Strangeness photoproduction at the BGO-OD experiment

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On behalf of the BGO-OD Collaboration

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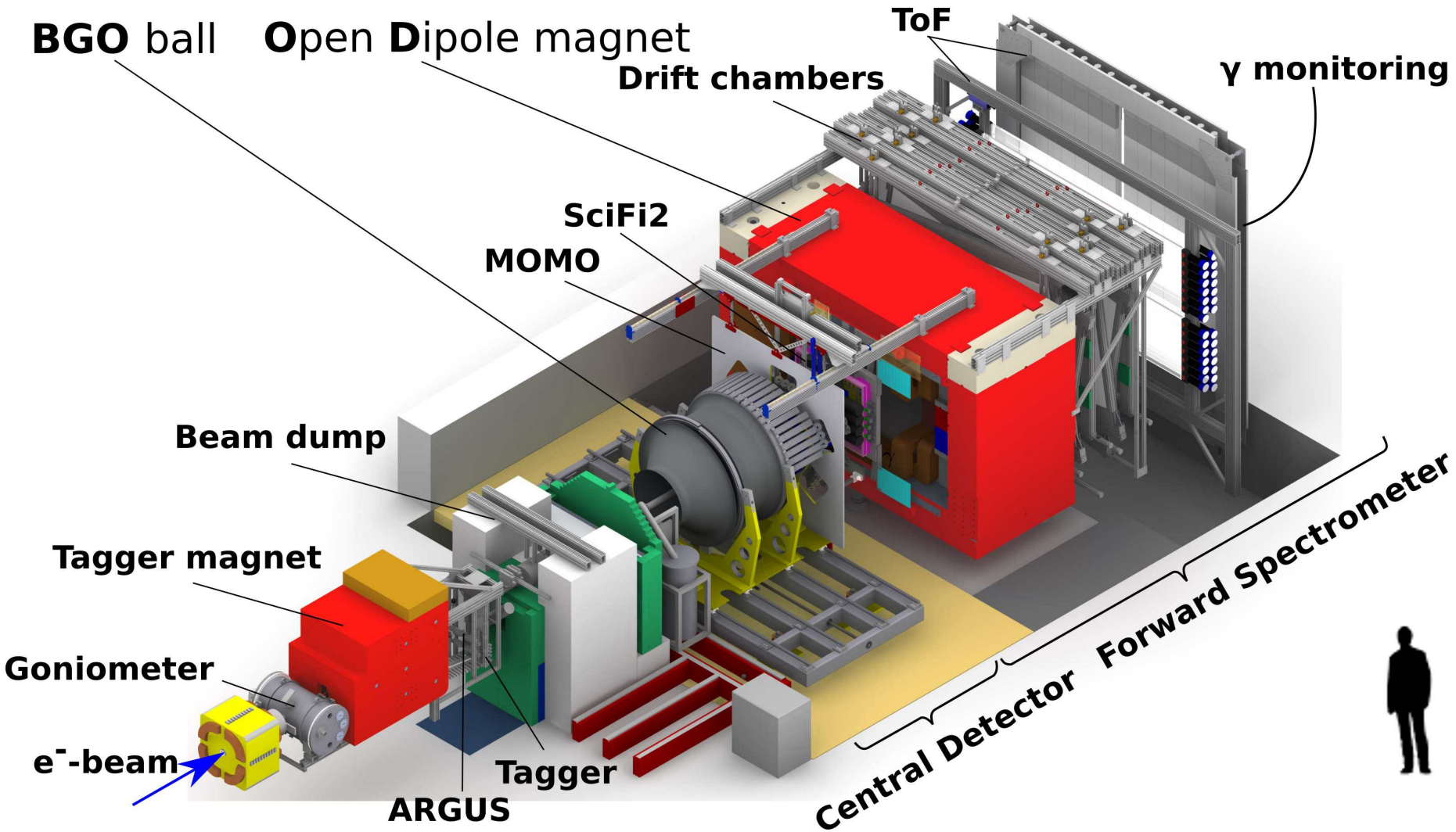
Supported by the DFG / tr-16

25/09/17

- The BGO-OD experiment
- Strangeness photoproduction - motivation & recent results

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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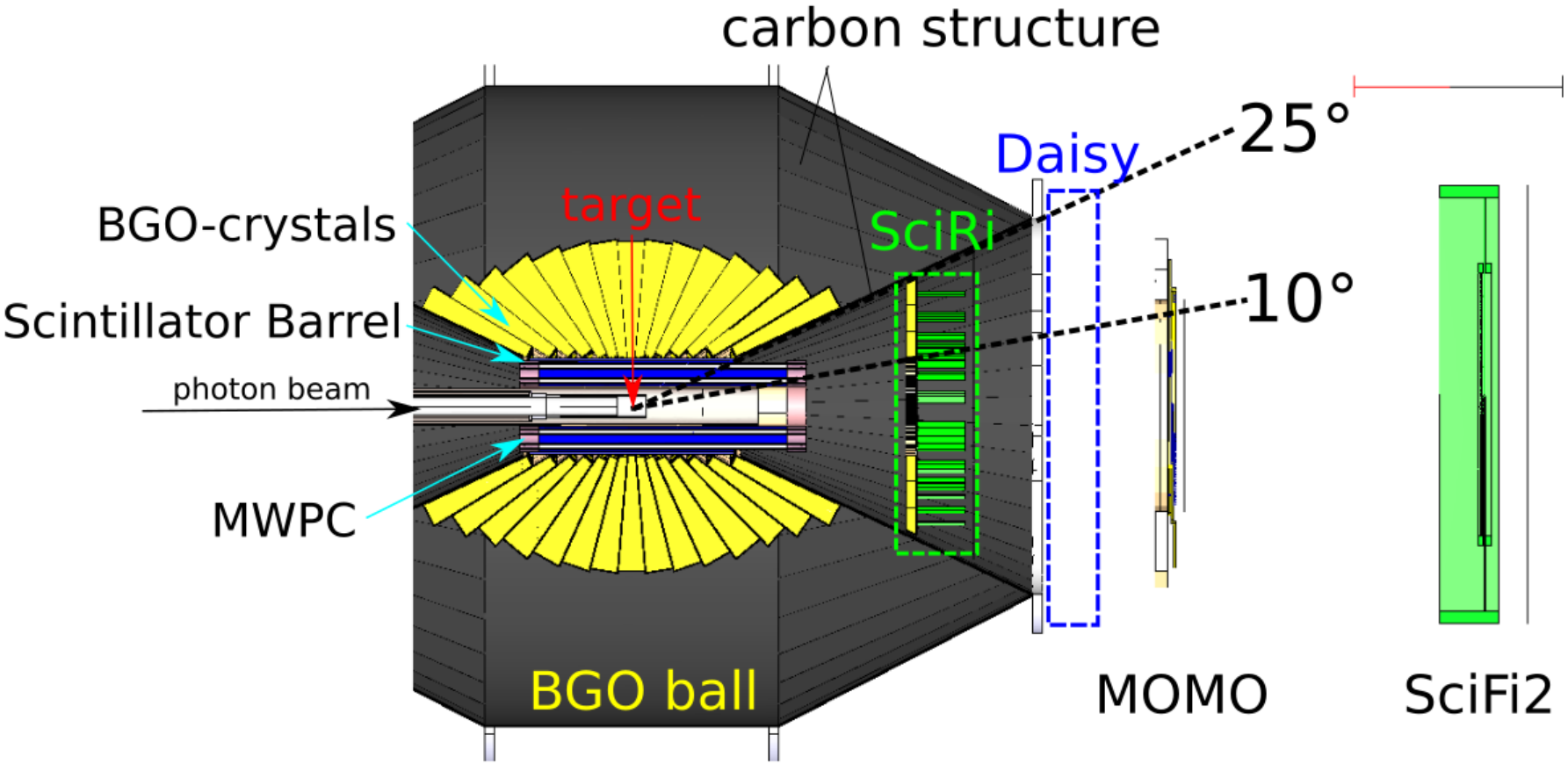

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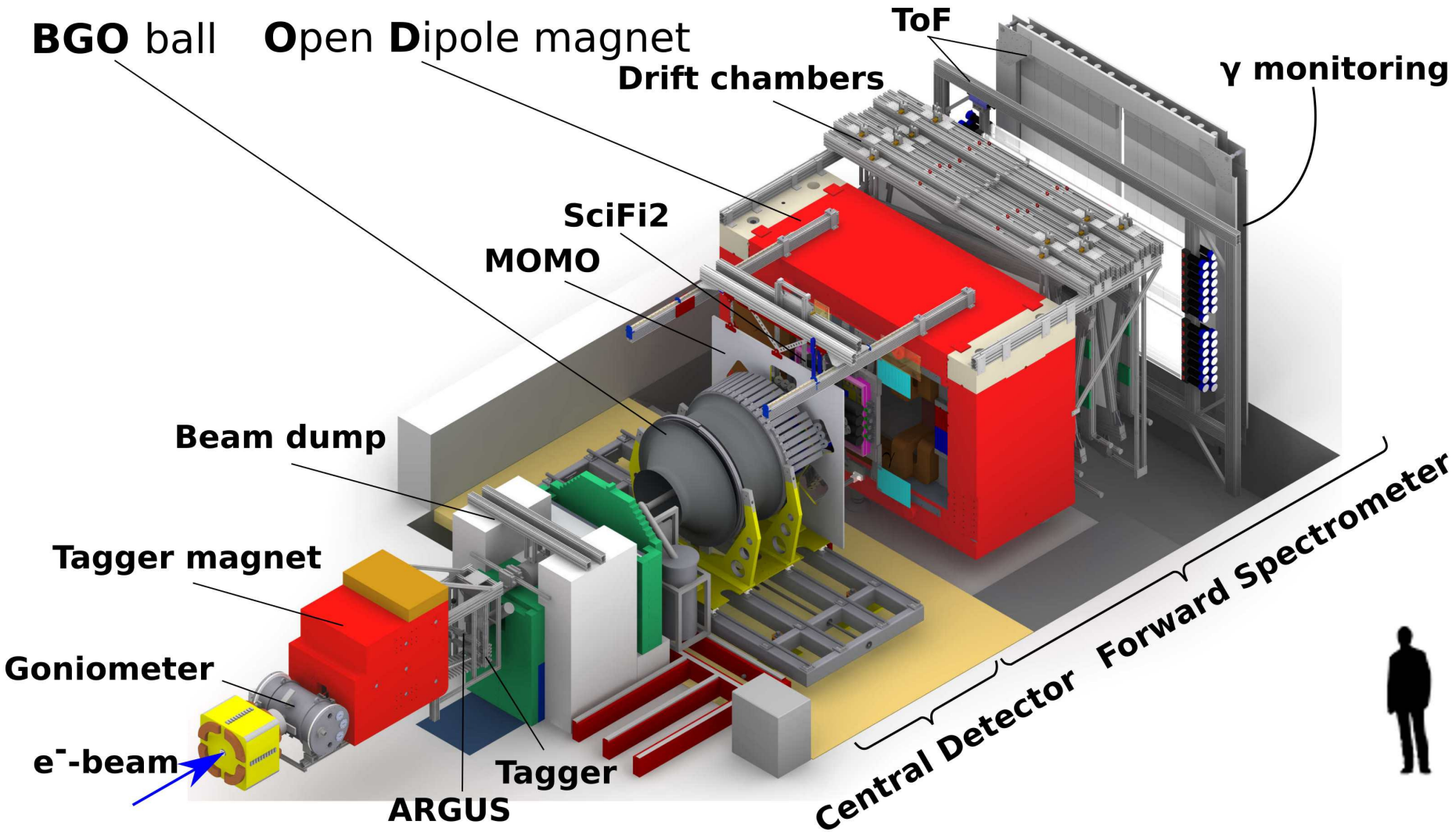
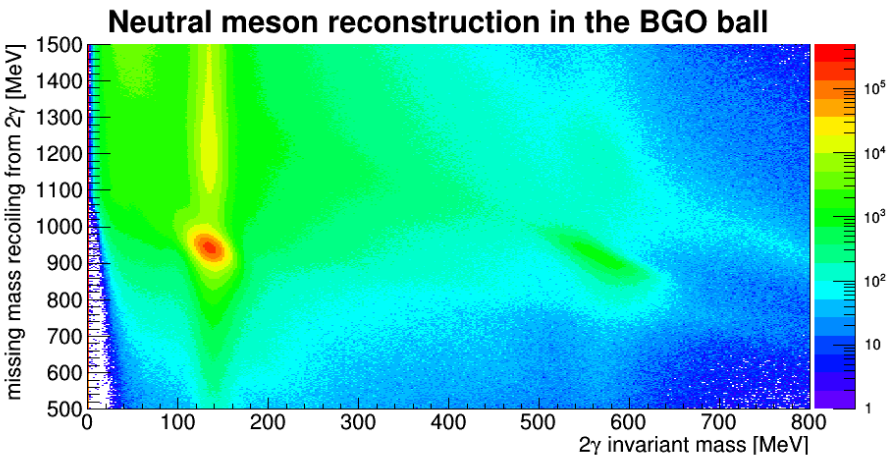
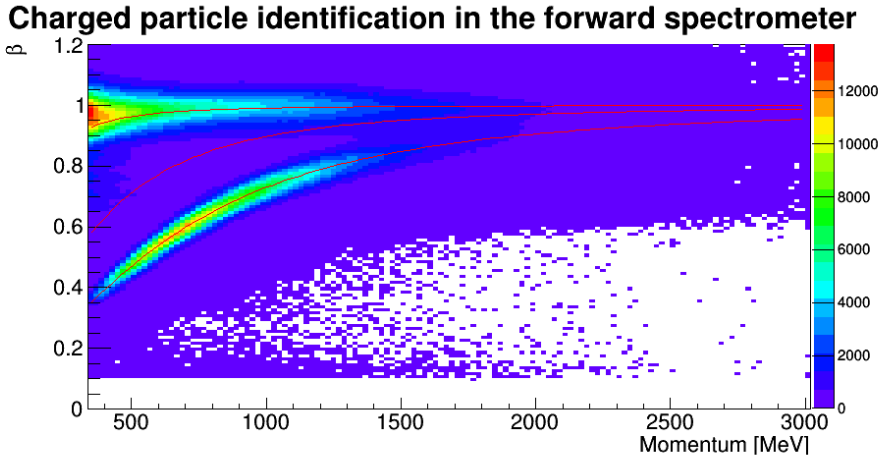
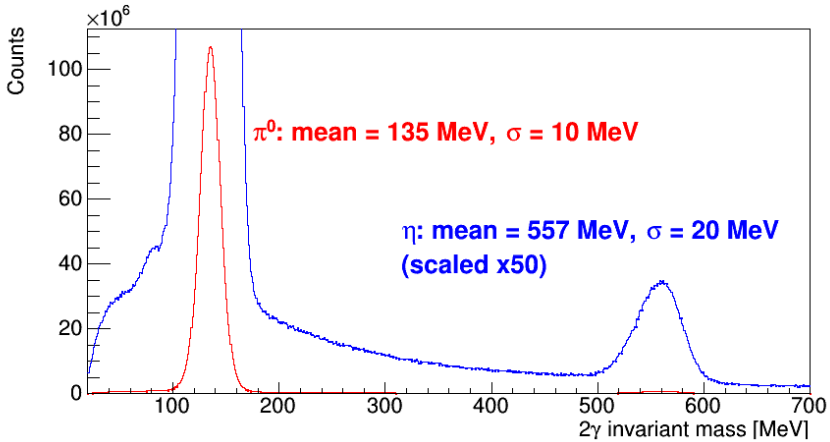


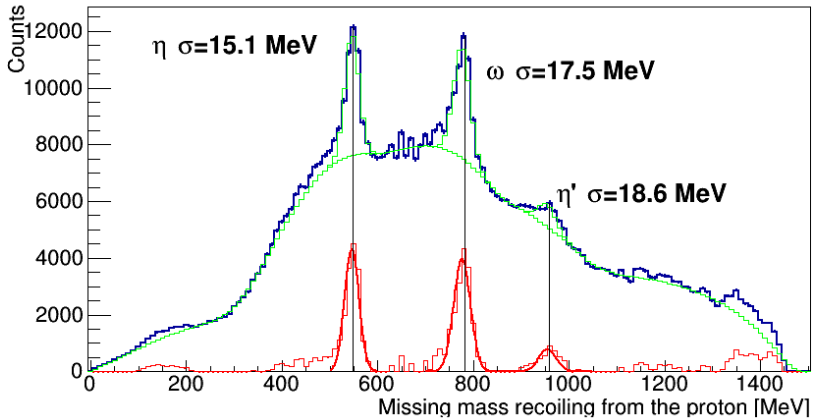
Analysis overview

- Example of recent data (IH_2 target, subset of data):





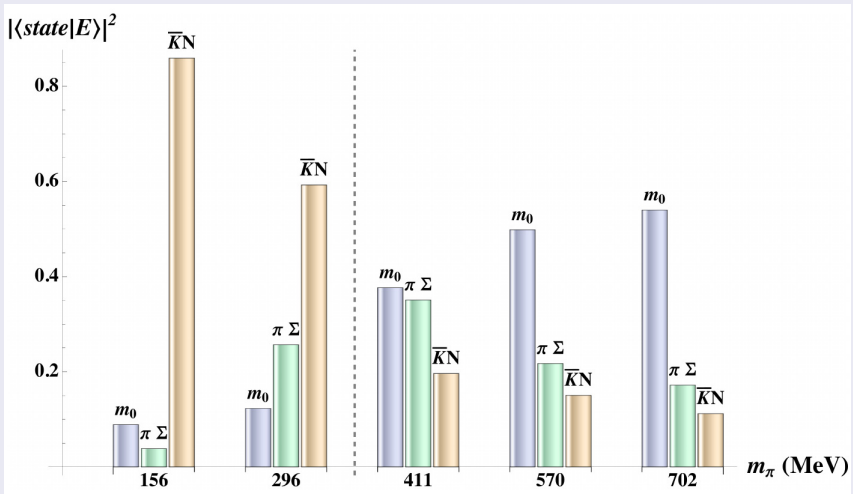




Strangeness photoproduction - physics motivation

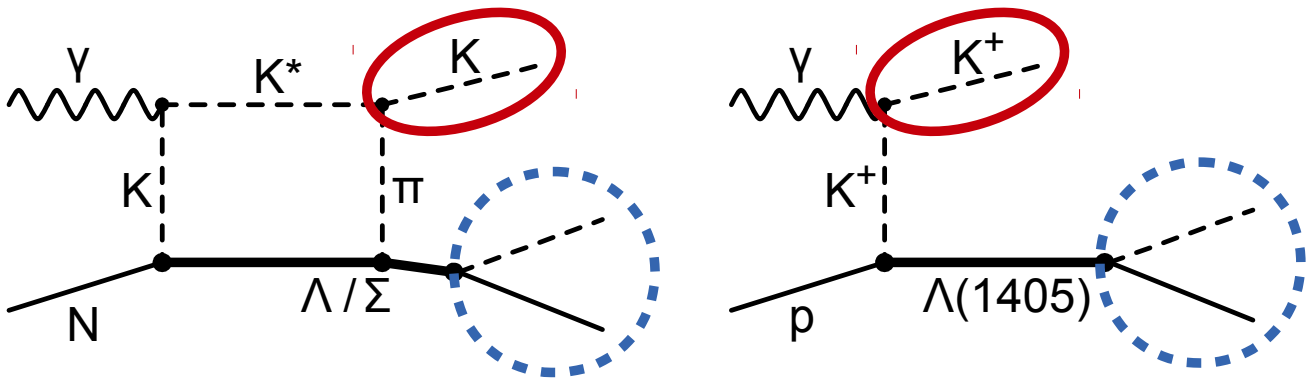
- BGO-OD - Identify final states of mixed charge - investigation of Y^* resonances, eg $K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0 \rightarrow K^+\pi^0\gamma\Lambda \rightarrow K^+\gamma\gamma\gamma p\pi^-$
- Y* spectrum - limited success with constituent quark models
- Models including meson-baryon 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, B. Borasoy, P.C. Bruns, U.-G. Meißner and R. Nißler, Eur. Phys. J. A 34 (2007) 161, P.C. Bruns, M. Mai, U.-G. Meißner, Phys. Lett. B 697 (2011) 254, J.A. Oller and U.-G- Meiner, Phys. Lett. B 500 (2001) 263, B. Borasoy, U.-G. Meiner and R. Niler, Phys. Rev C 74 (2006) 055201

- $\Lambda(1405)$ - 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 Σ^* 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)



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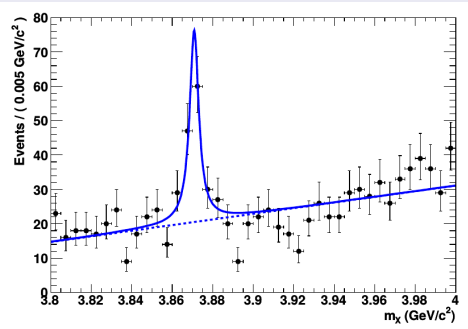
Evidence of hadronic molecules in the charmed sector

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

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

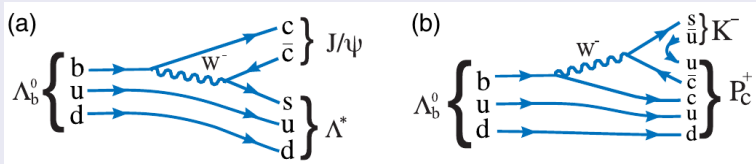
Close to $D^0\bar{D}^{0*}$ threshold, favouring DD^* decay

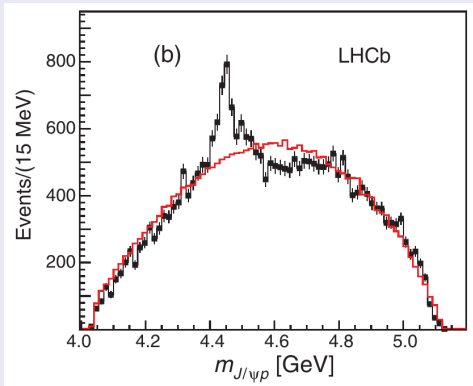


B. Aubert et al (BARBAR Collaboration), Phys. Rev. D77 111101 (2008)

Pentaquark candidates observed at LHCb

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



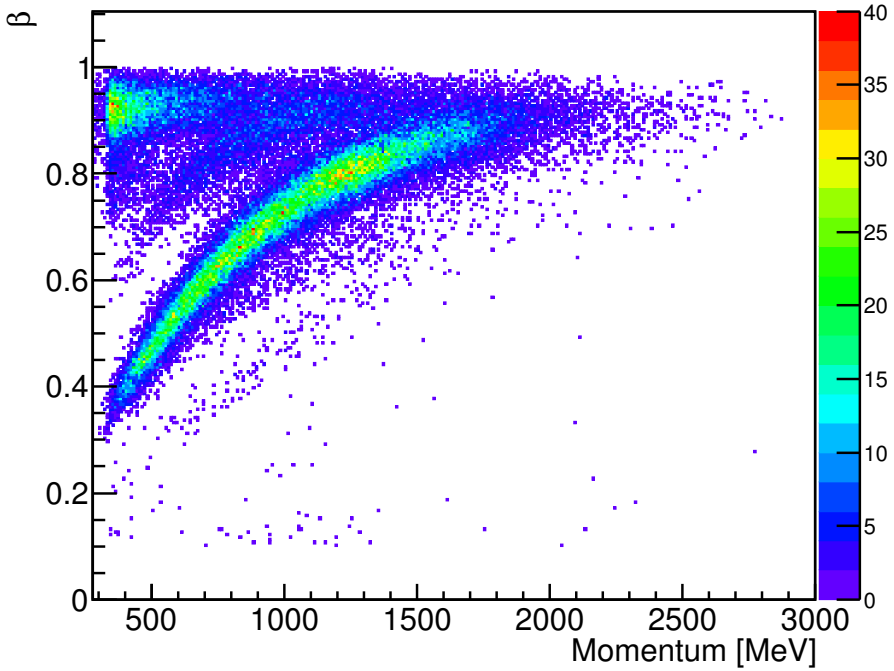


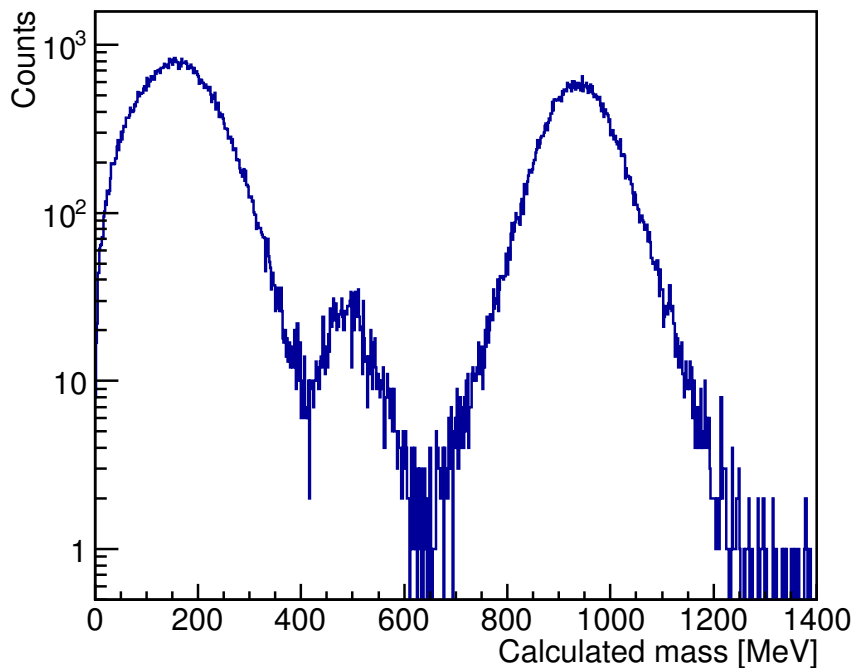
K^+ identification in the forward spectrometer

- β & momenta measured in the forward spectrometer

To enhance K^+ signal

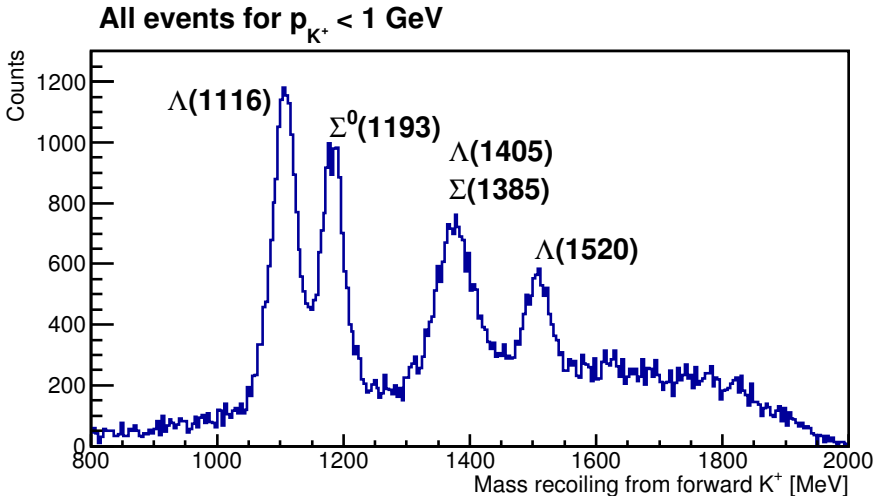
- $\pi^0 \rightarrow \gamma\gamma$ mass reconstructed in the BGO
- BGO total energy deposition $<$ 250 MeV
- Beam energies above $K^+\Lambda$ threshold

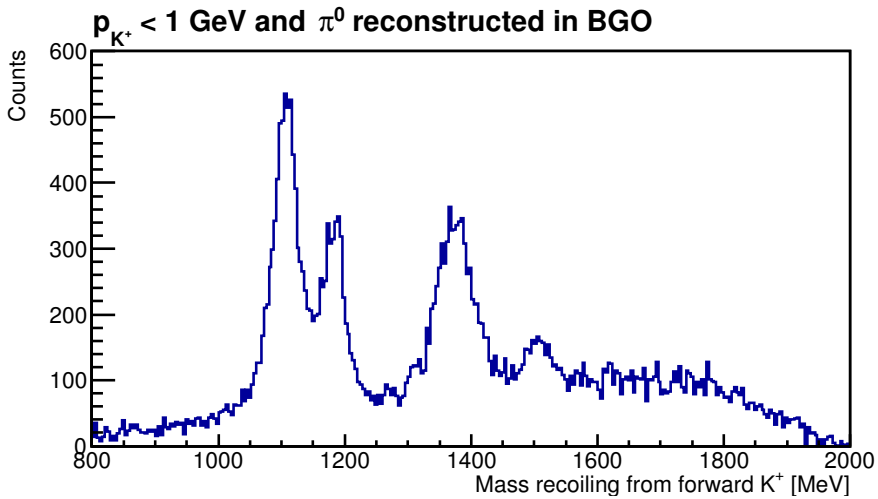


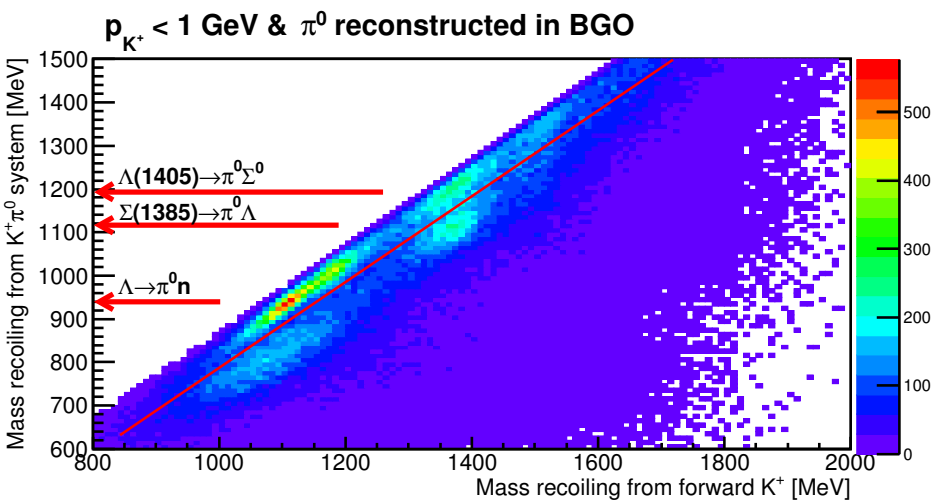


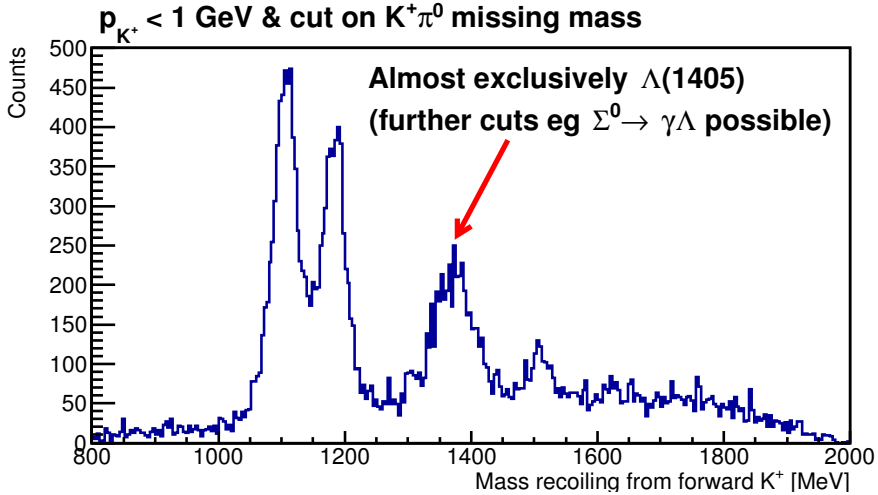
Mass recoiling from K^+ in the forward spectrometer

- Study of Y^* states in an extemely low momentum transfer region

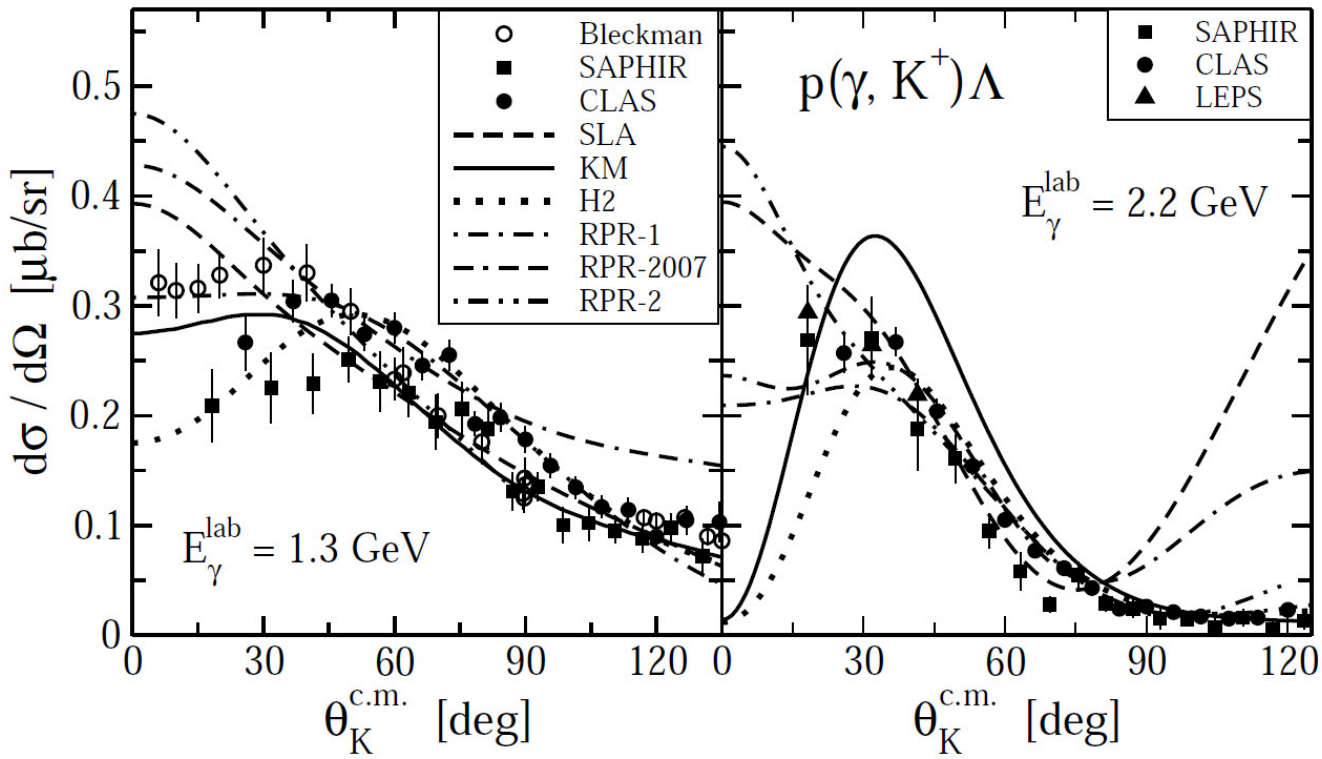








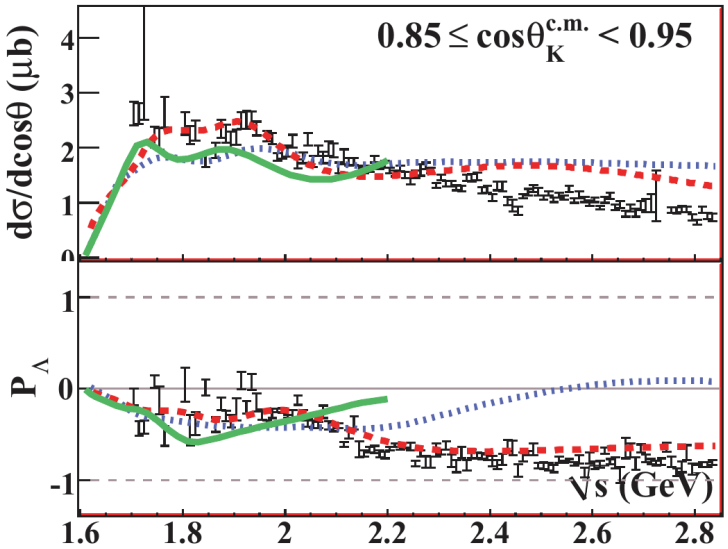
$K^+\Lambda$ at forward angles - motivation



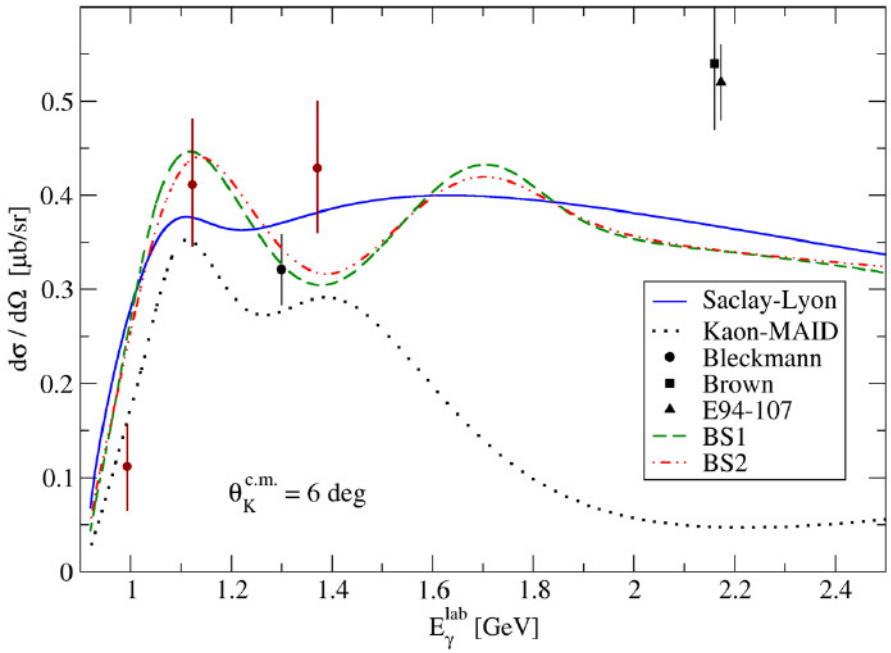
Bydzovsky and D. Skoupil, arXiv:1211.2684v1 (2012) Proceedings of SNP12

Important constraint for hypernuclei electroproduction

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



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



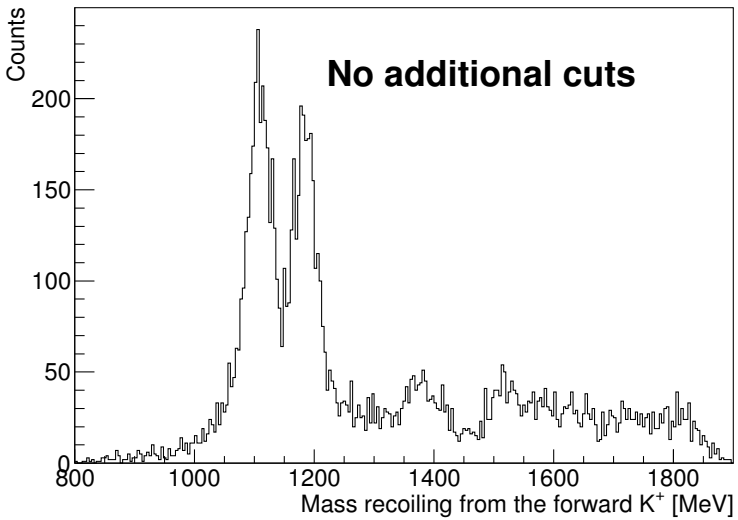
T. Zimmermann, PhD thesis, University of Bonn (2016)

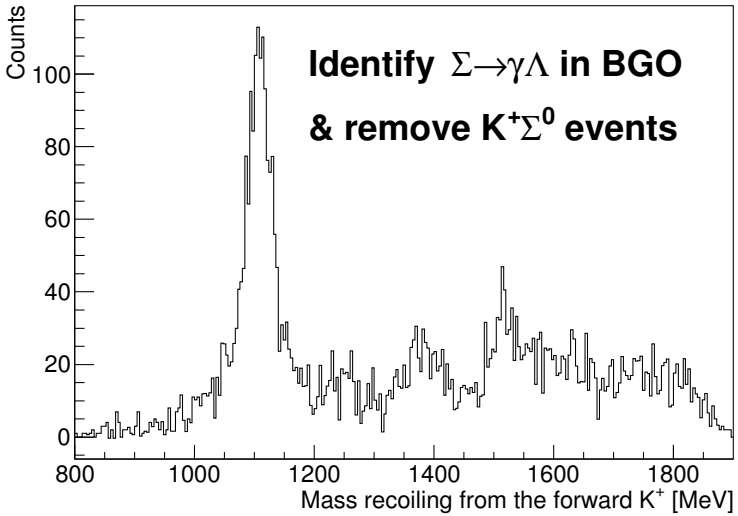
At BGO-OD

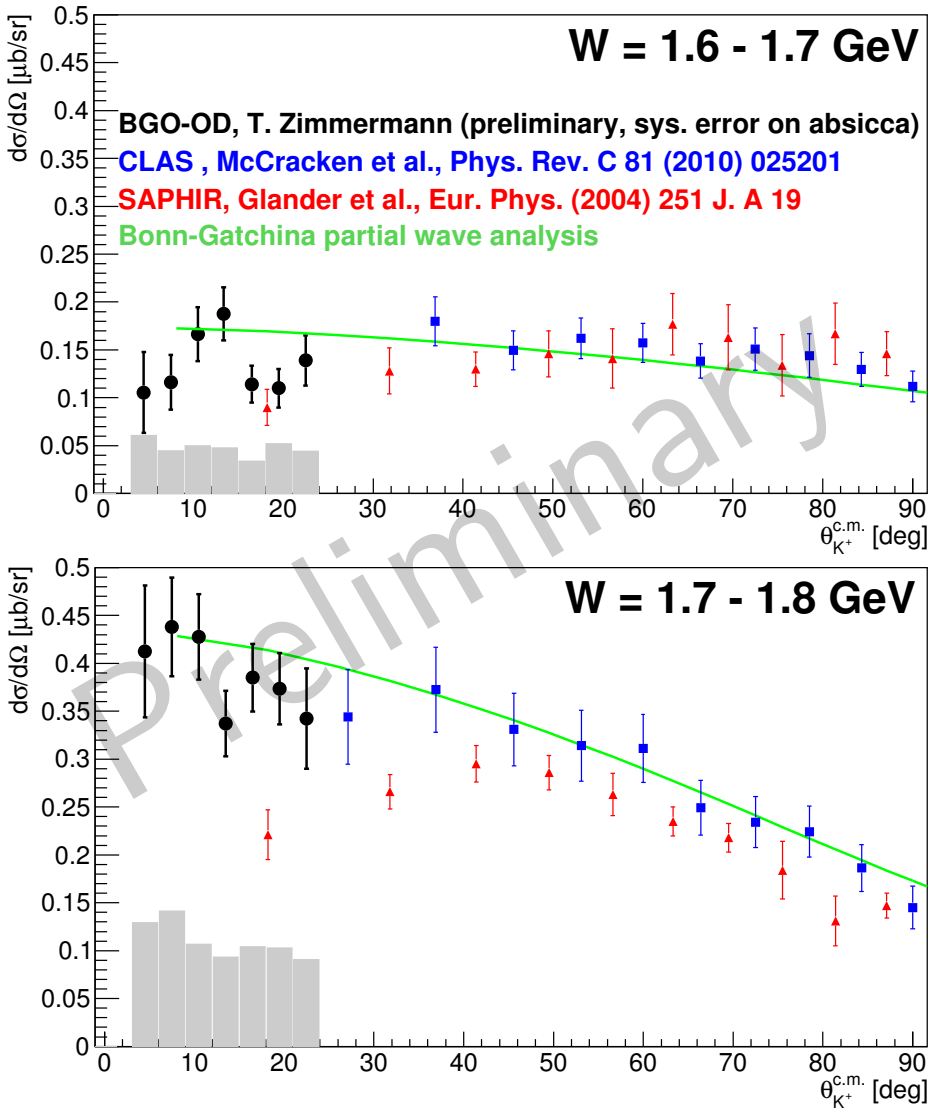
- Forward CM polar angle range approx. 4-26^0, $0.9 < \cos\theta_{cm}^{K^+} < 1.0$
- P_Λ - recoil Λ polarisation accessed by angular distribution of $\Lambda \rightarrow \pi^0 n$

Very forward $K^+\Lambda$ $d\sigma/d\Omega$ (preliminary, 11 days data)

T. Zimmermann, preliminary data, PhD thesis work

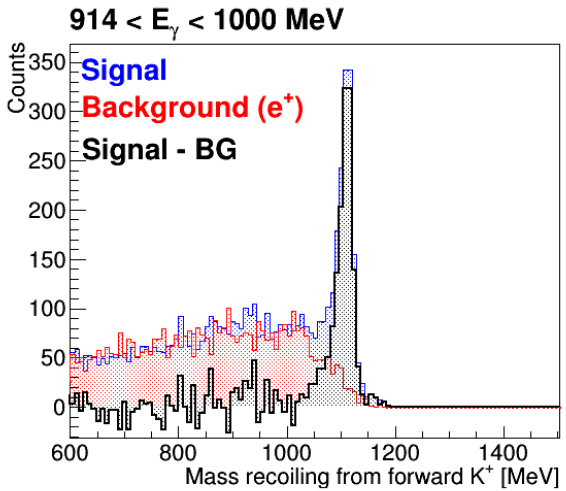


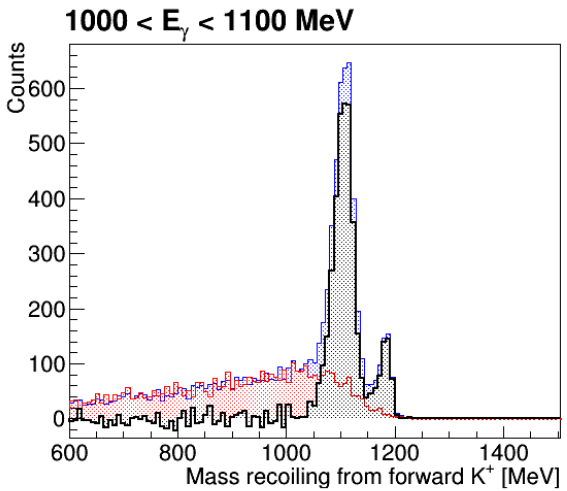


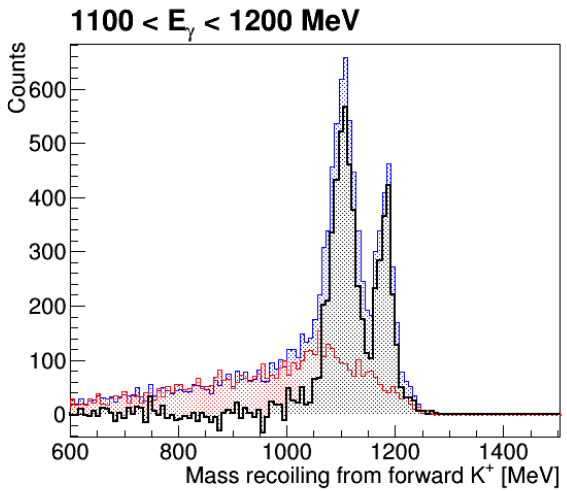


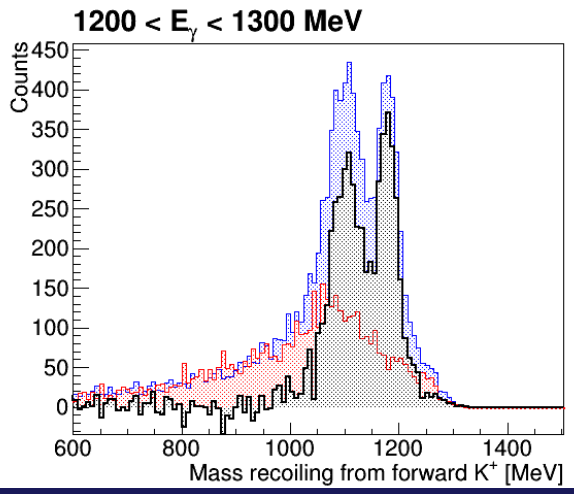
High statistics new dataset

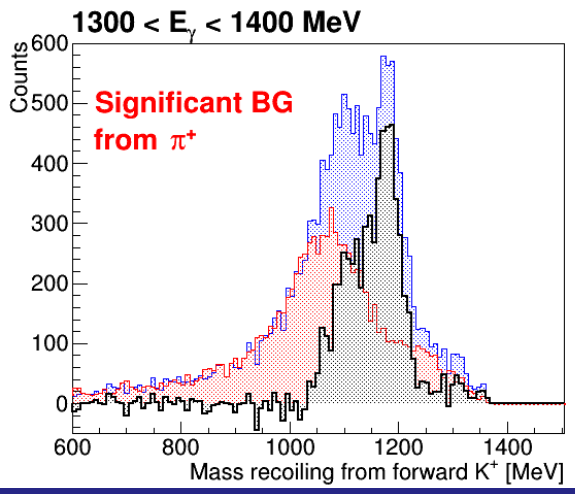
- Approx x10 statistics (more data, no restrictive cuts)
- Fit to background: e^+e^- from the beam, misidentifed π^+ at higher energy

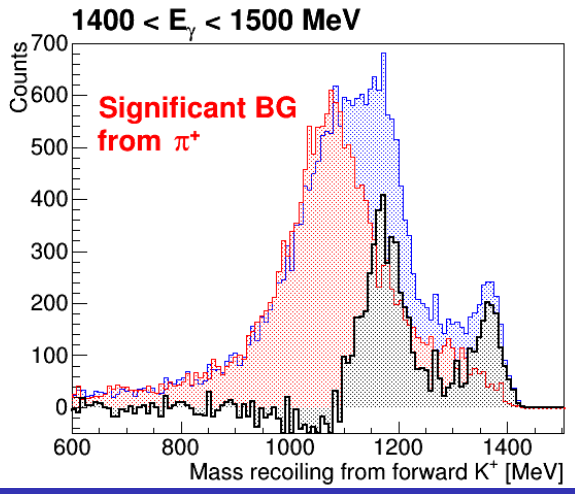






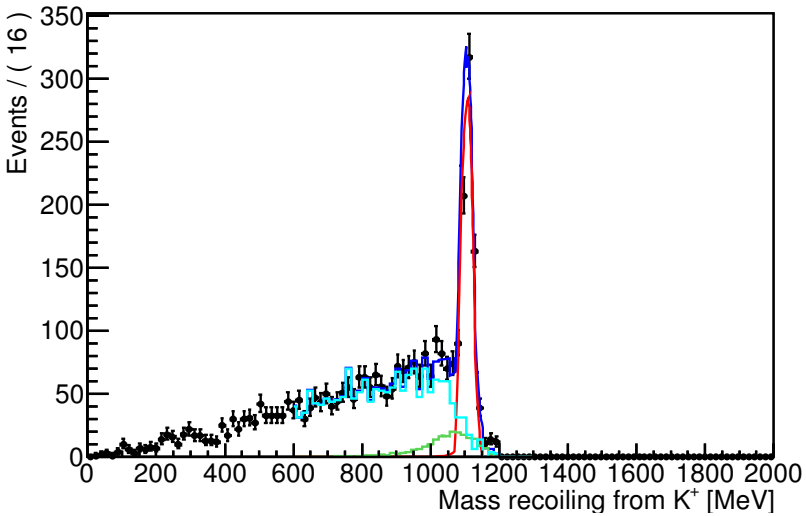




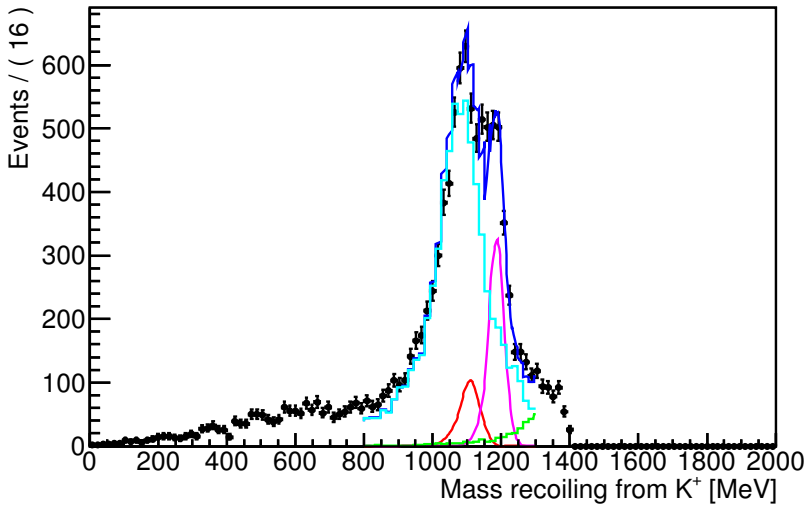


Extracting $K^+\Lambda$ & $K^+\Sigma^0$ signal from background

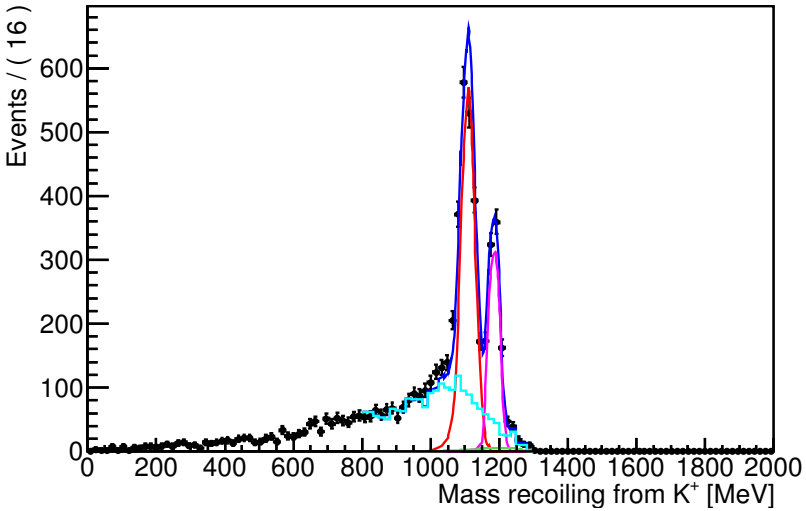
W = 1600 - 1700 MeV



W = 1800 - 1900 MeV



W = 1700 - 1800 MeV



Fitting with *RooFit*

- Signal
- Simulated $K^+\Lambda$ events
- Simulated $K^+\Sigma^0$ events
- False, negatively charged particles (ρ,$e^{\pm}$)
- Wrongly correlated time events

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

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

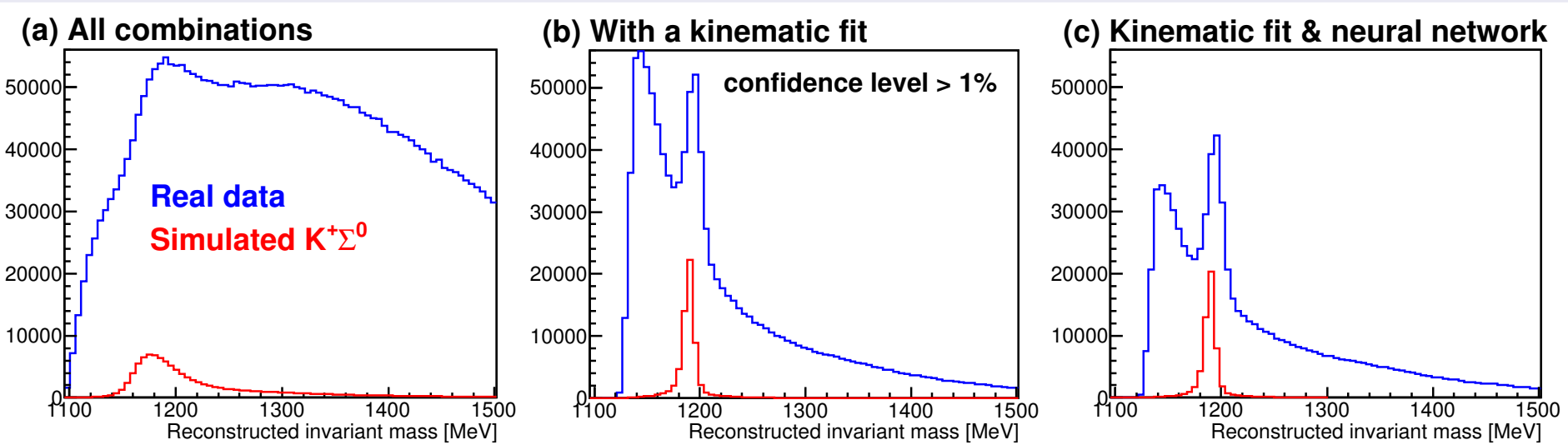
- K^+ & $\Lambda \rightarrow p\pi^-$ over large acceptance region ($1^0 < \theta < 155^0$)
- Σ^0 decay photon in the BGO ($\Sigma^0 \rightarrow \Lambda\gamma$)
- Technique used for higher lying Y* states (eg $\Lambda(1405) \rightarrow \pi^0\Sigma^0$)

Reconstructing the Σ^0 invariant mass

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

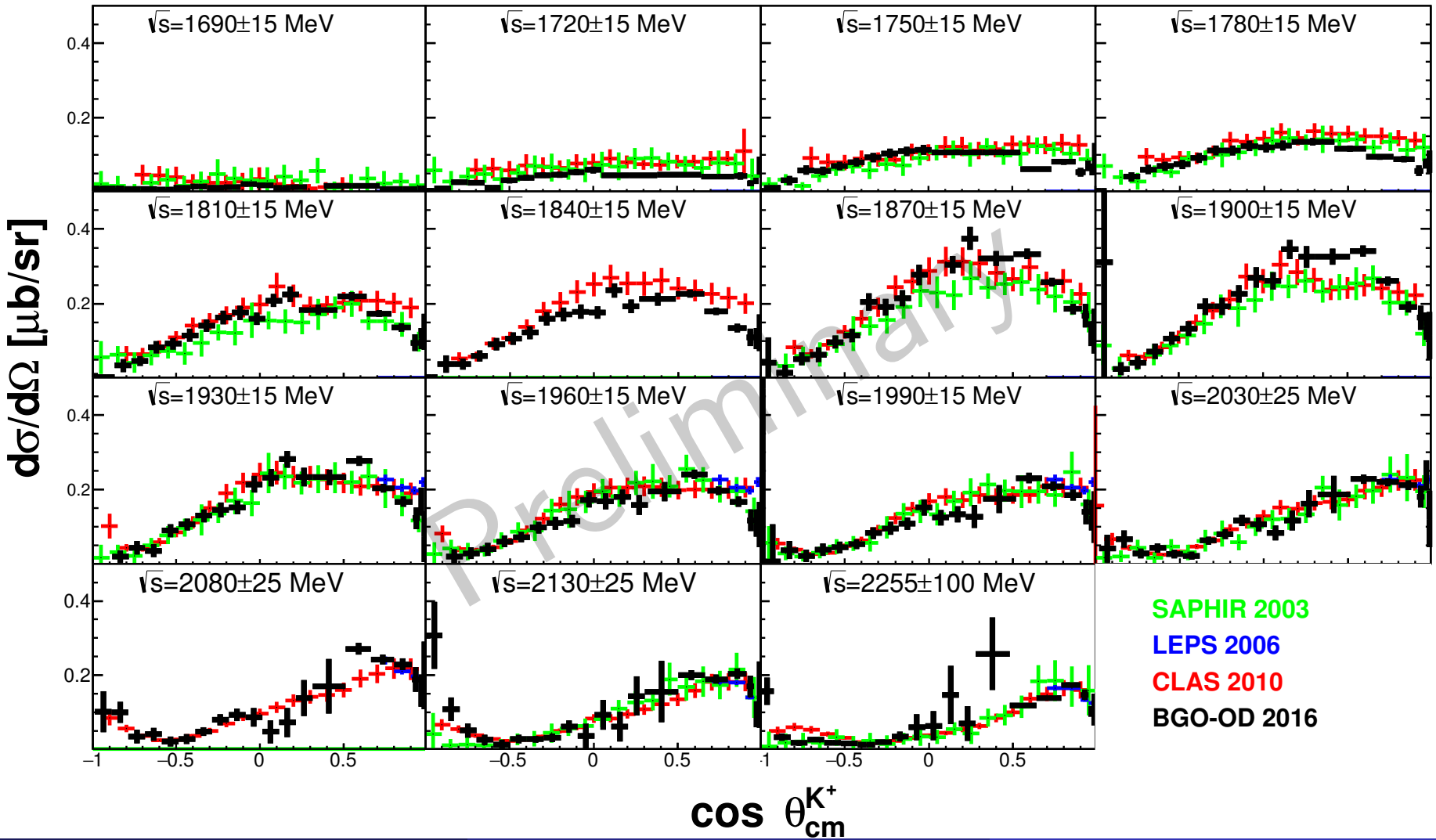
(b) Kinematic fit & confidence level cut

(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)

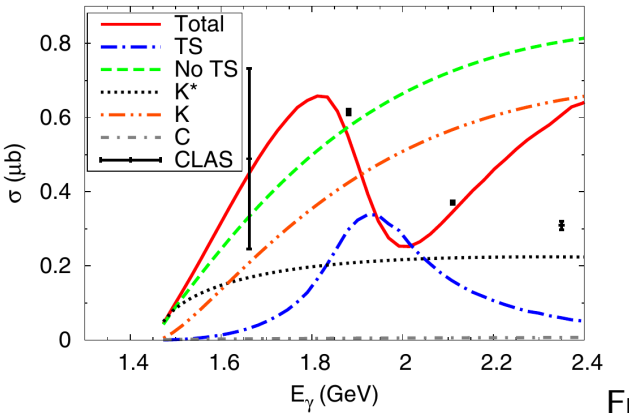


$\Lambda(1405)$ over a broad kinematic range

G. Scheluchin, PhD thesis work

Complements CLAS data (K. Moriya et al., Phys. Rev. **C 88**, 045201 (2013))

Triangle singularity can describe peak at $W = 2110$ MeV & $\cos\theta = 0$: E. Wang et al., Phys. Rev. **C 95**, 015205 (2017)

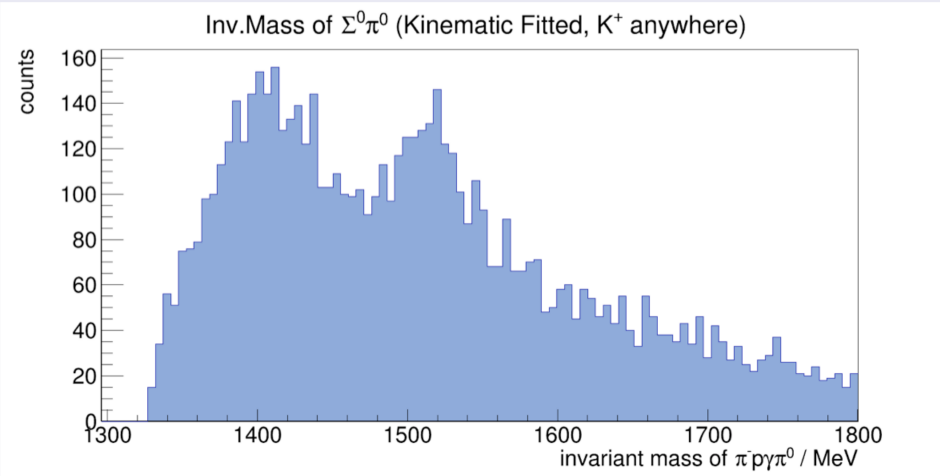


From E. Wang et al., Phys. Rev. **C 95**, 015205 (2017)

Full final state reconstruction

$K^+\Lambda(1405)$ and $K^+\Lambda(1520)$ reconstruction

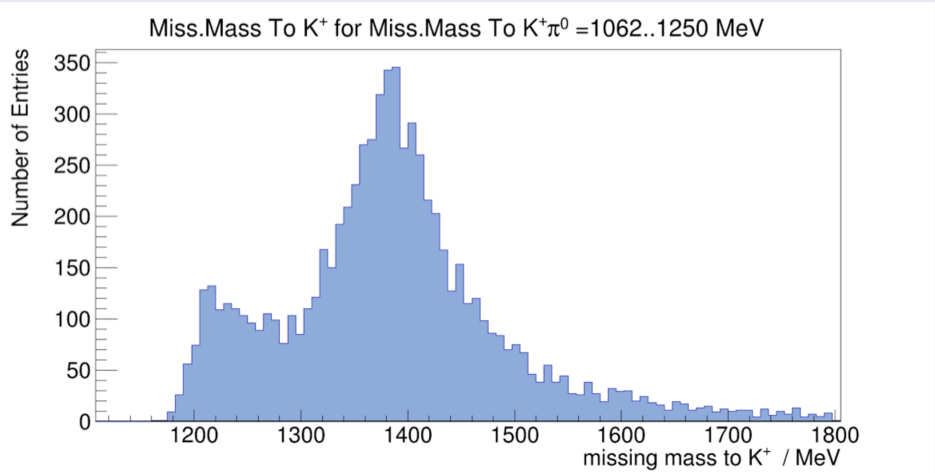
$$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0 \rightarrow K^+\gamma\gamma\gamma\pi^-p$$



K^+ decay identification in BGO

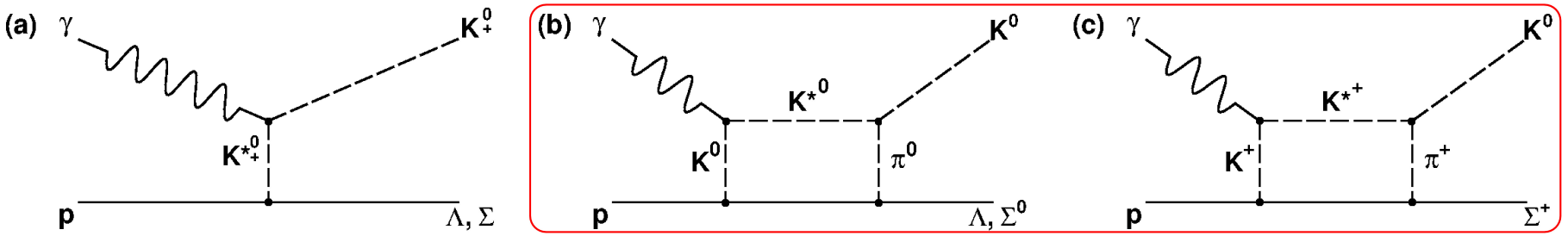
Time delayed decay in segmented calorimeters: $K^+ \rightarrow \mu^+\nu_\mu$

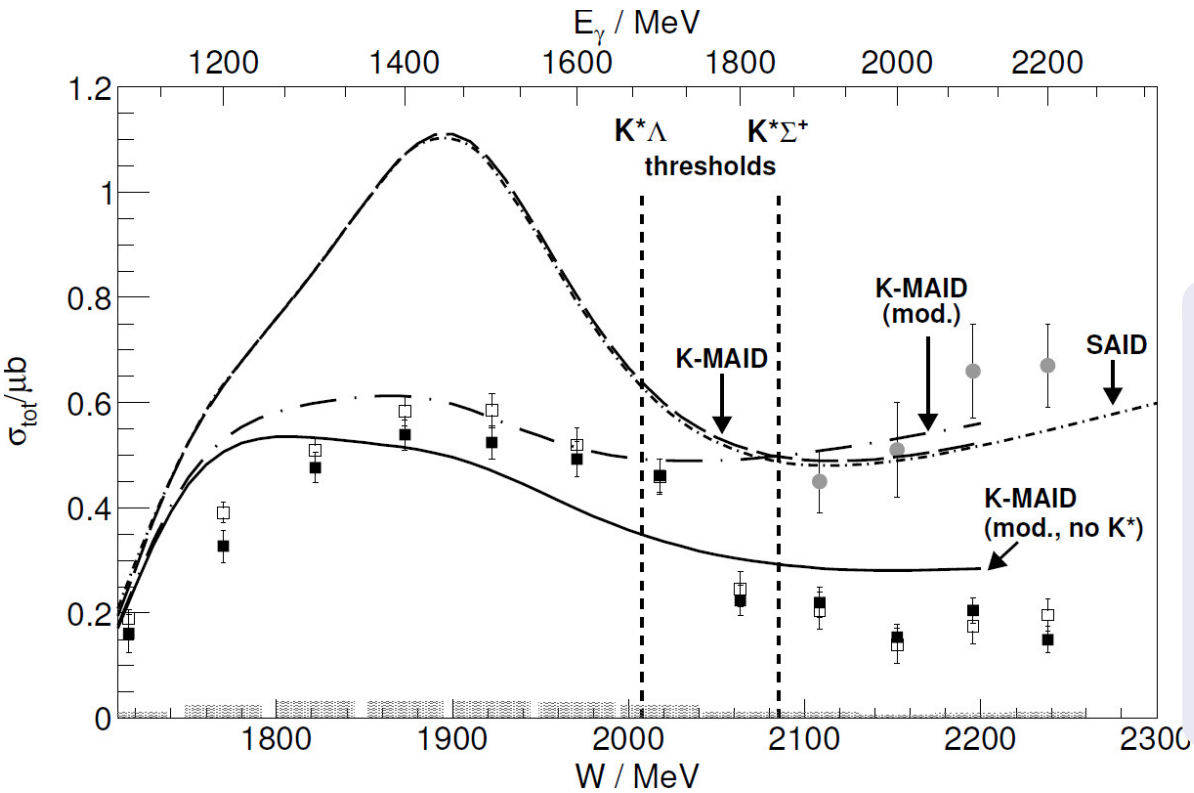
T.C. Jude, et al., Phys. Lett. **B 735**, 112501 (2014)



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

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





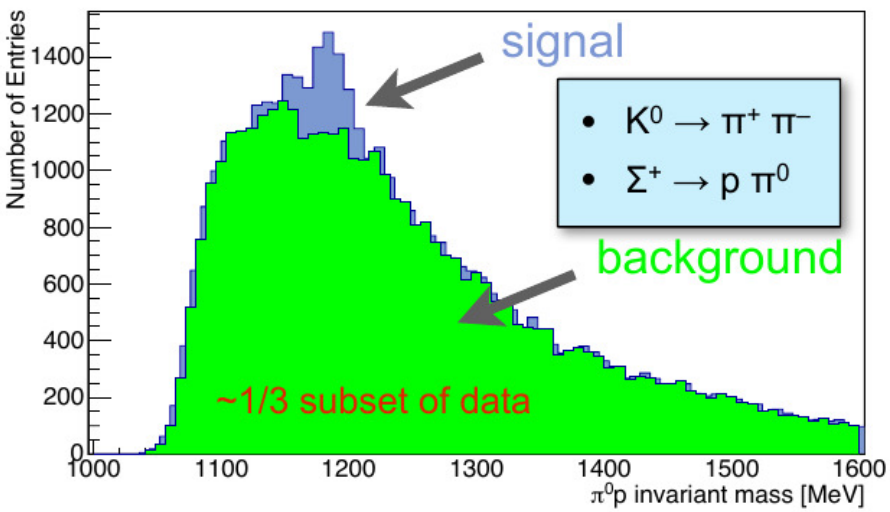
Grey points - $K^0\Sigma^+$ + $K^*\Sigma^+$ M. Nanova et al., EPJ A35 (2008) 333

- Cusp-like structure due to K^{*0} subthreshold production rescattering to π^0 & K^0?
- Further analysis at BGO-OD

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

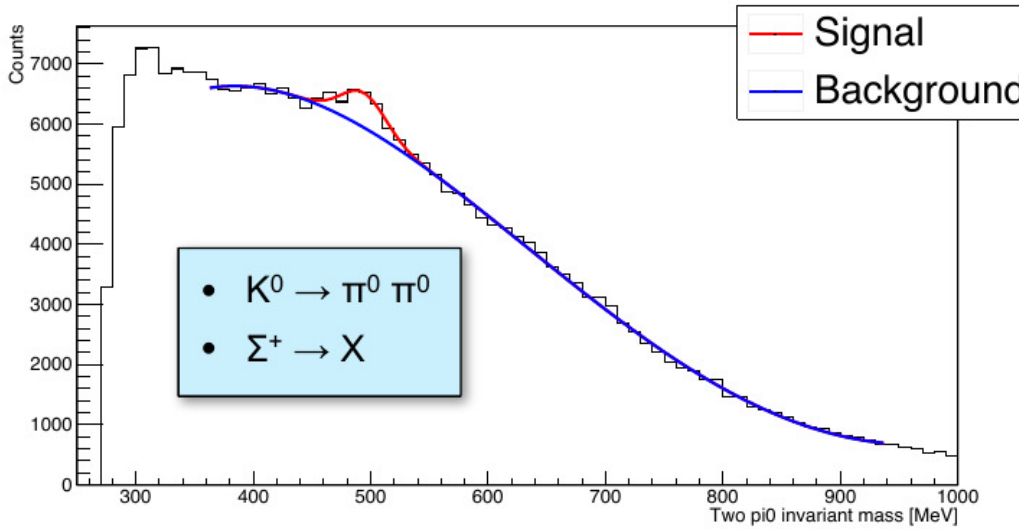
- Access $\gamma p \to K^0\Sigma^+$ via different decay modes at BGO-OD
- Reduction of background & improved momentum resolution acheivable with the MWPC (analysis underway)

work of B.-E. Reitz



w/ kinematic fit

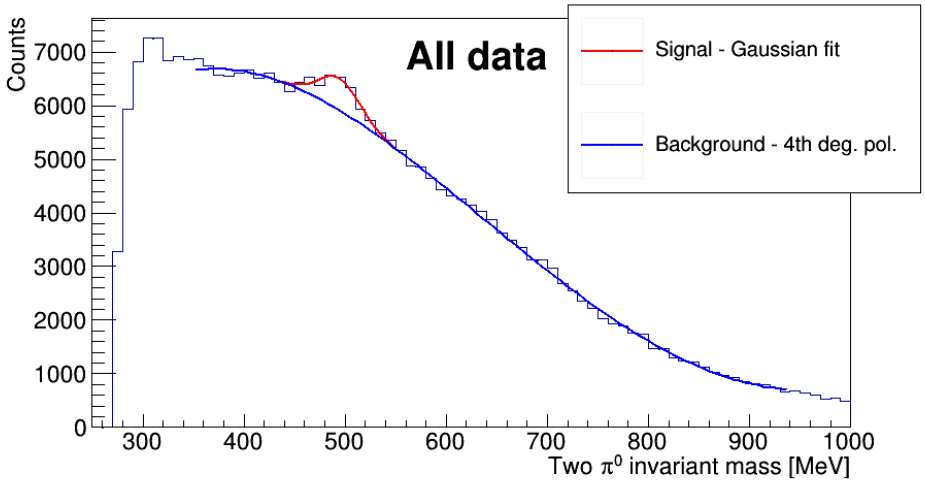
work of S. Alef

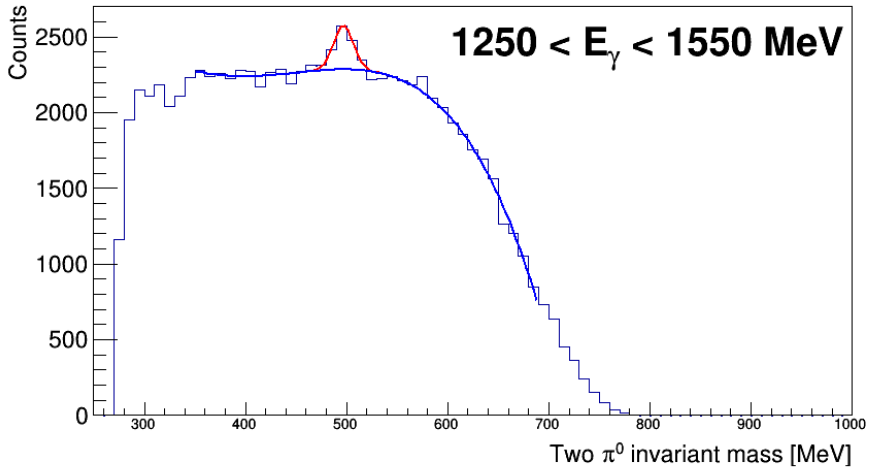


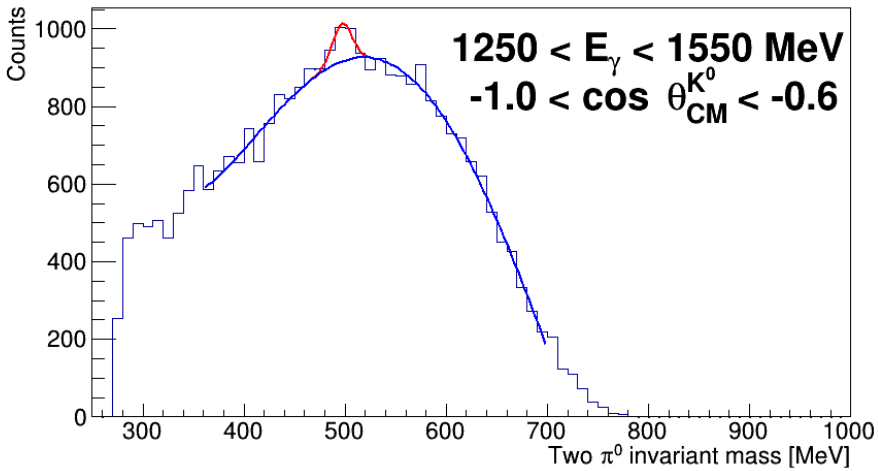
prior to kinematic fit

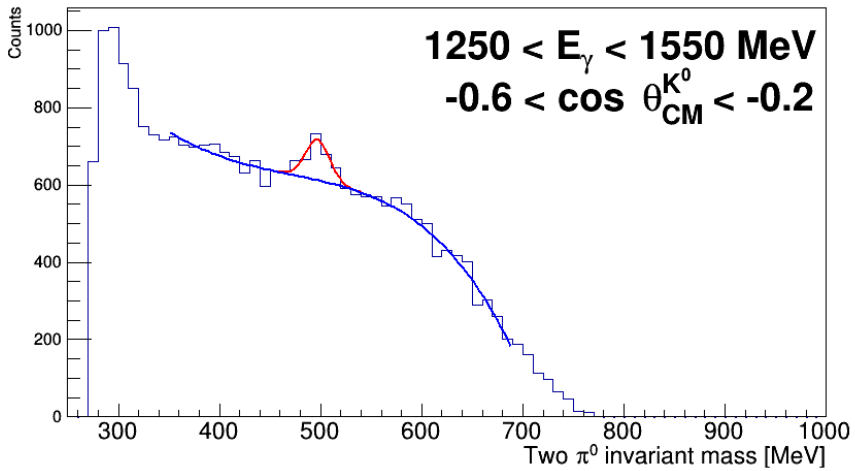
Preliminary identification of $K^0\Sigma^+$ with BGO-OD

Analysis by S. Alef



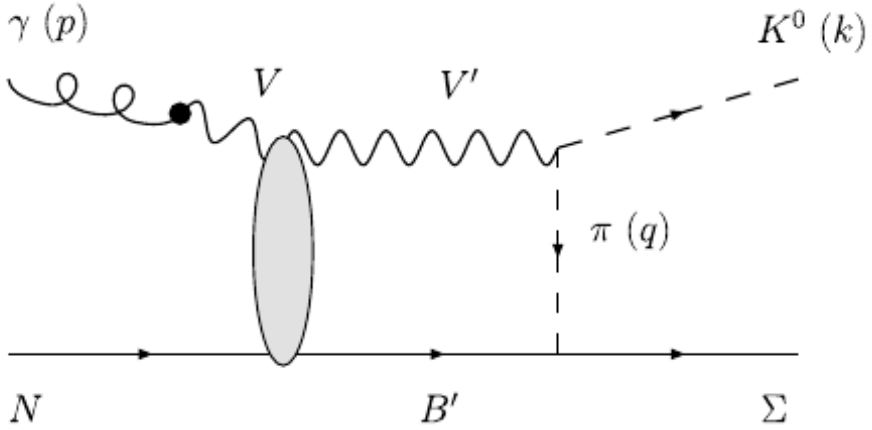


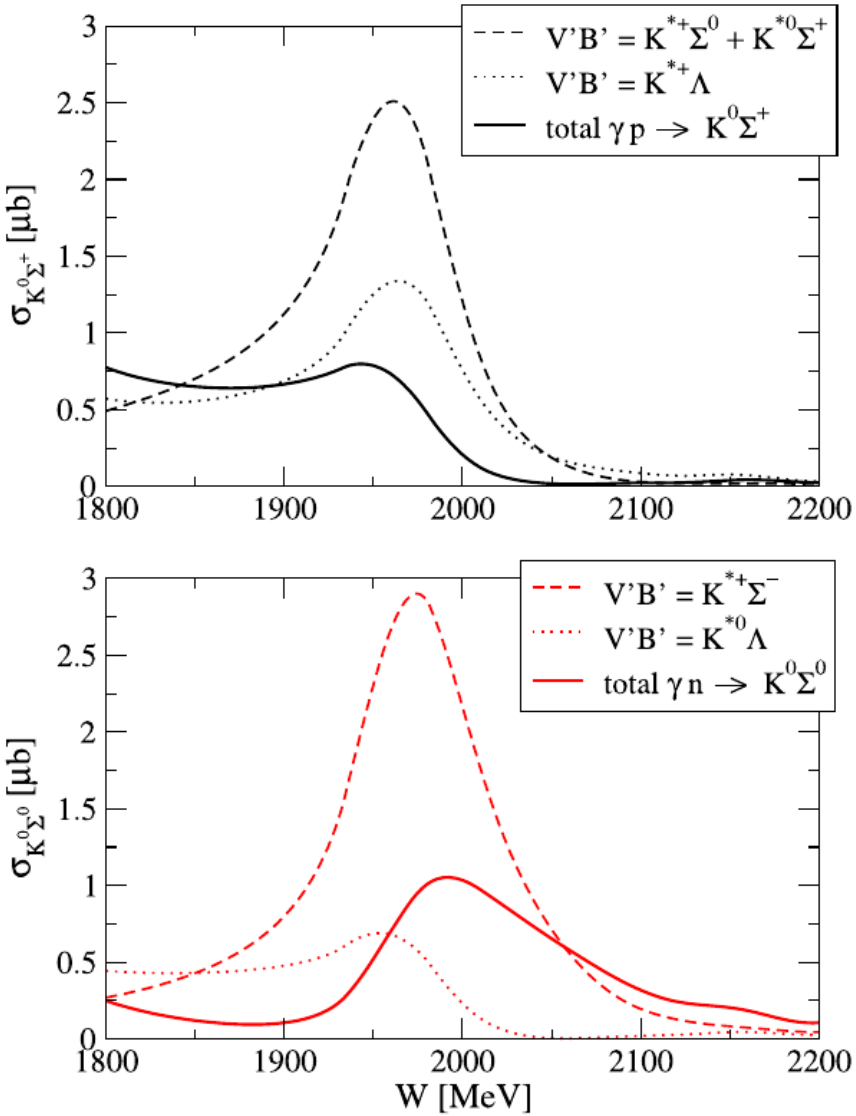




K^0 photoproduction off the neutron

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





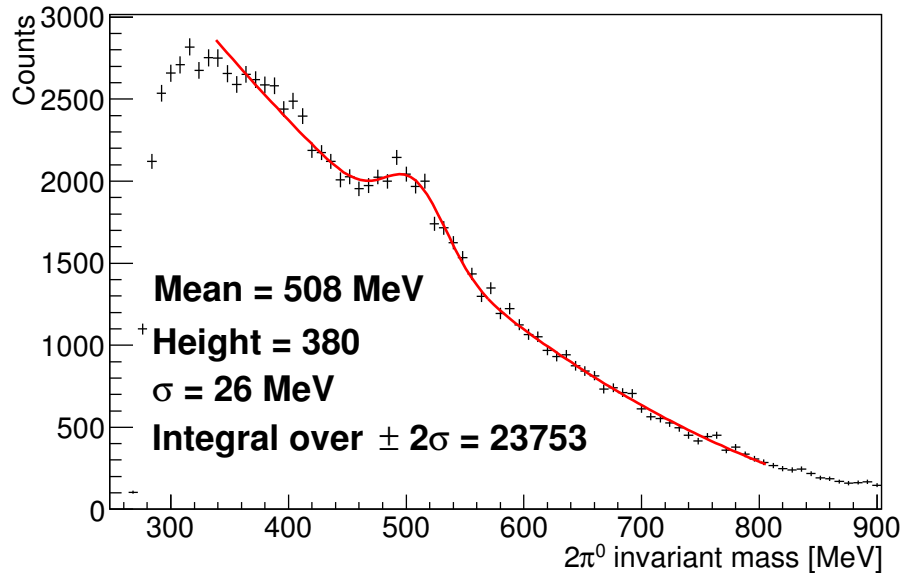
- Complementary to $K^+\Lambda$ - relate hadronic coupling constants
- Limited available data, K. Tsukada et al, Phys. Rev. C 78, 014001 (2008)

Test beam time data (Deuterium target), 2 days

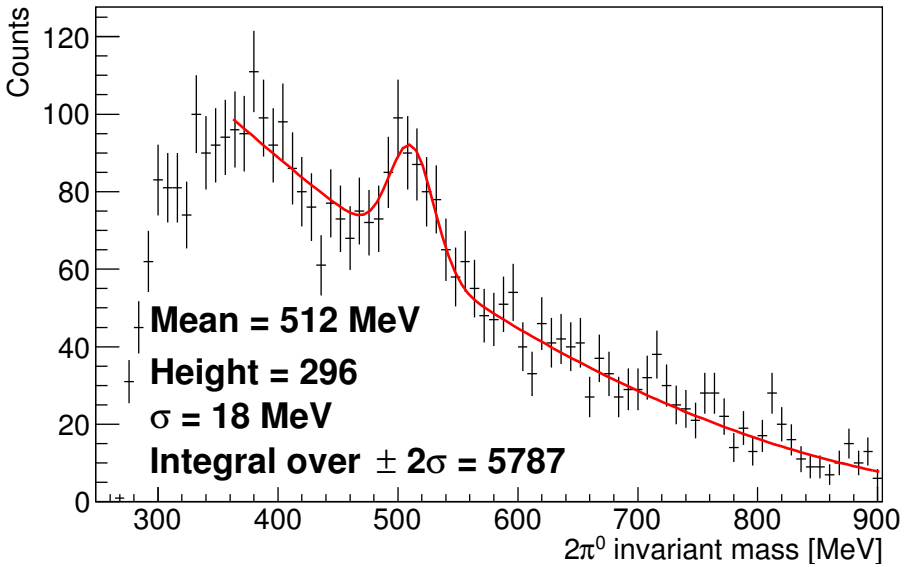
- $K^0 \rightarrow 2\pi^0$ reconstructed in the BGO
- Total neutral particles < 6
- Total charged particles < 3

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

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



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



Conclusions

BGO-OD

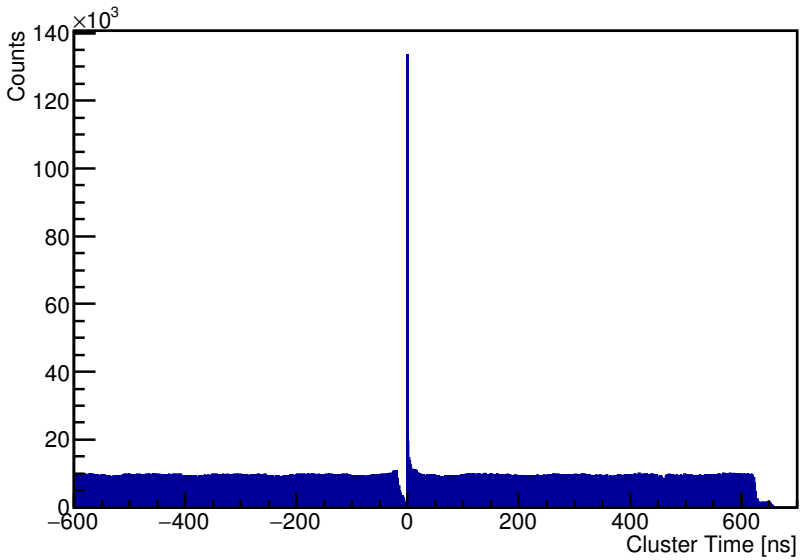
- Neutral & charged particle reconstruction - central, intermediate & forward angles
- Unique combination - extemely forward angle acceptance for charged particles

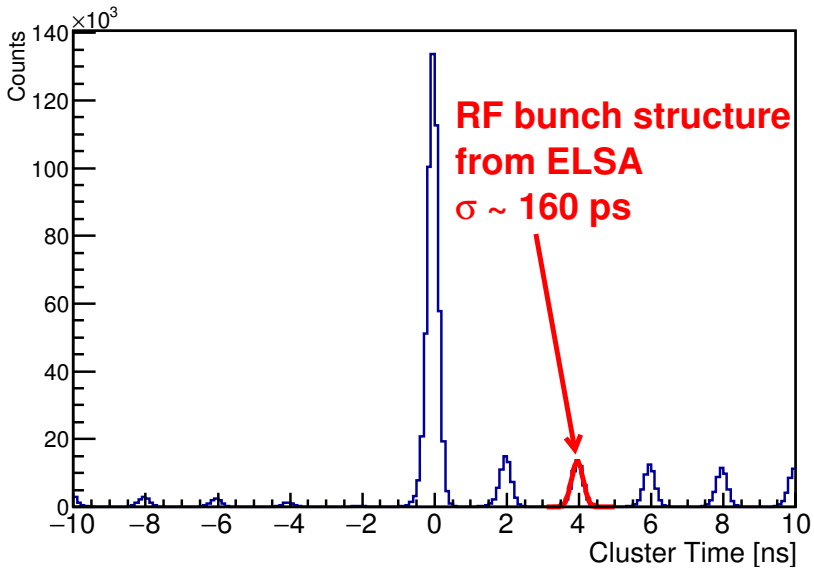
Strangeness photoproduction

- Access low momentum exchange regions for K^+Y^* final states
- Forward $K^+\Lambda/\Sigma^0$ differential cross sections and recoil polarisation measurements
- The study of higher lying hyperons at extremely forward angles (eg $\Lambda(1405)$)
- $K^0\Sigma^+$ reconstruction via multiple decay modes
- Proof of concept analysis with deuterium target for $\gamma n \to K^0\Lambda/K^0\Sigma^0$

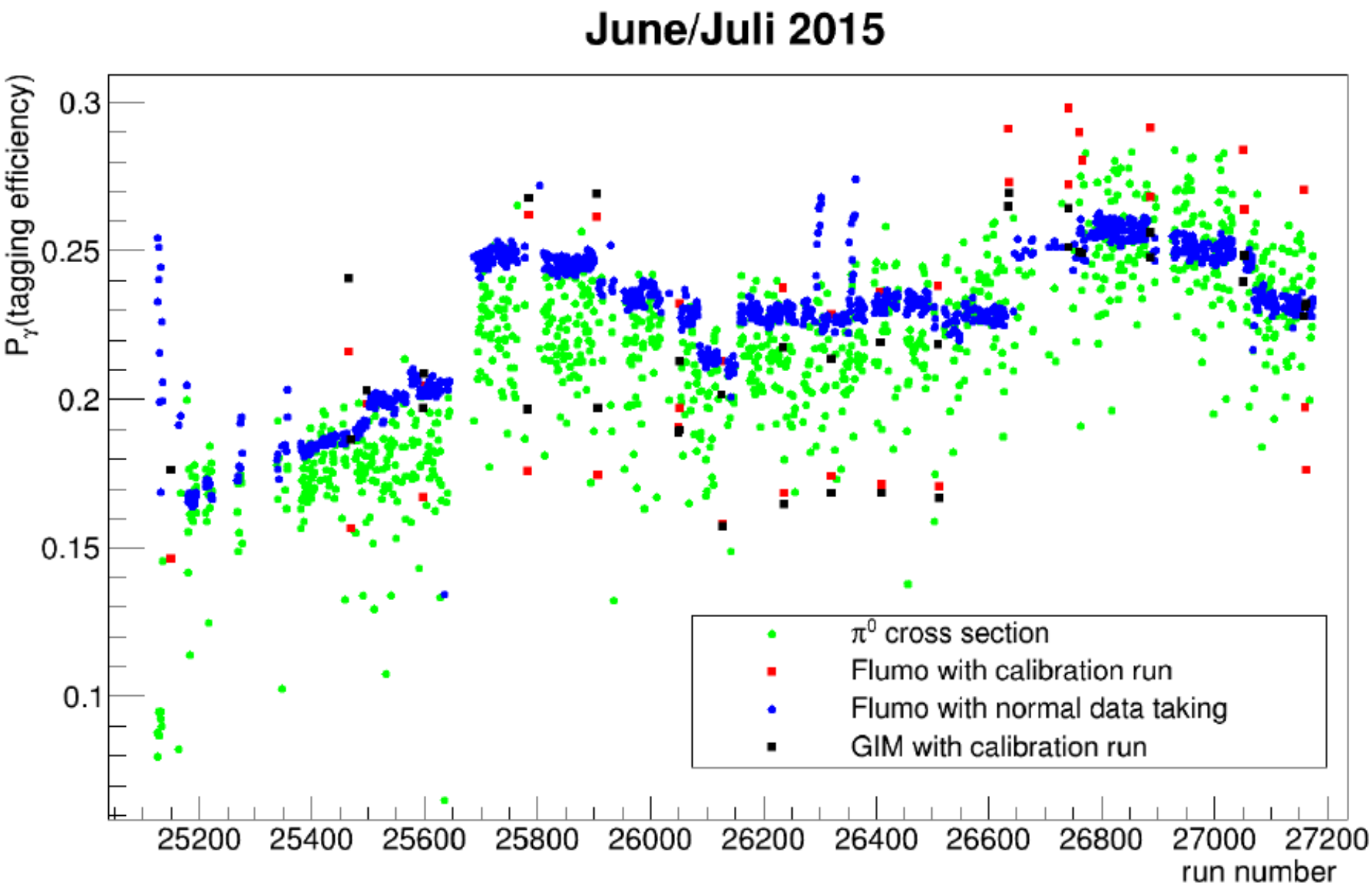
Extra slides

Tagger timing

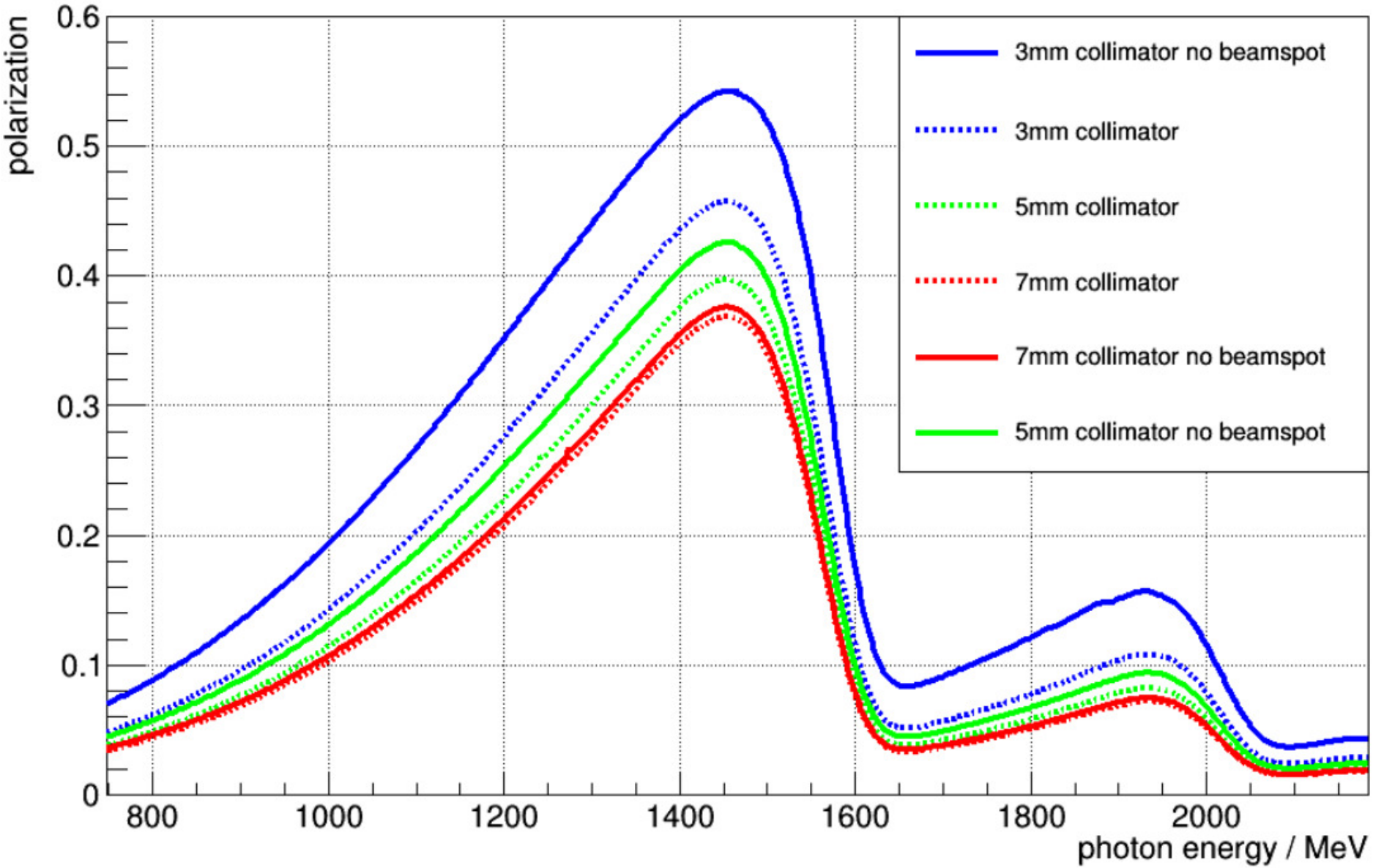




Normalising $p\pi^0$ cross section, run-by-run

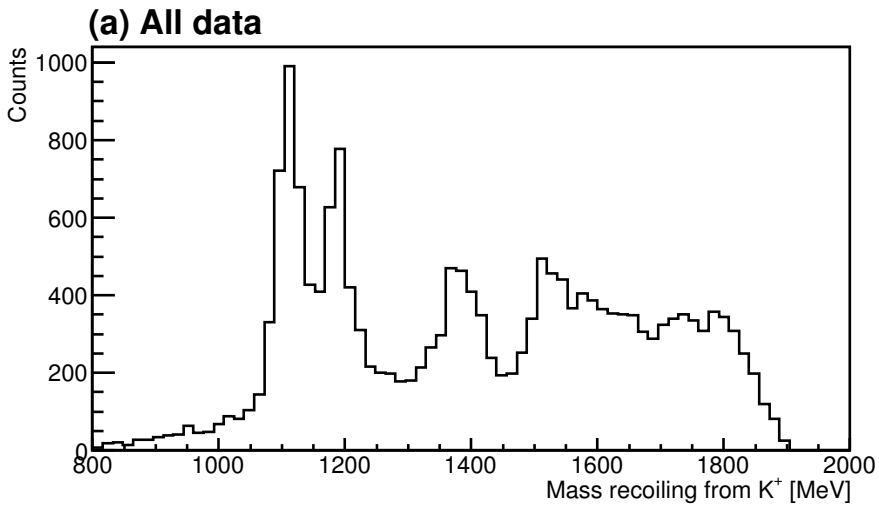


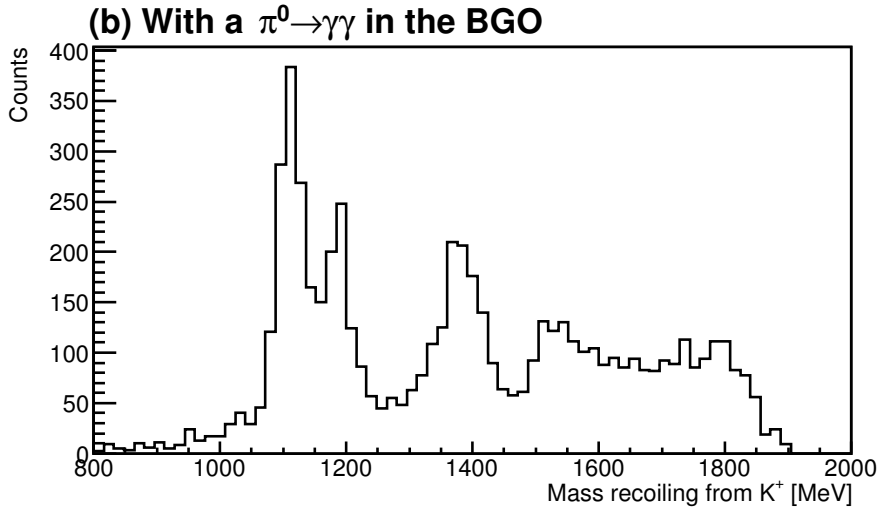
Degree of polarisation with different collimation

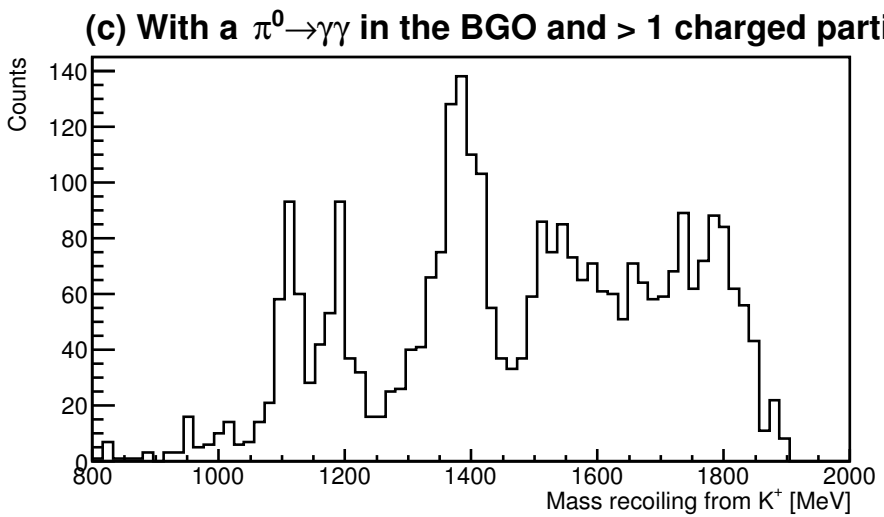


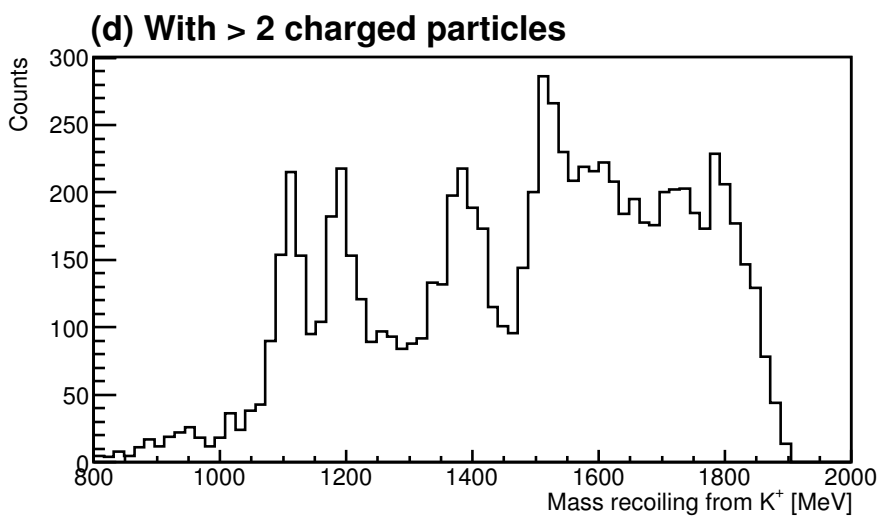
Mass recoiling from K^+ in the forward spectrometer

- Additional cuts reveal different topologies



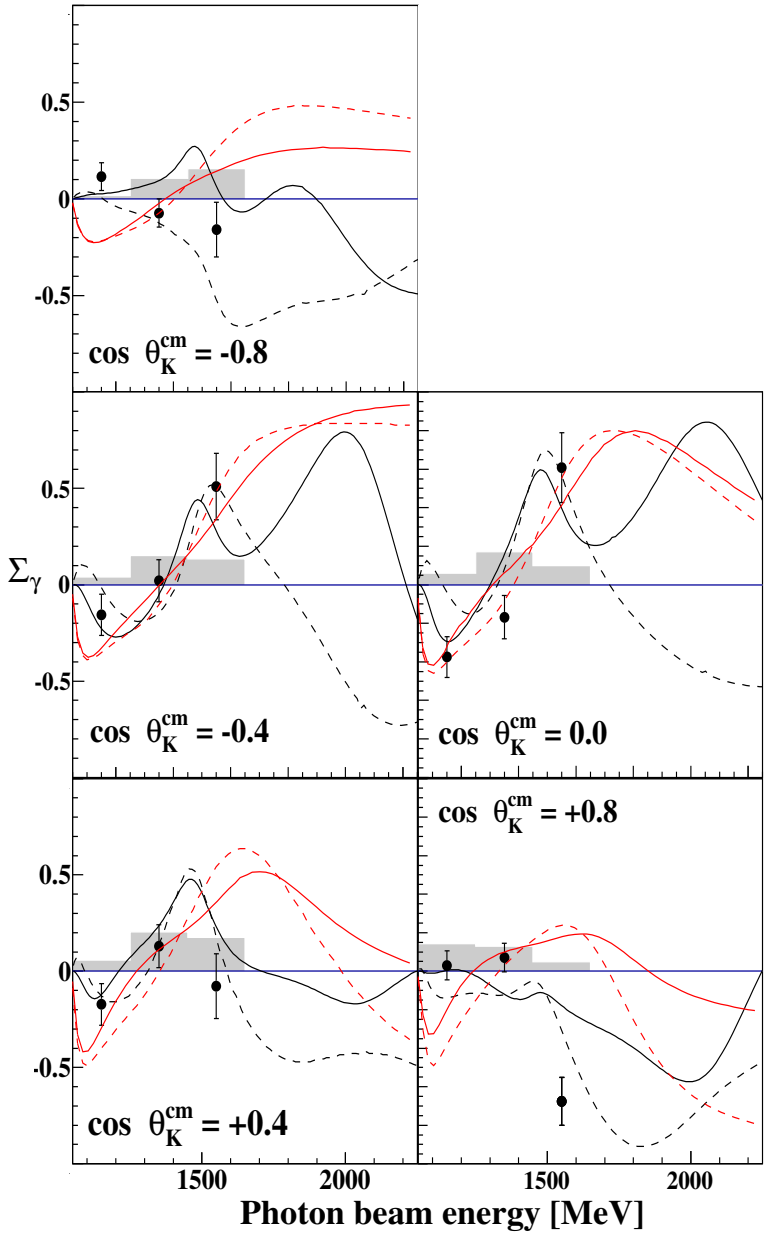






Previous $\gamma p \to K^0\Sigma^+$ measurements

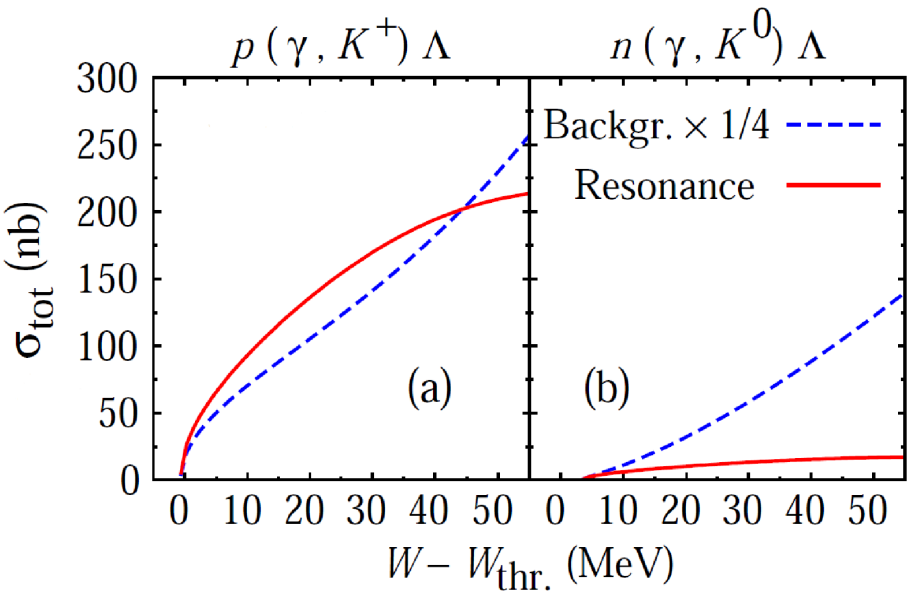
- The 1st beam asymmetry measurement
  R. Ewald *et.al*, PLB 738 (2014) 268
  (CBELSA/TAPS Collaboration)



K^0 photoproduction off the neutron

- 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

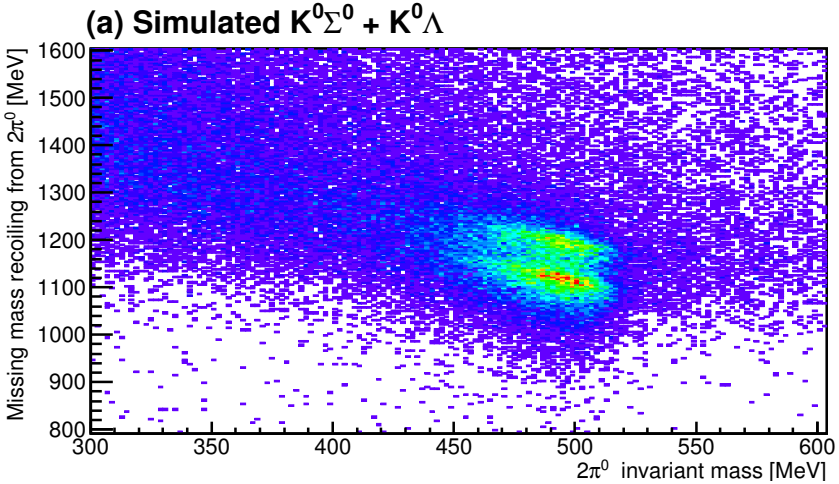
$$
\begin{aligned}
g_{K^+\Lambda_p} &= g_{K^0\Lambda_n} \\
g_{K^+\Sigma^0_p} &= -g_{K^0\Sigma^0_n} \\
g^{V,T}_{K^{*+}\Lambda_p} &= g^{V,T}_{K^{*0}\Lambda_n}
\end{aligned}
$$

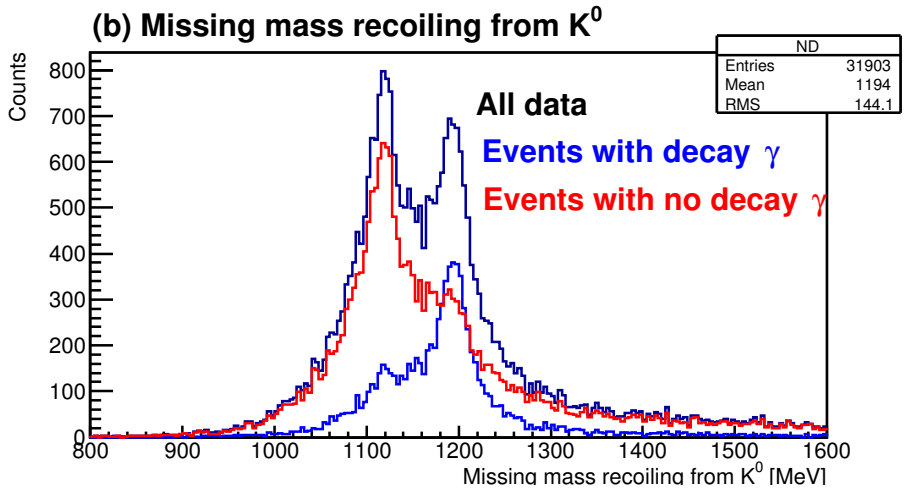


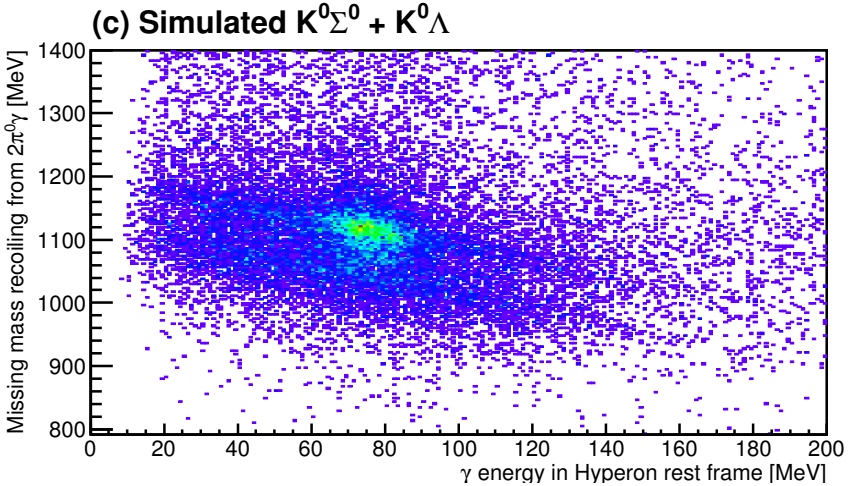
- BGO-OD - 1st differential cross section measurement to $E_\gamma = 3$ GeV & polarisation observables
- Higher statistics - K^0 identification via both main decay modes

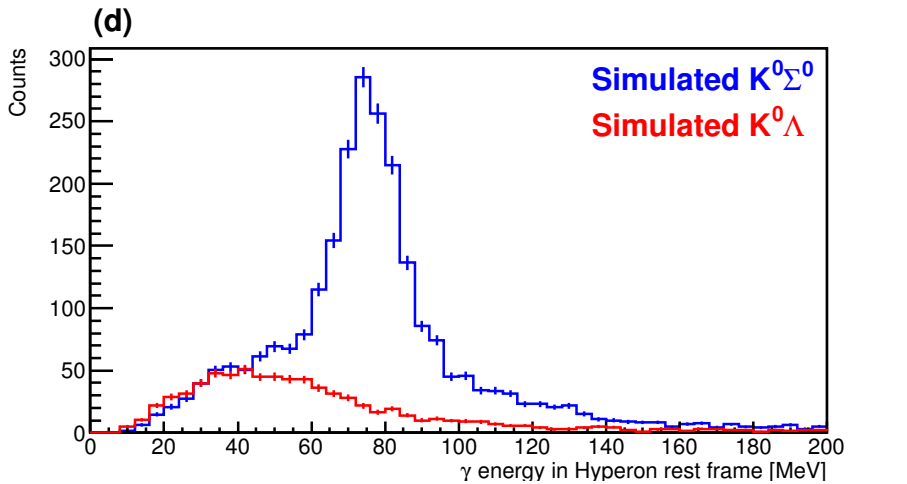
Separating $K^0\Lambda$ and $K^0\Sigma^0$ final states

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









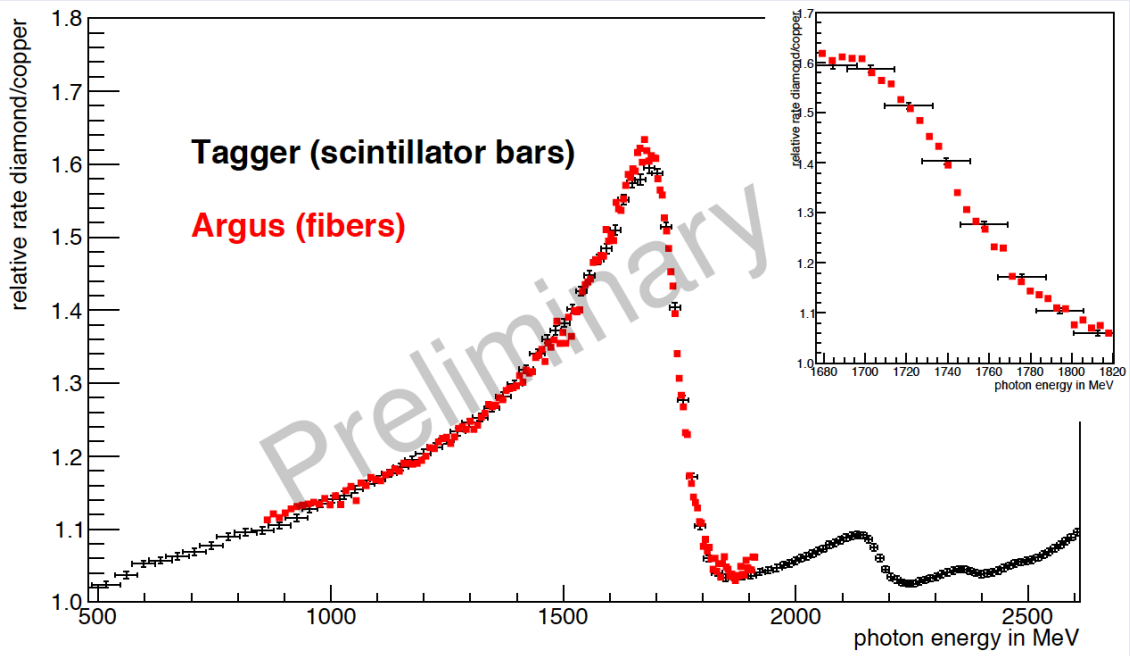
Incident photon beam parameters

- Energy tagged γ beam $\leq$ 3 GeV, 250 ps time resolution
- Moller polarimeter for determining degree of circular polarisation

Coherent bremsstrahlung using a diamond radiator

A. Bella, PhD thesis, University of Bonn (2016), S. Alef & B-E. Reitz, Masters theses, Bonn University (2015)

- ARGUS - fine resolution to accurately map the coherent edge

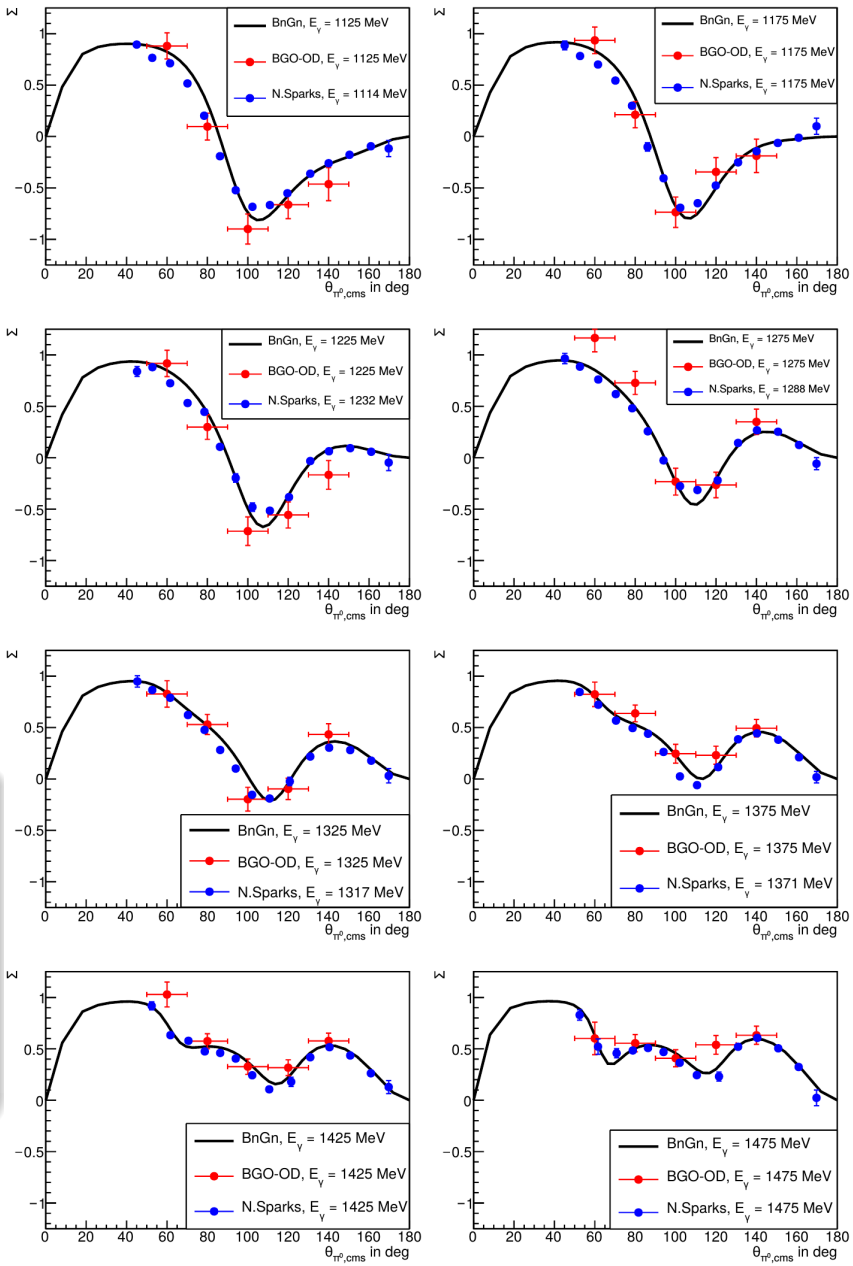


Incident photon beam parameters

A. Bella, PhD thesis, University of Bonn (2016)

- $\gamma p \rightarrow p\pi^0$ beam asymmetry measurements
- To test degree of polarisation only - low stats, pol. peak at too high energy for $p\pi^0$

- BGO-OD (preliminary)
- N. Sparks et al., Phys. Rev. C 81 (2010) 065210
- black line: BnGn2014_02 solution

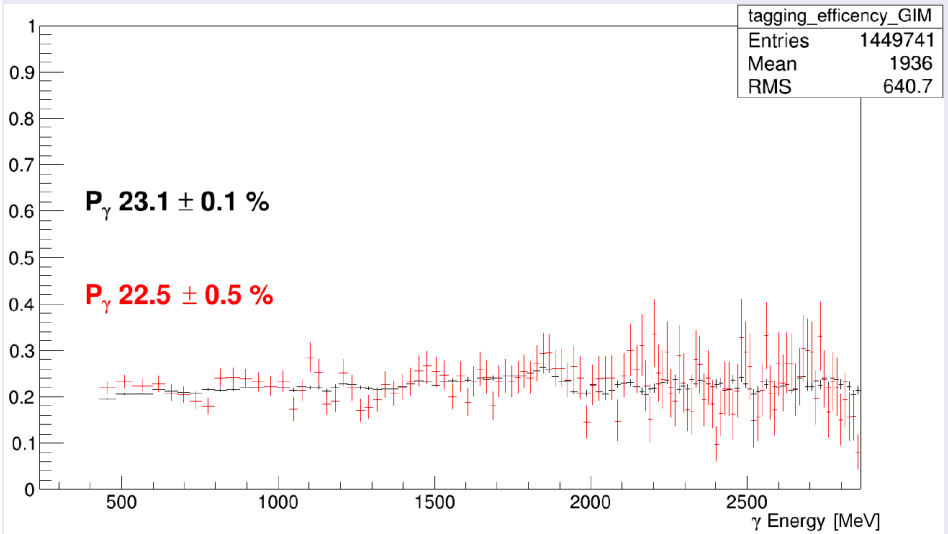


Photon flux determination

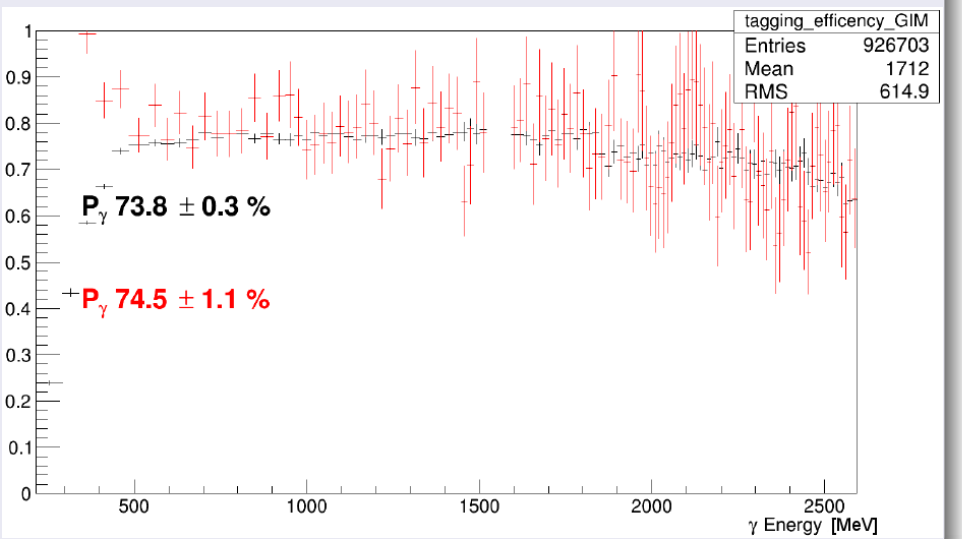
K. Kohl, Master thesis (2016), G. Scheluchin

- P_γ - fraction of tagged photons which impinge upon the target
- Depend upon collimation/beam spot size and shape
- Tighter collimation - higher degree of linear polarisation
- At low current, P_γ measured by GIM (black) & FluMo

- 3 mm collimator (previous data)



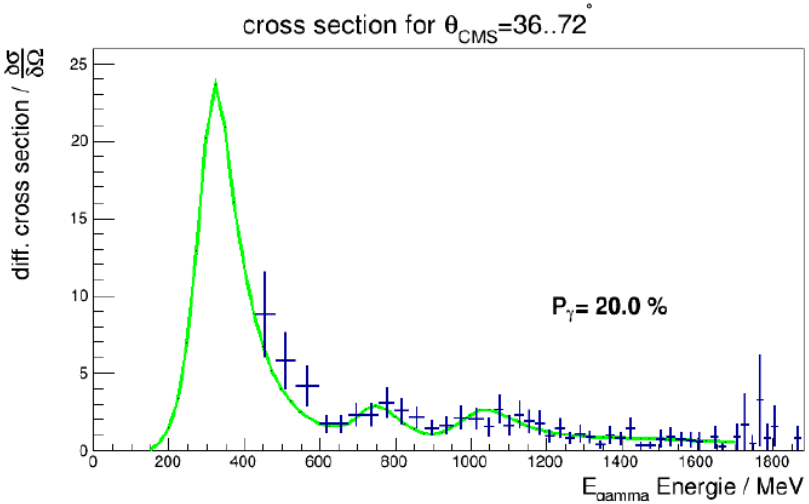
- 7 mm collimator (last week)

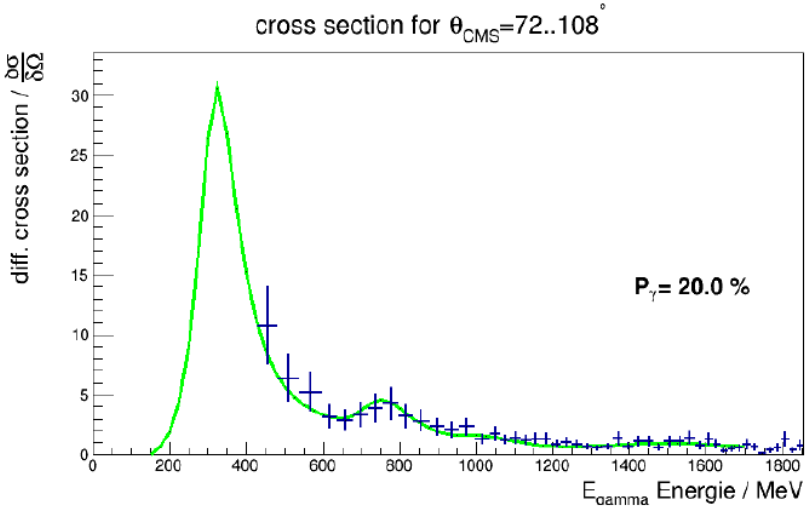


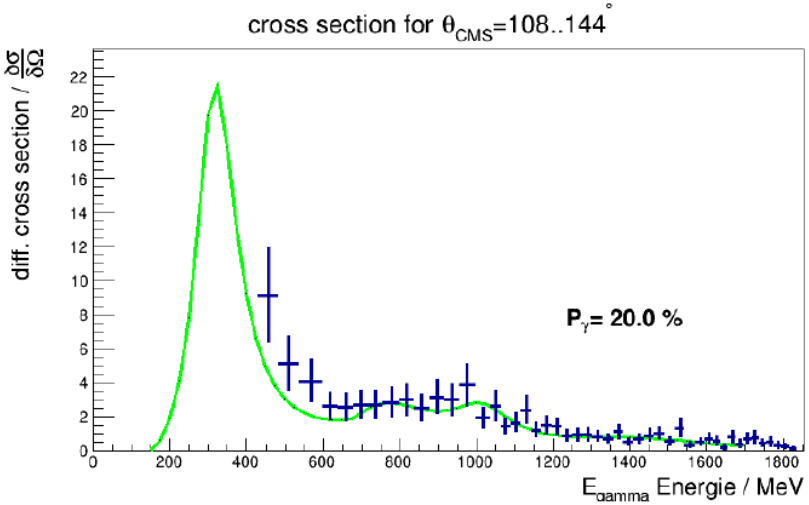
Photon flux determination

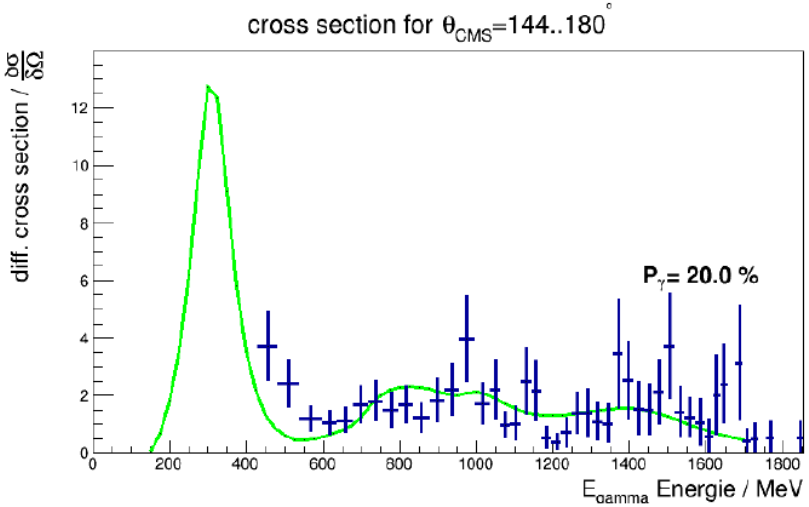
G. Scheluchin

- Compare to nomalising $\gamma p \rightarrow p\pi^0$ (old data, $P_\gamma \approx 23$ %)
- Quick/preliminary analysis - eg no trigger conditions modelled





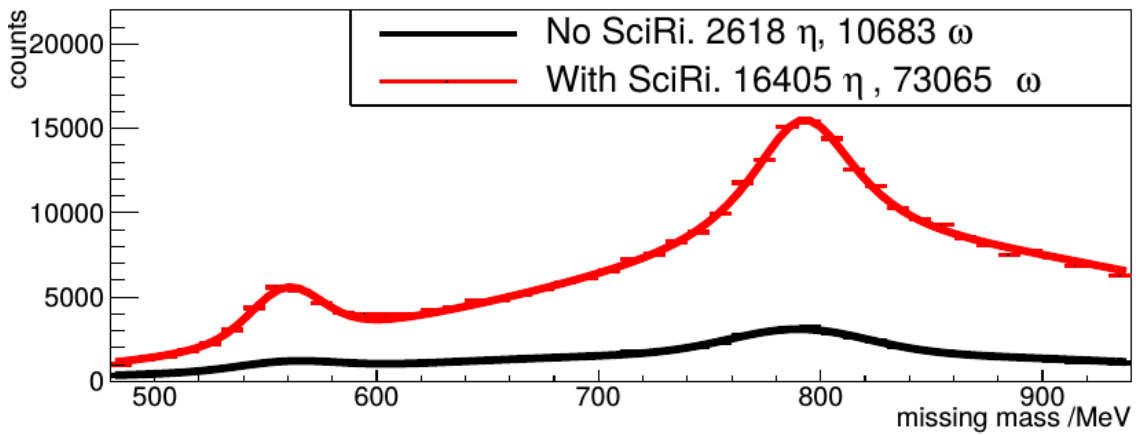




Covering the intermediate gap, $10^0 < \theta < 25^0$

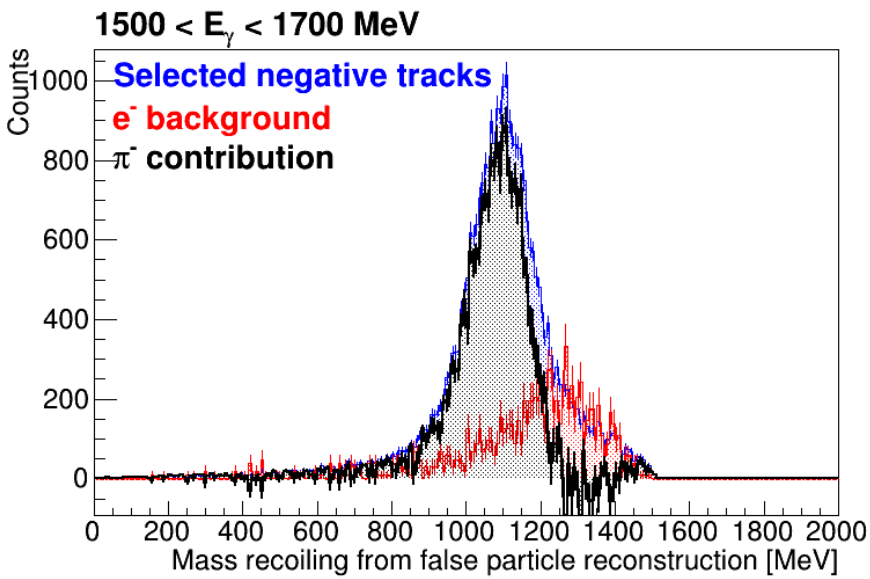
G. Scheluchin, Master Thesis, University of Bonn (2015)

- Intermediate charged track ($10^0 < \theta < 25^0$) reconstruction with SciRi:
- eg, $\gamma p \rightarrow p\pi^0\pi^+\pi^-$ (reconstruct η & ω):



High statistics forward differential cross sections anticipated soon...

- Negatively charged tracks -
- Study background from e^- and π^-



To do:

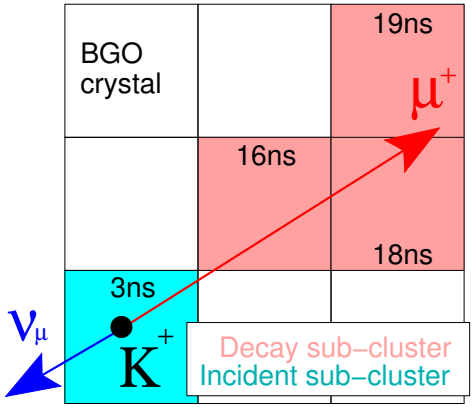
- Finalise the modelling of hardware triggers & drift chamber efficiencies
- High precision checks of photon flux

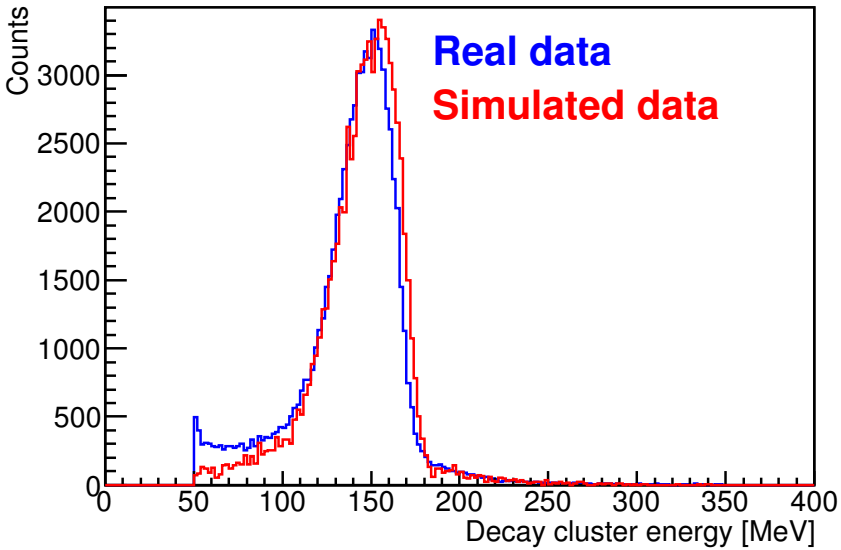
K^+ identification in the BGO

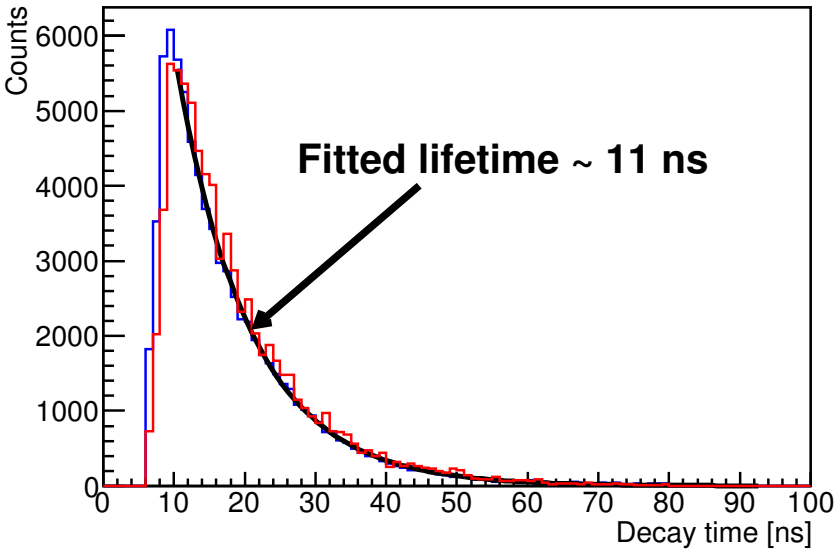
- With Crystal Ball: T.C Jude, D.I. Glazier, D.P. Watts, *et al*, PLB, 735 (2014) 112
- Time delayed, K^+ weak decay within the crystals of the BGO ball:

Lifetime 12 ns,
2 main decay modes:

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



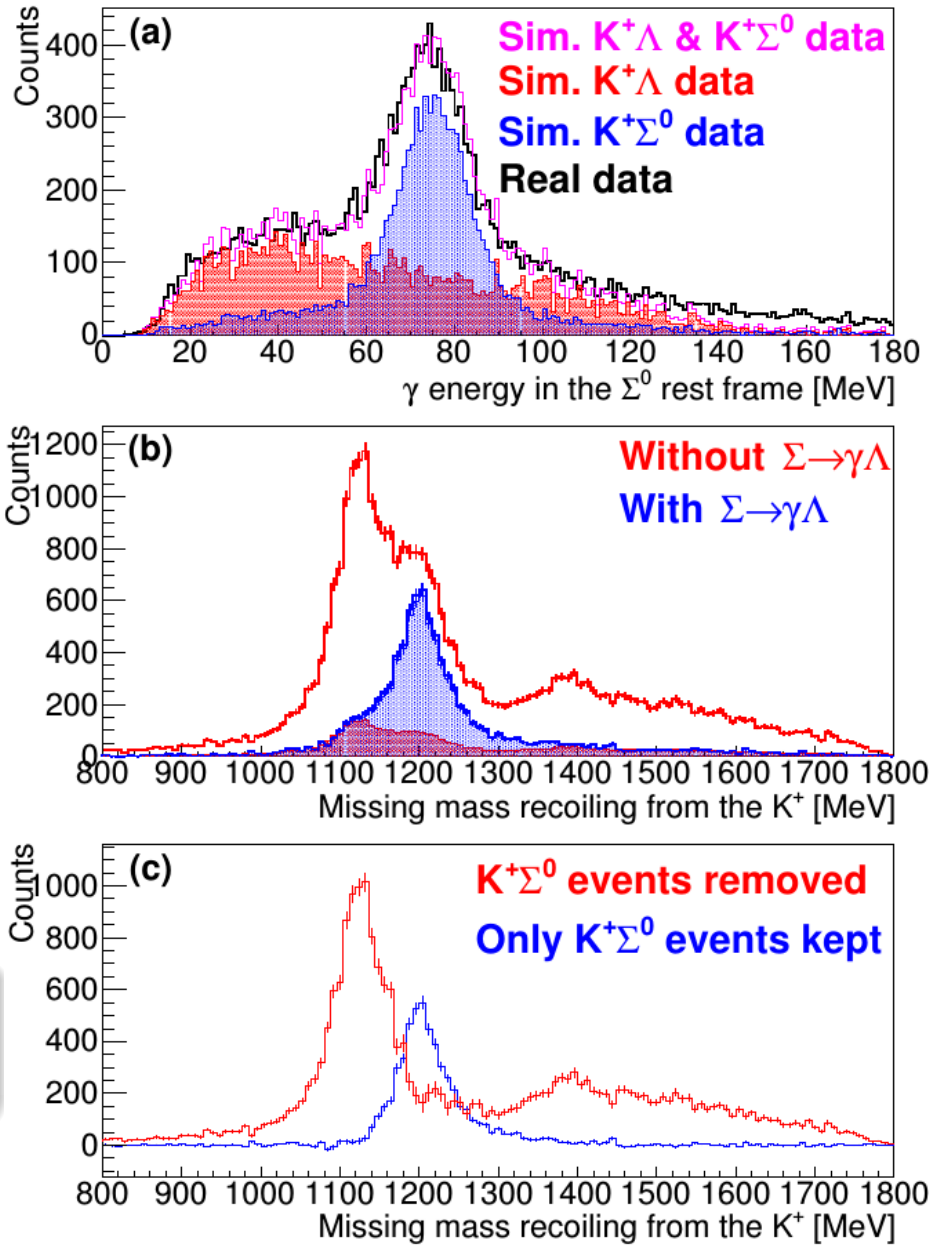




Identifying the $\Sigma^0 \to \Lambda\gamma$ decay ($\Gamma = 100\%$)

- 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!



Reject K^+ punching through BGO crystals

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