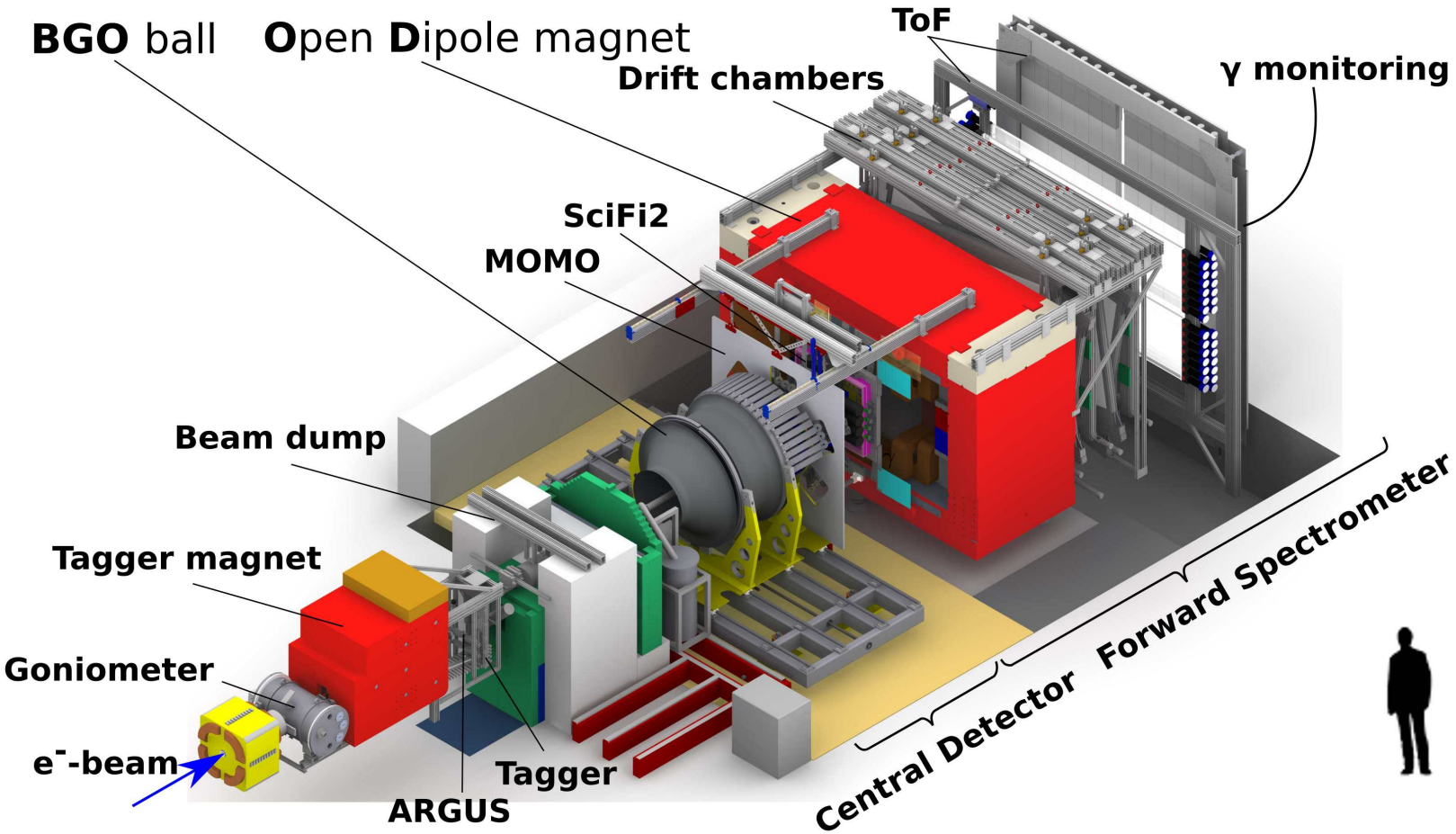
A 3 stage e^- accelerator delivering continuous electron beams up to ~ 3.2 GeV



2. The BGO-OD experiment at ELSA

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

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



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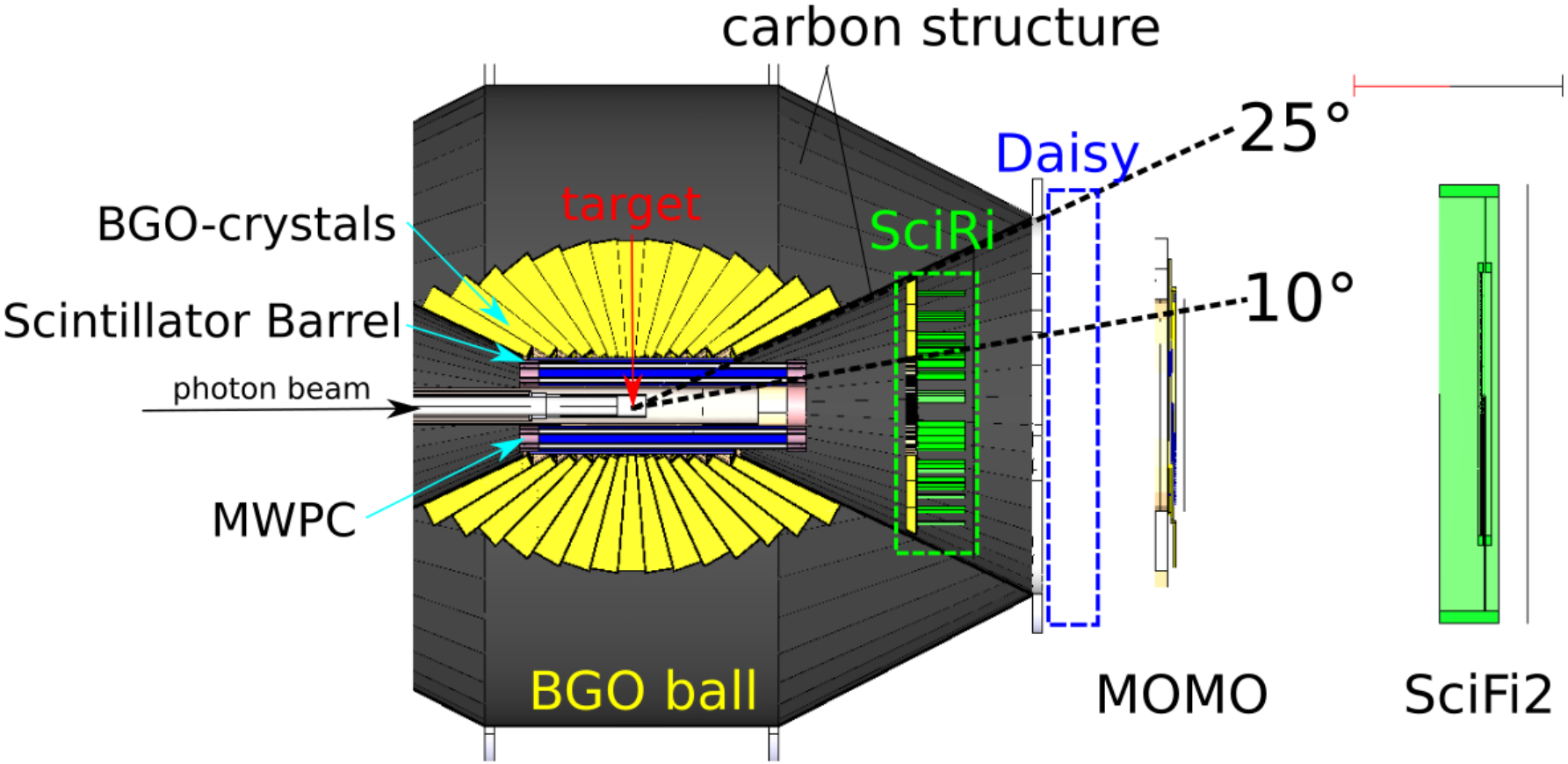

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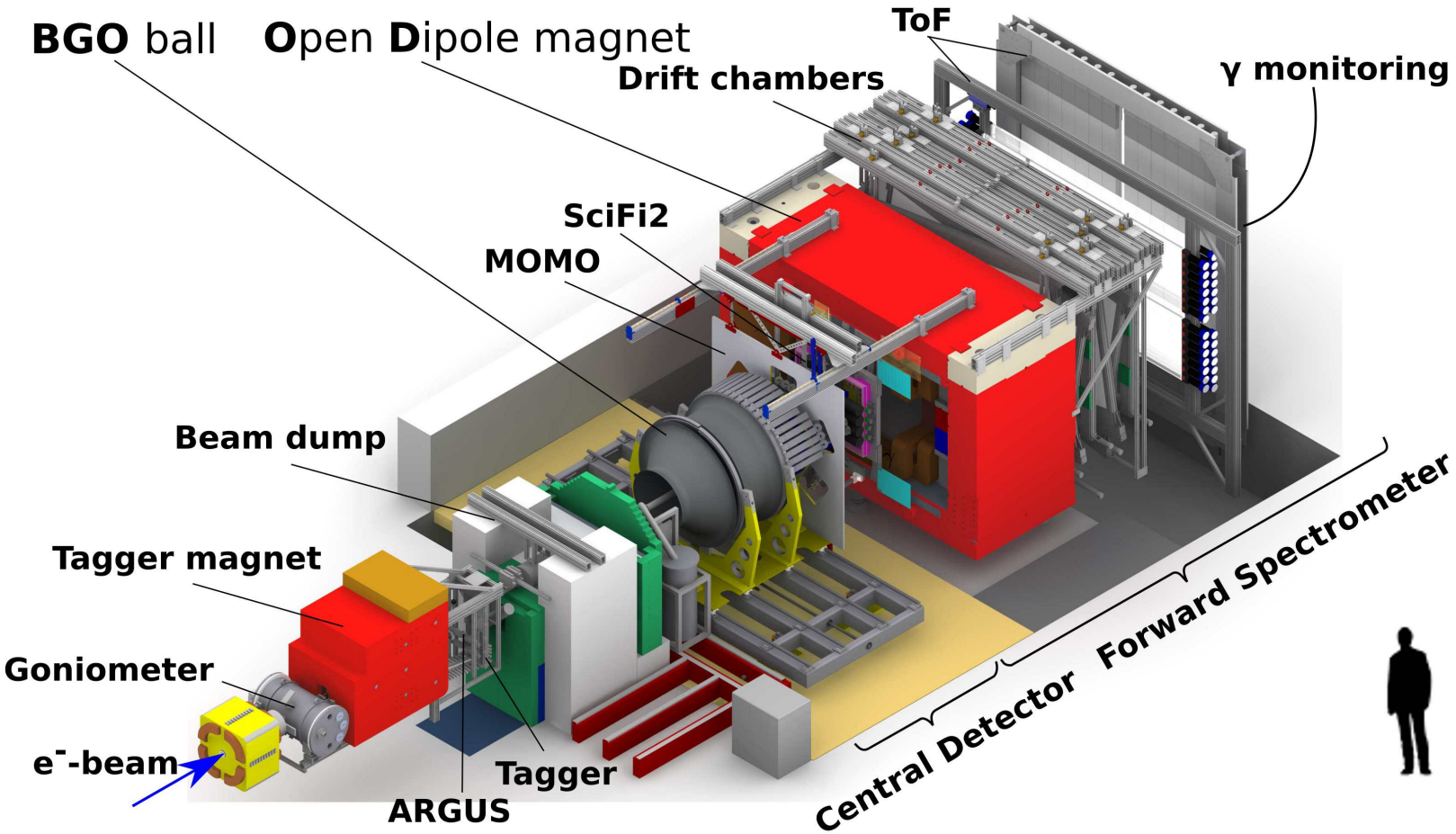
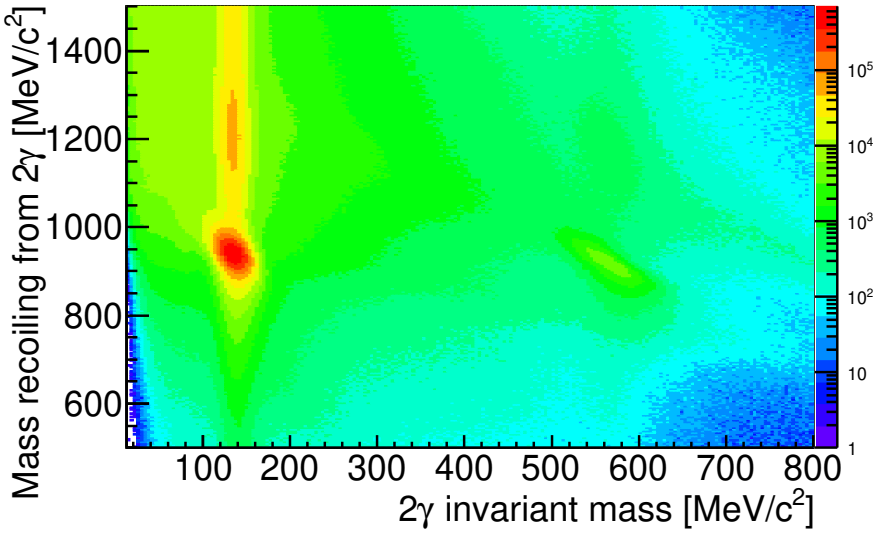
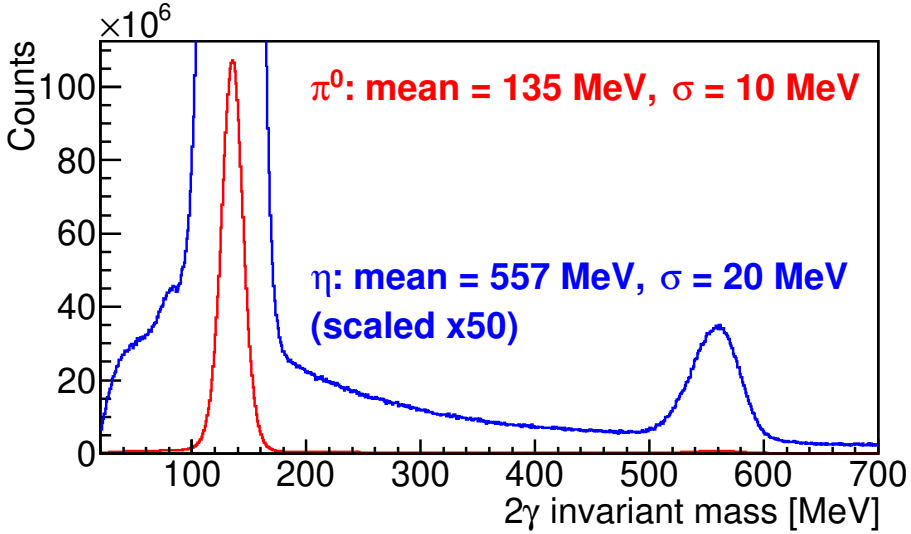


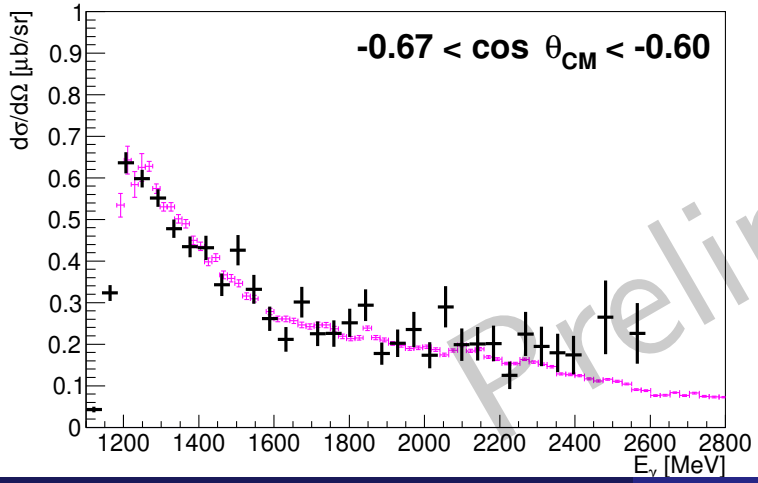
2. BGO-OD Detector performance - central region

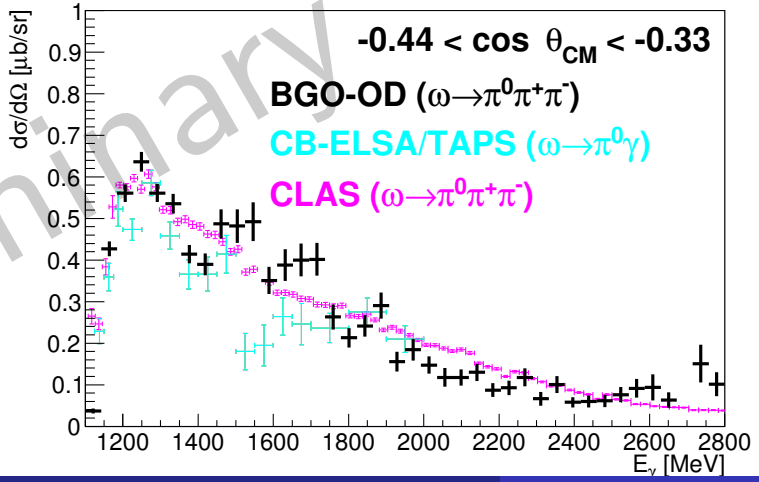
- Neutral meson reconstruction in the BGO - $\pi^0 \to \gamma\gamma$ & $\eta \to \gamma\gamma$





Demonstration - $\gamma p \to \omega p$ $d\sigma/d\Omega$ via $\omega \to \pi^0\pi^+\pi^-$ (G. Scheluchin PhD thesis)





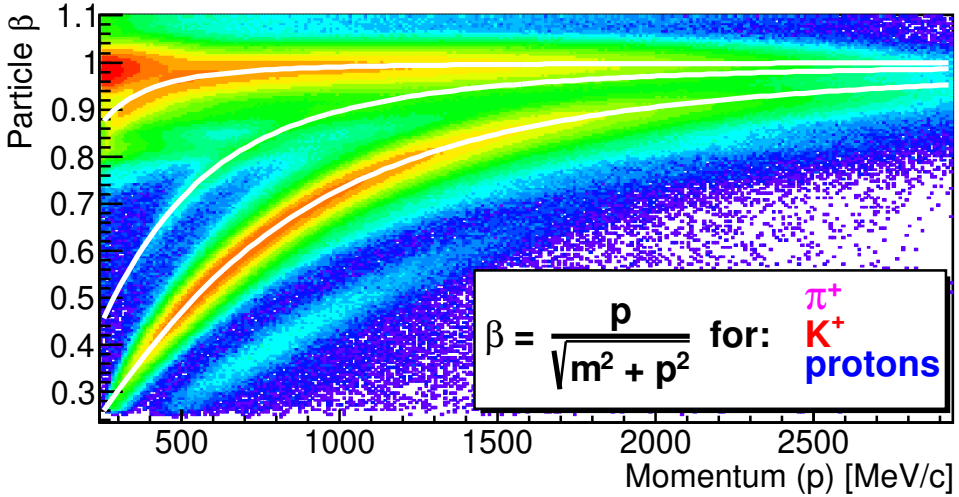
Preliminary

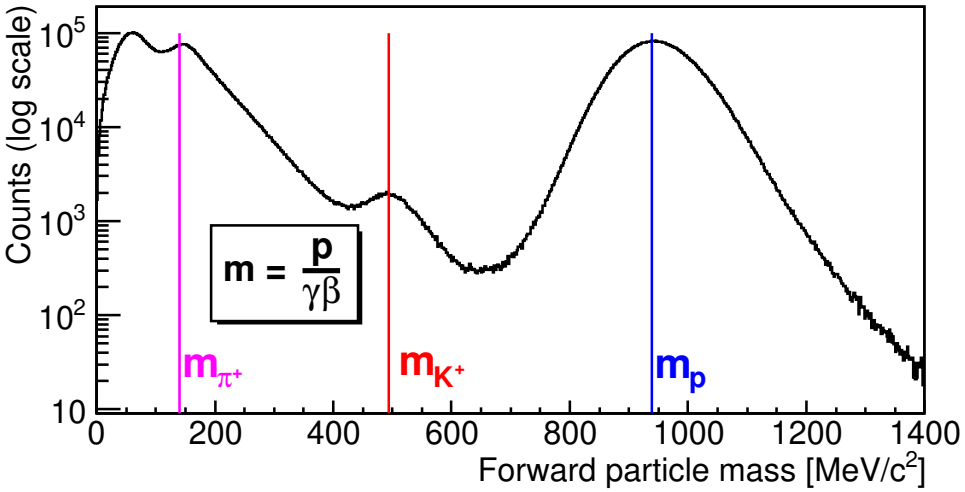
F. Dietz *et al.* (CB-ELSA/TAPS), Eur. Phys. J. **A** **51**, 6 (2015)

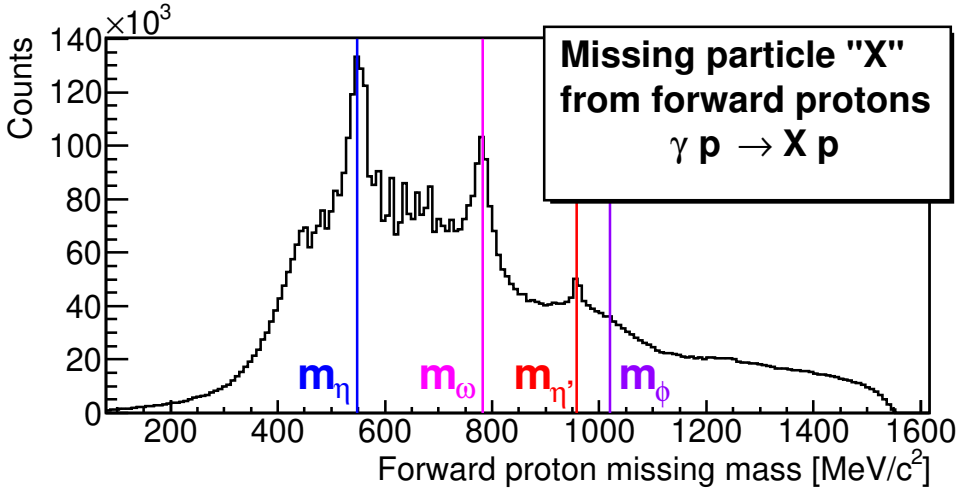
M. Williams *et al.* (CLAS), Phys. Rev. **C** **80**, 065208 (2009)

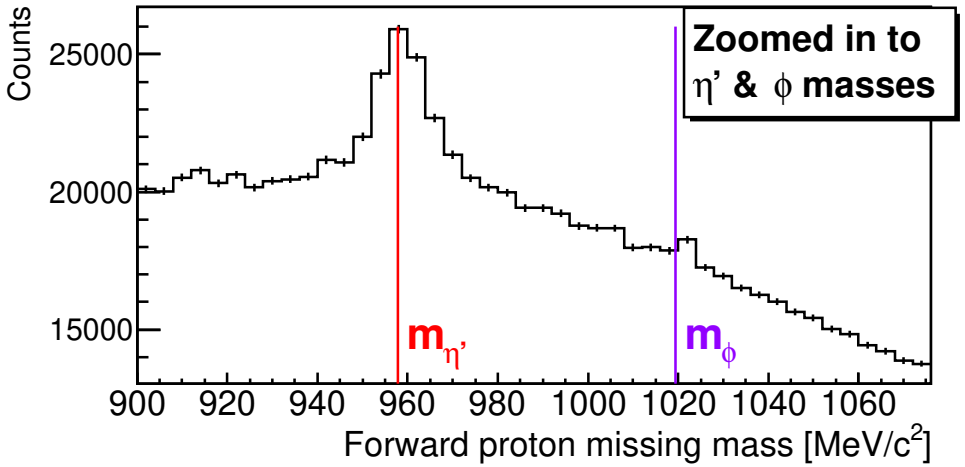
2. BGO-OD Detector performance - forward spectrometer

Particle identification & "Missing mass" from forward protons









Strangeness photoproduction at the BGO-OD experiment

1. Introduction
2. Motivation: Exotic hadron structure - parallels in strange & charmed quark sectors?
3. The BGO-OD experiment at ELSA, Bonn
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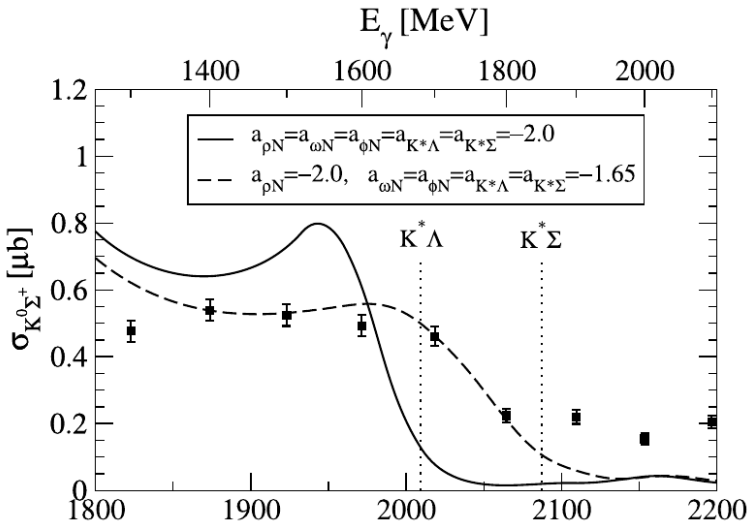
   - K^0 photoproduction off proton & neutron (deuterium) targets
   - Extreme forward cross sections for K^+Y and excited hyperons
   - Future opportunities with BGO-OD

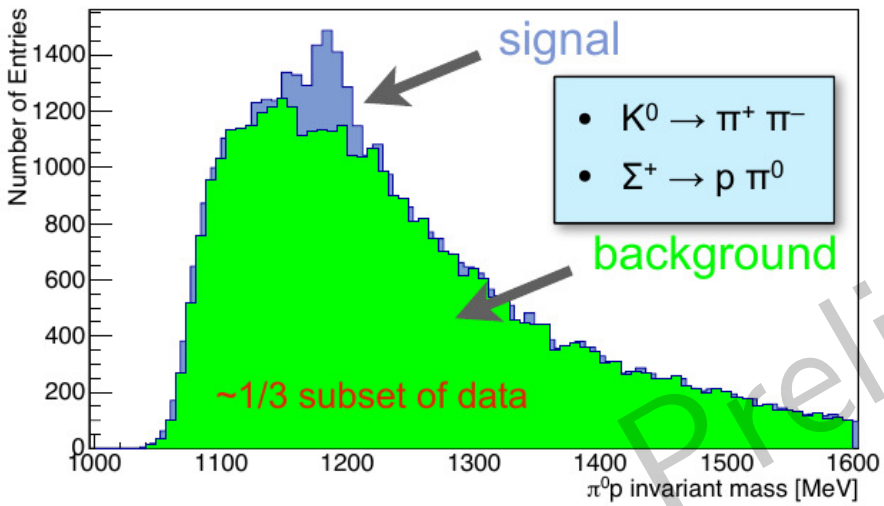
3. First results - Identification of $K^0\Sigma^+$ with BGO-OD

- Cusp-like structure in the cross section. K^{*0} subthreshold production rescattering to π^0 & K^0?
- Access $\gamma p \to K^0\Sigma^+$ via different decay modes!
- K^0 decay vertex determination with MWPC (analysis underway)

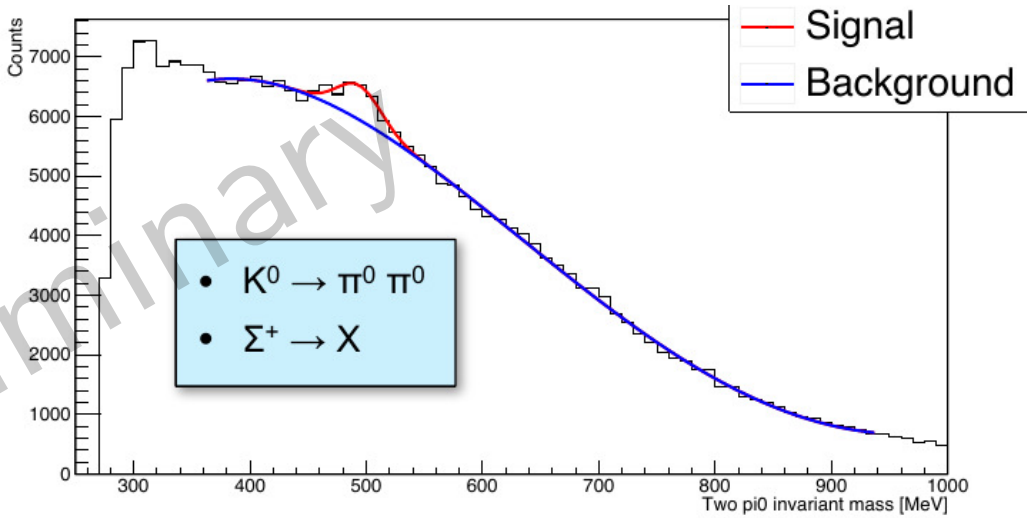


A. Ramos & E. Oset, Phys. Lett. **B 727**, (2013) 287

B. -E Reitz PhD thesis work



S. Alef PhD thesis work



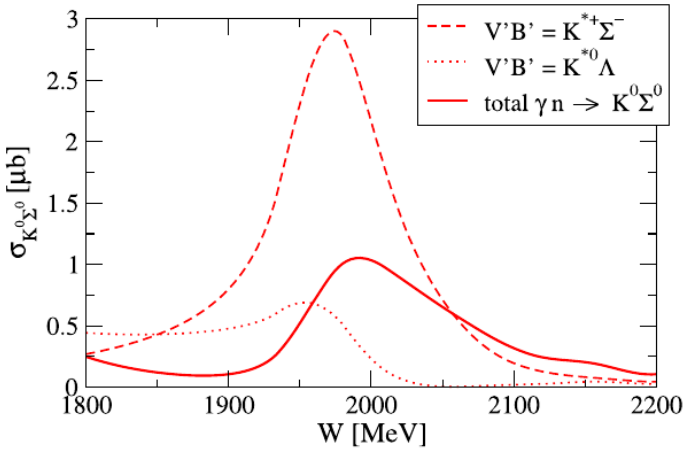
Preliminary

3. First results - $\gamma n(p) \to K^0\Sigma^0$ using a deuterium target

Peak predicted - "smoking gun" for reaction mechanism!

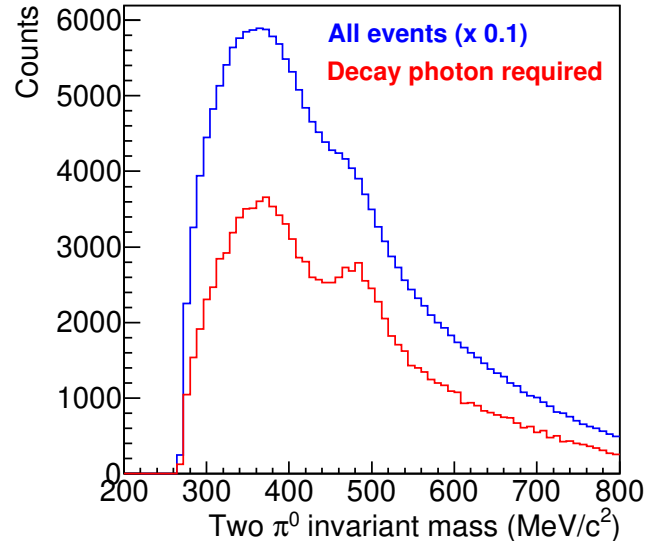
A. Ramos and E. Oset, Phys. Lett. **B 727**, (2013) 287

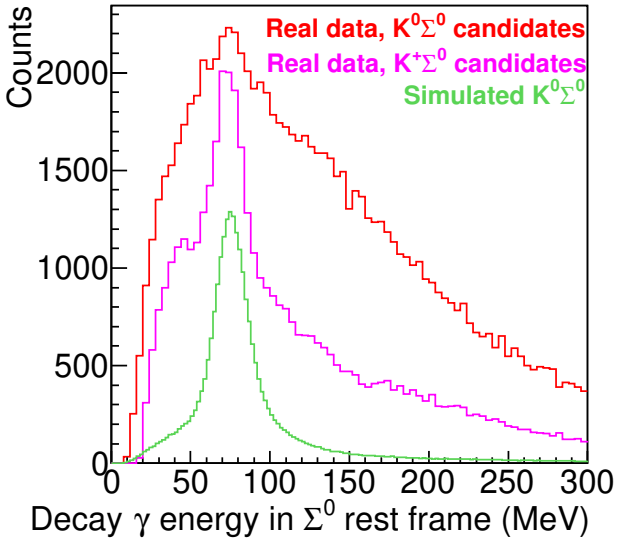
K. Kohl PhD thesis analysis - 18:00, parallel session C today



$\gamma n(p) \to K^0\Sigma^0$ at BGO-OD

- $K^0 \to 2\pi^0$ in the BGO
- γ from $\Sigma^0 \to \gamma\Lambda$: $\Sigma^0 - \Lambda$ mass difference (Σ^0 rest frame)

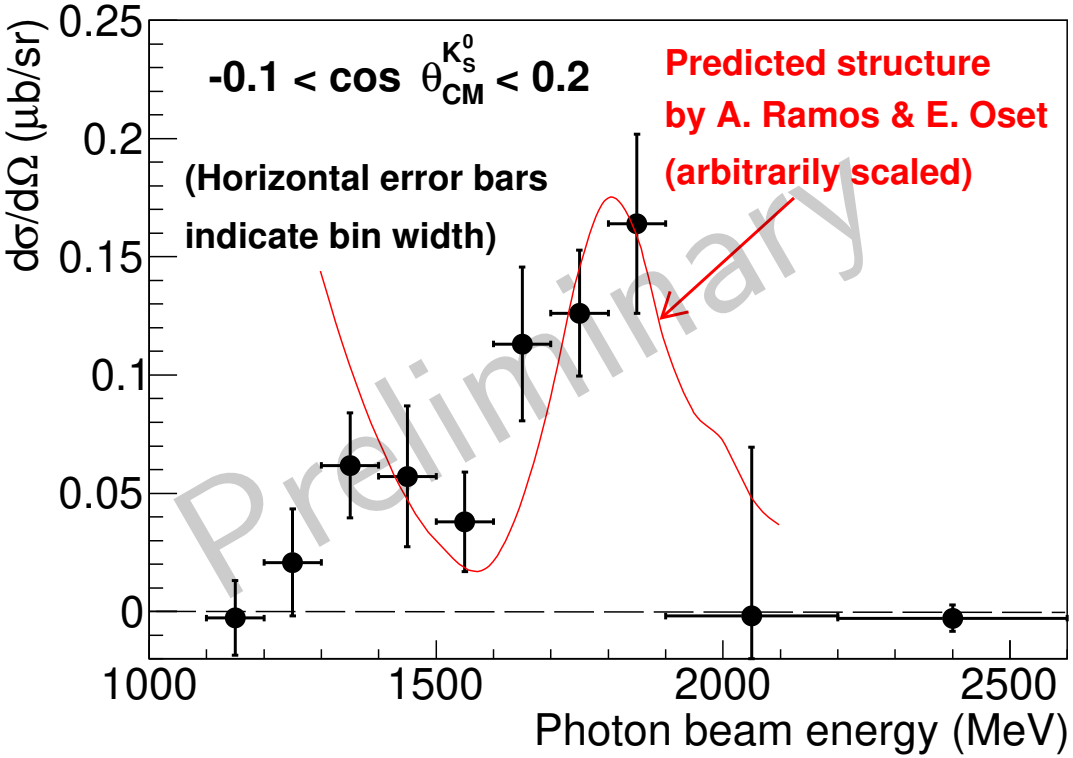




3. First results - $\gamma n(p) \rightarrow K^0\Sigma^0$ using a deuterium target

K. Kohl PhD thesis analysis - 18:00, parallel session C today

- Consistent with prediction from coherent interference of vector meson-baryon dynamically generated resonances



Identification via $K^0 \rightarrow \pi^+\pi^-$

B.E Reitz PhD thesis analysis

- Detached decay vertex ID using the MWPC ($c\tau \sim 2.7$ cm)
- Improve statistics & forward acceptance

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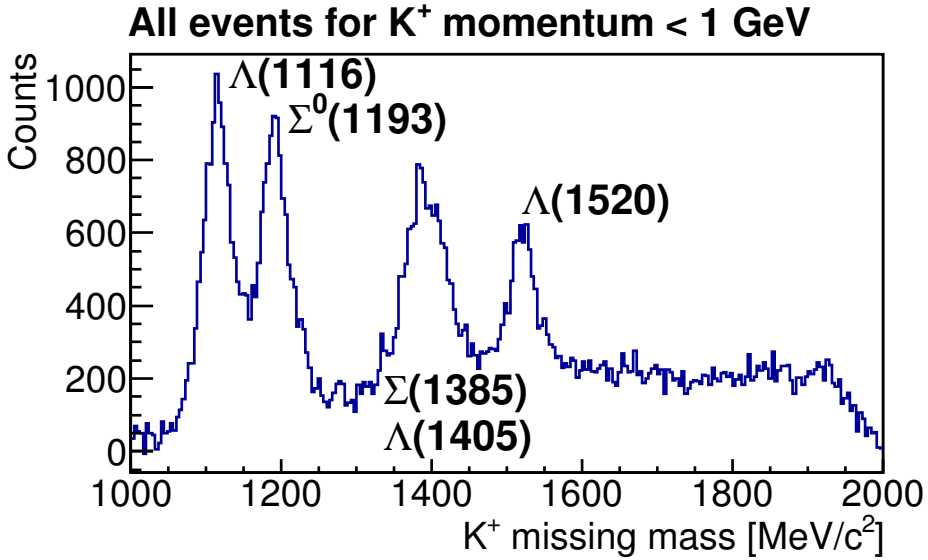
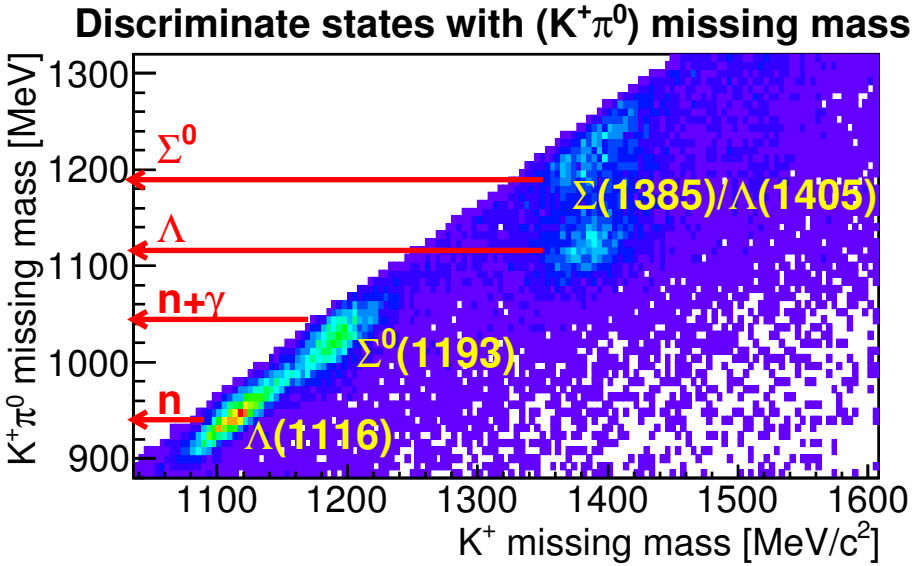
3. First results - Mass recoiling from forward K^+

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





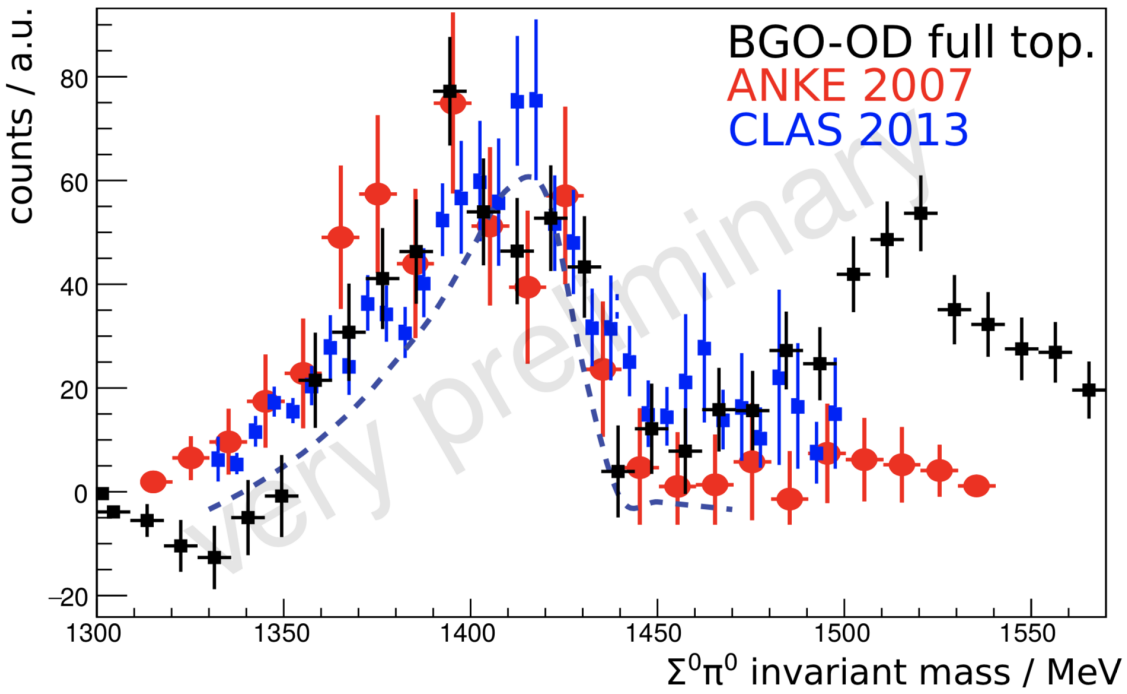
Identify Y^* states from $K^+\pi^0$ recoiling mass

- $K^+\Lambda \rightarrow K^+\pi^0 n$ (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)

3. First results - $\gamma p \to K^+(\Lambda(1405) \to \Sigma^0\pi^0)$

G. Scheluchin PhD thesis analysis - 16:30, parallel session C today

- Line shape for $\Lambda(1405) \to \Sigma^0\pi^0$
- High statistics data with access to low momentum transfer (forward) region



CLAS: K. Moriya, R. A. Schumacher et al Phys. Rev. C 87, 035206 (2013)

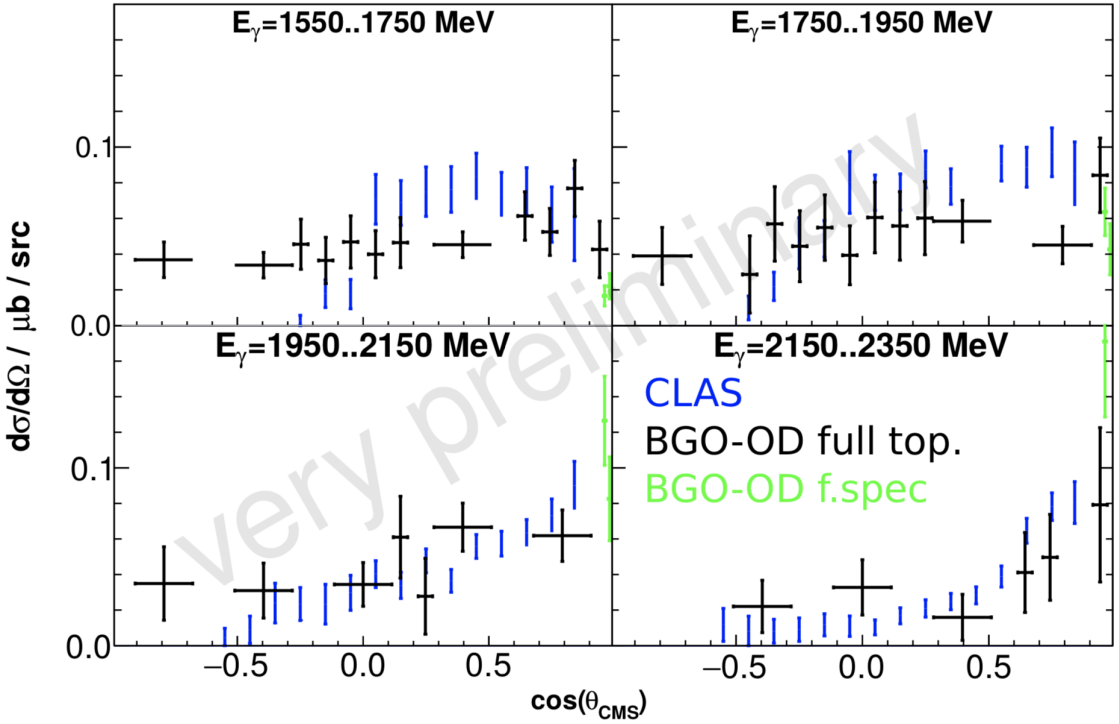
ANKE: I. Zychor et al, Phys. Lett. B 660, 167 (2008)

Dashed line: J.C. Nacher et al. Phys.Lett. B455, 55 (1999)

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

G. Scheluchin PhD thesis analysis - 16:30, parallel session C today

- Differential cross section for $\Lambda(1405) \rightarrow \Sigma^0\pi^0$
- Two data sets -
  - Full topology using all detectors (black points)
  - High momentum resolution at forward angles (green points)

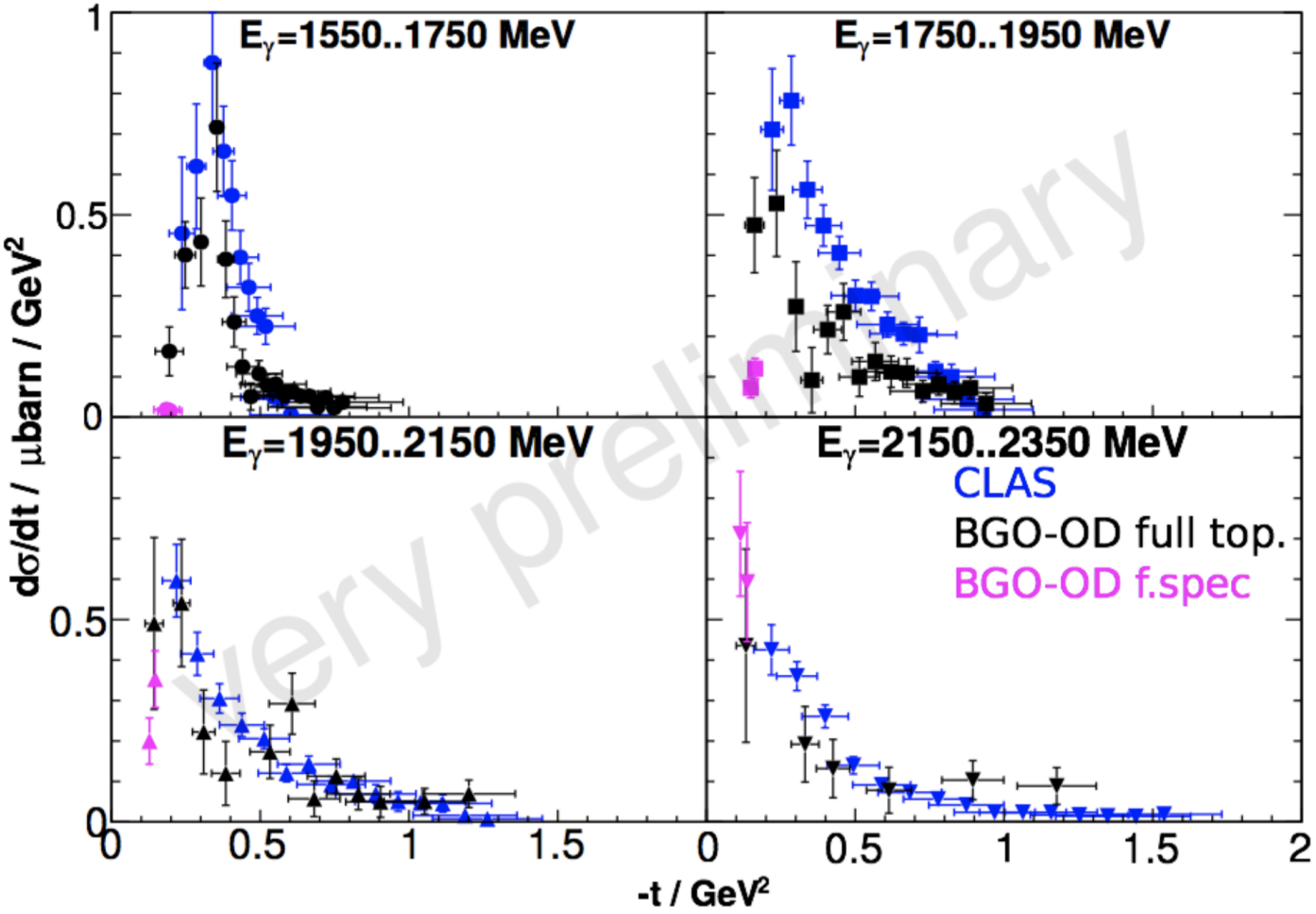


CLAS: K. Moriya, R. A. Schumacher et al Phys. Rev. C 87, 035206 (2013)

3. First results - $\gamma p \to K^+(\Lambda(1405) \to \Sigma^0\pi^0)$

G. Scheluchin PhD thesis analysis - 16:30, parallel session C today

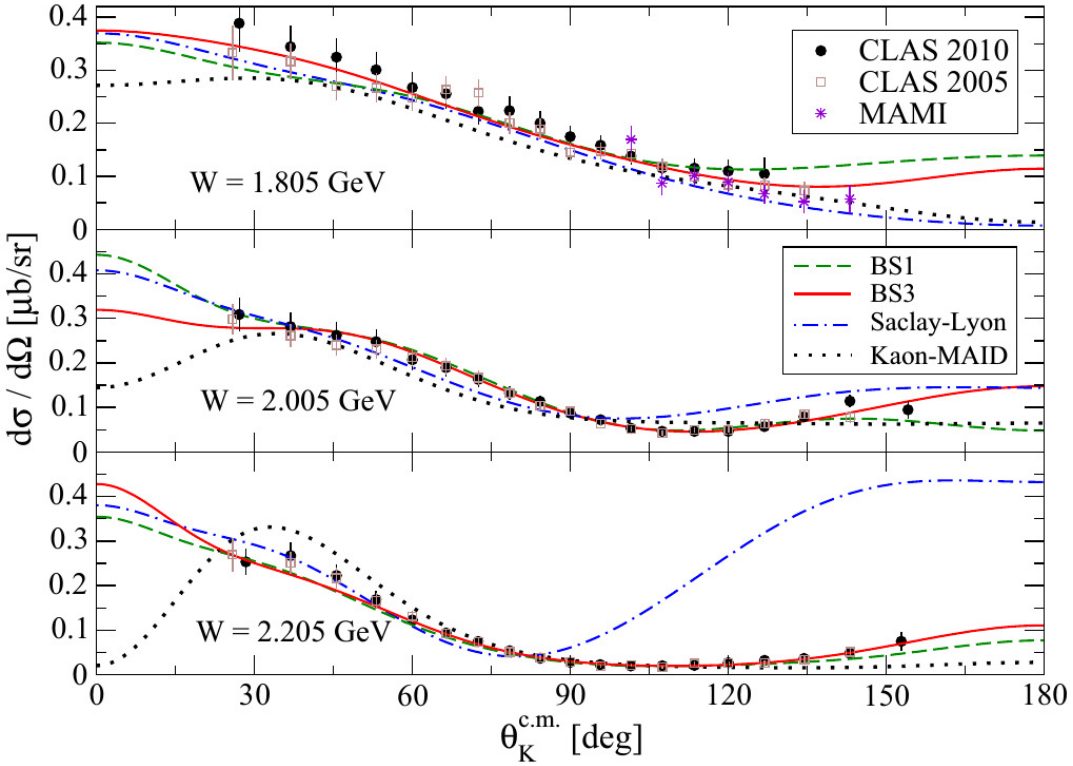
- Differential cross section vs $\sqrt{t}$ for $\Lambda(1405) \to \Sigma^0\pi^0$



CLAS: K. Moriya, R. A. Schumacher et al Phys. Rev. C 87, 035206 (2013)

3. First results - $K^+\Lambda$ at forward angles (motivation)

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



Isobar models

- Effective meson-baryon Lagrangian
- Explicitly added resonances: > 20 for strangeness photoproduction!

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

MAMI - T. C. Jude et al., Phys. Lett. B 735, 112 (2014)

CLAS 2005 - R. Bradford et al., Phys. Rev. C 73, 035202 (2006)

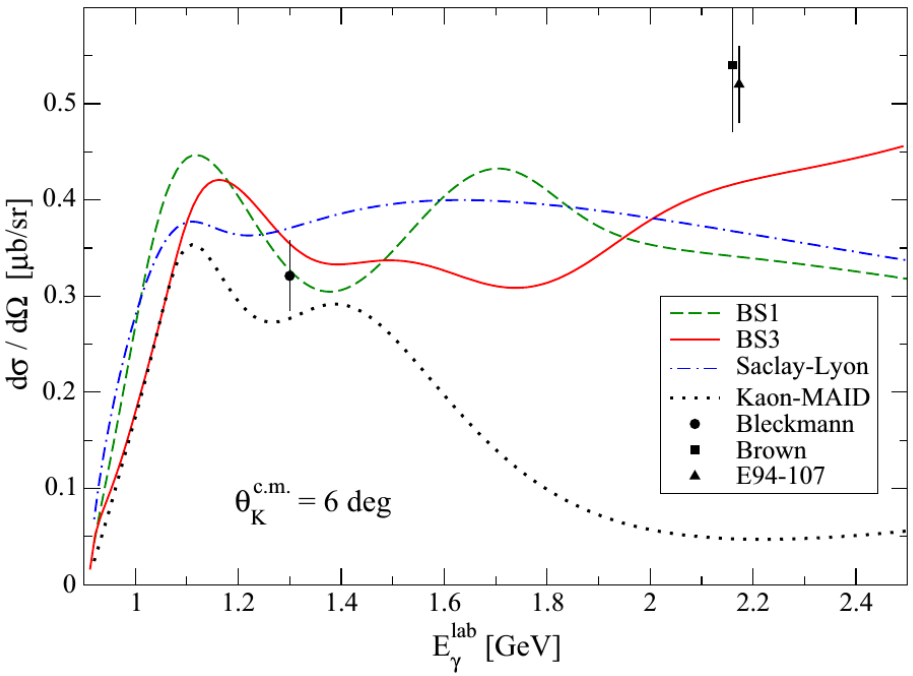
CLAS 2010 - M. E. McCracken et al., Phys. Rev. C 81, 025201 (2010)

3. First results - $K^+\Lambda$ at forward angles (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)

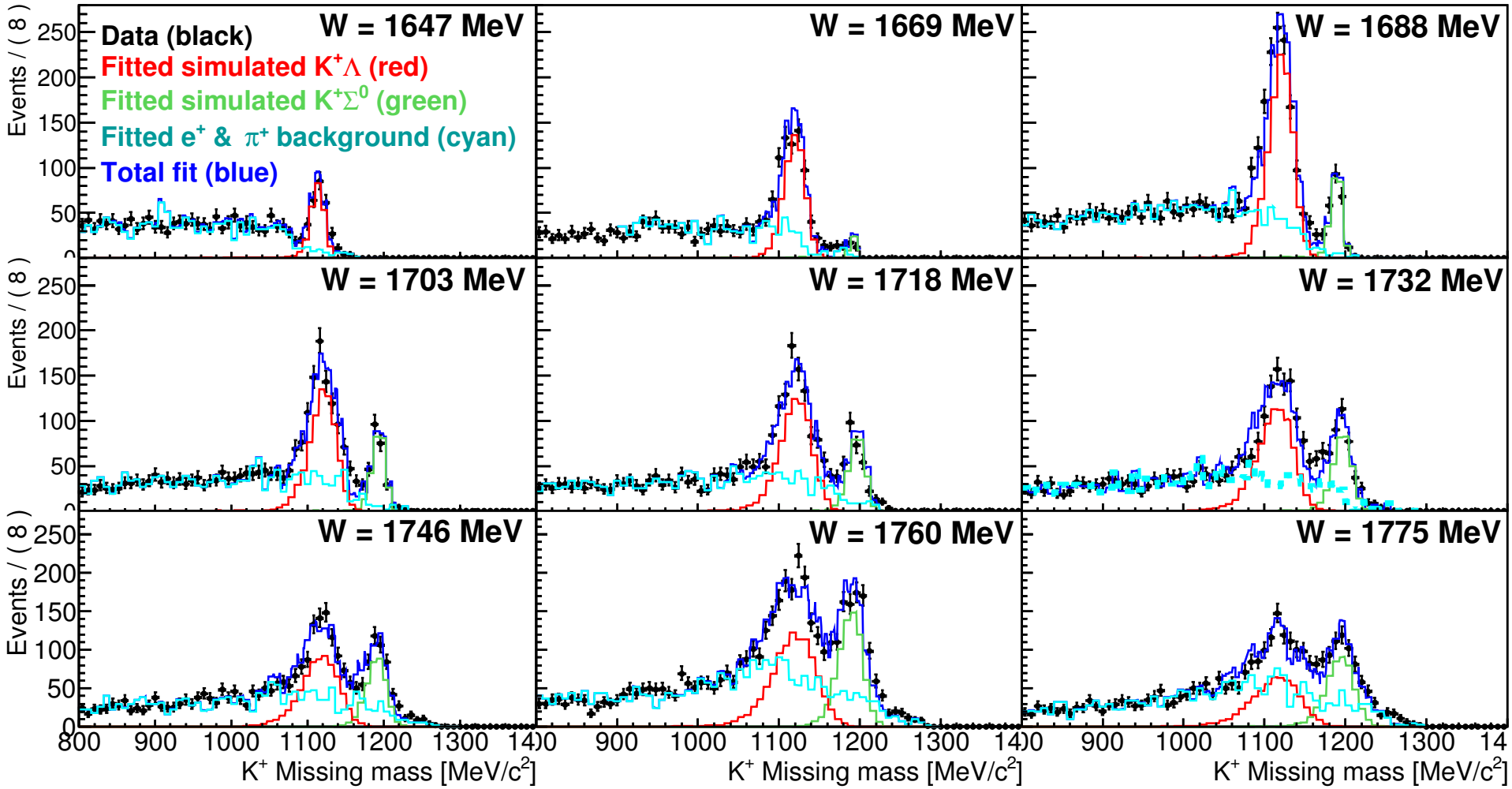


D. Skoupil, P. Bydzovsky, Phys. Rev. **C97**, 025202 (2018)

At BGO-OD

- Forward CM polar angle range approx. 3-26^0, $0.9 < \cos\theta_{cm}^{K^+} < 1.0$
- Unprecedented $\theta_{cm}^{K^+}$ resolution ($< 1^0$)!

3. First results - Forward K^+ Missing mass



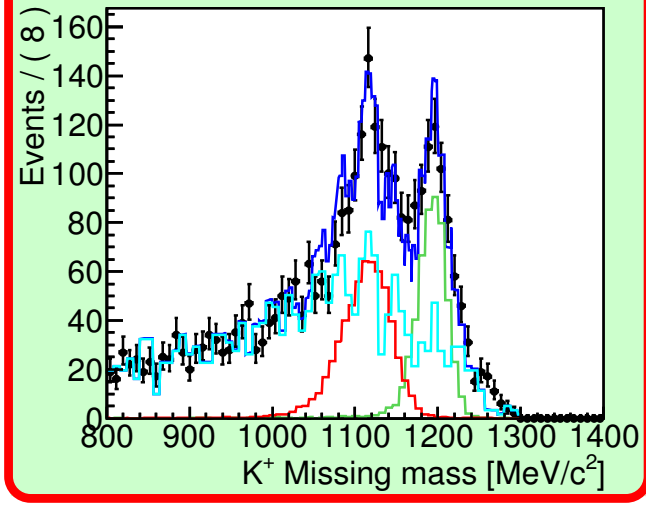
Distribution of e^+ & π^+ background determined by comparison to e^- and π^-

Fitting routines using *RooFit* https://root.cern.ch/roofit

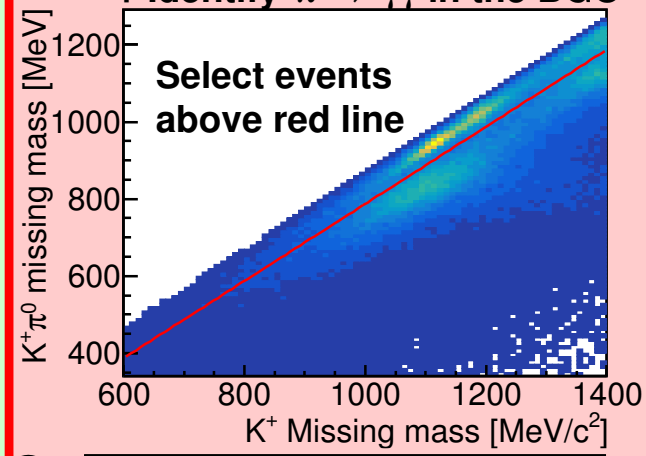
3. First results - Forward K^+: different selection cuts

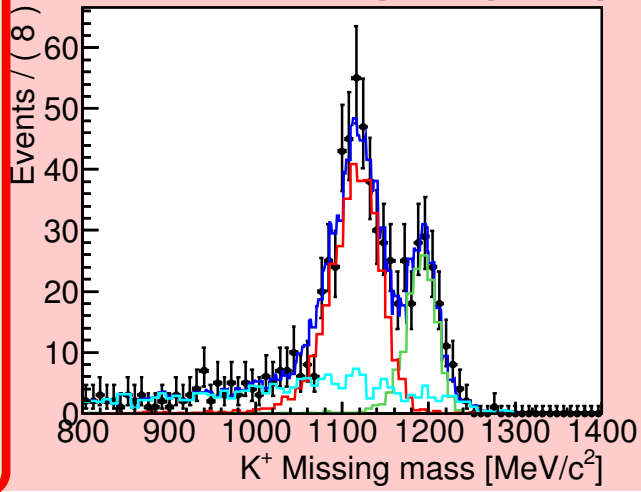
Option 1: Standard analysis

Missing mass from forward K^+
W = 1789 (beam energy 1236 MeV)
Select $\pm 2\sigma$ forward K^+ mass

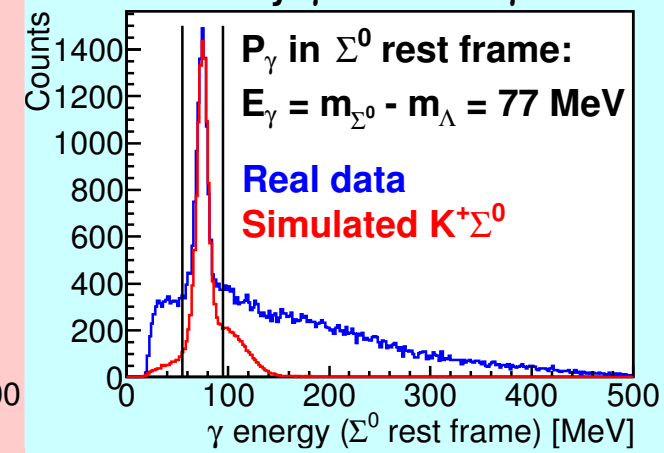


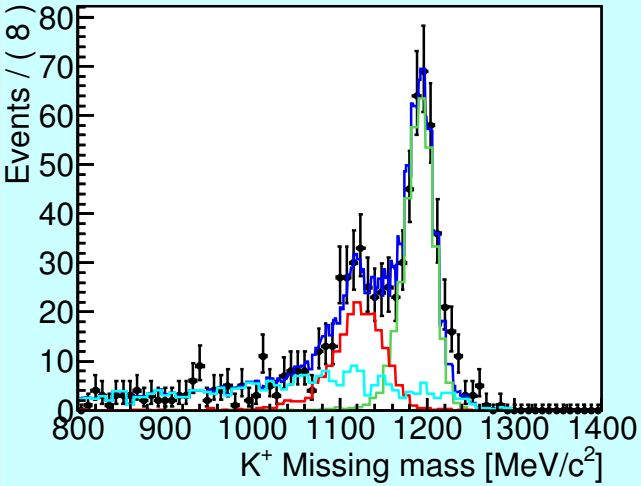
+ Identify $\pi^0 \rightarrow \gamma\gamma$ in the BGO





+ Identify γ from $\Sigma^0 \rightarrow \gamma\Lambda$

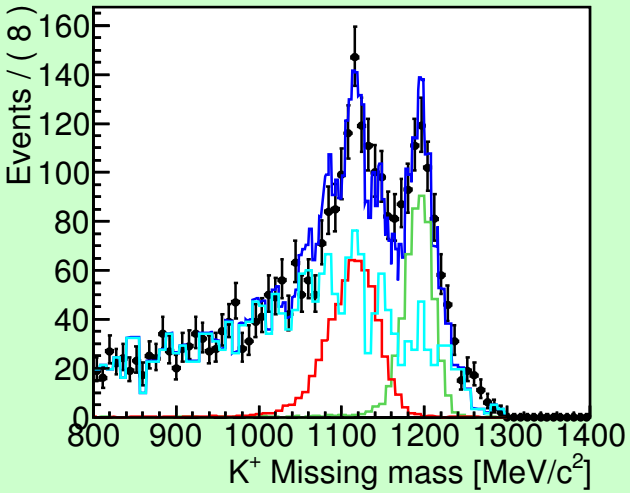




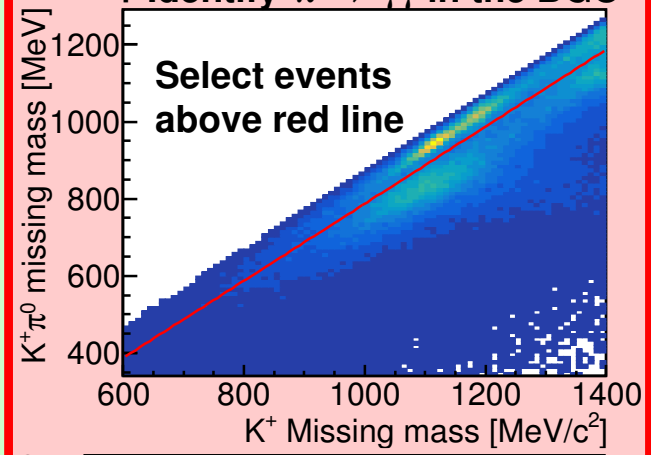
3. First results - Forward K^+: different selection cuts

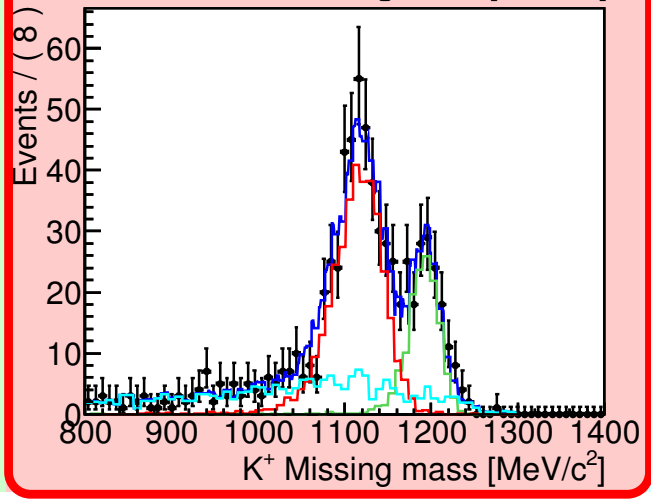
Option 2: π^0 analysis (identify $\Lambda \to \pi^0 n$)

Missing mass from forward K^+
W = 1789 (beam energy 1236 MeV)
Select $\pm 2\sigma$ forward K^+ mass

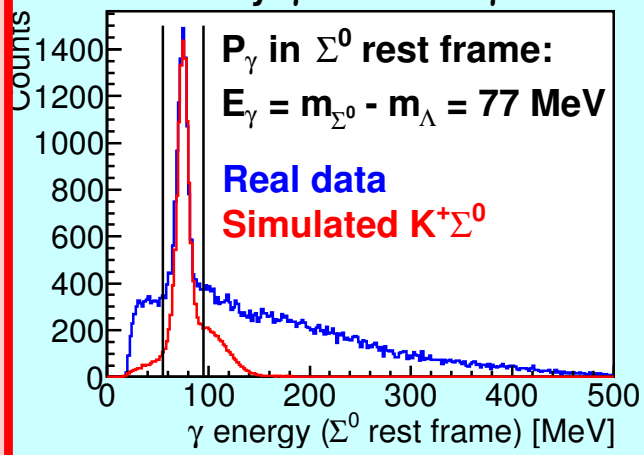


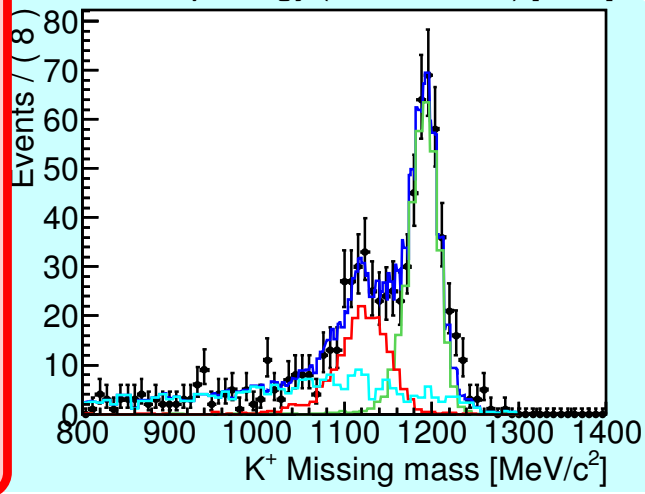
+ Identify $\pi^0 \to \gamma\gamma$ in the BGO





+ Identify γ from $\Sigma^0 \to \gamma\Lambda$

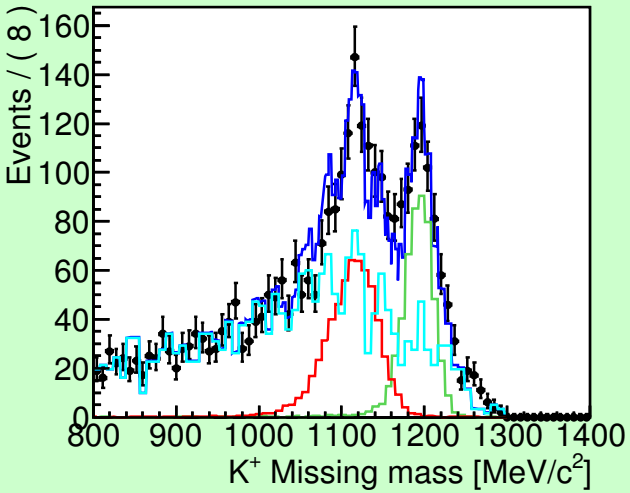




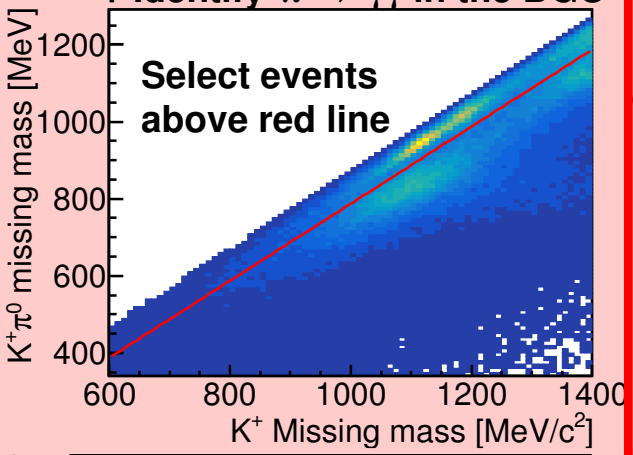
3. First results - Forward K^+: different selection cuts

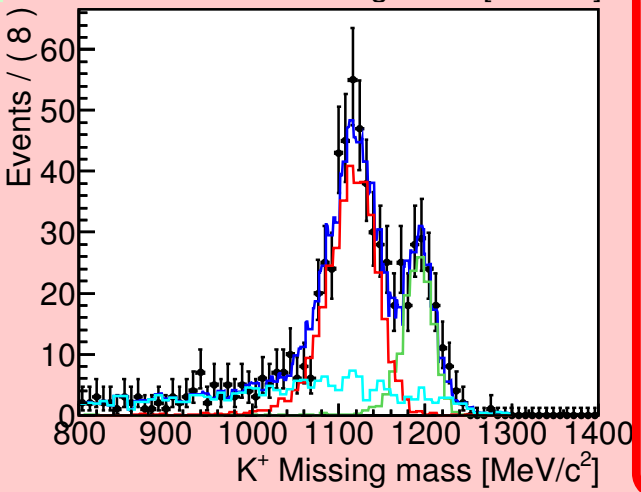
Option 3: Σ^0 decay analysis (identify $\Sigma^0 \to \gamma\Lambda$)

Missing mass from forward K^+
W = 1789 (beam energy 1236 MeV)
Select $\pm 2\sigma$ forward K^+ mass

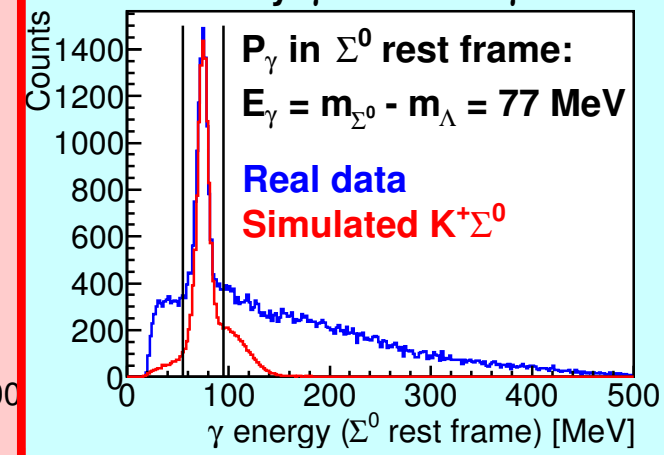


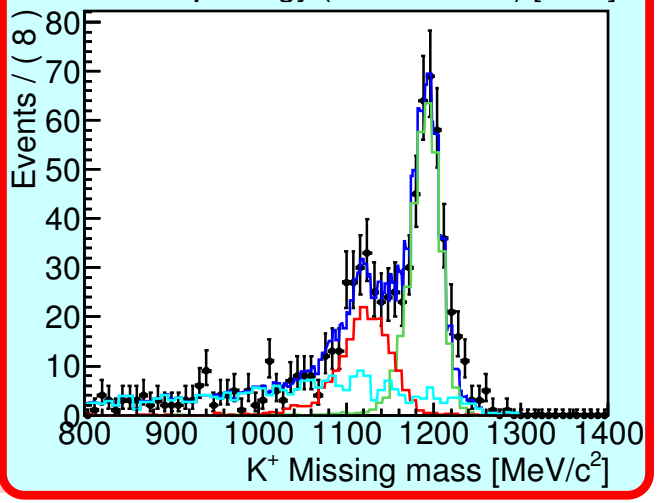
+ Identify $\pi^0 \to \gamma\gamma$ in the BGO



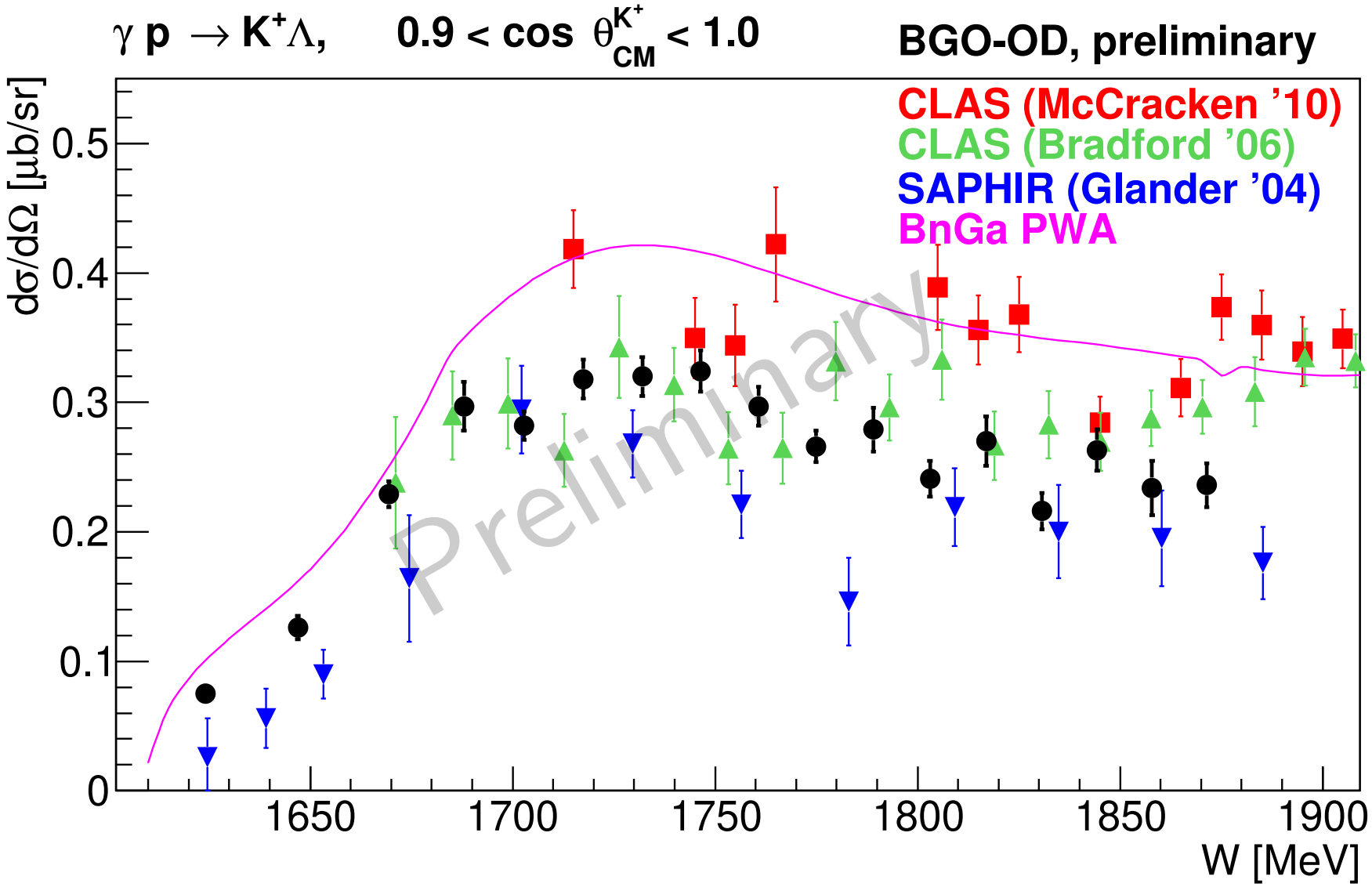


+ Identify γ from $\Sigma^0 \to \gamma\Lambda$





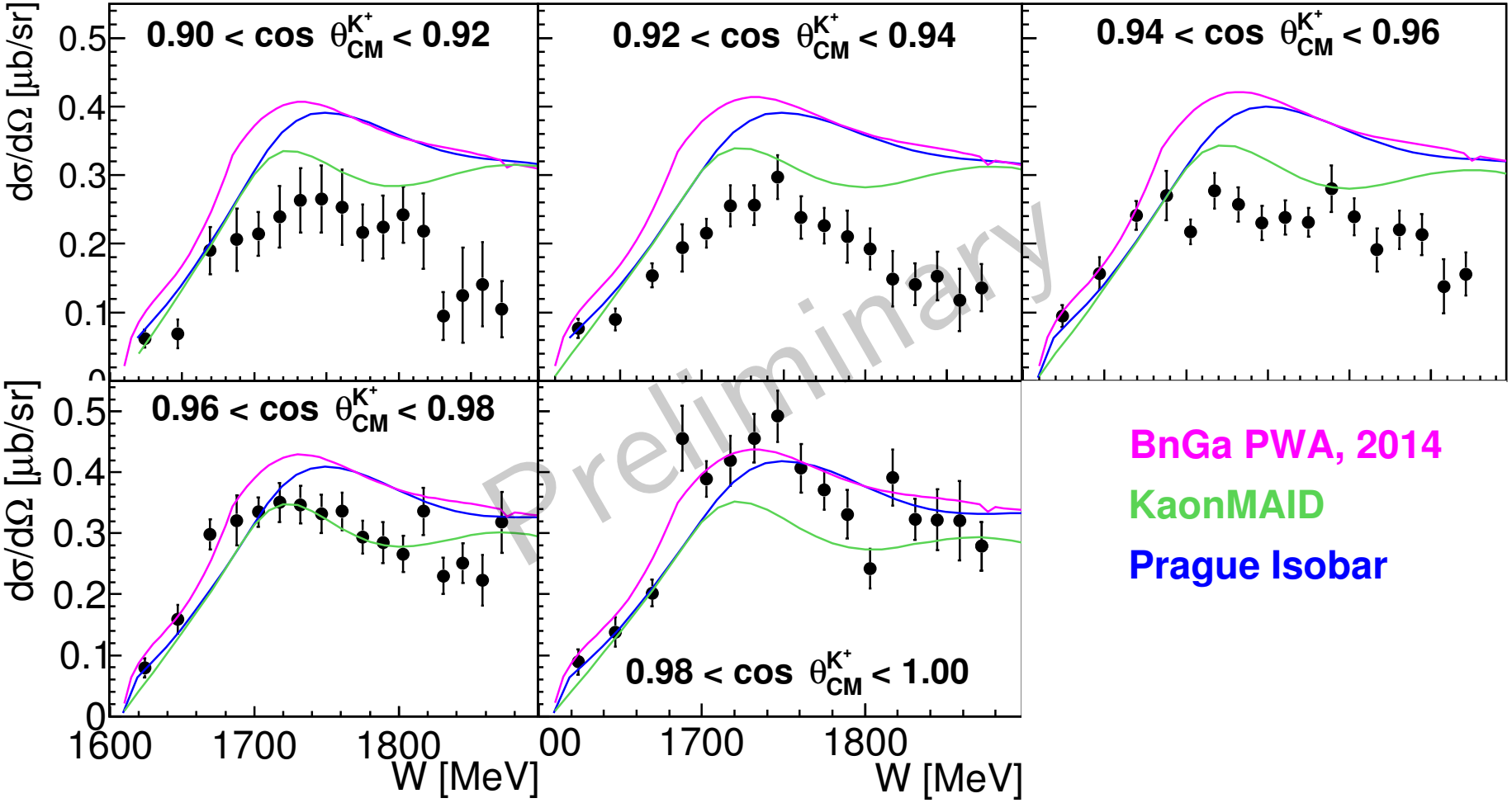
3. First results - Forward $K^+\Lambda$ differential cross sections



R. Bradford *et al.*, Phys. Rev. C73, 035202 (2006), M.E.McCracken *et al.*, Phys.Rev. C81, 025201 (2010), K.H. Glander *et al.*, Eur. Phys. J. A19, 251 (2004), Bonn-Gatchina PWA: Eur.Phys.J. A50 74 (2014) CLAS $0.85 < \cos\theta^{CM}_{K^+} < 0.95$.

3. First results - Forward $K^+\Lambda$ differential cross sections

- Unprecedented angular resolution ~ 0.01 in $\cos\theta^{K^+}_{CM}$!

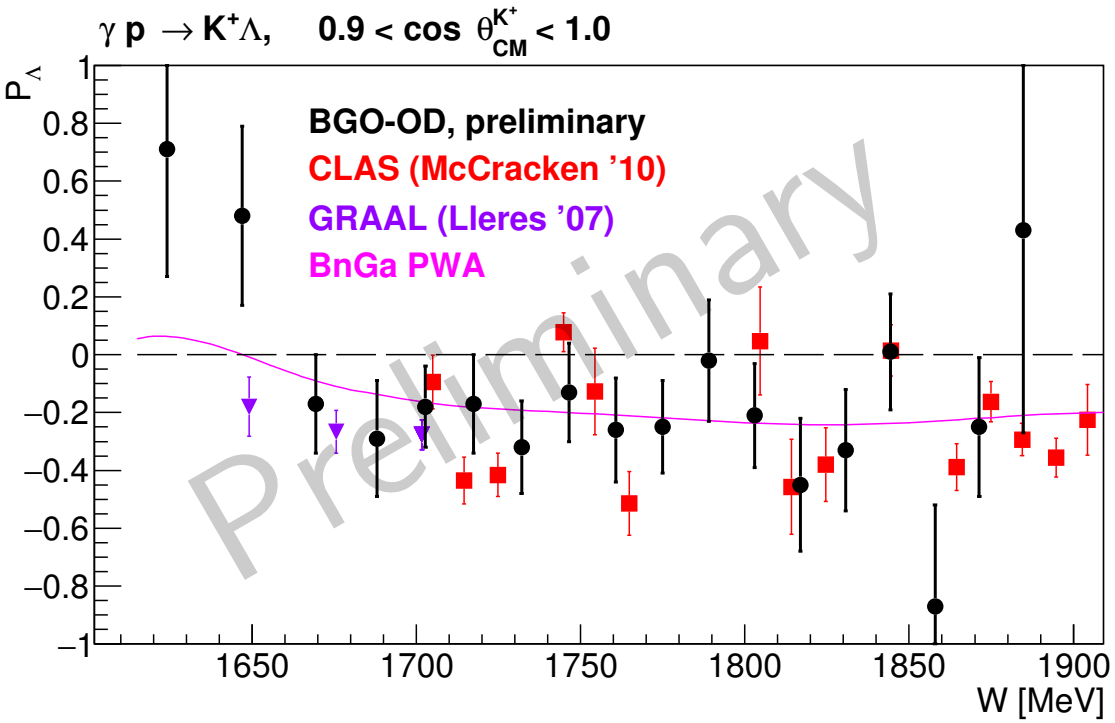


Prague Isobar model: D. Skoupil and P. Bydžovský Phys. Rev. C 97, 025202 (2018) Bonn-Gatchina PWA: Eur.Phys.J. A50 (2014) 74 KaonMAID: F.X. Lee, T. Mart, C. Bennhold, H. Haberzettl, L.E. Wright, Nucl. Phys. A695 (2001) 237

3. First results - Forward $K^+\Lambda$ recoil polarisation

First ever data set at extreme forward angles!

- 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
- $P_\Lambda = \frac{2}{\alpha} \frac{N_{\mathrm{up}} - N_{\mathrm{down}}}{N_{\mathrm{up}} + N_{\mathrm{down}}}$
- $\alpha = 0.642$ (Λ decay parameter)

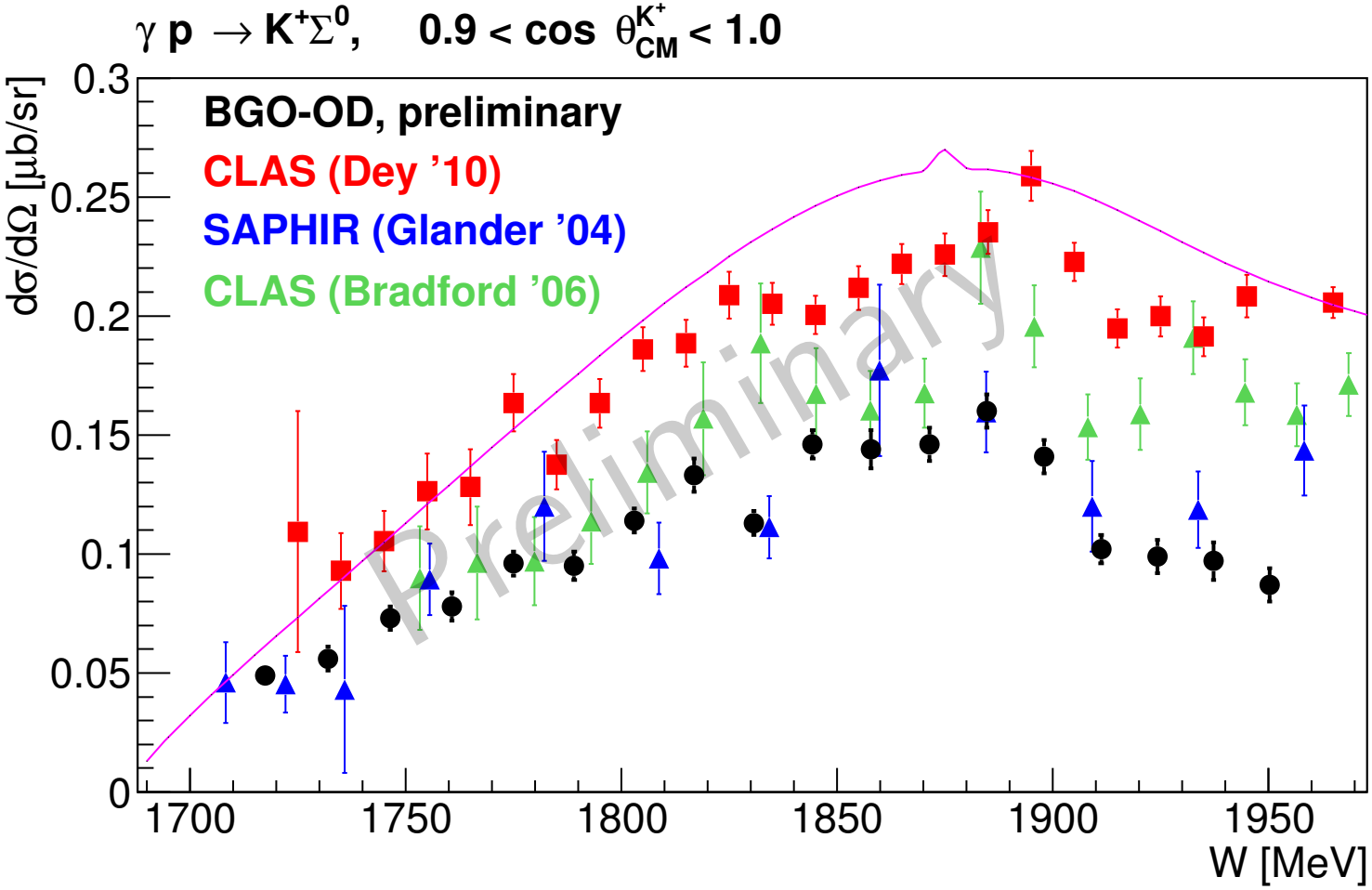


M.E.McCracken *et al.* (CLAS), Phys.Rev. C81, 025201 (2010).

A. Lleres *et al.* (GRAAL), Eur. Phys. J. **A 31**, 79 (2007)

3. First results - Forward $K^+\Sigma^0$ differential cross sections

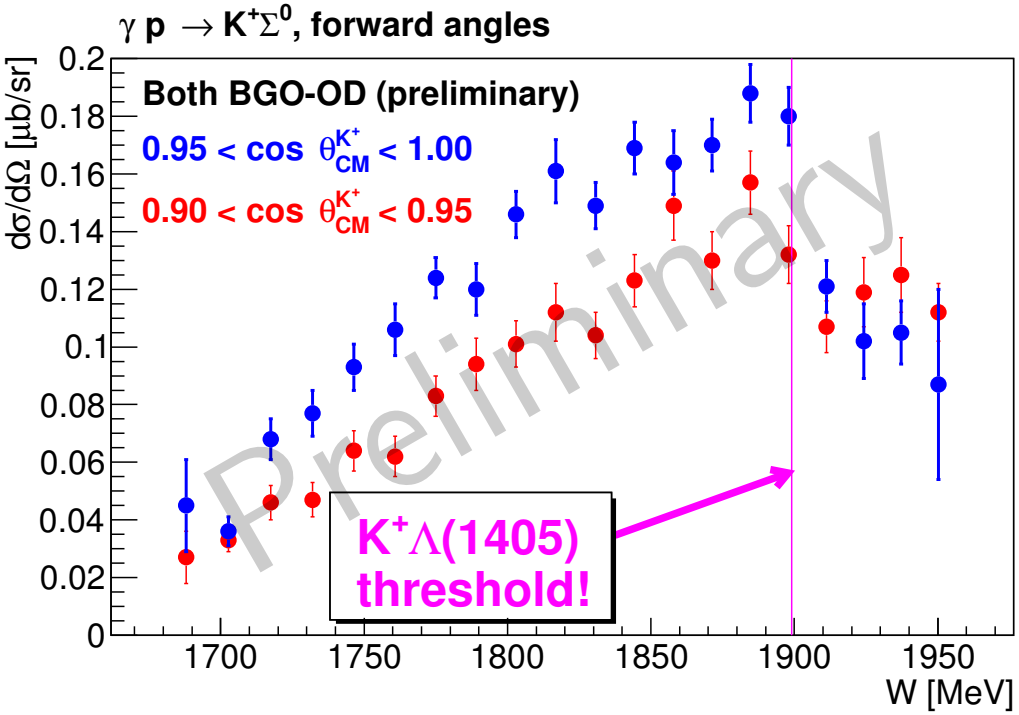
- "cusp" like structure at $W = 1900$ MeV? (maybe hints in previous data?)



R. Bradford *et al.*, Phys. Rev. C73, 035202 (2006), B.Dey *et al.*, Phys.Rev. C82, 025202 (2010), K.H. Glander *et al.*, Eur. Phys. J. A19, 251 (2004), CLAS data in $\cos\theta^{CM}_{K^+}$ 0.85 to 0.95 interval

3. First results - Forward $K^+\Sigma^0$ differential cross sections

- "Cusp" appears more pronounced at most forward angles!



Threshold effects at low momentum transfer?

- At $W \sim 1900$ MeV, close to several thresholds:
  - $K^+\Lambda(1405)$
  - $p\ f_0(980)$
  - $p\eta'$

Strangeness photoproduction at the BGO-OD experiment

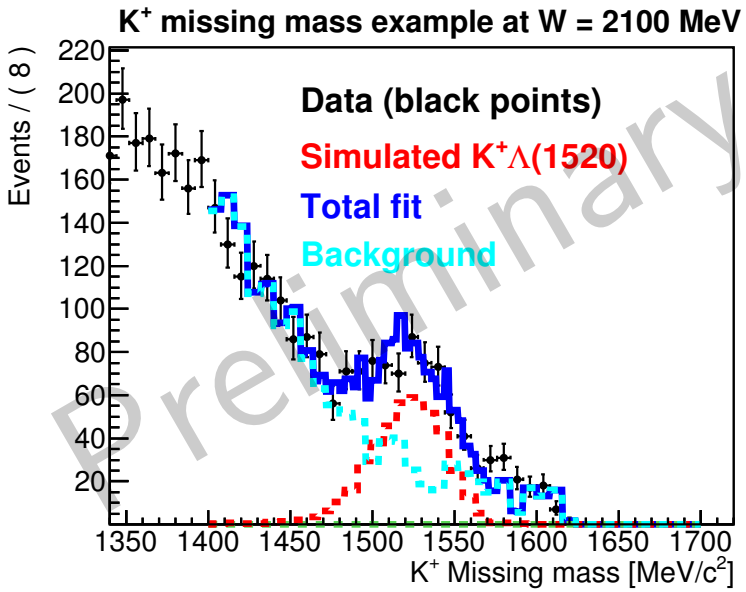
1. Introduction
2. Motivation: Exotic hadron structure - parallels in strange & charmed quark sectors?
3. The BGO-OD experiment at ELSA, Bonn
4. Strangeness photoproduction - first results:
   - K^0 photoproduction off proton & neutron (deuterium) targets
   - Extreme forward cross sections for K^+Y and excited hyperons
   - Future opportunities with BGO-OD

4. Future opportunities in strangeness photoproduction

- $\gamma p \to K^+\Lambda(1520)$ - "Cusp" seen in forward cross section at LEPS

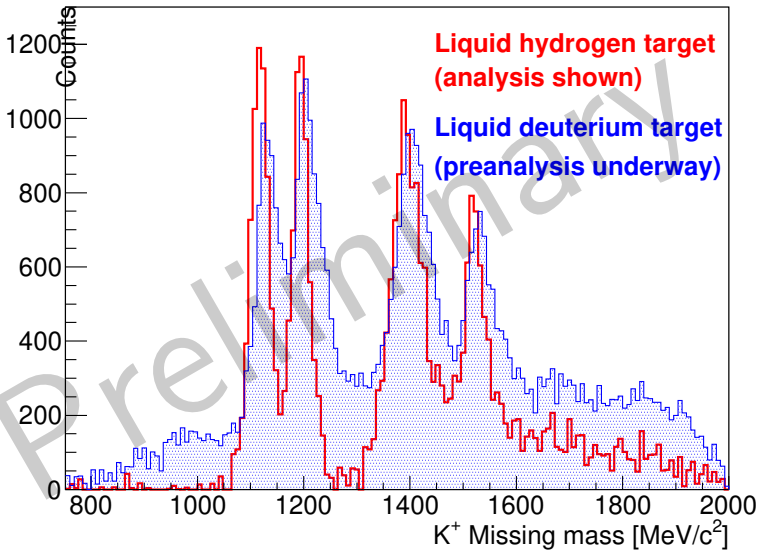
  H. Kohri et al. (LEPS), Phys. Rev. Lett. 104, 172001 (2010)

- $\Lambda(1520)$ observed at BGO-OD:



- Deuterium target: $\gamma n \to K^+\Sigma^-$ & $\gamma n \to K^+\Sigma^-(1385)$ (limited data at forward angles, S. Anefalos Pereira et al. (CLAS), Phys. Lett. **B688** 289 (2010). H. Kohri et al. (LEPS) ,Phys. Rev. Lett. 97, 082003 (2006). K. Hicks, D. Keller, H. Kohri et al., ,Phys. Rev. Lett. 102, 012501 (2009))

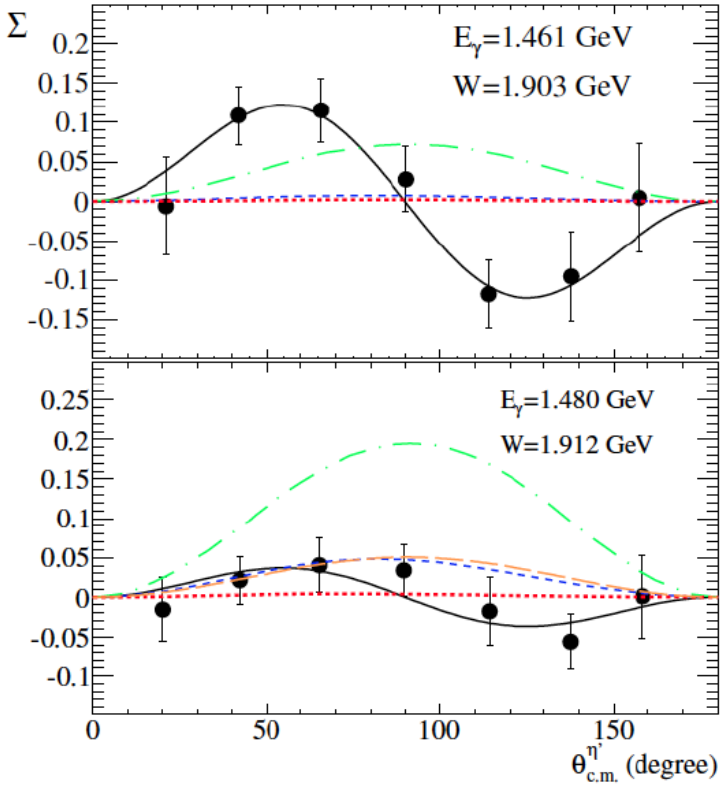
- 1st analysis at BGO-OD:



$K^+\Sigma^-$ Photoproduction - Johannes Groß Master's thesis analysis

Beam asymmetry for $\gamma p \to \eta' p$ near threshold - motivation

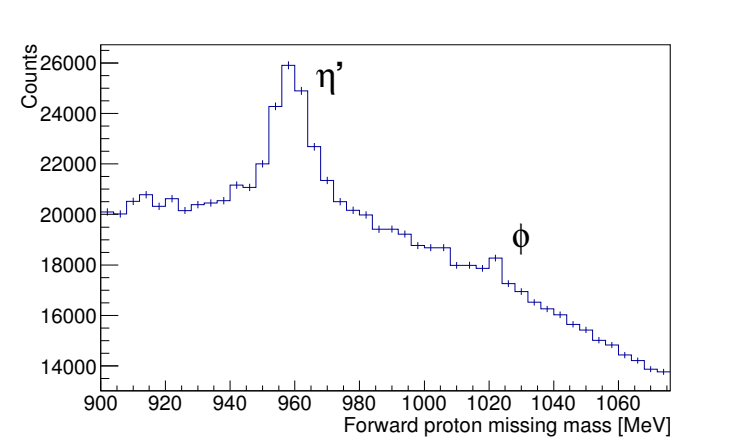
Previous GRAAL data:
A. Fantini, R. Di Salvo, P. Levi Sandri



- Strong variation in $\gamma p \to \eta' p$ beam asymmetry near threshold
- Suggested evidence of narrow resonance at W=1903 MeV, $J^P = 1/2^-$, $\Gamma \sim 2.1$ MeV

η and η' Photoproduction on the Nucleon with the Isobar Model EtaMAID2018, L. Tiator et al., arXiv:1807.04525 (2018)

Near threshold the recoil proton is always in our forward spectrometer!

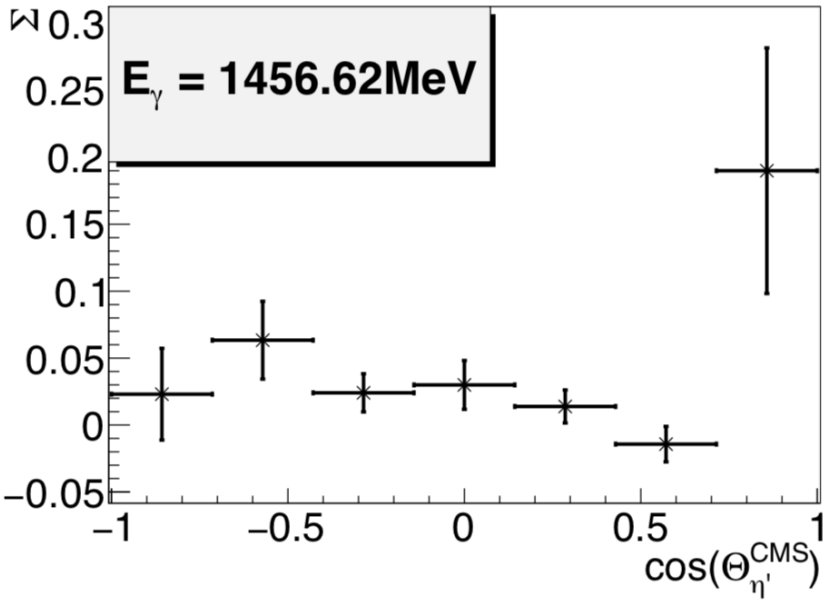


Beam asymmetry for $\gamma p \rightarrow \eta' p$ near threshold - motivation

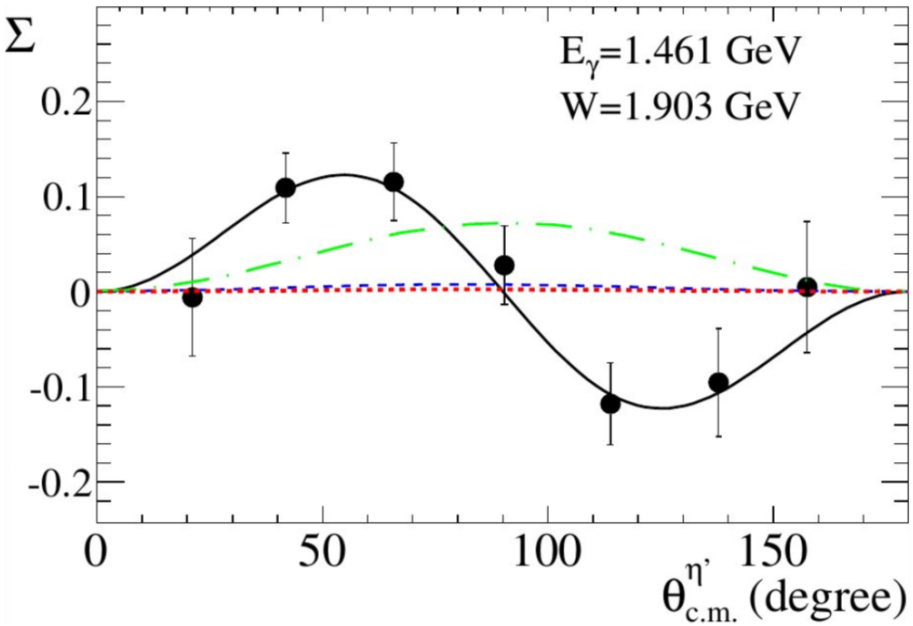
S. Alef PhD thesis analysis - 18:00, parallel session B Tuesday

This work:

(**very preliminary work in progress!**)



GRAAL results:



L. Tiator et. al., Eta and Etaprime Photoproduction on the Nucleon with the Isobar Model EtaMAID2018

Summary

- Molecular-like structure in the light quark system? Parallels between heavy charm and *uds* systems?
- BGO-OD - strangeness photoproduction at extremely forward angles & low momentum transfer
- $K^0\Sigma^0$ photoproduction - preliminary results consistent with dynamically generated meson-baryon resonance contributions
- $\gamma p \to K^+\Lambda(1405) \to \Sigma^0\pi^0$ - lineshapes & differential cross sections
- K^+Y photoproduction at forward angles - cusp in $\gamma p \to K^+\Sigma^0$ at $W \sim 1900$ MeV

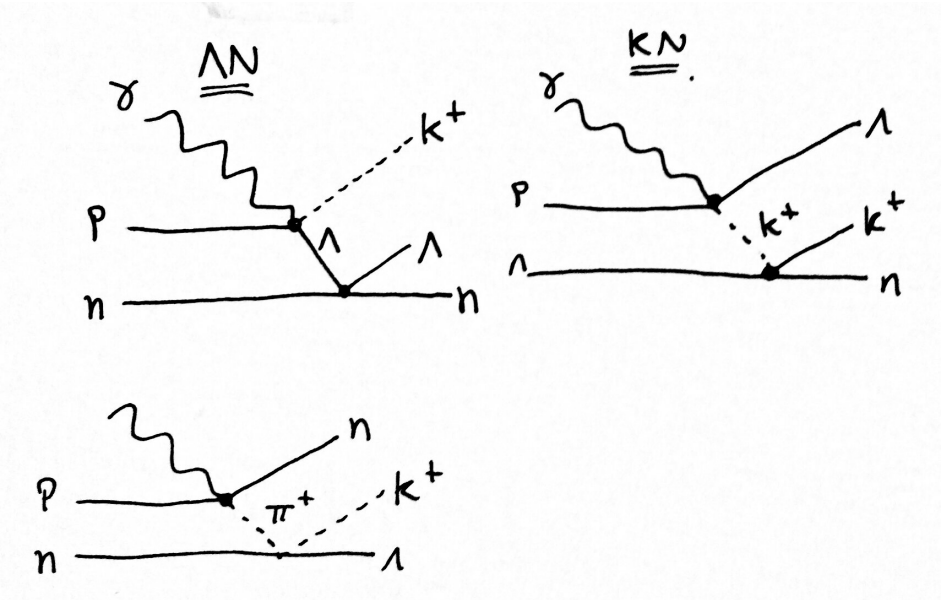
BGO-OD presentations

- 18:00 Tuesday
  η' beam asymmetry at threshold
  Stefan Alef
- 16:30 Thursday
  $K^+\Lambda(1405)$ photoproduction
  Georg Scheluchin
- 18:00 Thursday
  $K^0_S\Sigma^0$ photoproduction
  Katrin Kohl

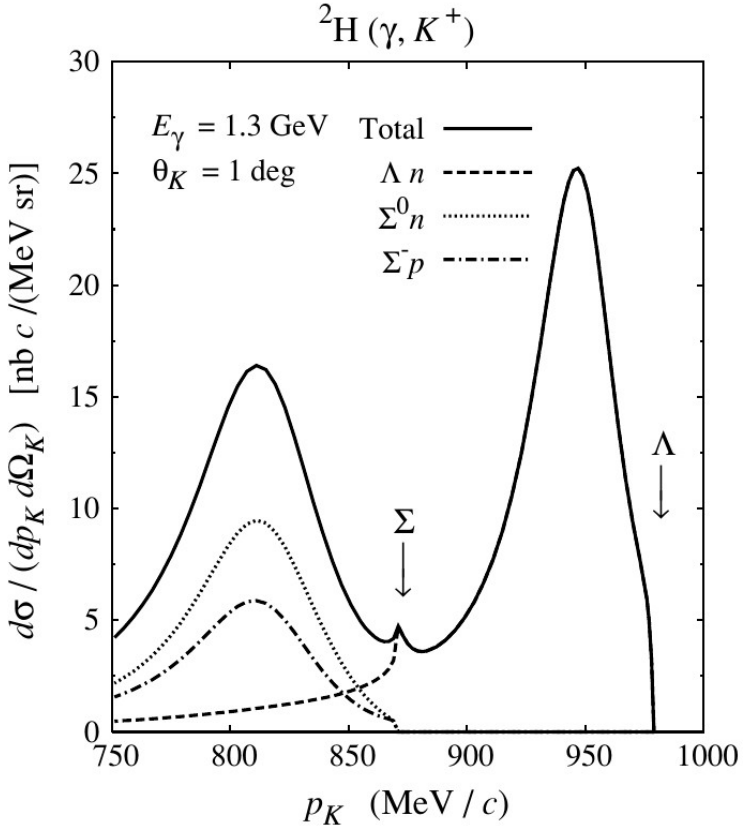
Extra slides

4. Future opportunities in strangeness photoproduction

- Study the $\Lambda - n$ interaction - Very little data available!
- Final state interactions for $\gamma d \to K^+\Lambda + (n)$
- KN, YN & pion mediated
- $\theta_K < 30^0$ - FSI dominated by Y-N



Models of YN forces - cusps at ΣN & YN thresholds

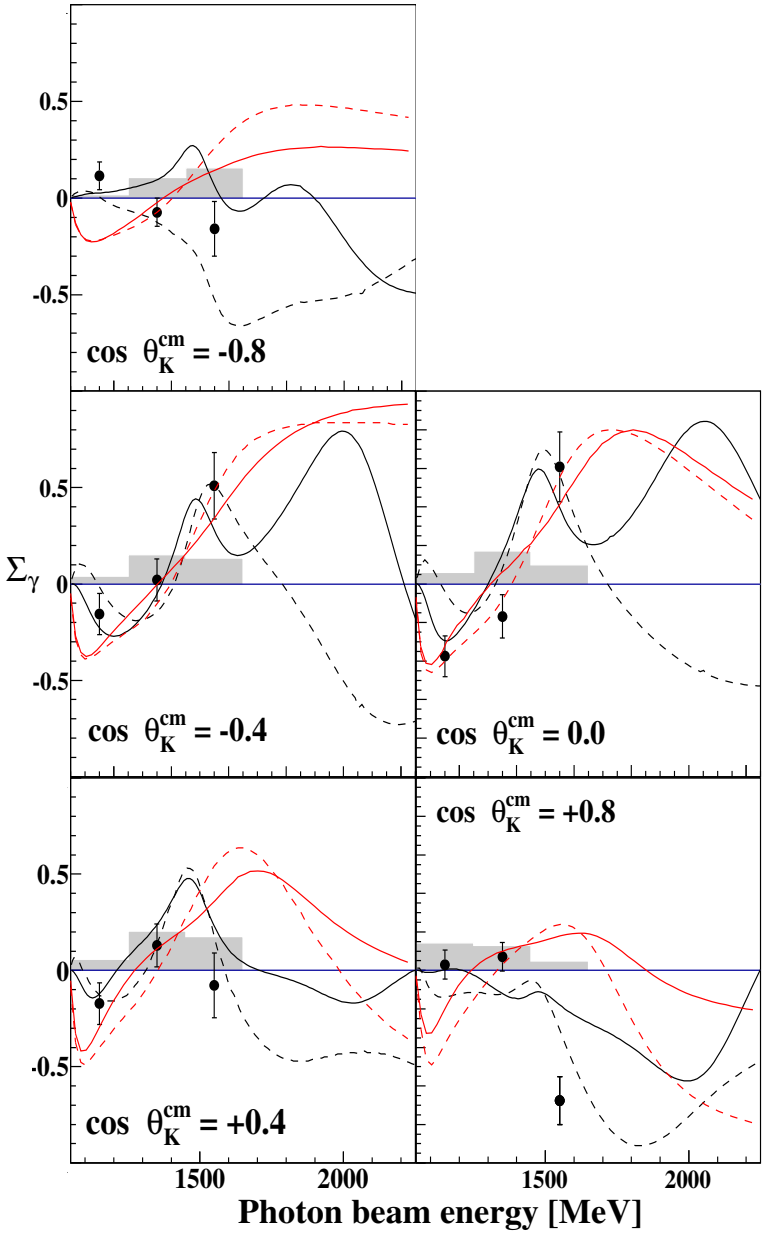


K. Miyagawa, T. Mart, C. Bennhold, W. Glöckle, Phys. Rev. **C74** (2006) 034002

Hypernuclei photoproduction at BGO-OD?

Previous $\gamma p \rightarrow K^0\Sigma^+$ measurements

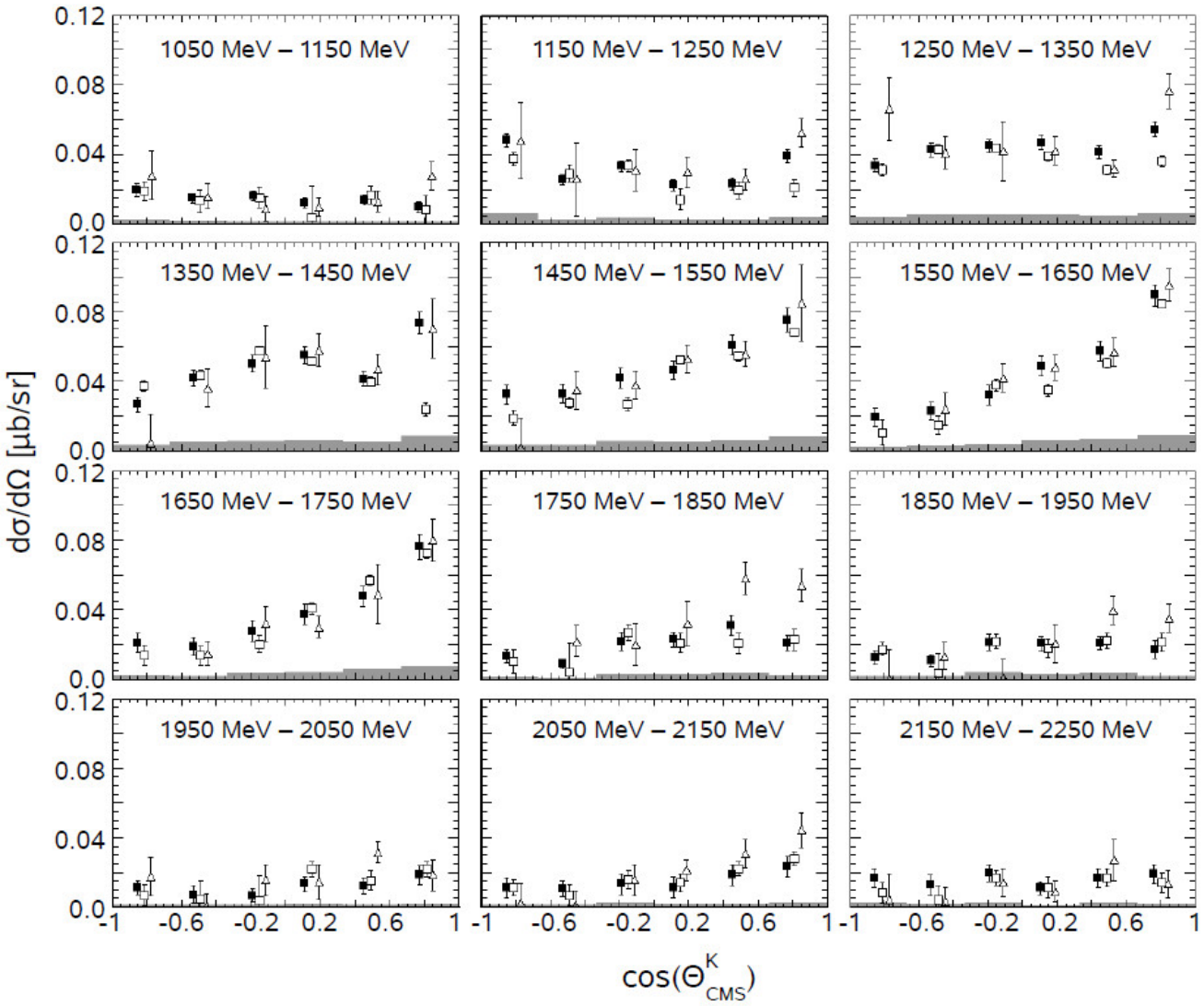
- The 1st beam asymmetry measurement
  R. Ewald *et.al*, PLB 738 (2014) 268
  (CBELSA/TAPS Collaboration)



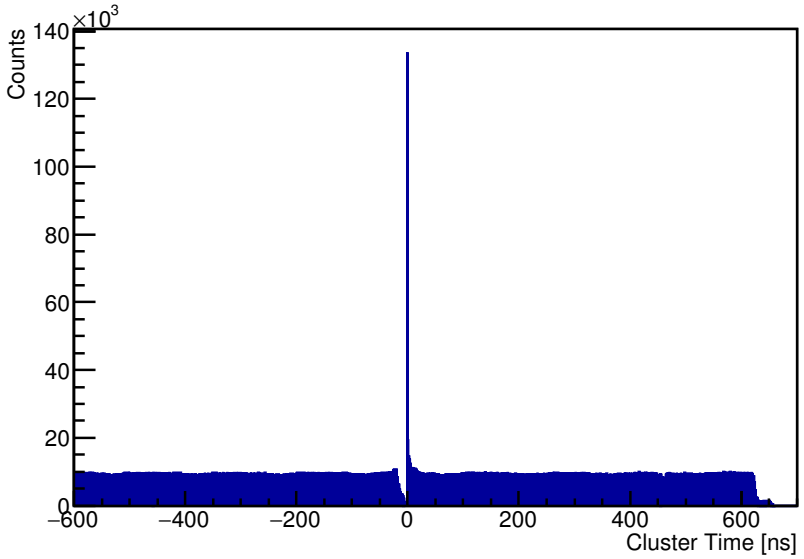
Previous $\gamma p \rightarrow K^0\Sigma^+$ measurements

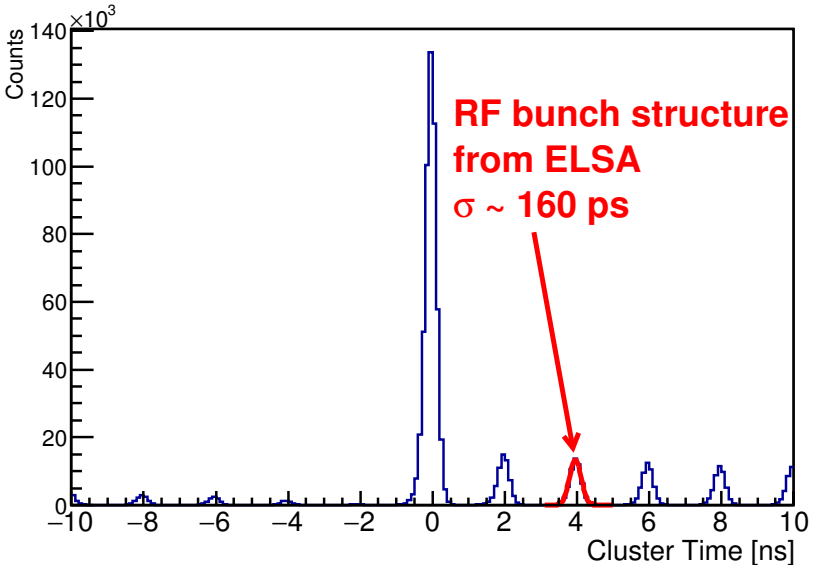
R. Ewald *et al.*,Phys. Lett. B 713 (2012) 180 (CBELSA/TAPS Collaboration).

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



Tagger timing



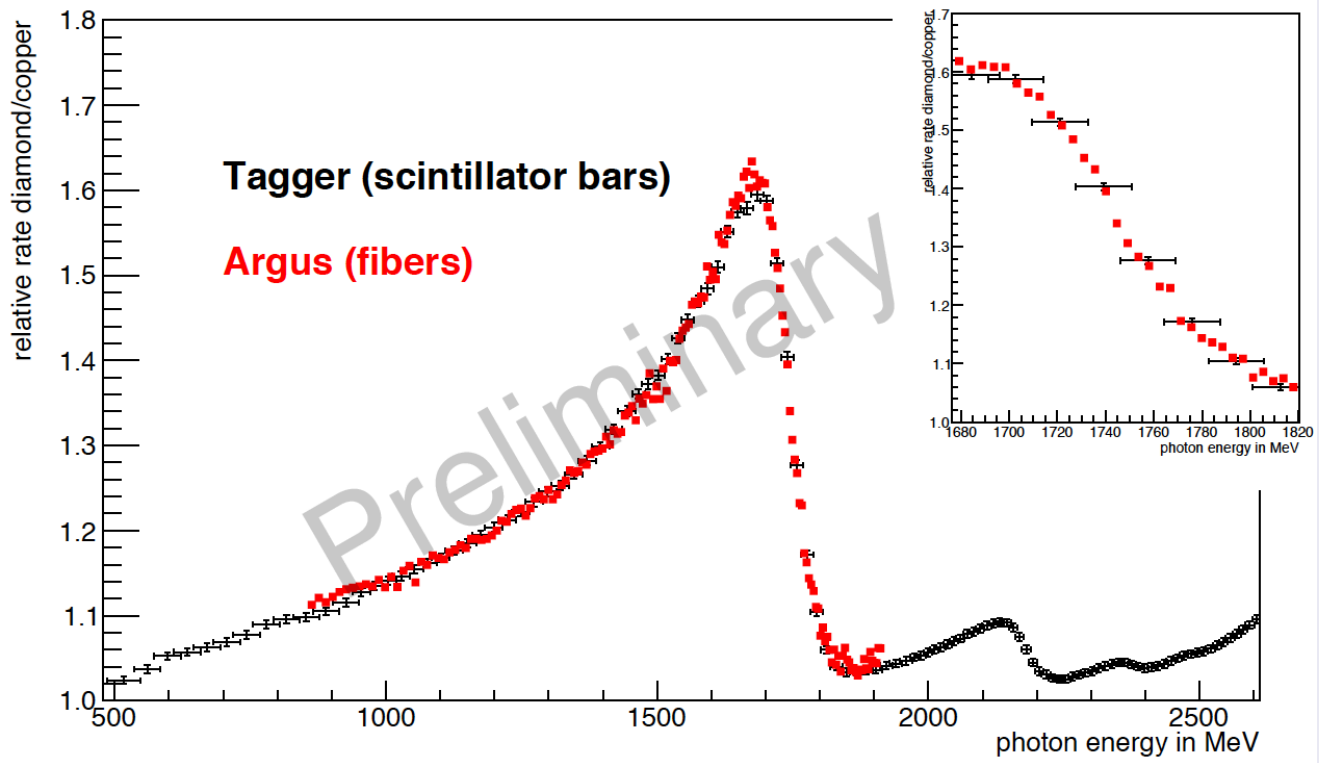


Incident photon beam parameters

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

Coherent bremsstrahlung using a diamond radiator

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

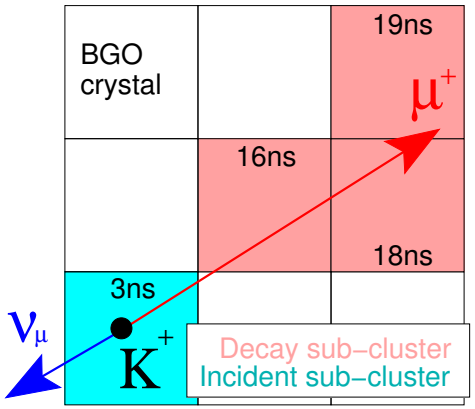


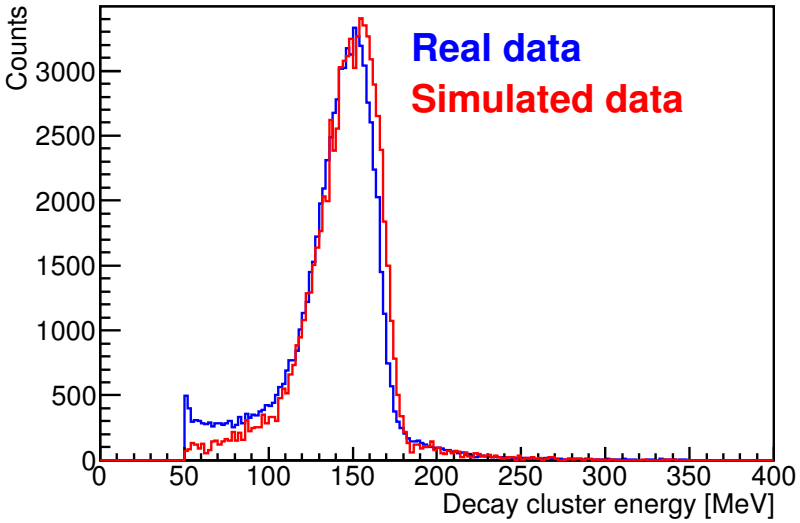
K^+ identification in the BGO

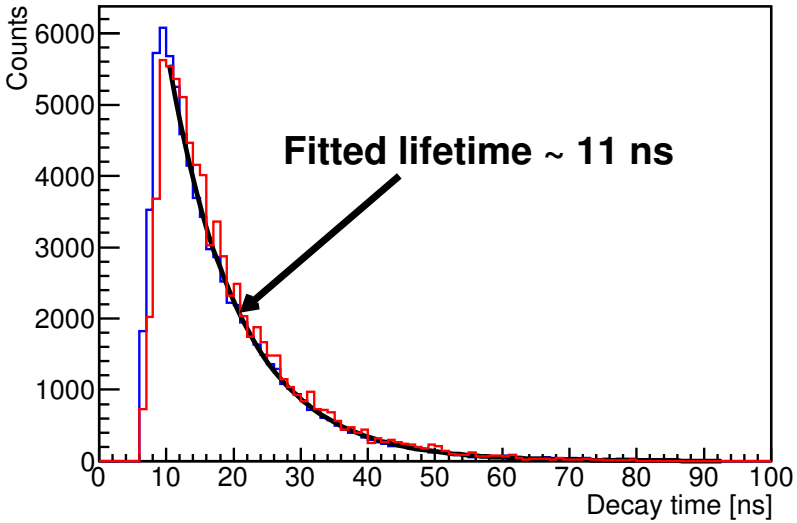
- Time delayed, K^+ weak decay within the crystals of the BGO ball
- T.C Jude, D.I. Glazier, D.P. Watts, *et al*, PLB, 735 (2014) 112

Lifetime 12 ns,
2 main decay modes:

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



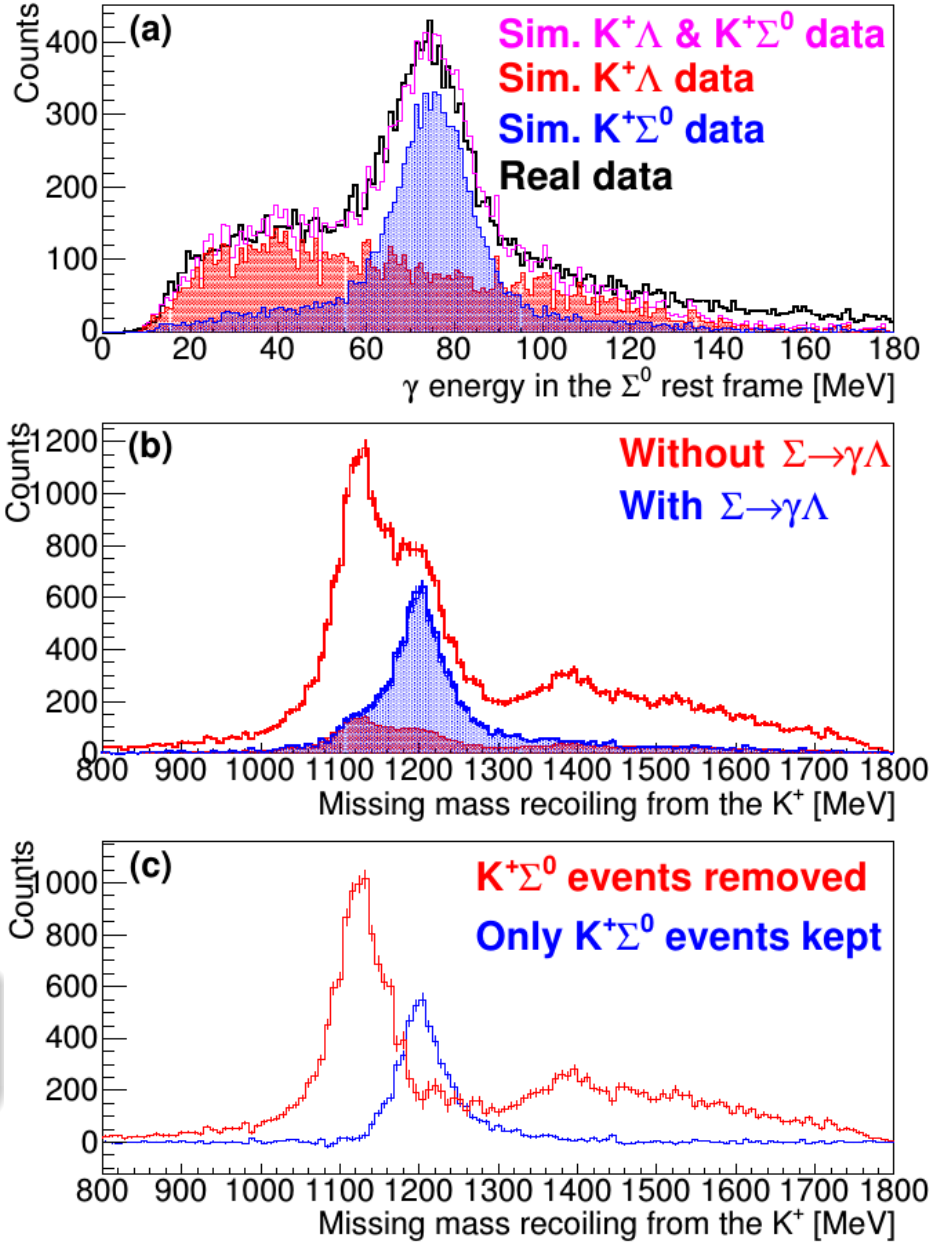




Identifying the $\Sigma^0 \to \Lambda\gamma$ decay ($\Gamma = 100\%$)

- Boost all neutral particles in the BGO into missing hyperon rest frame
- If $K^+\Sigma^0$:
- γ energy (Σ^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!



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

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

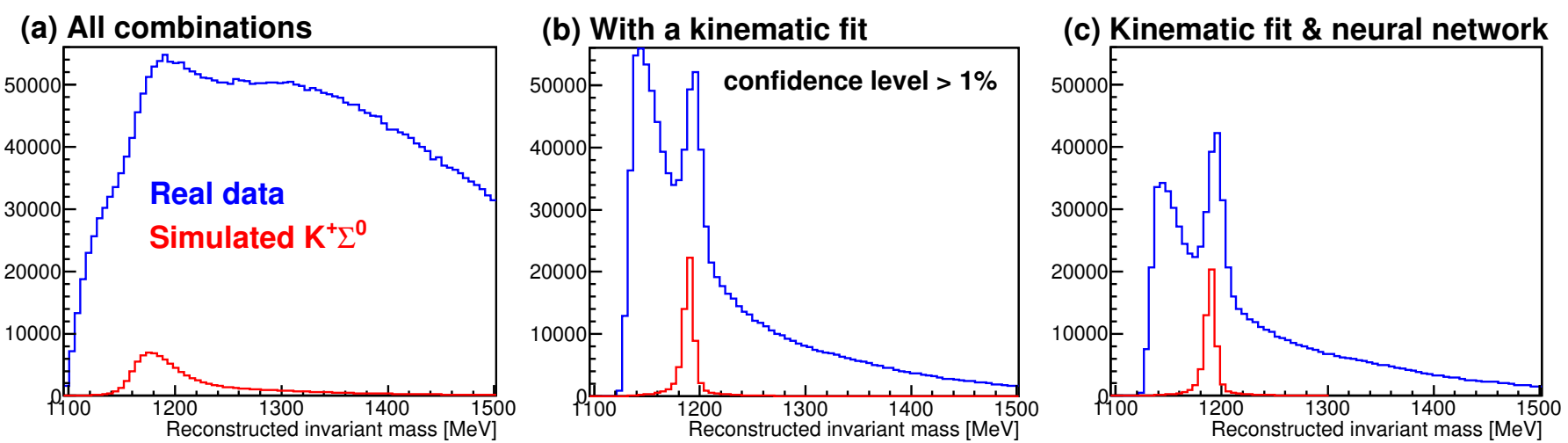
- K^+ & $\Lambda \rightarrow p\pi^-$ over large acceptance region ($1^0 < \theta < 155^0$)
- Σ^0 decay photon in the BGO ($\Sigma^0 \rightarrow \Lambda\gamma$)
- Technique used for higher lying Y* states (eg $\Lambda(1405) \rightarrow \pi^0\Sigma^0$)

Reconstructing the Σ^0 invariant mass

(a) Momentum conservation & K^+ "missing mass" cut

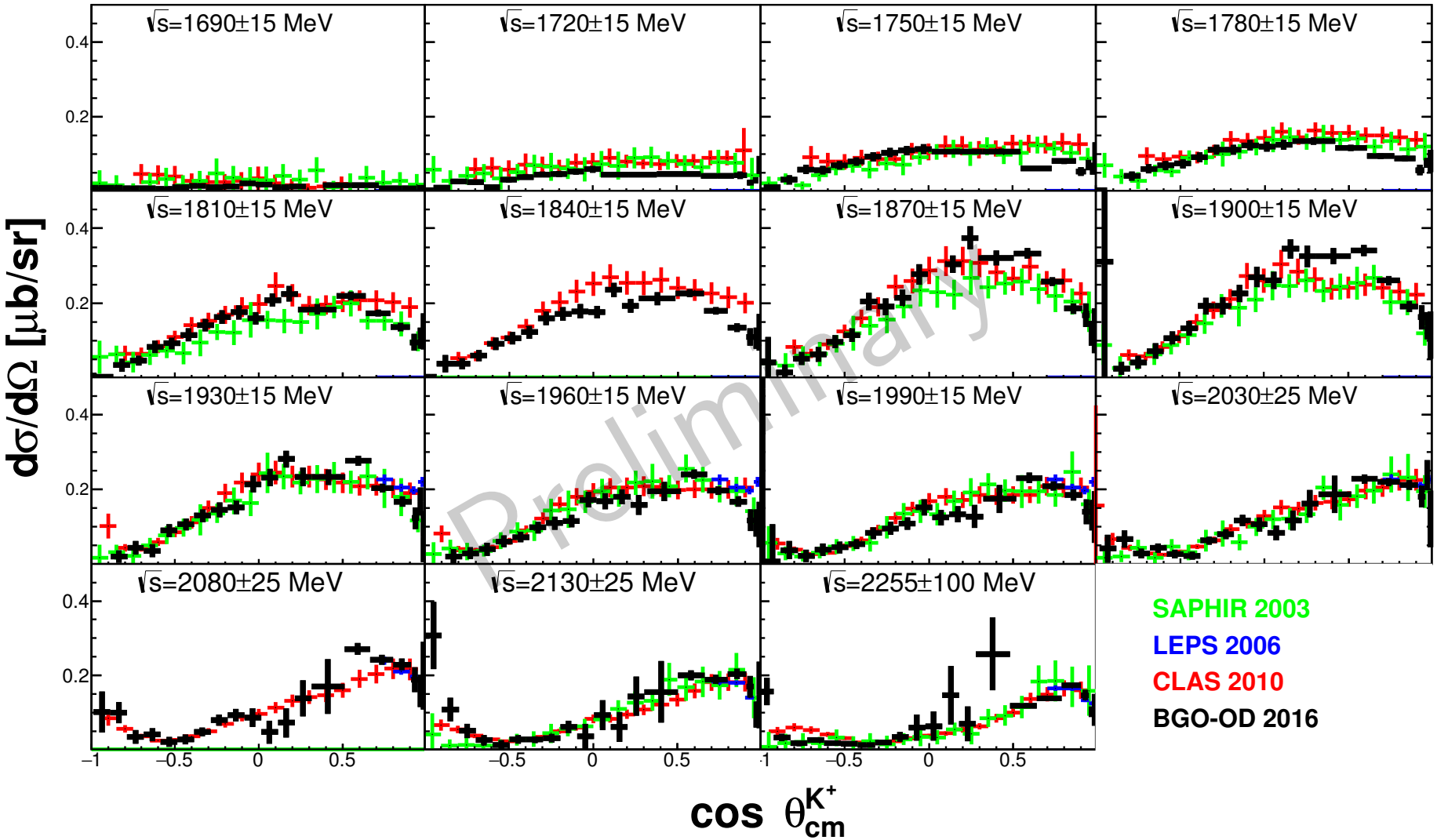
(b) Kinematic fit & confidence level cut

(c) Neural network to suppress background



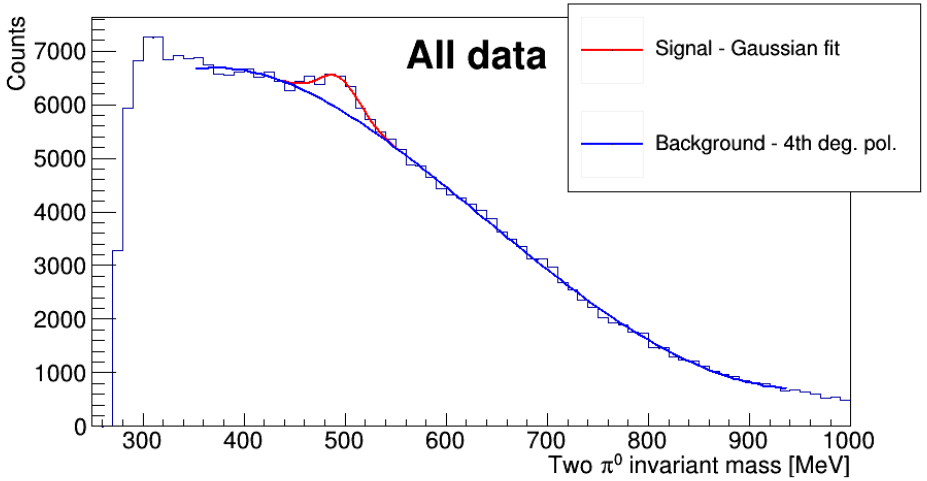
$\gamma p \rightarrow K^+\Sigma^0$ with no initial particle Identification

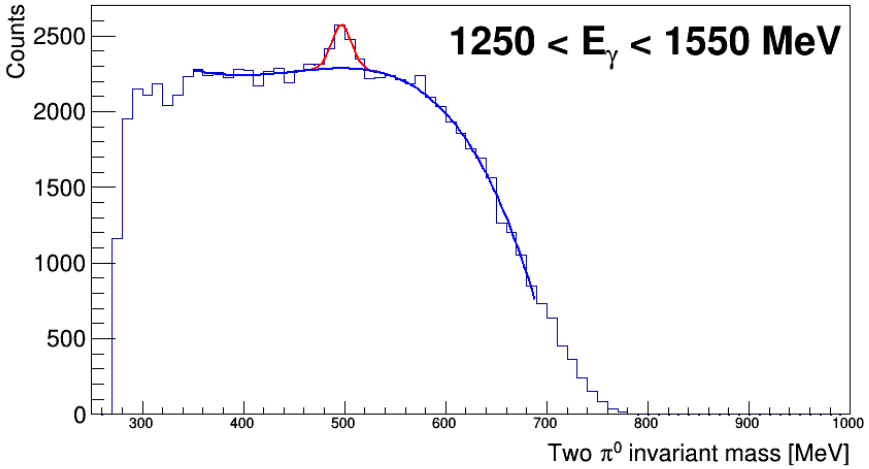
BGO-OD (preliminary), CLAS: B. Dey, *et al.*, Phys. Rev. **C82** 025202 (2010)
SAPHIR: K.-H. Glander *et al.*, Eur. Phys. J. **A19** 251 (2004), LEPS: M. Sumihama *et al.*, Phys. Rev. **C73** 035214 (2006)

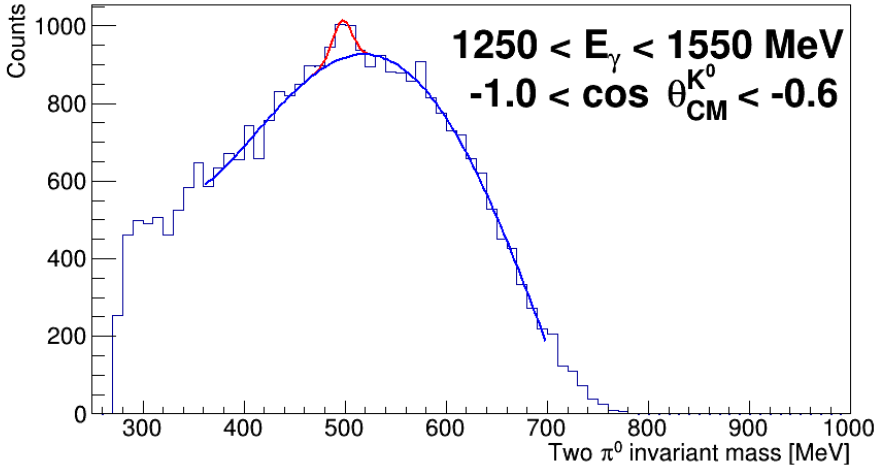


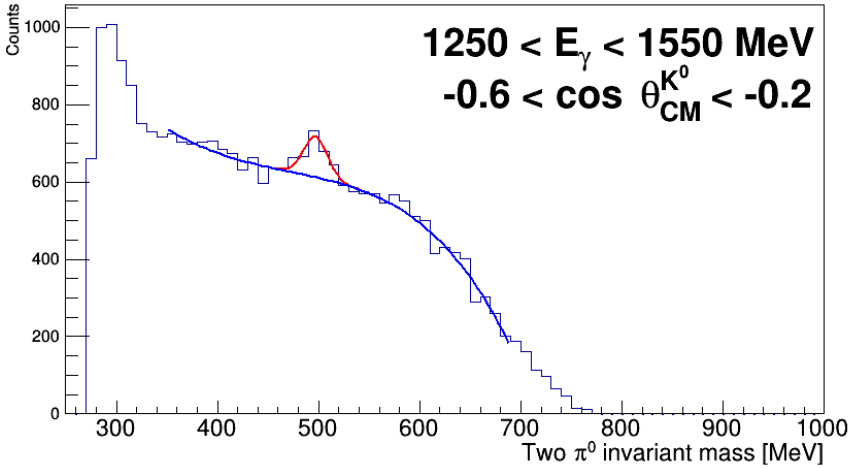
Preliminary identification of $K^0\Sigma^+$ with BGO-OD

Analysis by S. Alef



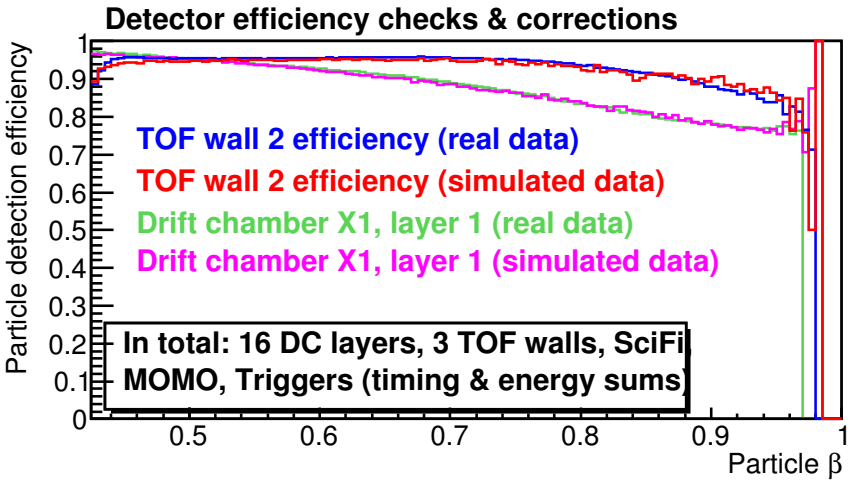


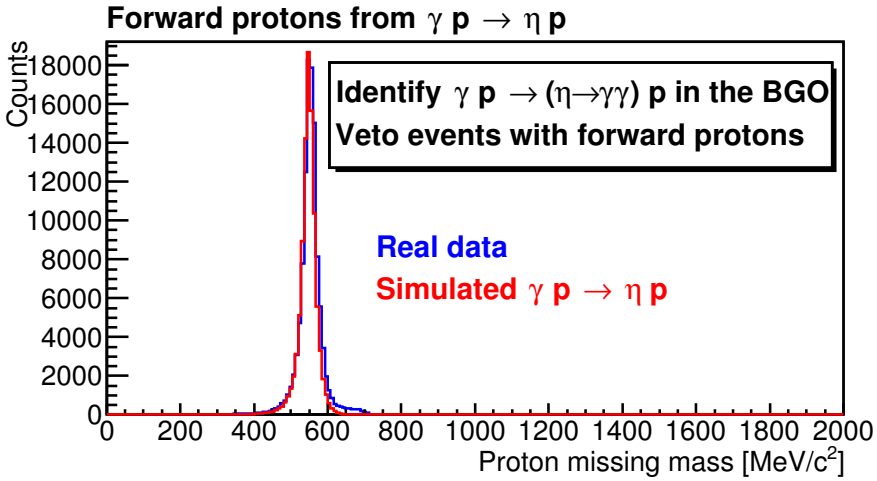


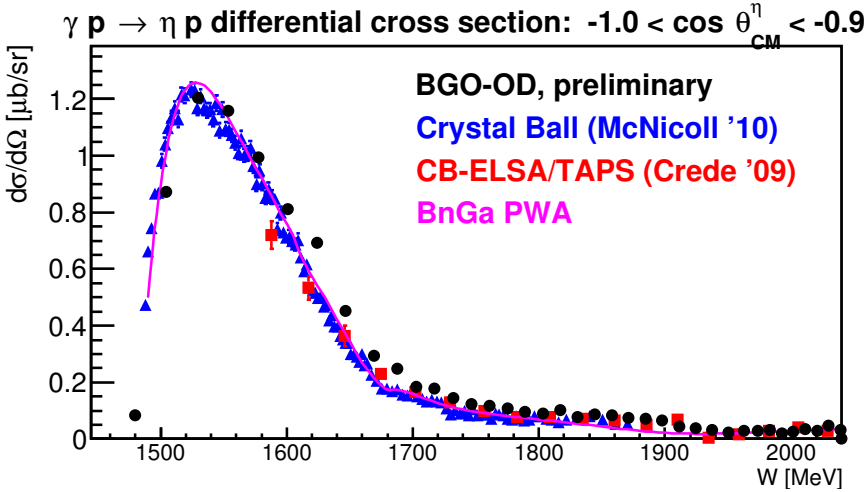


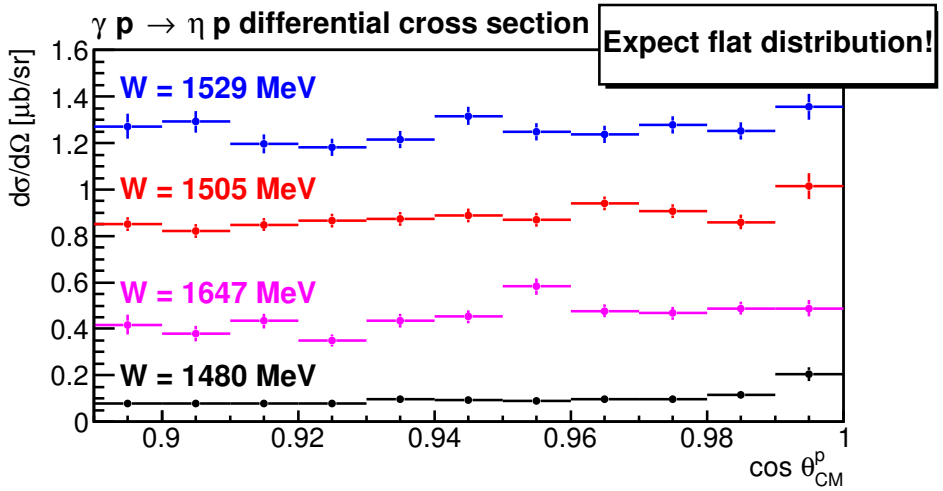
Forward spectrometer - Systematic checks

- Efficiencies calculated and simulated for all detectors & triggers
- Use $\gamma p \rightarrow \eta p$ to test forward spectrometer systematics





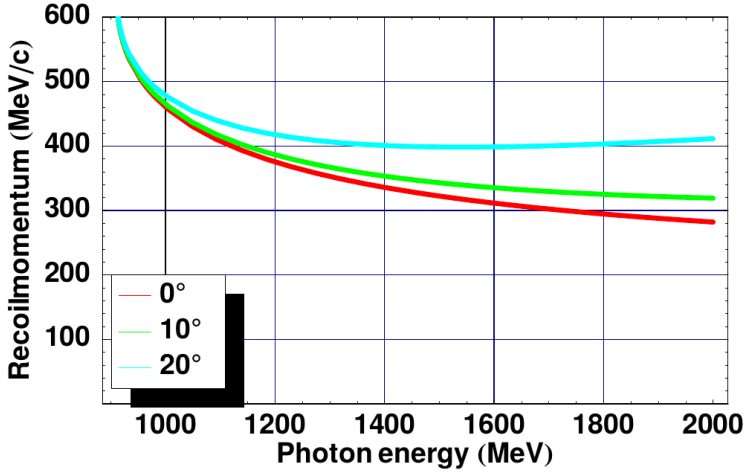




V.Crede et al. (CB-ELSA), Phys.Rev. **C80**, 055202 (2009), E.F.McNicoll et al. (Crystal Ball), Phys.Rev. **C82**, 035208 (2010)

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 Λ within the Fermi surface of the residual nuclei



P. Achenbach, arXiv:1101.4395 (2008)

Opportunities for first real photon beam photoproduction?

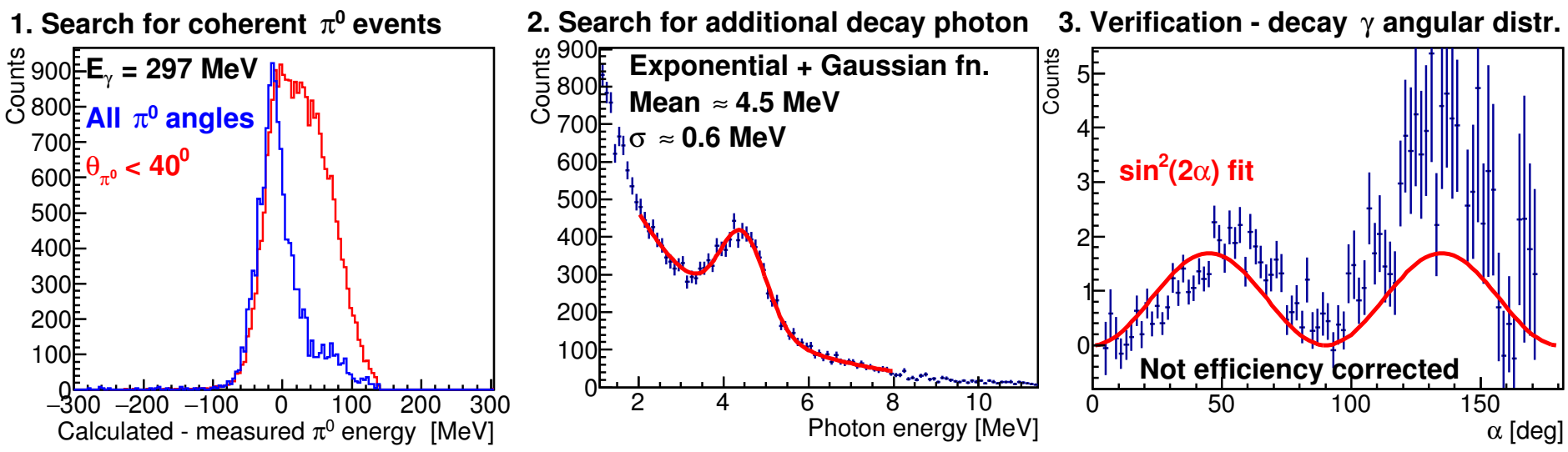
In conversation with P. Achenbach & J. Pochodzalla, 2018

- 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...

Future opportunities: Hypernuclei production

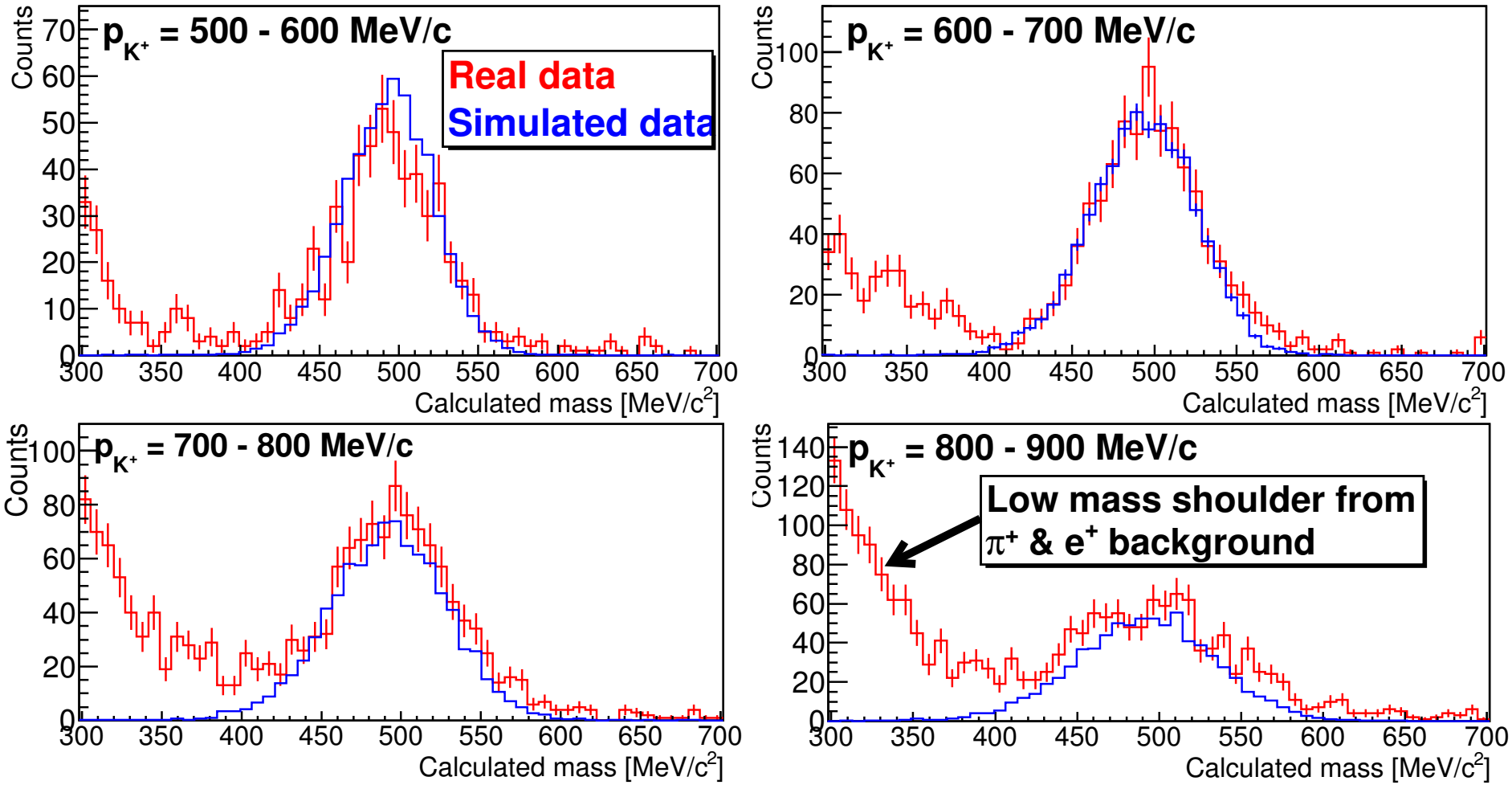
Coherent pion production ("non-strange" example)

- Method similar to C.M. Tarbert, D.P. Watts *et. al* (A2 Collaboration) Phys Rev. Lett. 100 (2008) 13
- $\gamma +^{12} C \rightarrow \pi^0 +^{12} C^* \rightarrow \pi^0 +^{12} C + \gamma'$ (4.4 MeV)
- E2 transition, $J^\pi : 2^+ \rightarrow 0^+$, $\sin^2(2\alpha)$ distr. between nuclear recoil & γ'
- $\sim$ 2 hours of commissing data with BGO-OD:



4. First results - Selecting forward K^+ at BGO-OD

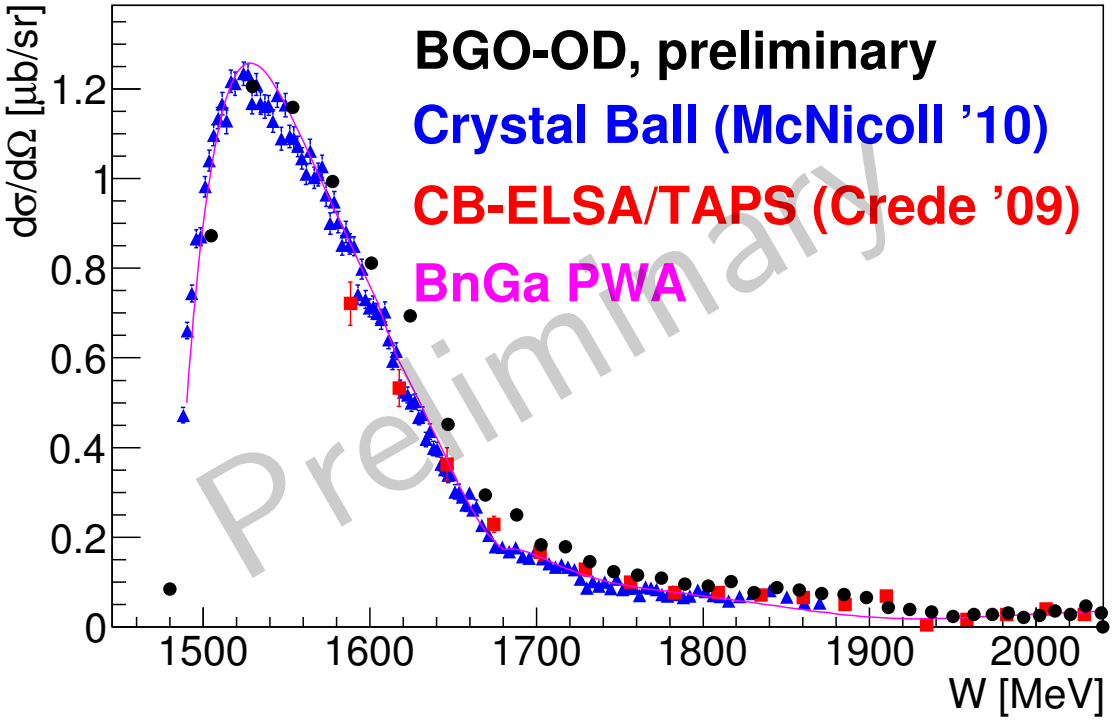
- Mass calculated from momentum and β
- Select events $\pm 2\sigma$ for a given K^+ momentum, p_{K^+}



3. BGO-OD Detector performance - forward spectrometer

Demonstration - $\gamma p \rightarrow \eta p$ differential cross section with forward proton

- $-1.0 < \cos\theta^{\eta}_{CM} < -0.9$
- Good agreement with existing data - systematics well understood!



V.Crede et al., (CB-ELSA), Phys.Rev. **C80**, 055202 (2009) E.F.McNicoll et al., (Crystal Ball), Phys.Rev. **C82**, 035208 (2010)

The BGO-OD collaboration

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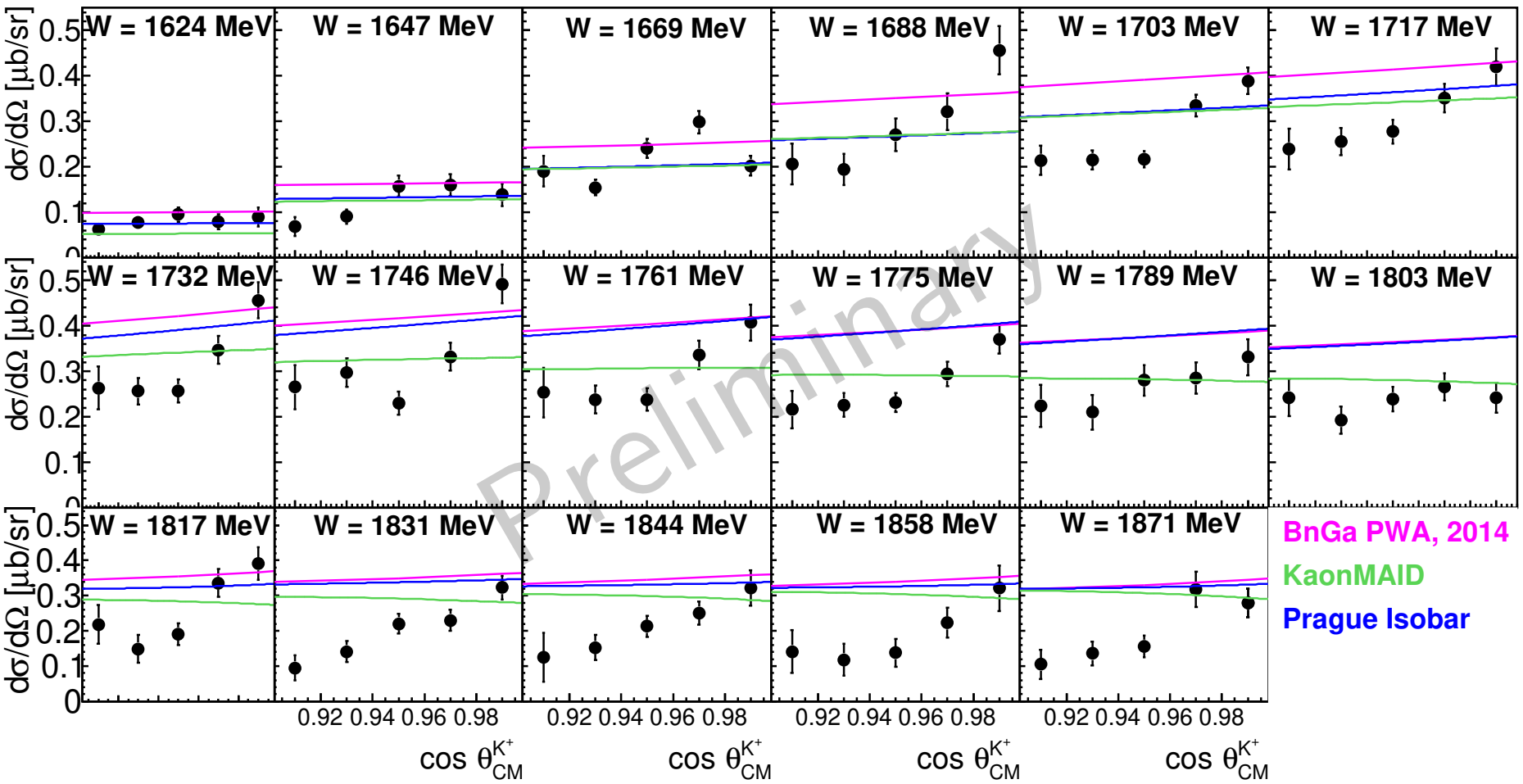
A special thanks to group members!

S. Alef, A. Bella, D. Hammann, J. Hannappel, K. Kohl, F. Messi, B. Reitz, G. Scheluchin, H. Schmieden, T. Zimmermann & present Masters & Bachelor students: J. Groß, C. Tillmanns, S Heider & J. Glowacz

A special thanks to the ELSA technical staff and previous BGO-OD technical coordinators (D. Elsner)!

4. First results - Forward $K^+\Lambda$ differential cross sections

- Unprecedented angular resolution ~ 0.01 in $\cos\theta^{K^+}_{CM}$!



Prague Isobar model: D. Skoupil and P. Bydžovský Phys. Rev. C 97, 025202 (2018) Bonn-Gatchina PWA: Eur.Phys.J. A50 (2014) 74 KaonMAID: F.X. Lee, T. Mart, C. Bennhold, H. Haberzettl, L.E. Wright, Nucl. Phys. A695 (2001) 237