Strangeness photoproduction at the BGO-OD experiment

Georg Scheluchin

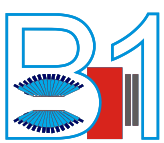
for the BGO-OD-Collaboration

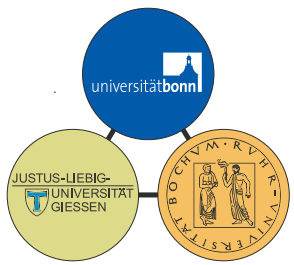
Physikalisches Institut
Universität Bonn

HADRON2019

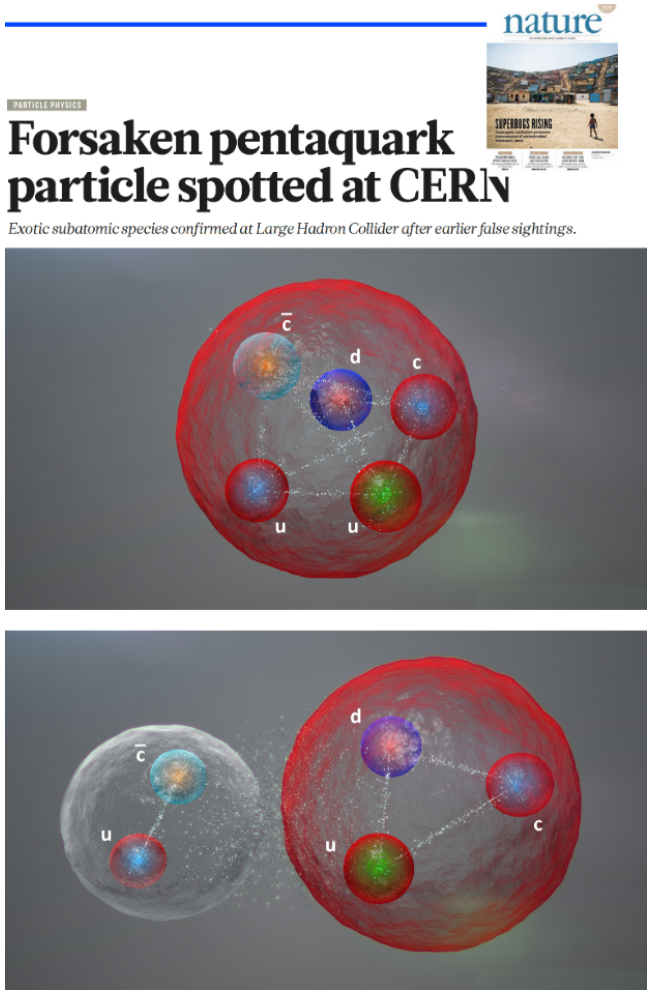
16-21 August 2019

Supported by the DFG (PN 388979758, 405882627)



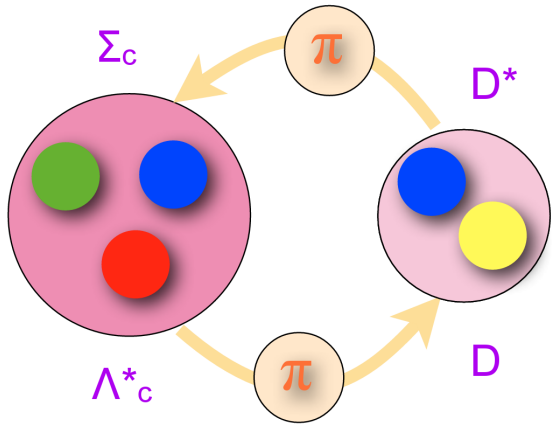


Unconventional states

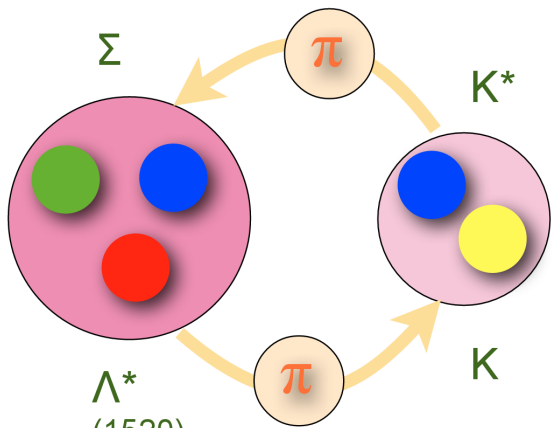


Nature 523, p 267 (2015)

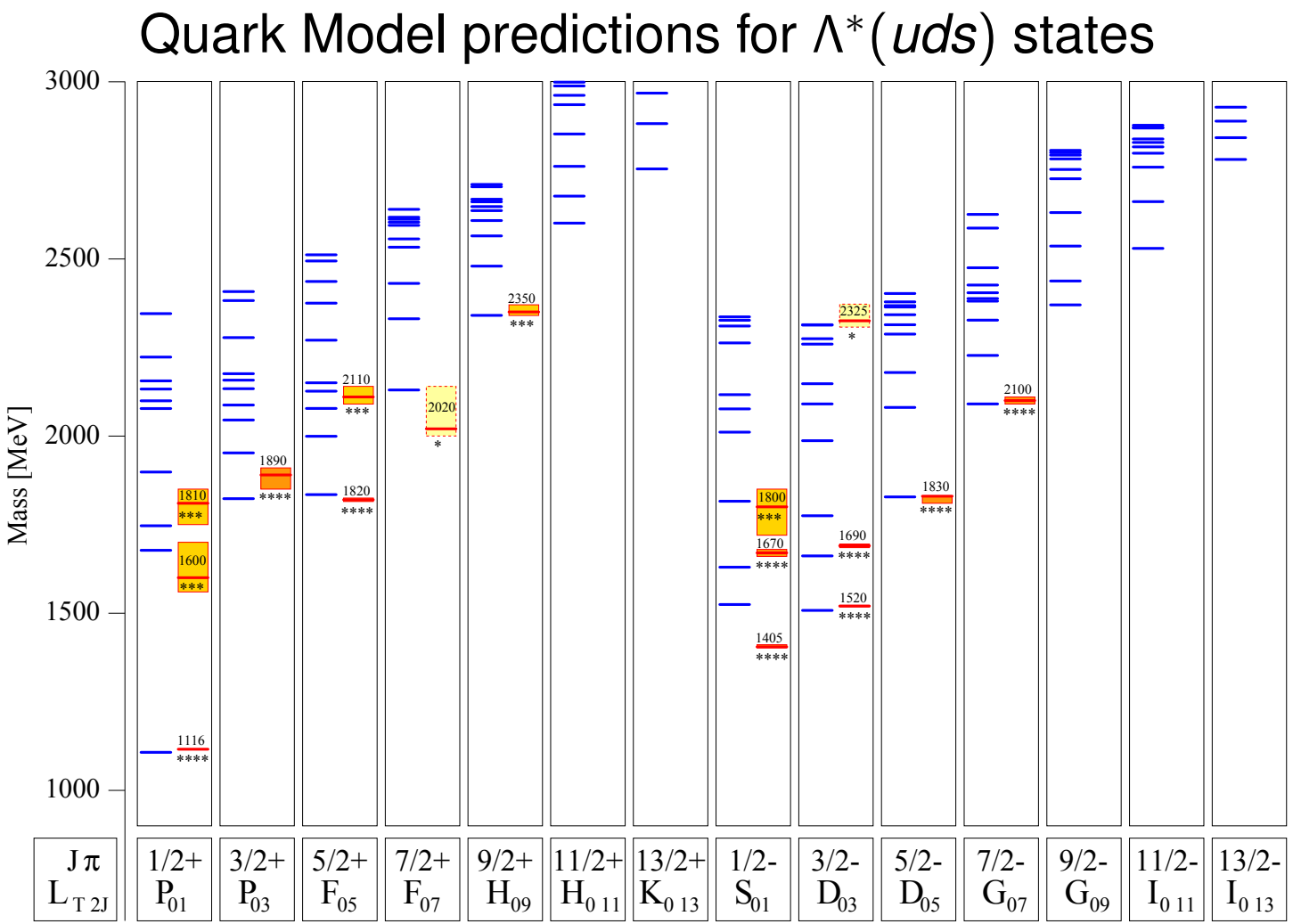
Charm:



Strange:

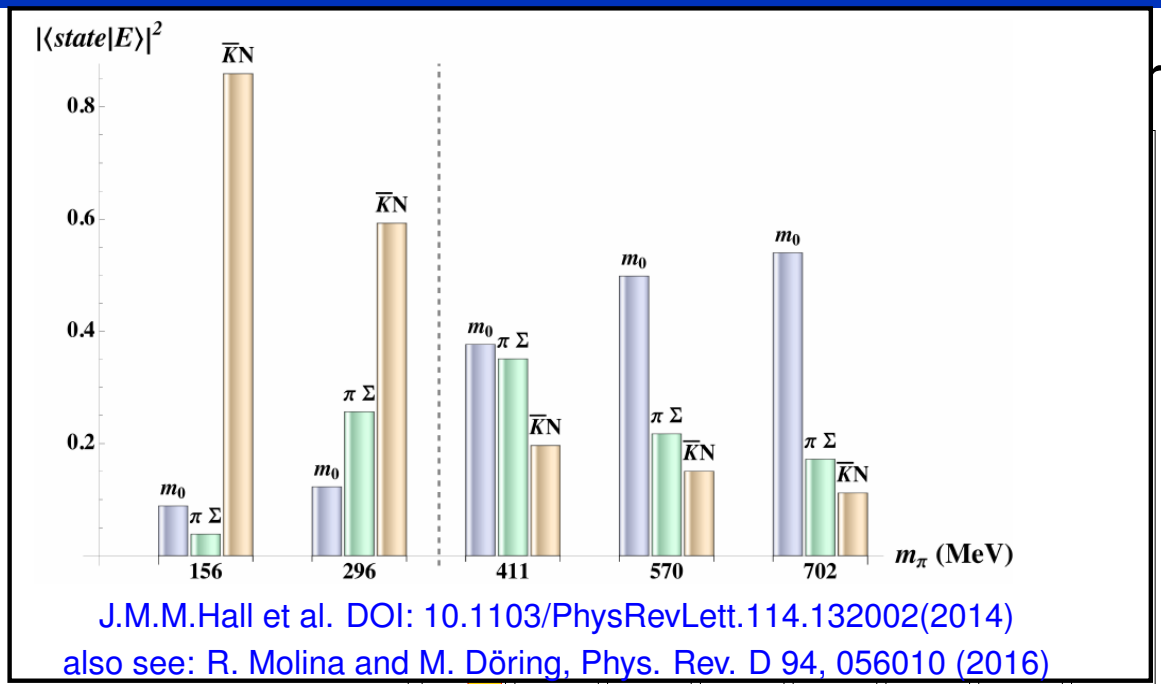


Unconventional states in the strangeness sector?



U.Loering, B.C. Metsch and H.R. Petry Eur.Phys.J. A10, 447-486 (2001)

Unconventional states in the strangeness sector?



J.M.M.Hall et al. DOI: 10.1103/PhysRevLett.114.132002(2014)
also see: R. Molina and M. Döring, Phys. Rev. D 94, 056010 (2016)

Λ*(*uds*) states

Λ(1405) deviates from conventional quark models

U.Loering, B.C. Metsch and H.R. Petry Eur.Phys.J. A10, 447-486 (2001)

Experimental requirements

photoproduction

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

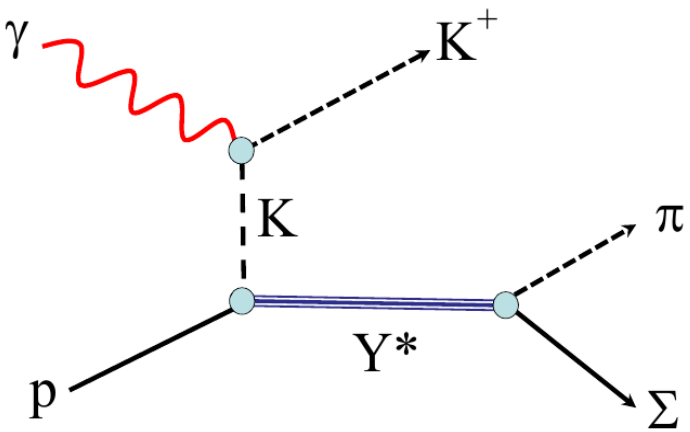
Experimental requirements

photoproduction

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

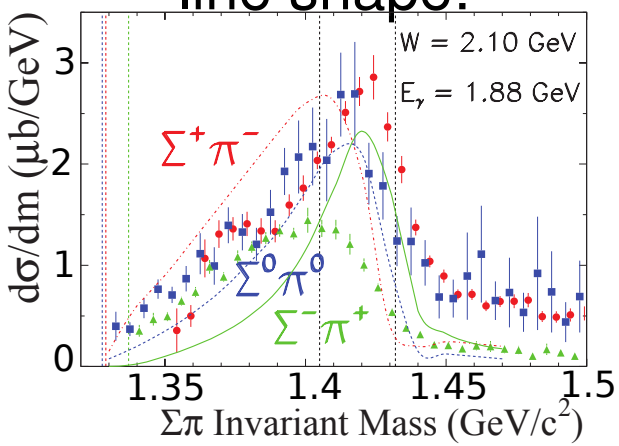
$\Lambda(1405)$

T. Hyodo et al.
DOI:10.1016/j.ppnp.2011.07.002(2011)

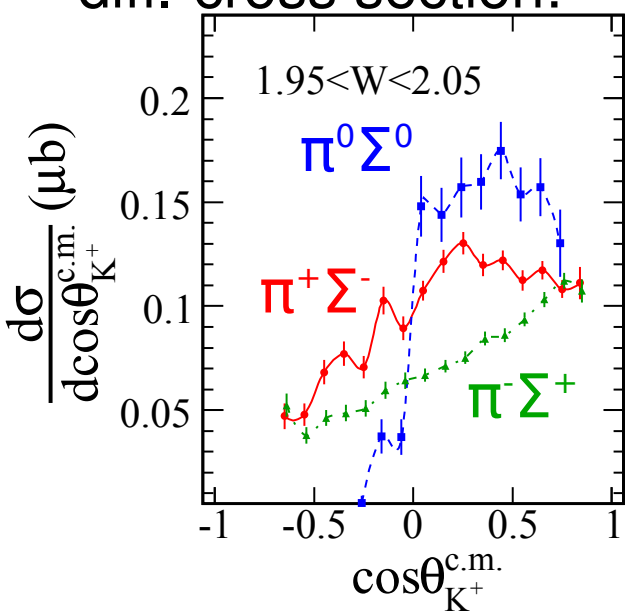


R.A.Schumacher et al.
DOI:10.1016/jnuclphysa.2013.03.003 (2013)

line shape:

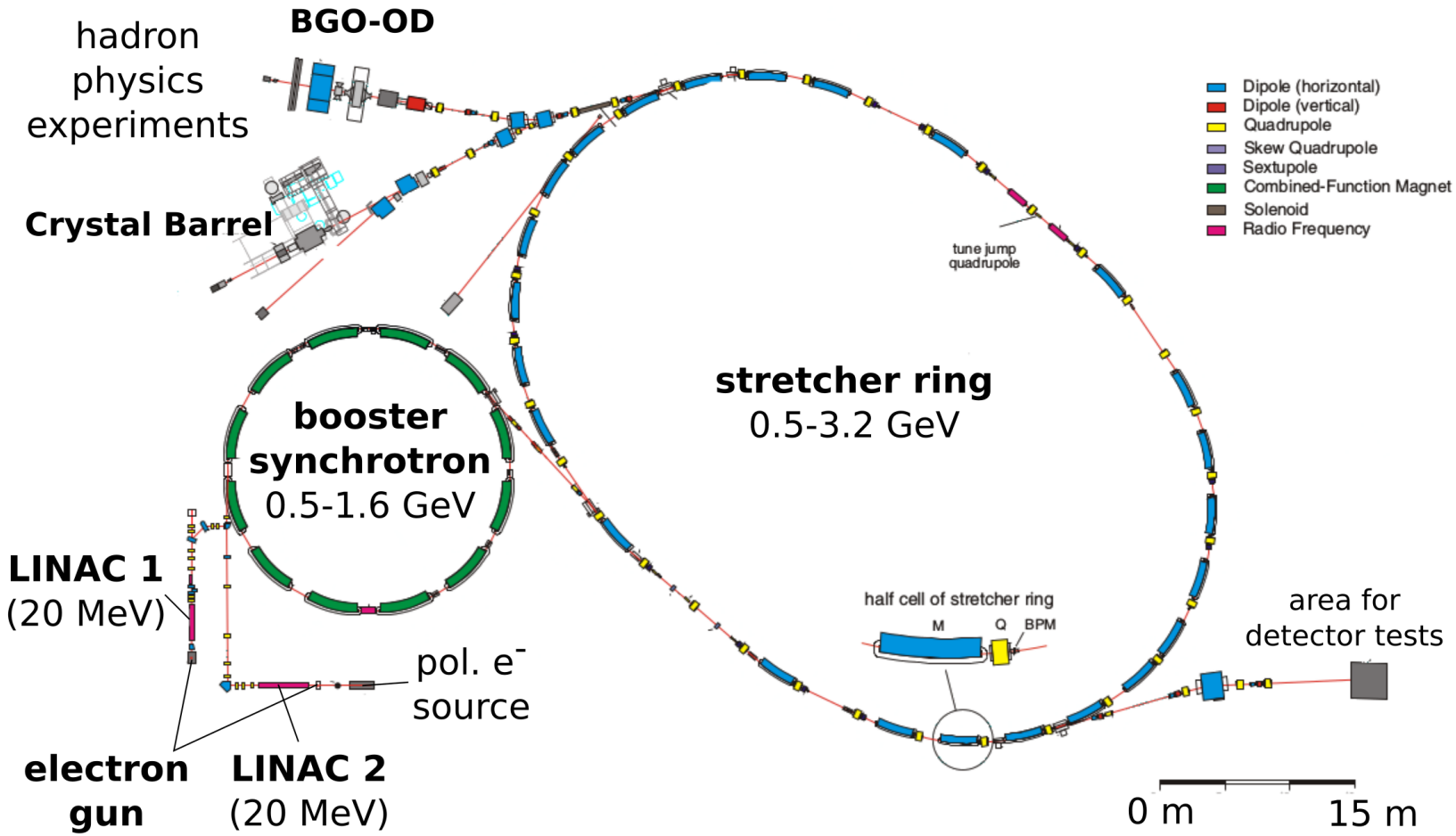


diff. cross section:

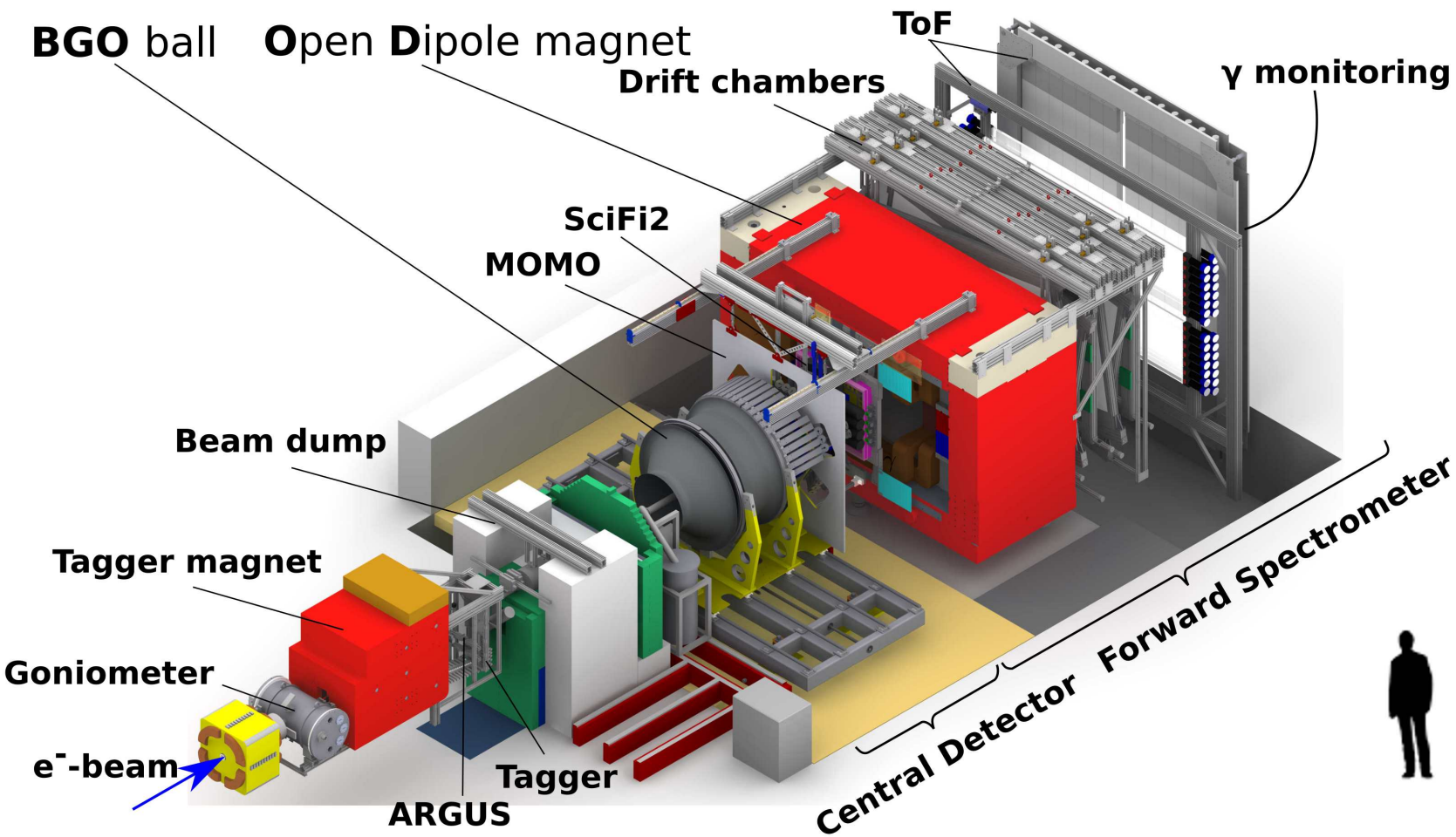


K. Moriya et al. (CLAS Collaboration), Phys. Rev. C 88 (2013)

Electron Stretcher Accelerator (ELSA) in Bonn

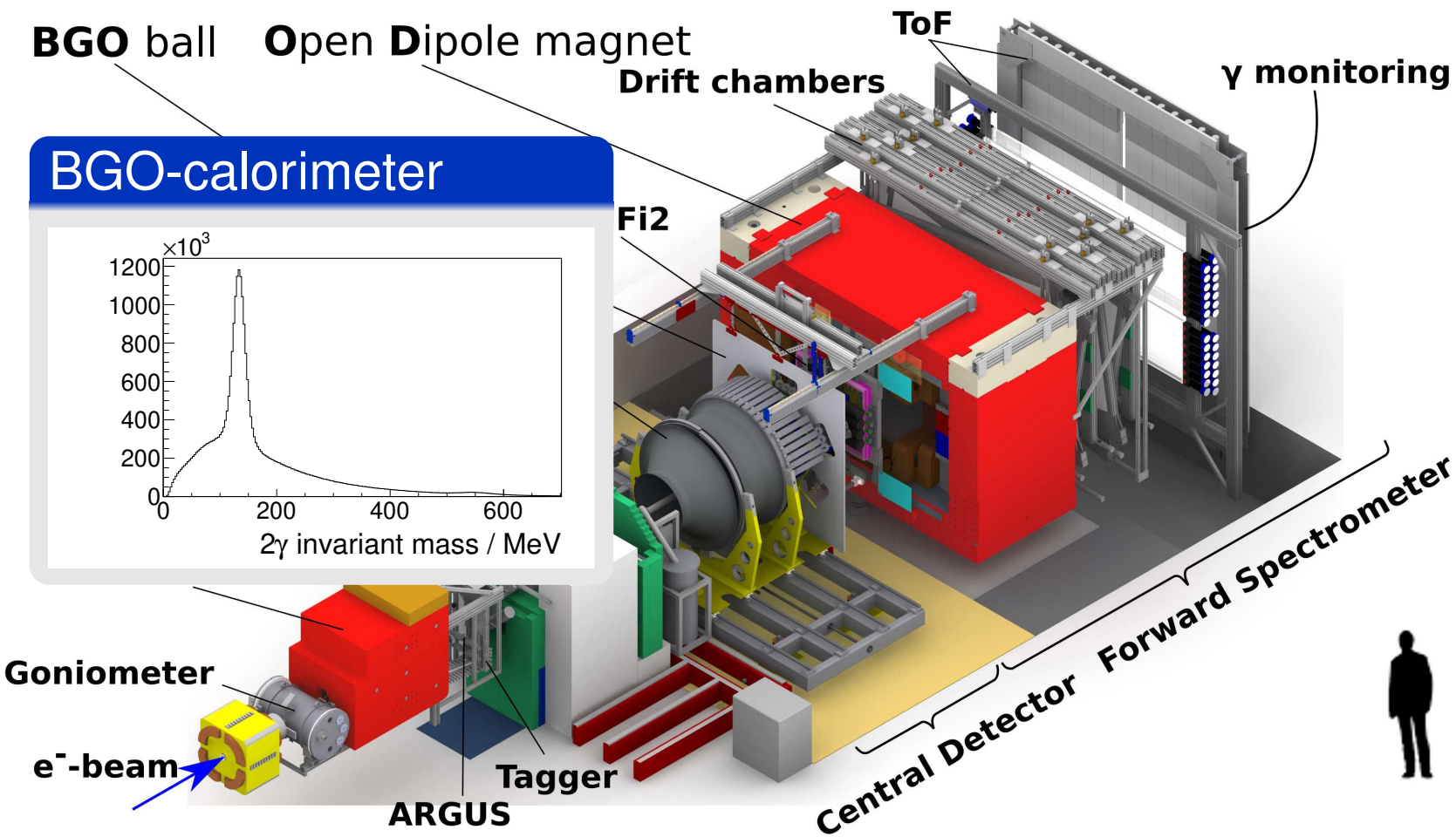


BGO-OD



Spokespersons: P. Levi Sandri (INFN), H. Schmieden (Uni Bonn)

BGO-OD

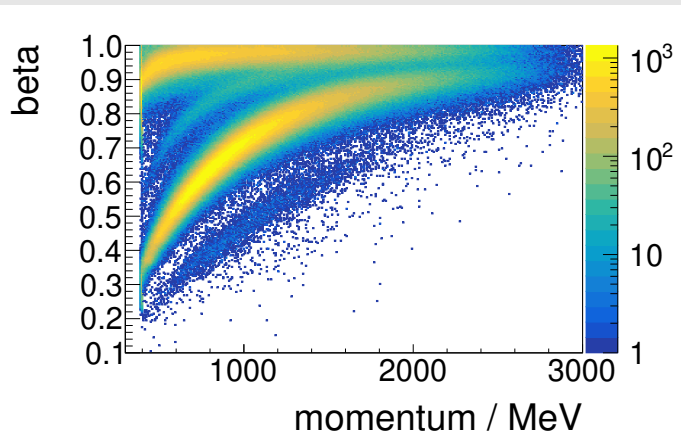


Spokespersons: P. Levi Sandri (INFN), H. Schmieden (Uni Bonn)

UNIVERSITÄT BONN

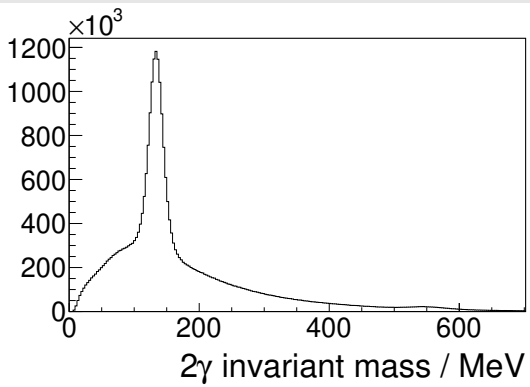
BGO-OD

Forward Detector



acceptance: $\theta^{lab} \approx 2..10°$

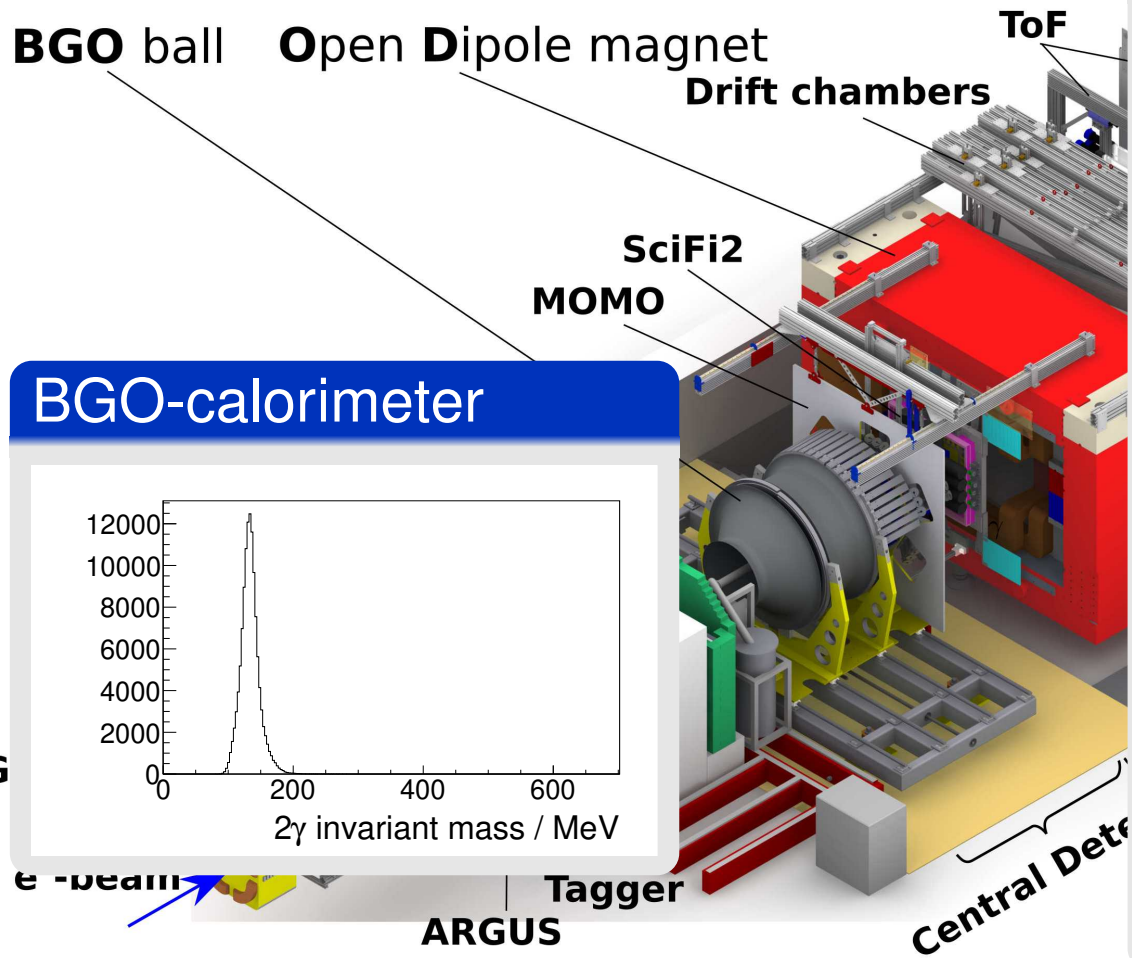
BGO-calorimeter



Spokespersons: P. Levi Sandri (INFN), H. Schmieden (Uni Bonn)

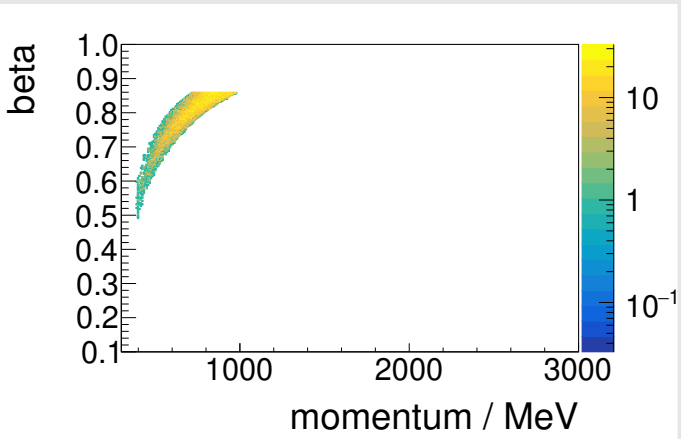
UNIVERSITÄT BONN

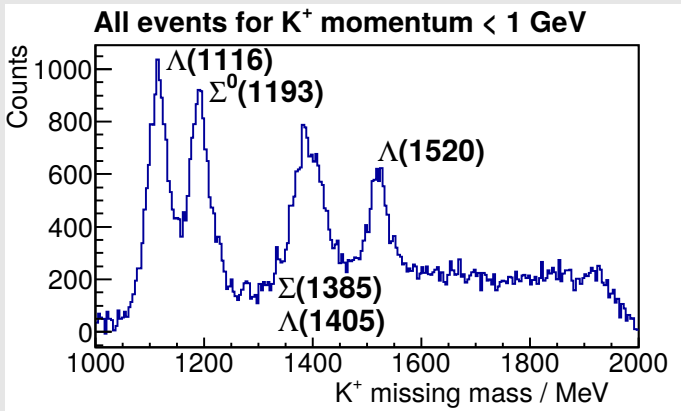
$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$



BGO-calorimeter

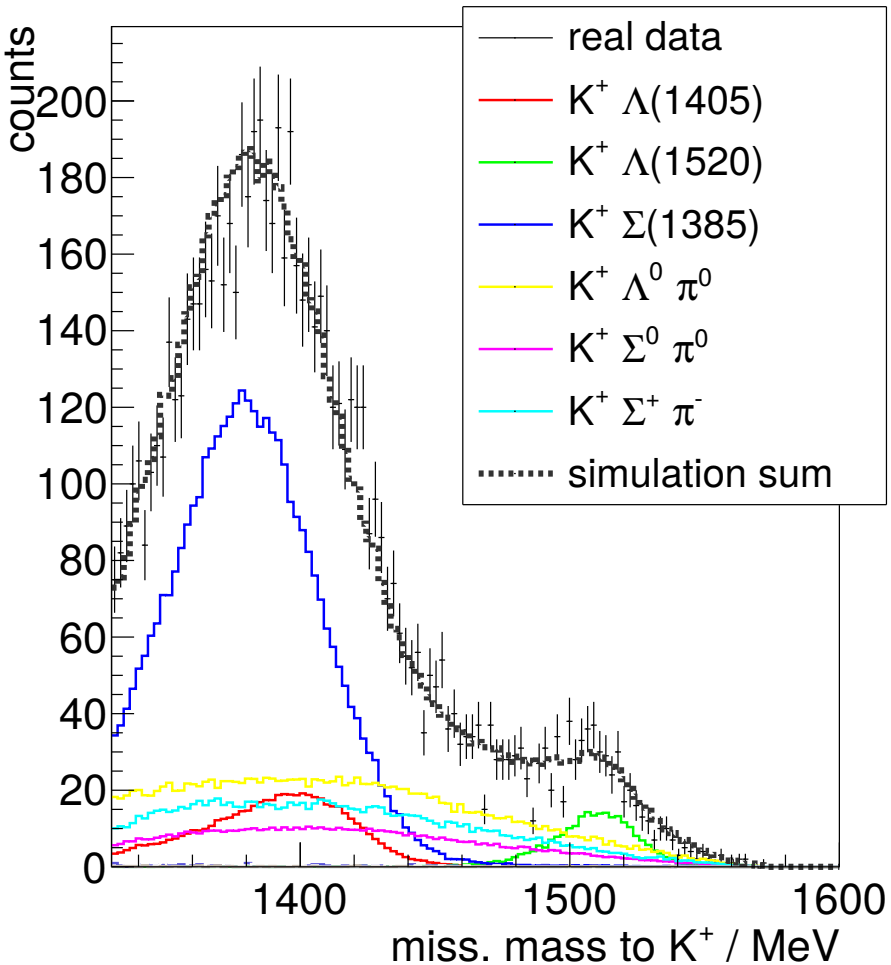
Forward Detector

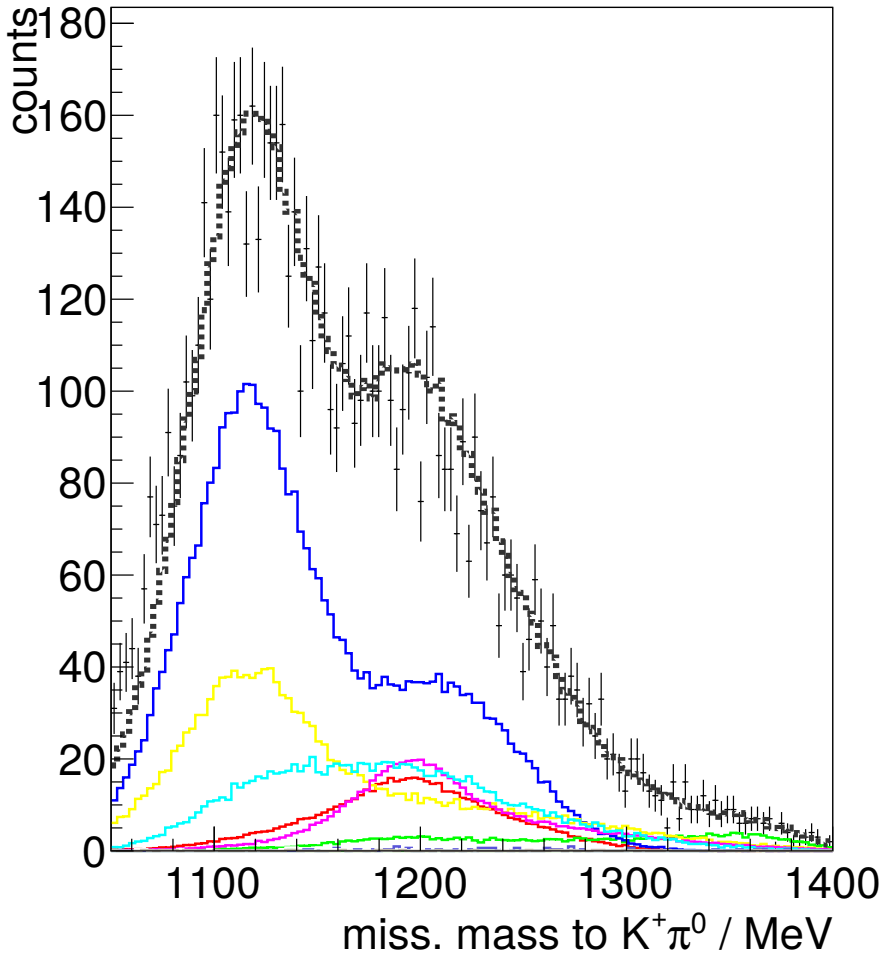




acceptance: $\theta^{lab} \approx 2..10°$

2D Fits projections ($\gamma p \rightarrow K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$)





Used: Toolkit for Data Modeling with ROOT (RooFit)

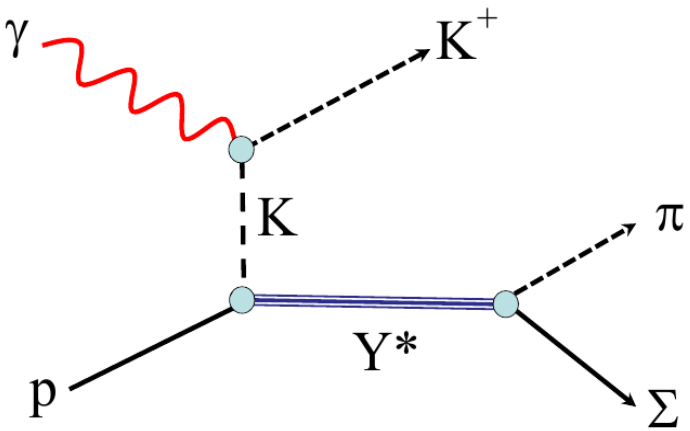
Λ(1405)

photoproduction

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

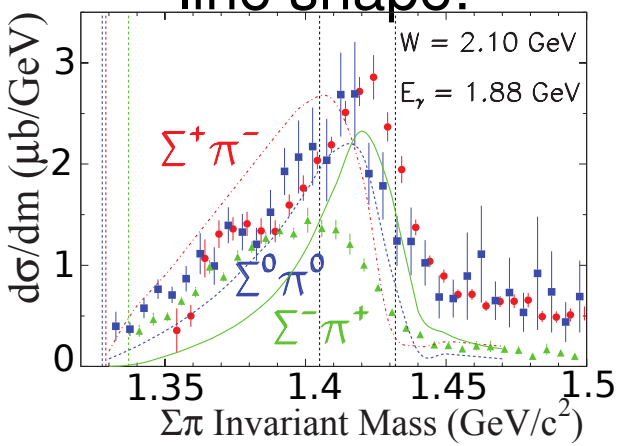
$\Lambda(1405)$

T. Hyodo et al.
DOI:10.1016/j.ppnp.2011.07.002(2011)

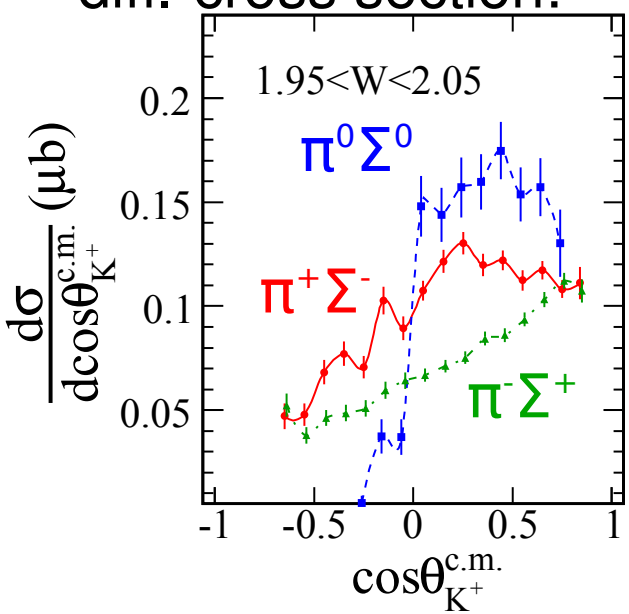


R.A.Schumacher et al.
DOI:10.1016/jnuclphysa.2013.03.003 (2013)

line shape:



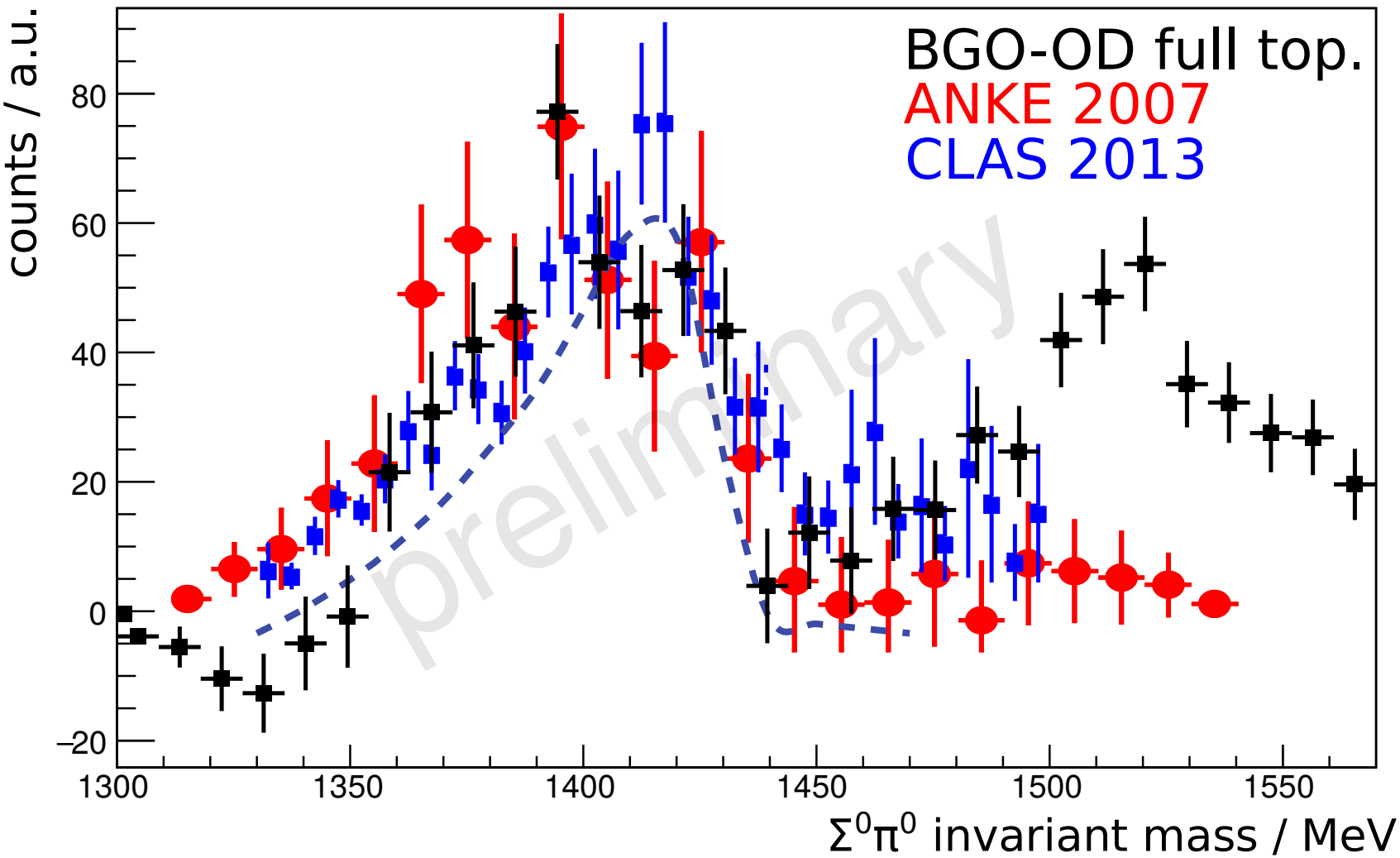
diff. cross section:



K. Moriya et al. (CLAS Collaboration), Phys. Rev. C 88 (2013)

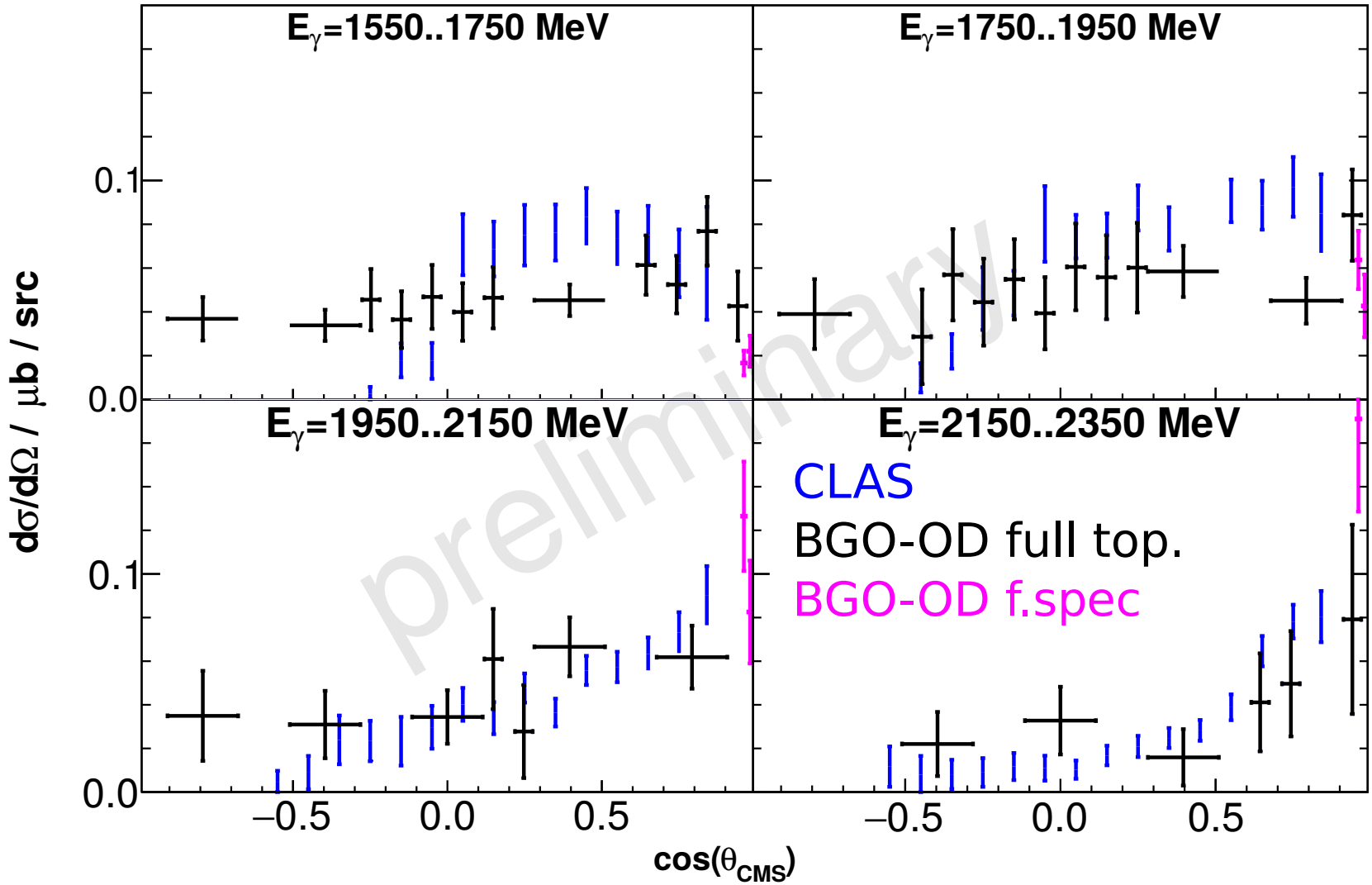
UNIVERSITÄT BONN

Line shape compared to other experiments



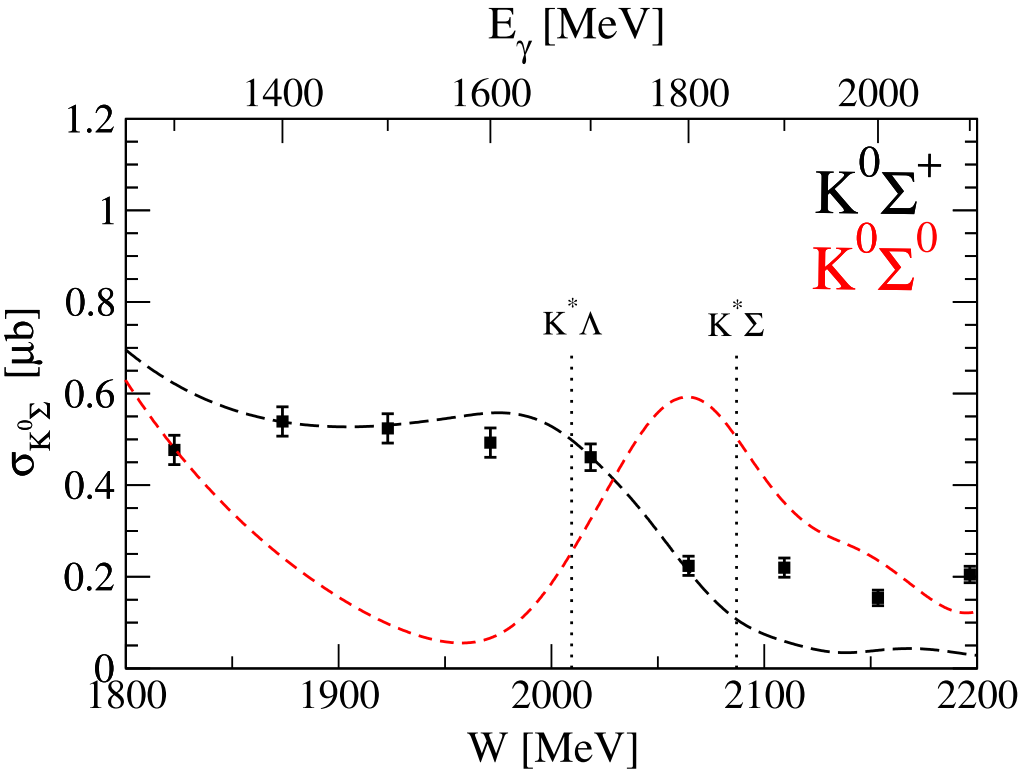
CLAS: K. Moriya et al. (CLAS Collaboration), Phys. Rev. C 87 (2013)
ANKE: I. Zychor et al. Phys.Lett.B660:167-171 (2008)
dashed line: J.C.Nacher et al. Phys.Lett. B455, 55-61 (1999)

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



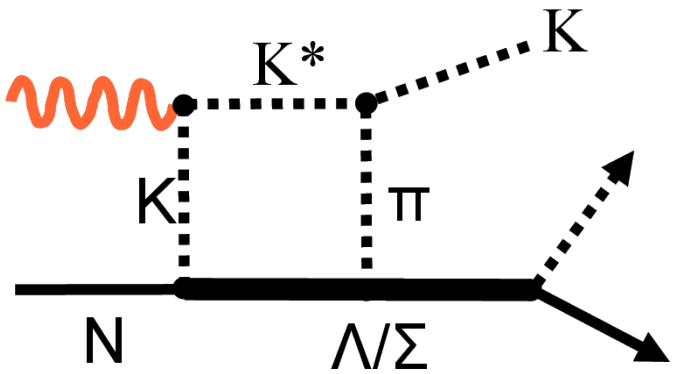
CLAS: K. Moriya et al. (CLAS Collaboration), Phys. Rev. C 88 (2013)

K^0 photoproduction



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

Data points: R. Ewald *et al.*,Phys. Lett. B 713 (2012) 180 (CBELSA/TAPS Collaboration) [Most forward bin: $cos\ \Theta_K^{cms} = 0.83$]

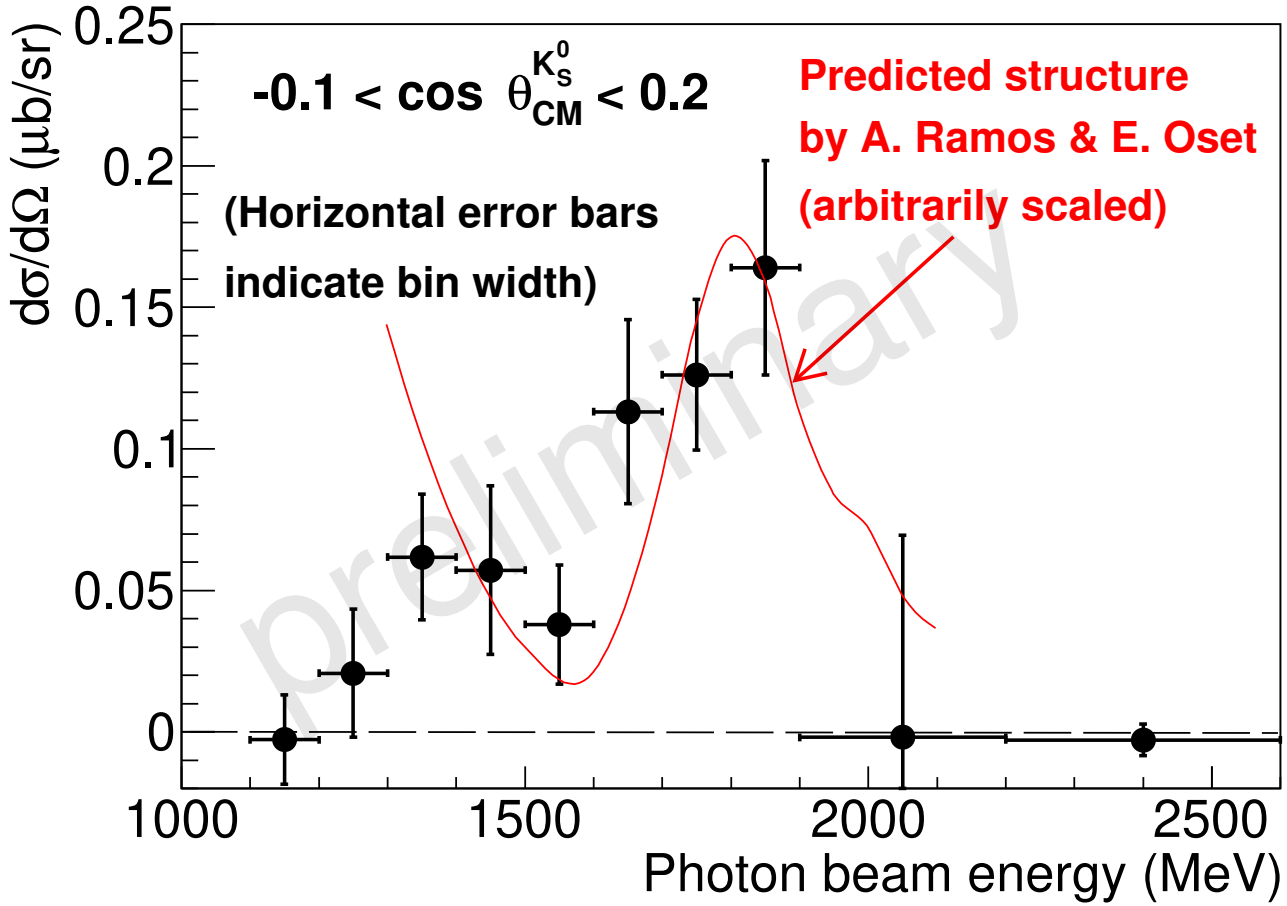


A. Ramos and E. Oset, Phys. Lett. **B 727**, (2013) 287

Same model that predicted the LHCb pentaquark

$\gamma n(p) \to K^0\Sigma^0$ using a deuterium target

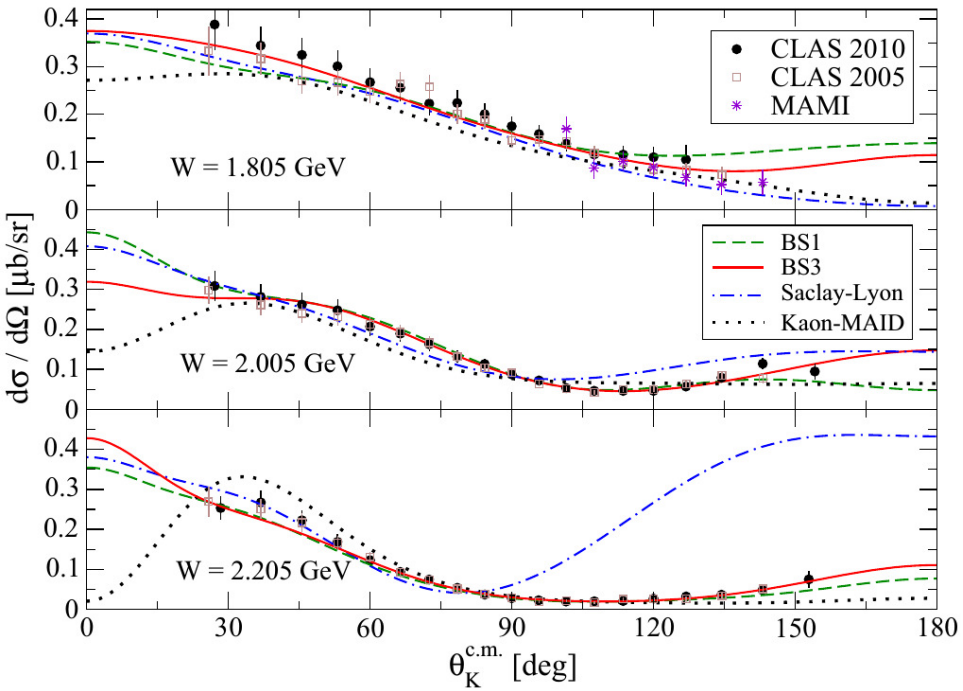
work of K. Kohl PhD



Consistent with prediction of a meson-baryon dynamically generated state

$K^+\Lambda$ at forward angles

Photoproduction of ground state hyperons at low t virtually unconstrained by data!



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)

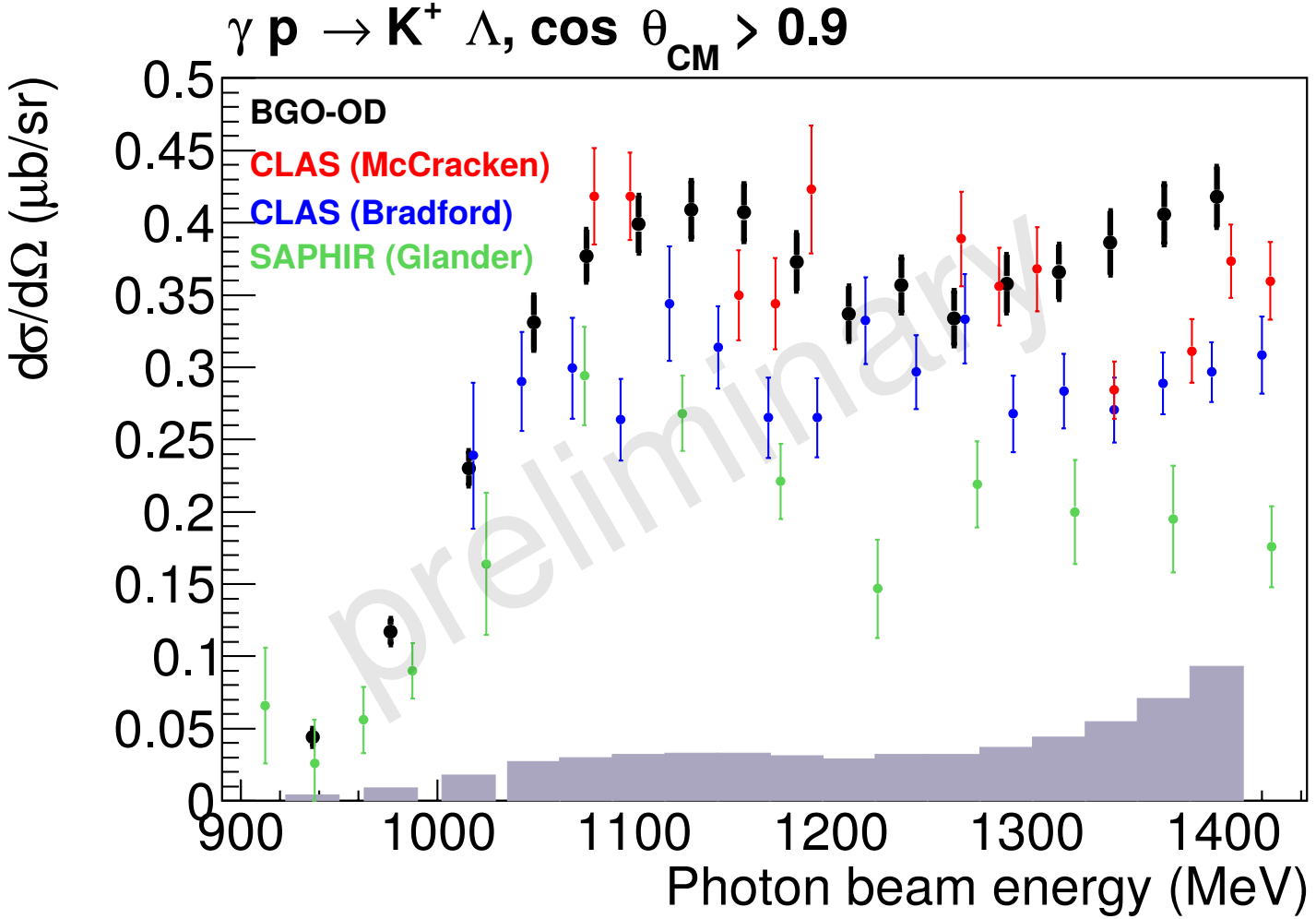
Crucial for hypernuclei electroproduction

Isobar models

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

Forward $K^+\Lambda$ differential cross sections

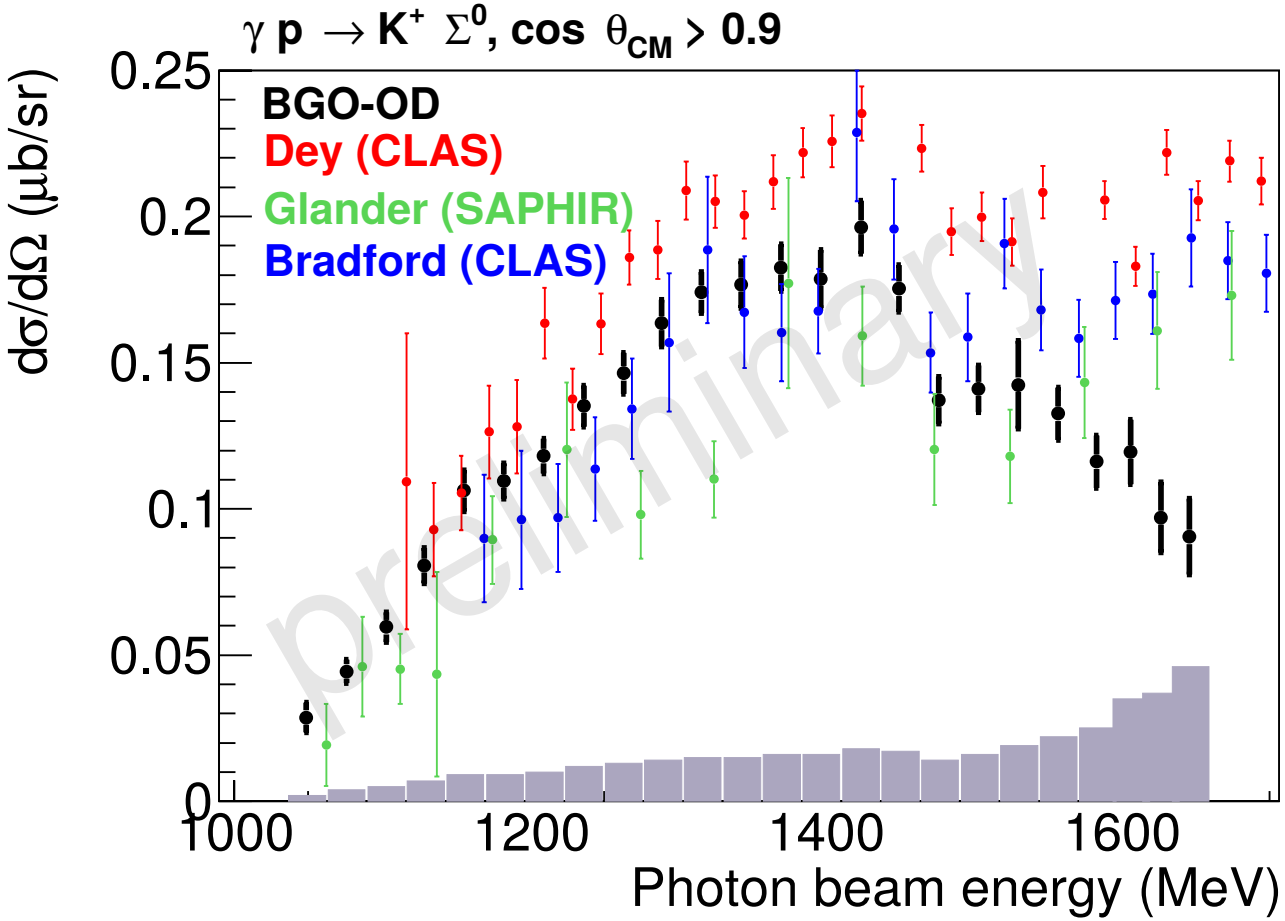
work of Tom Jude



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 $0.85 < \cos\theta^{CM}_{K^+} < 0.95$.

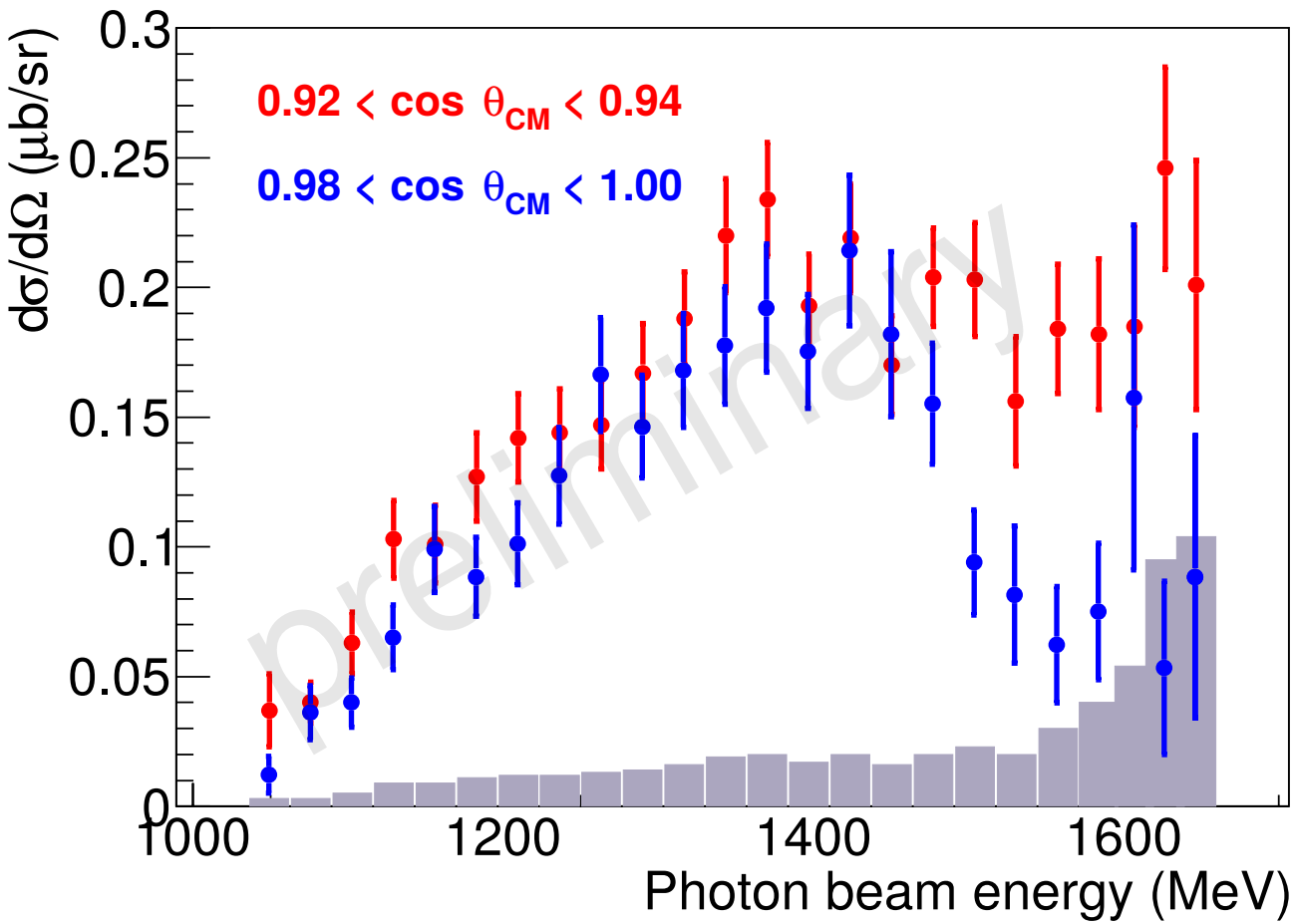
Forward $K^+\Sigma^0$ differential cross sections

- "cusp" like structure at $W = 1900$ MeV?



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

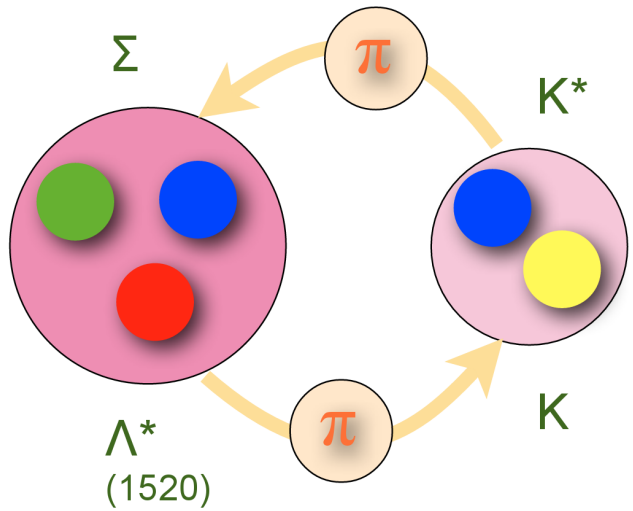
Forward $K^+\Sigma^0$ differential cross sections, “cusp“



Threshold effects at low momentum transfer?
$K^+\Lambda(1405)$, $f_0(980)p$, $\eta' p$, ...

Summary & outlook

- meson-baryon bound states?
- BGO-OD: unique setup
  - extreme forward angles
- current projects
  - strangeness photoproduction
    e.g. $K^+\Lambda$, $K^+\Sigma^0$, $K^0\Sigma^0$, ...
    $\rightarrow$ differential cross section
  - Threshold effects?
    e.g. $K^0\Sigma^0$, $K^+\Sigma^0$, ...
  - Λ(1405) meson-baryon bound state? $\rightarrow$ line shapes
  - non-strange photoproduction
    e.g. $\eta' p$, ...



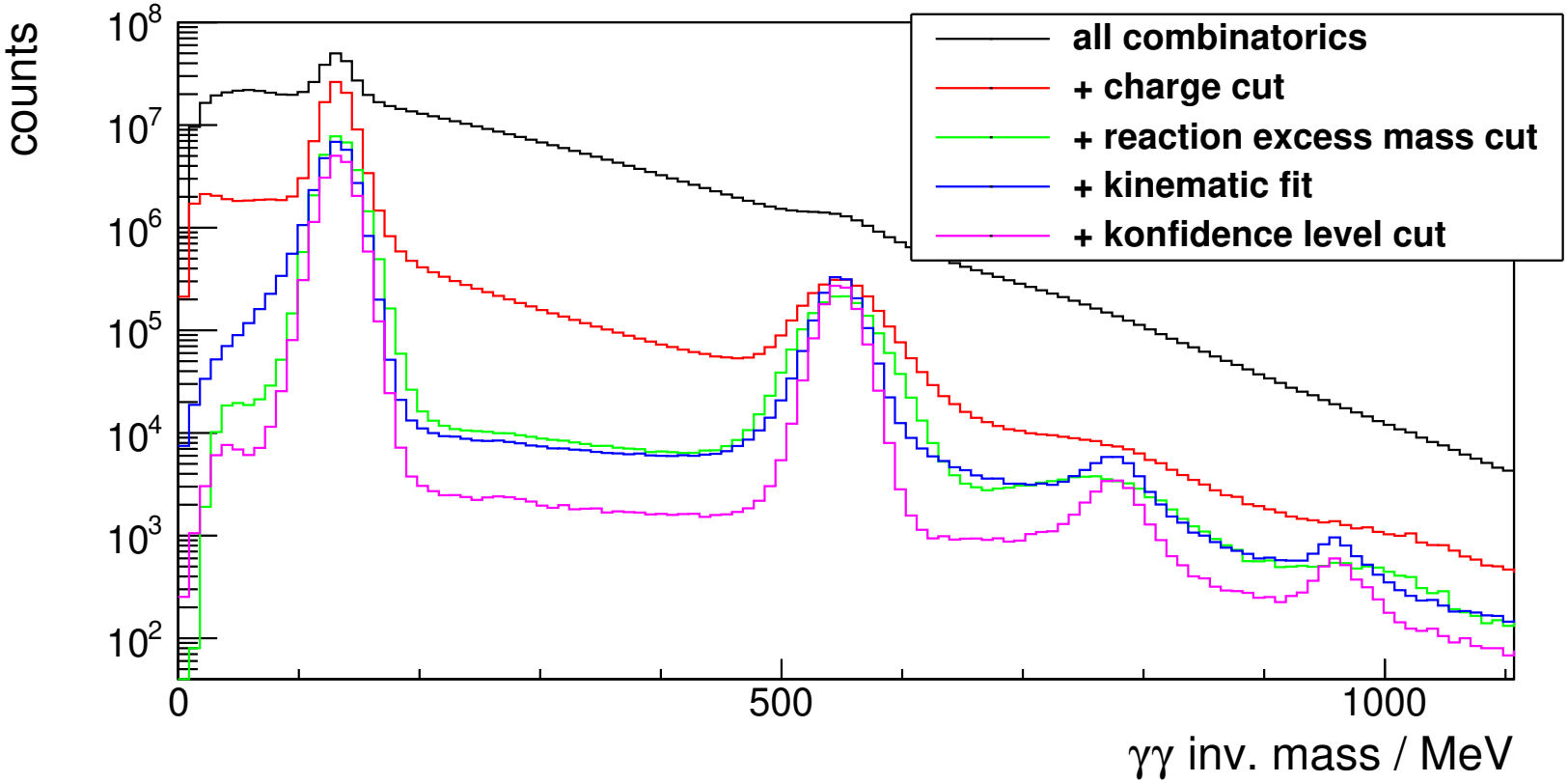
The BGO-OD collaboration

S. Alef[1], P. Bauer[1], D. Bayadilov[2,3], R. Beck[2], M. Becker[2], A. Bella[1], J. Bieling[1], S. Böse[2], A. Braghieri[4], K.-Th. Brinkmann[5], P. 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], W. Hillert[1], R. Jahn[2], R. Joosten[2], T.C. Jude[1], F. Klein[1], K. Kohl[1], K. Koop[2], N. Kozlenko[3], B. Krusche[13], A. Lapik[14], P. Levi Sandri[15,a], V. Lisin[14], I. Lopatin[3], G. Mandaglio[16,17], F. Messi[1], R. Messi[7,8], D. Moricciani[7], A. Mushkarenkov[14], V. Nedorezov[14], D. Novinskiy[3], P. Pedroni[4], A. Polonskiy[14], B. Reitz[1], M. Romaniuk[5], T. Rostomyan[13], G. Scheluchin[1], H. Schmieden[1,b], A. Stugelev[3], V. Sumachev[3], V. Tarakanov[3], V. Vegna[1], D. Walther[2], H.-G. Zaunick[2,5], and T. Zimmermann[1]

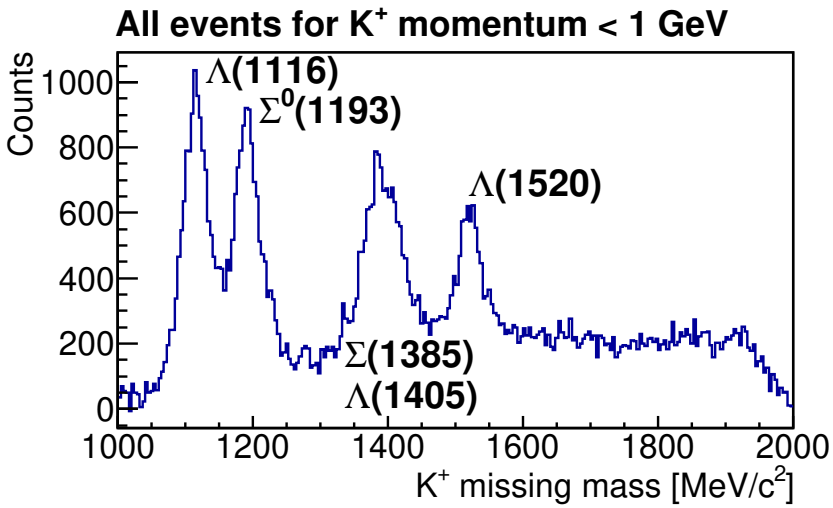
[1] Rheinische Friedrich-Wilhelms-Universität Bonn, Physikalisches Institut, Nußallee 12, 53115 Bonn, Germany
[2] Rheinische Friedrich-Wilhelms-Universität Bonn, Helmholtz-Institut für Strahlen und Kernphysik, Nußallee 14-16, 53115 Bonn, Germany
[3] Petersburg Nuclear Physics Institute, Gatchina, Leningrad District, 188300, Russia
[4] INFN sezione di Pavia, Via Agostino Bassi, 6 - 27100 Pavia, Italy
[5] Justus-Liebig-Universität Gießen, II. Physikalisches Institut, Heinrich-Buff-Ring 16, 35392 Gießen, Germany
[6] Lamar University, Department of Physics, Beaumont, Texas, 77710, USA
[7] INFN Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133, Rome, Italy
[8] Università di Roma "Tor Vergata", Dipartimento di Fisica, Via della Ricerca Scientifica 1, 00133, Rome, Italy
[9] INFN sezione di Torino, Via P.Giuria 1, 10125, Torino, Italy
[10] Università di Torino, Dipartimento di Fisica, via P. Giuria 1, 10125, Torino, Italy
[11] INFN sezione di Roma La Sapienza, P.le Aldo Moro 2, 00185, Rome, Italy
[12] Istituto Superiore di Sanità, Viale Regina Elena 299, 00161 Rome, Italy
[13] Institut für Physik, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
[14] Russian Academy of Sciences Institute for Nuclear Research, Prospekt 60-Letiya Oktyabrya 7a, 117312, Moscow, Russia
[15] INFN - Laboratori Nazionali di Frascati, Via E. Fermi 40, 00044, Frascati, Italy
[16] INFN sezione Catania, 95129, Catania, Italy
[17] Università degli Studi di Messina, Dipartimento MIFT, Via F. S. D'Alcontres 31, 98166, Messina, Italy

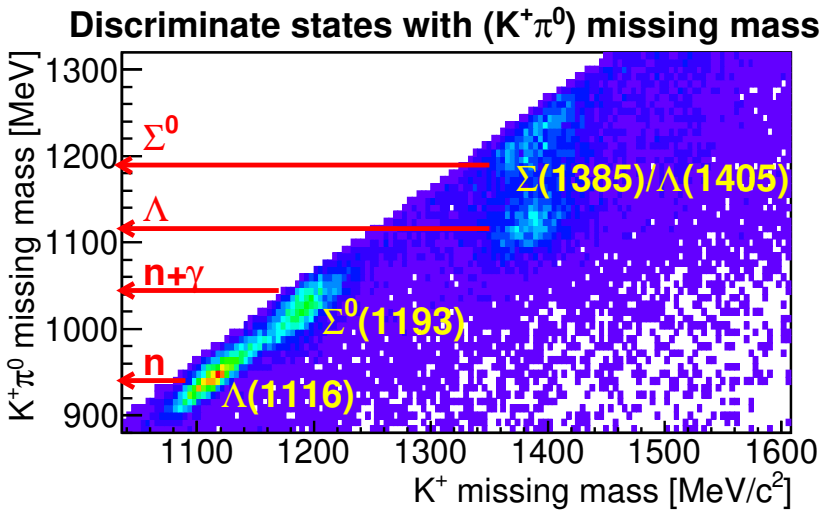
Thank you for your attention!

Meson Spectrum



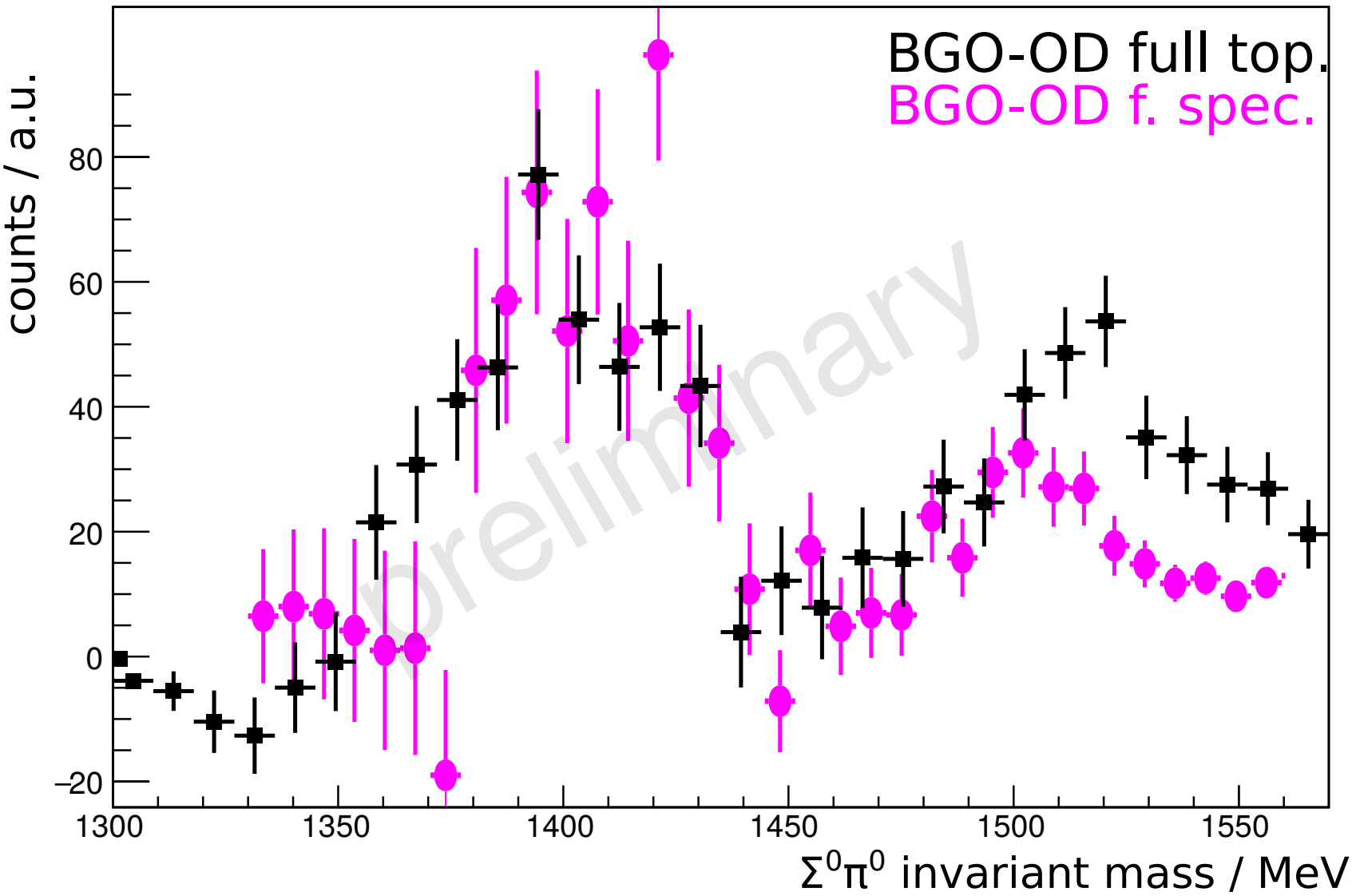
Mass recoiling from forward K^+





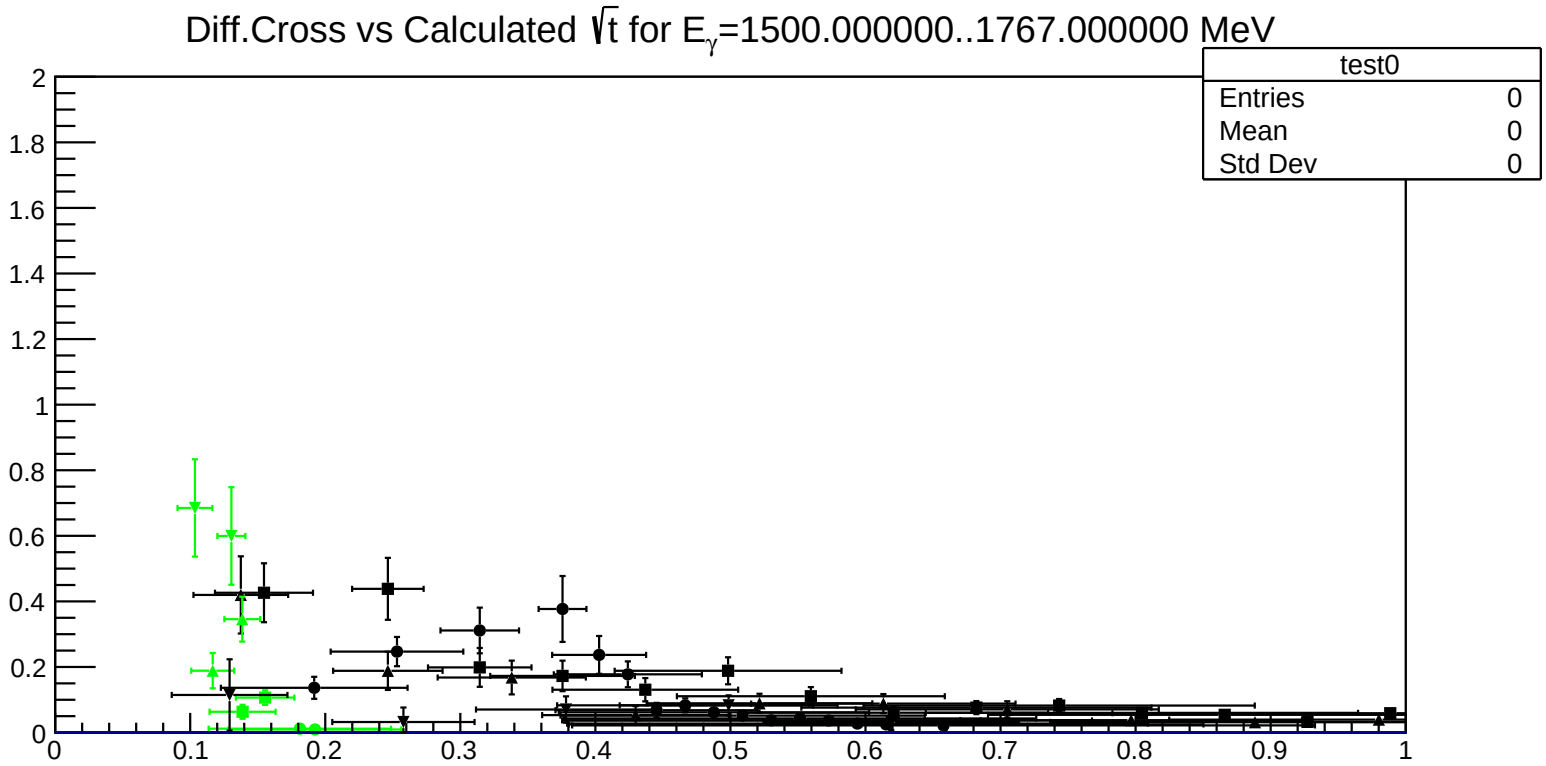
UNIVERSITÄT BONN

Line shape at BGO-OD

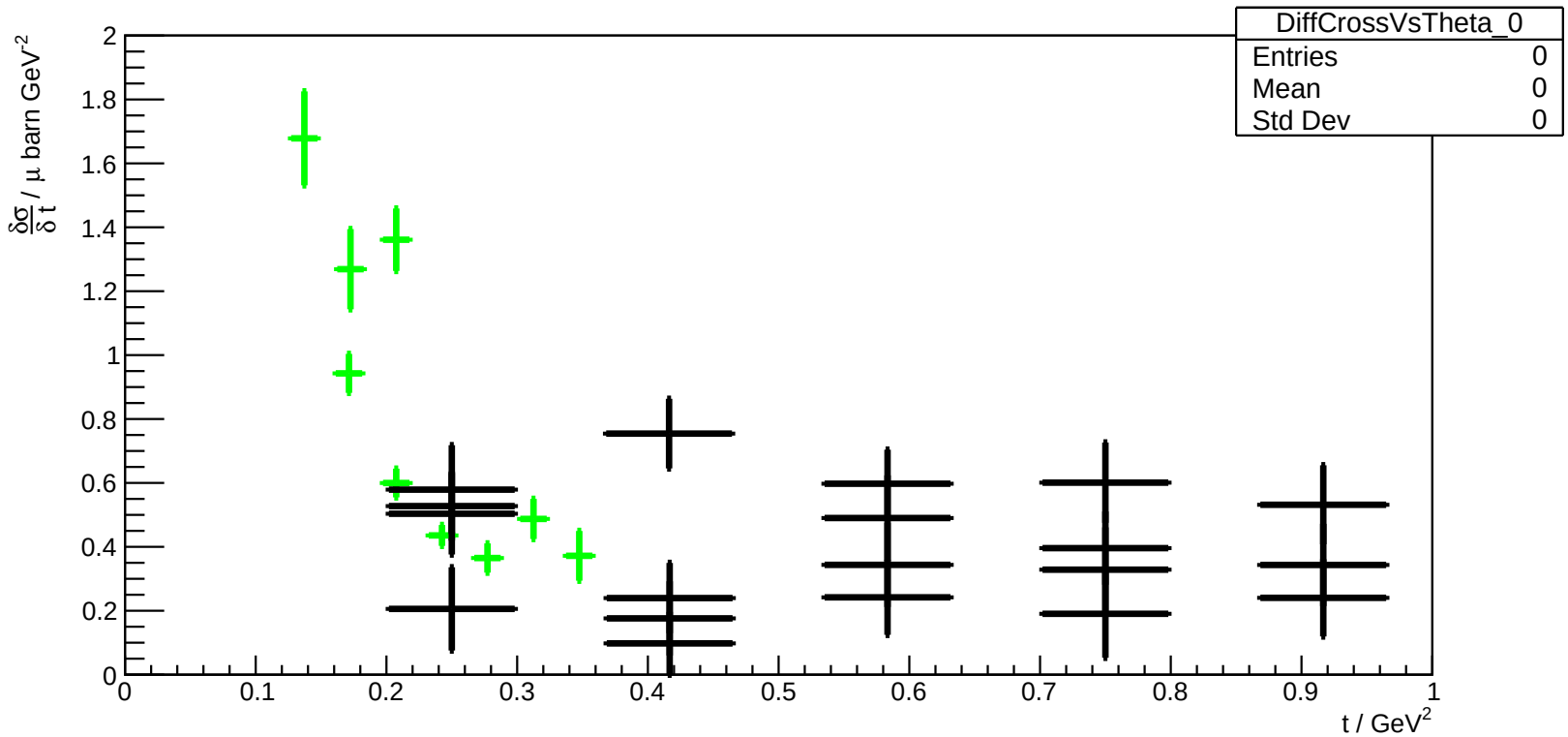


UNIVERSITÄT BONN

new t correlation results

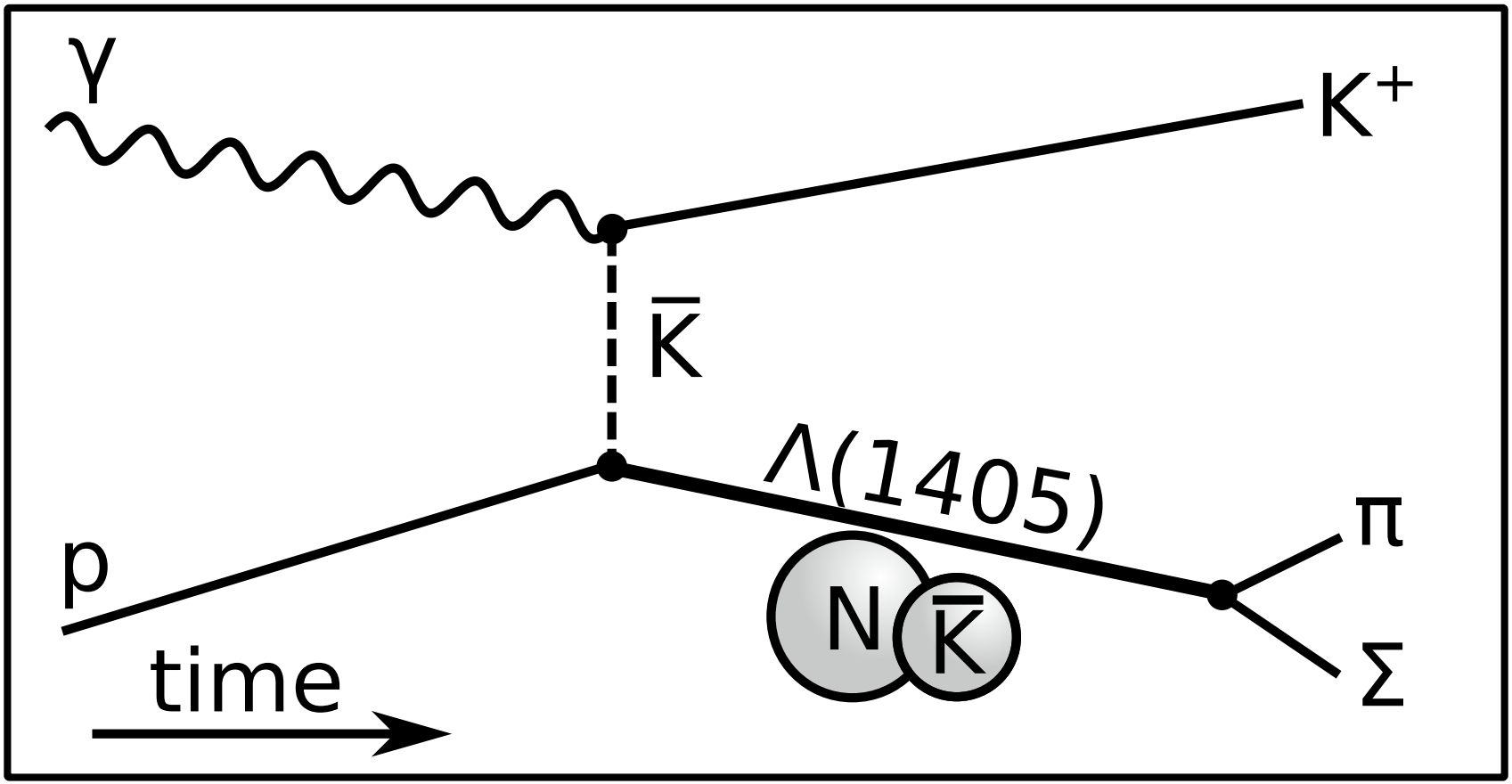


new t correlation direct results



UNIVERSITÄT BONN

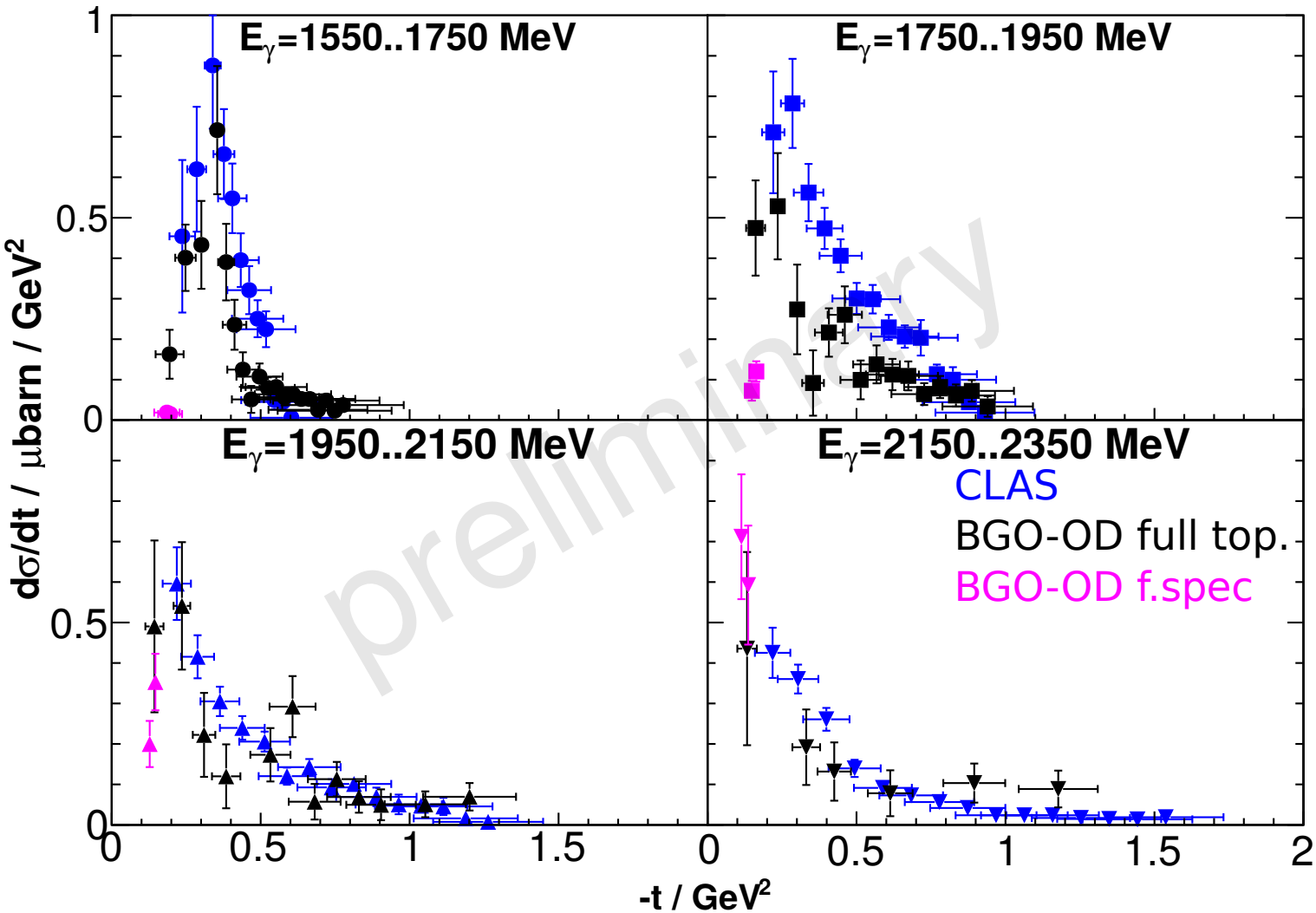
Differential cross section $\gamma p \to K^+\Lambda(1405) \to K^+\Sigma^0\pi^0$



Mandelstam variable $t = (\gamma - K^+)^2$

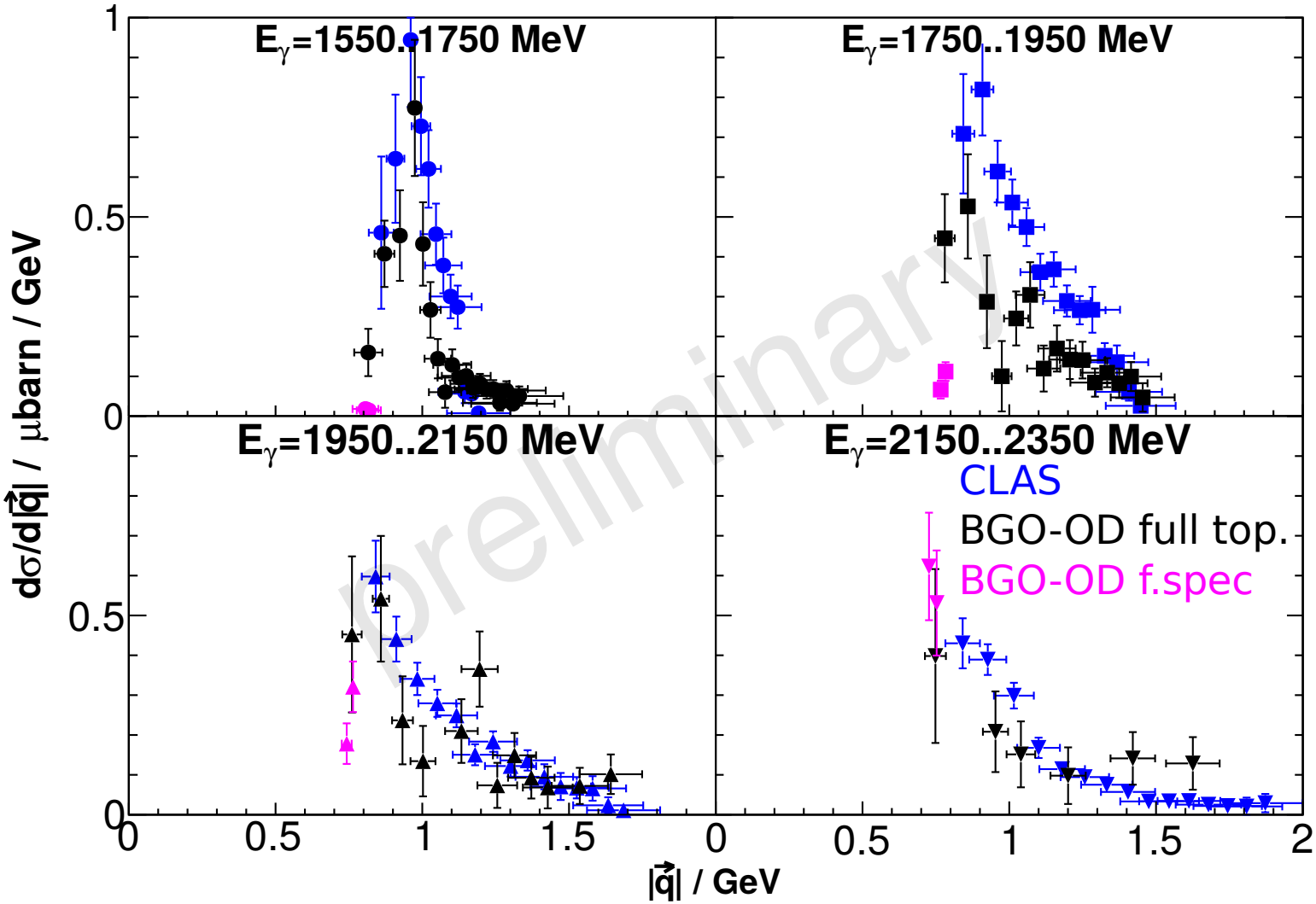
transfer momentum $\vec{q} = \vec{\gamma} - \vec{K^+}$

Differential cross section against *t*

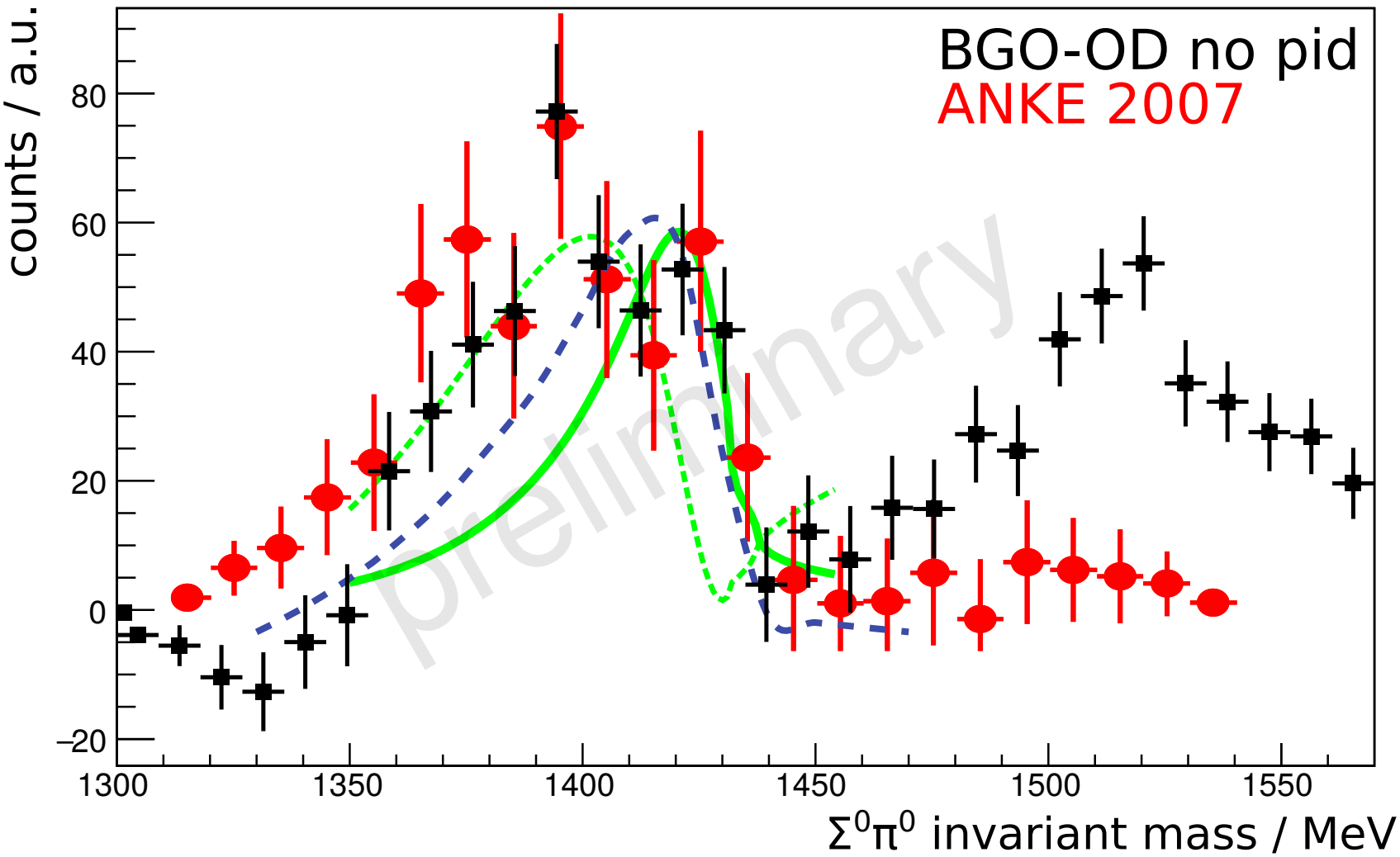


UNIVERSITÄT BONN

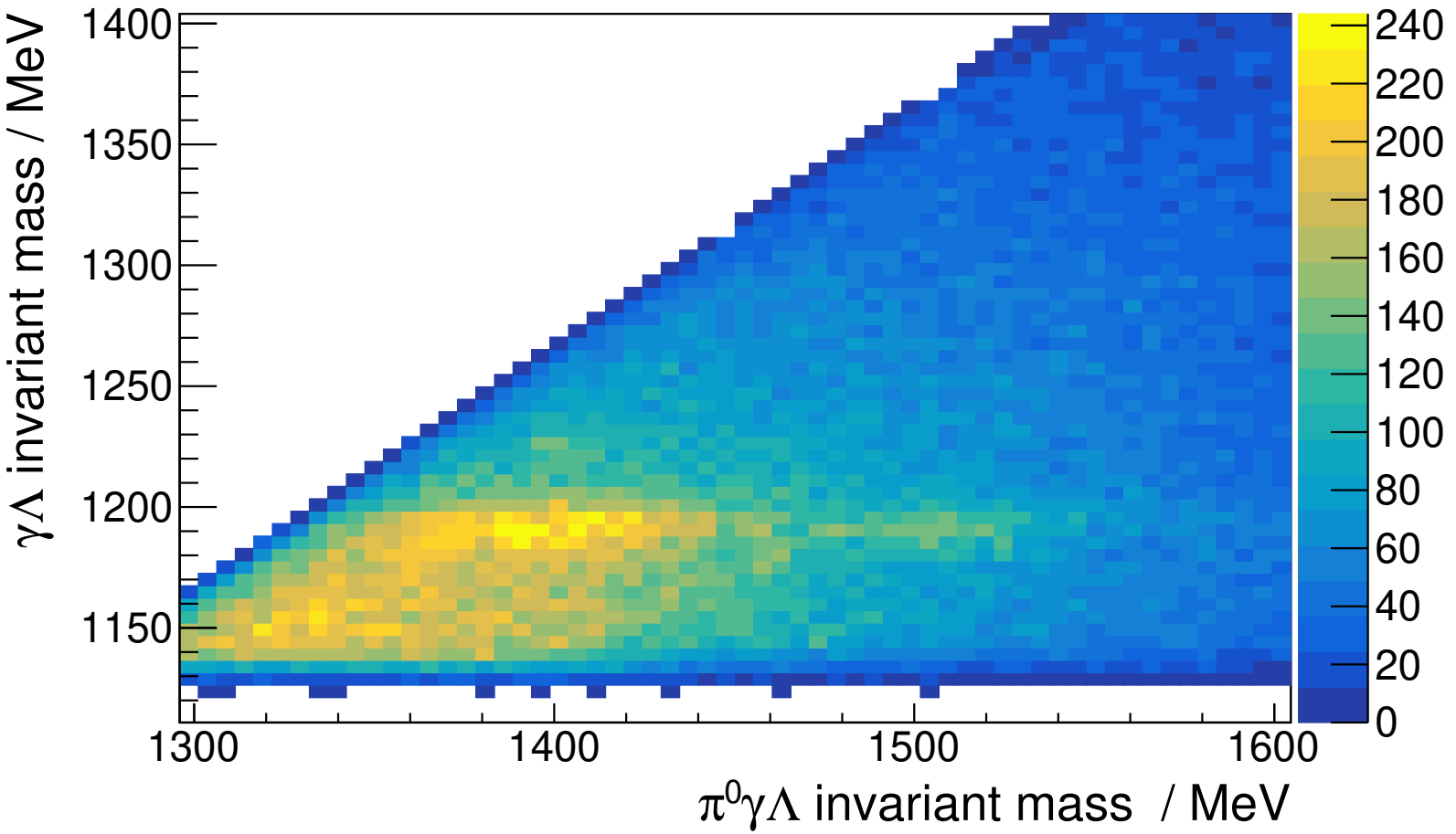
Differential cross section against $|\vec{q}|$



Doppel peak structure in line shape?



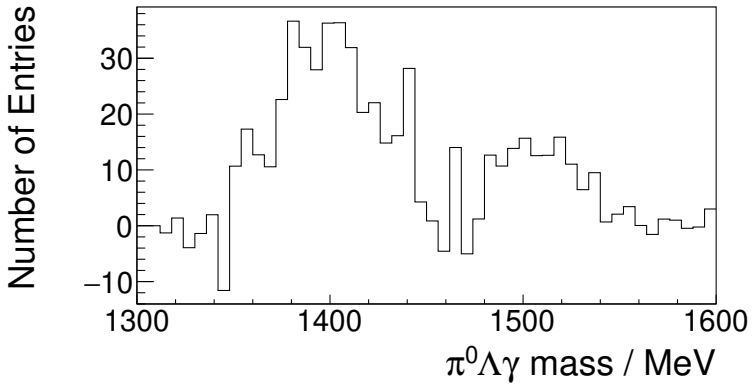
$K^+\pi^0\Sigma^0 \rightarrow K^+3\gamma\pi^-p$ (real data)



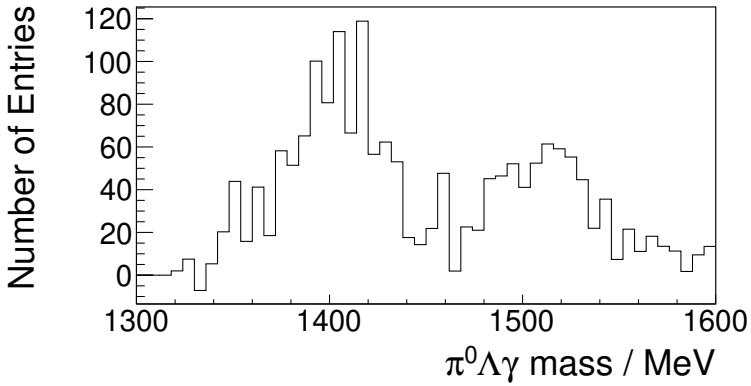
$\Sigma^0 \rightarrow \gamma\Lambda \rightarrow \gamma\pi^-p$(64%). No particle identification of K^+.

$K^+\pi^0\Sigma^0$ background subtracted (E_γ =1.6..2.0 GeV)

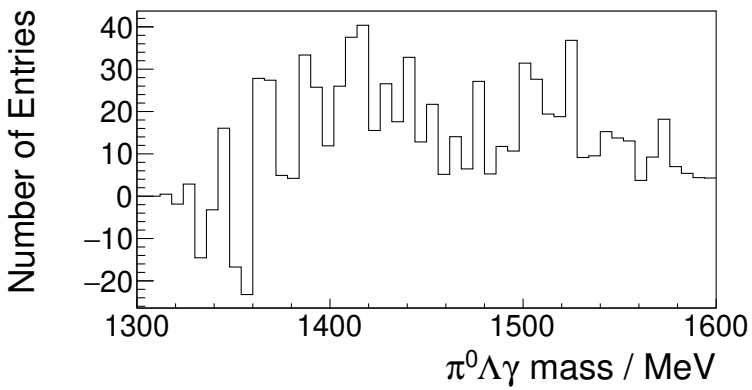
$\theta^{c.m.}_{K^+} = 0..45°$



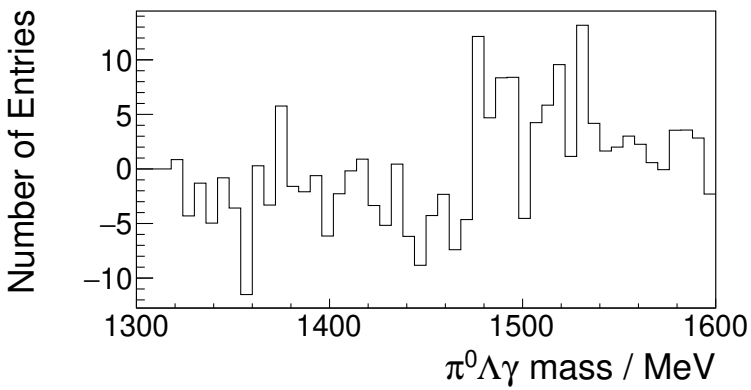
$\theta^{c.m.}_{K^+} = 45..90°$



$\theta^{c.m.}_{K^+} = 90..135°$

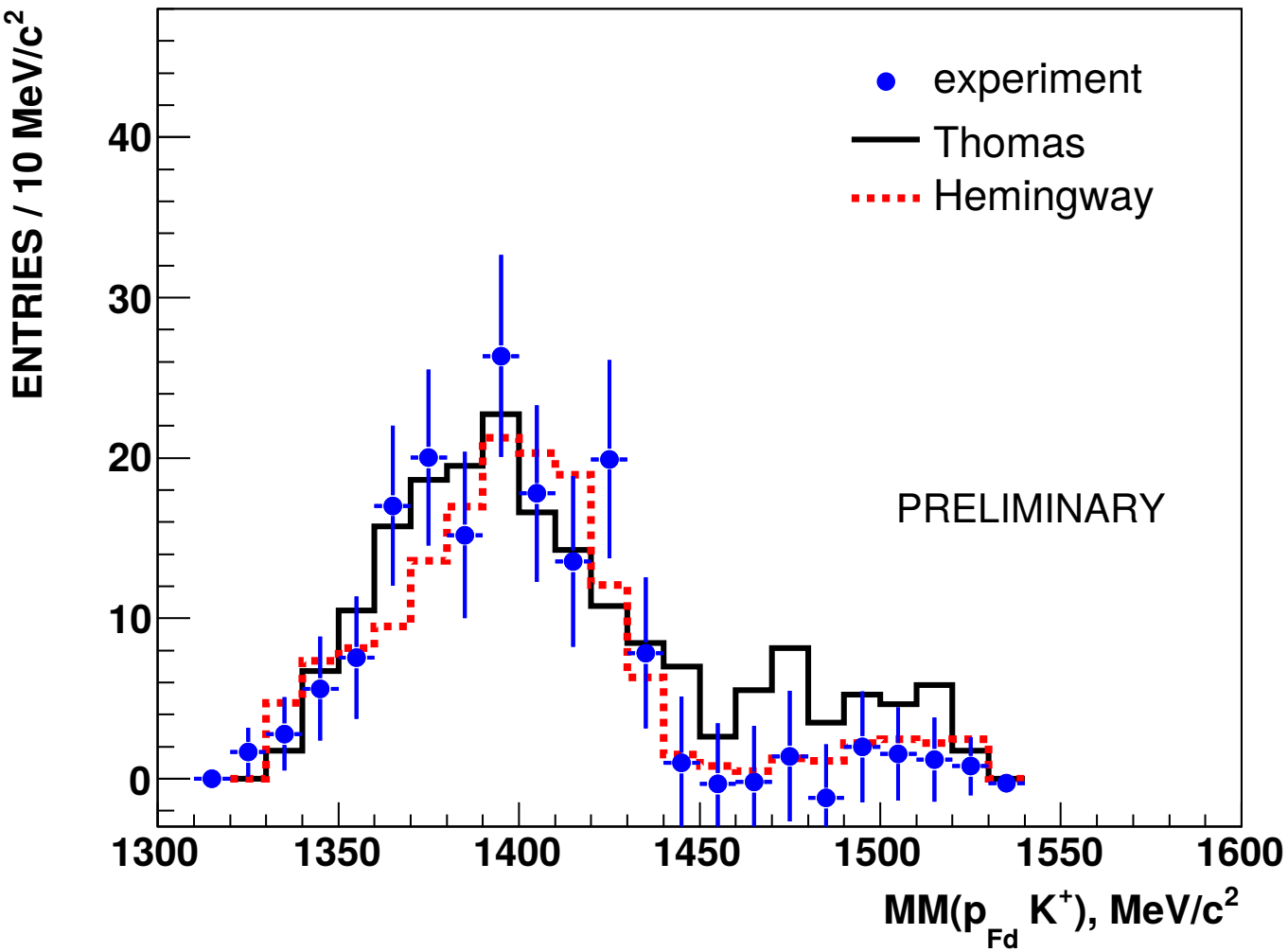


$\theta^{c.m.}_{K^+} = 135..180°$



Extraction of differential cross section possible

Line shape Λ(1405)

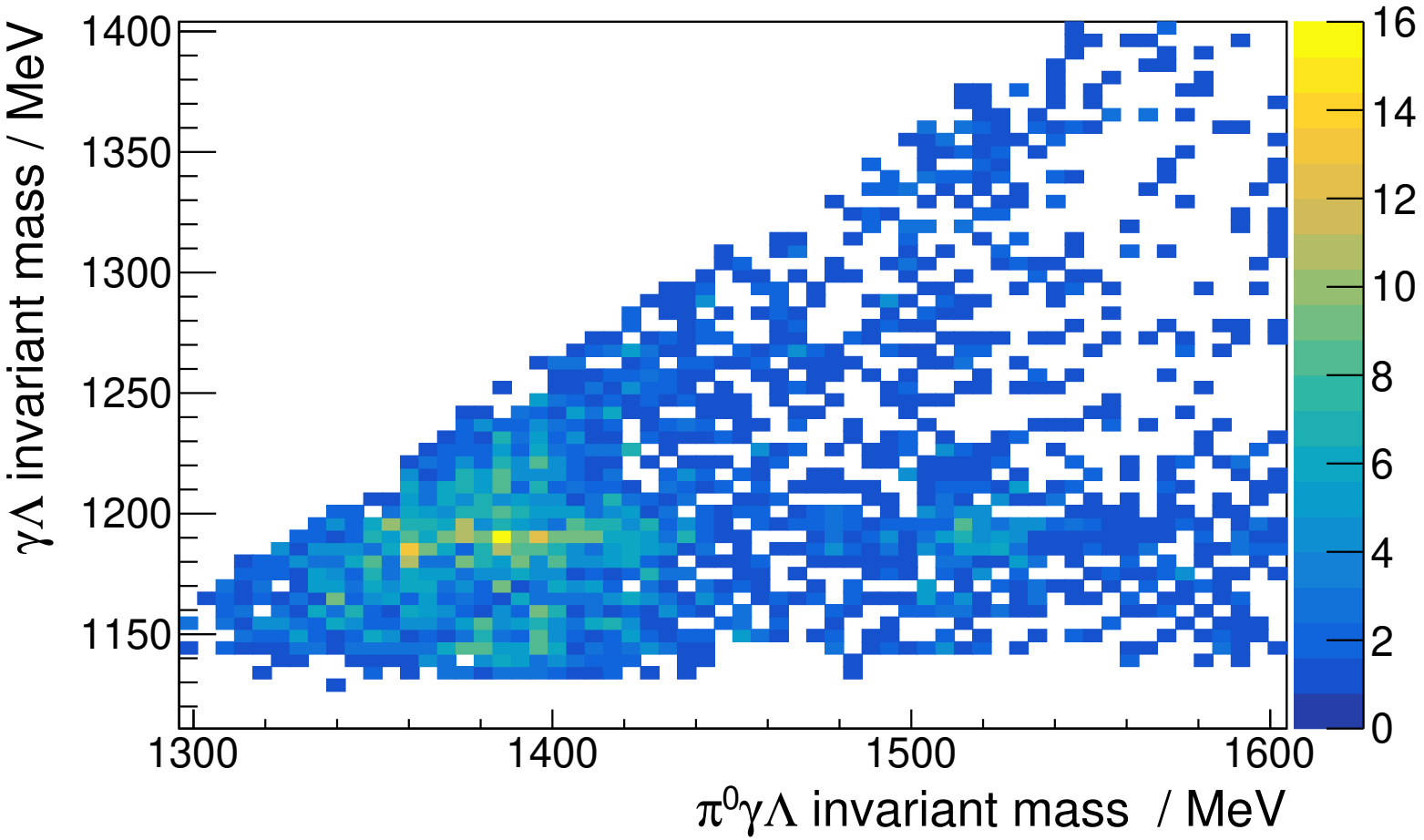


I.Zychor et al. (ANKE Collaboration) ECONFC070910:310,2007 (2007)

Beam time durations

Beamtime	datataking / days	P_γ / %	e-Beamcurrent / pA
6/2015	11	$\approx$25	1300
10/2015	16	$\approx$25	1190
2/2017	3	$\approx$75	1300-1700
5/2017	(15)	(75)	(1300)

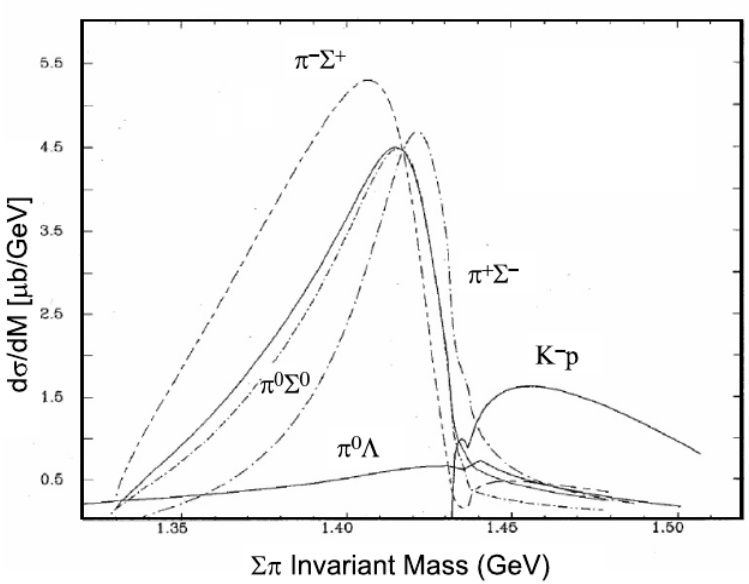
$K^+\pi^0\Sigma^0 \rightarrow K^+\pi^0\gamma + \Lambda(\text{missing})$ (real data)



$\Sigma^0 \rightarrow \gamma\Lambda(100\%)$. After a kinematic fit to the missing Λ mass.

Λ(1405) line shape

Prediction:



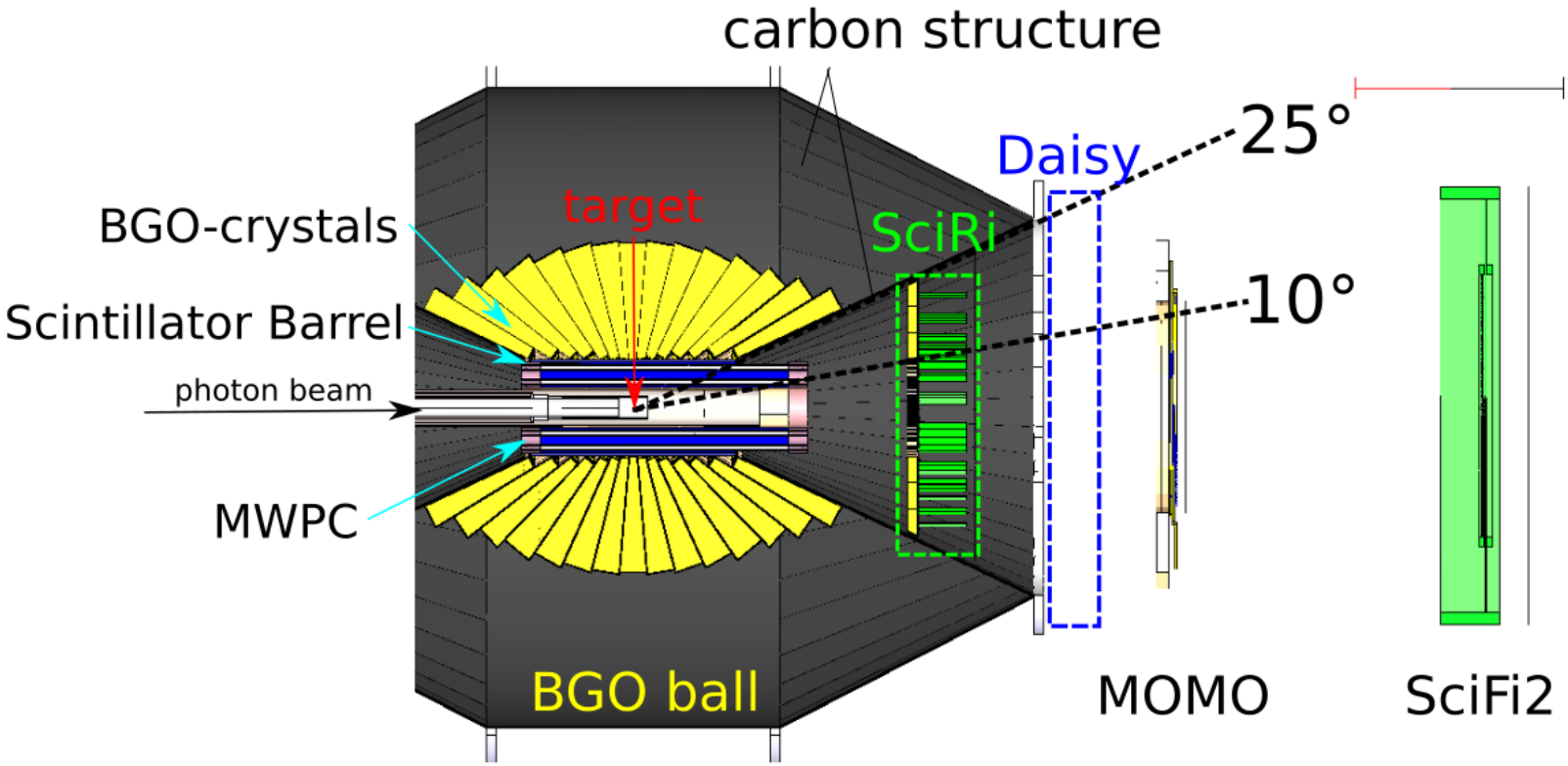
J.C.Nacher et al. Phys.Lett. B455, 55-61 (1999)
see also: D.Jido et al. Nucl.Phys.A. 725,181 (2003)

$$\Lambda(1405) \rightarrow \Sigma^0\pi^0$$
$$\Sigma^{\pm}\pi^{\mp}$$

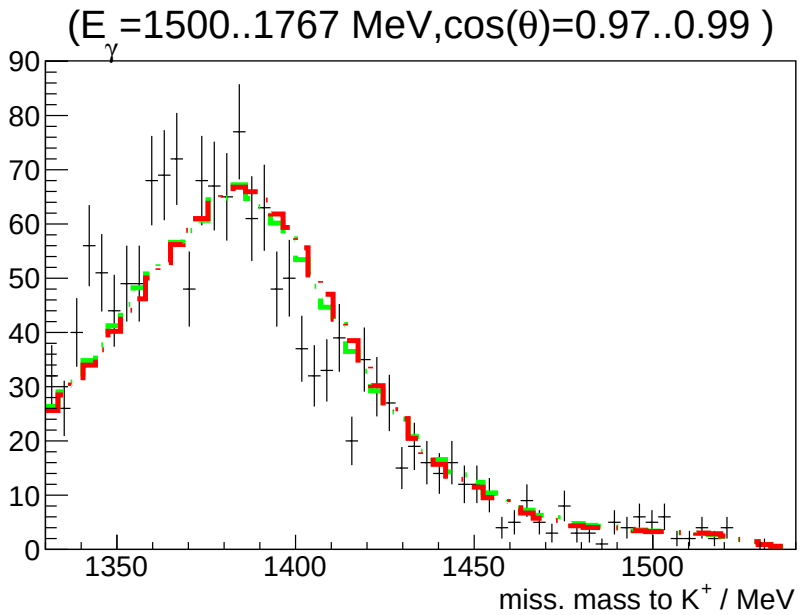
Free $N\bar{K}$ threshold at 1432 MeV $\rightarrow$ distorted mass line shape

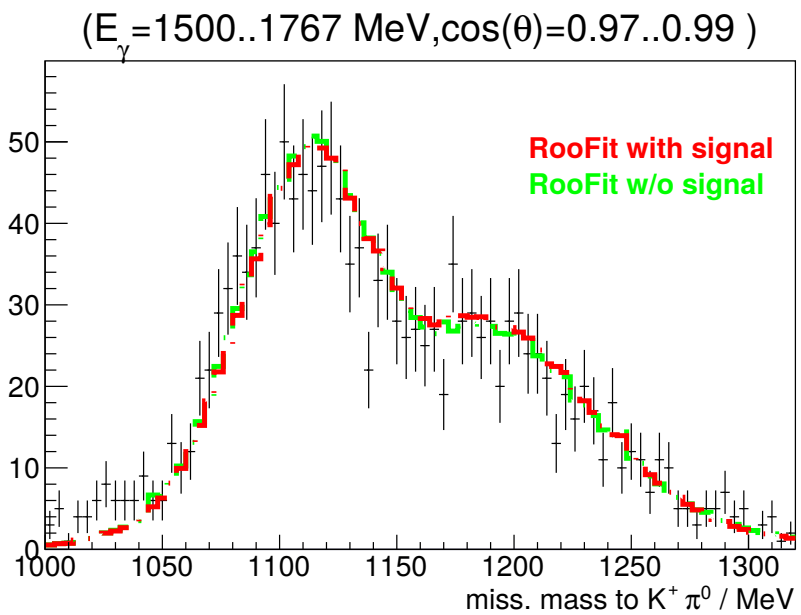
$\rightarrow$ different for decay channels

BGO-OD slice view



RooFit reliability





$\Rightarrow$ Results very preliminary

$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$ (33 %)

- K^+ in Forward Detector
- $\pi^0 \rightarrow 2\gamma$ in Central Detector
- Σ^0 missing

$\rightarrow$ f. spec.

$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$ (33 %)

- K^+ in Forward Detector
- $\pi^0 \rightarrow 2\gamma$ in Central Detector
- Σ^0 missing

$\rightarrow$ f. spec.

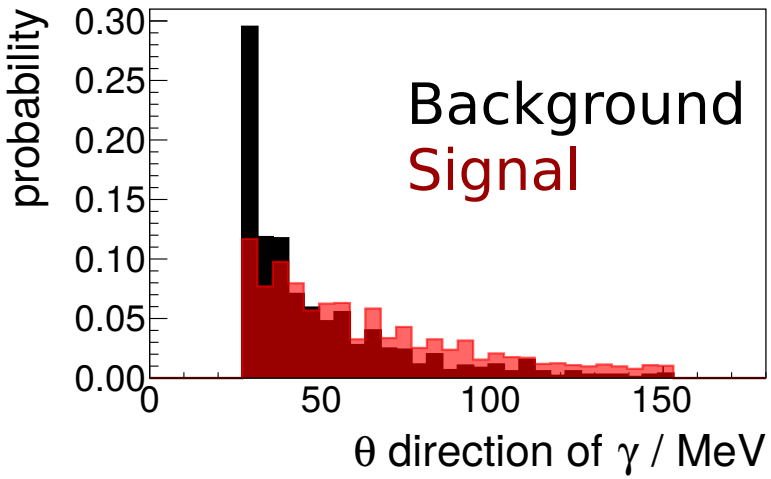
$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0 \rightarrow K^+\pi^0\gamma\Lambda$
$\rightarrow K^+\pi^0\gamma\pi^-p$ (21%)

- $\pi^0\gamma$ in BGO calorimeter ($\theta^{lab} = 25..155°$)
- $K^+\pi^-p$ with direction only ($\theta^{lab} = 2..155°$)
  $\rightarrow$ recalculated momentum
  $\rightarrow$ no particle identification
- kinematic fit

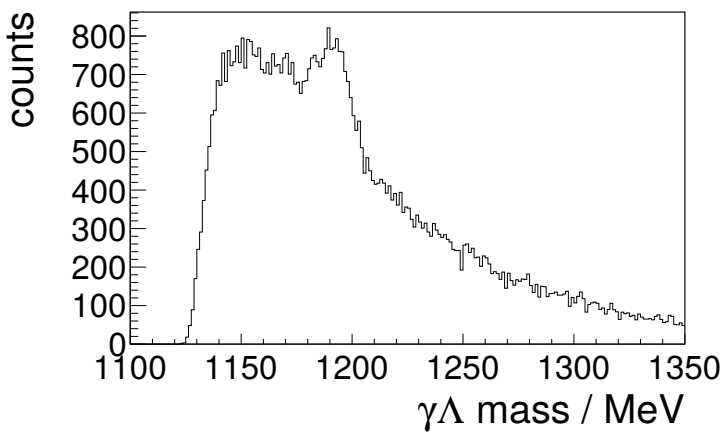
$\rightarrow$ full top.

Removing combinatorial background

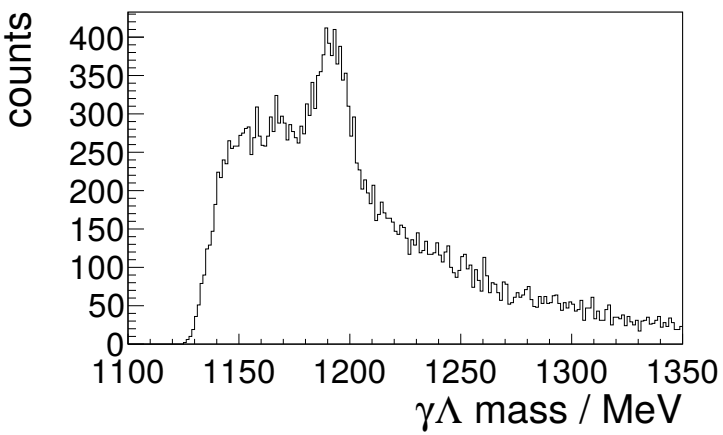
Angle distribution of γ from the $\Sigma \rightarrow \gamma\Lambda$ decay



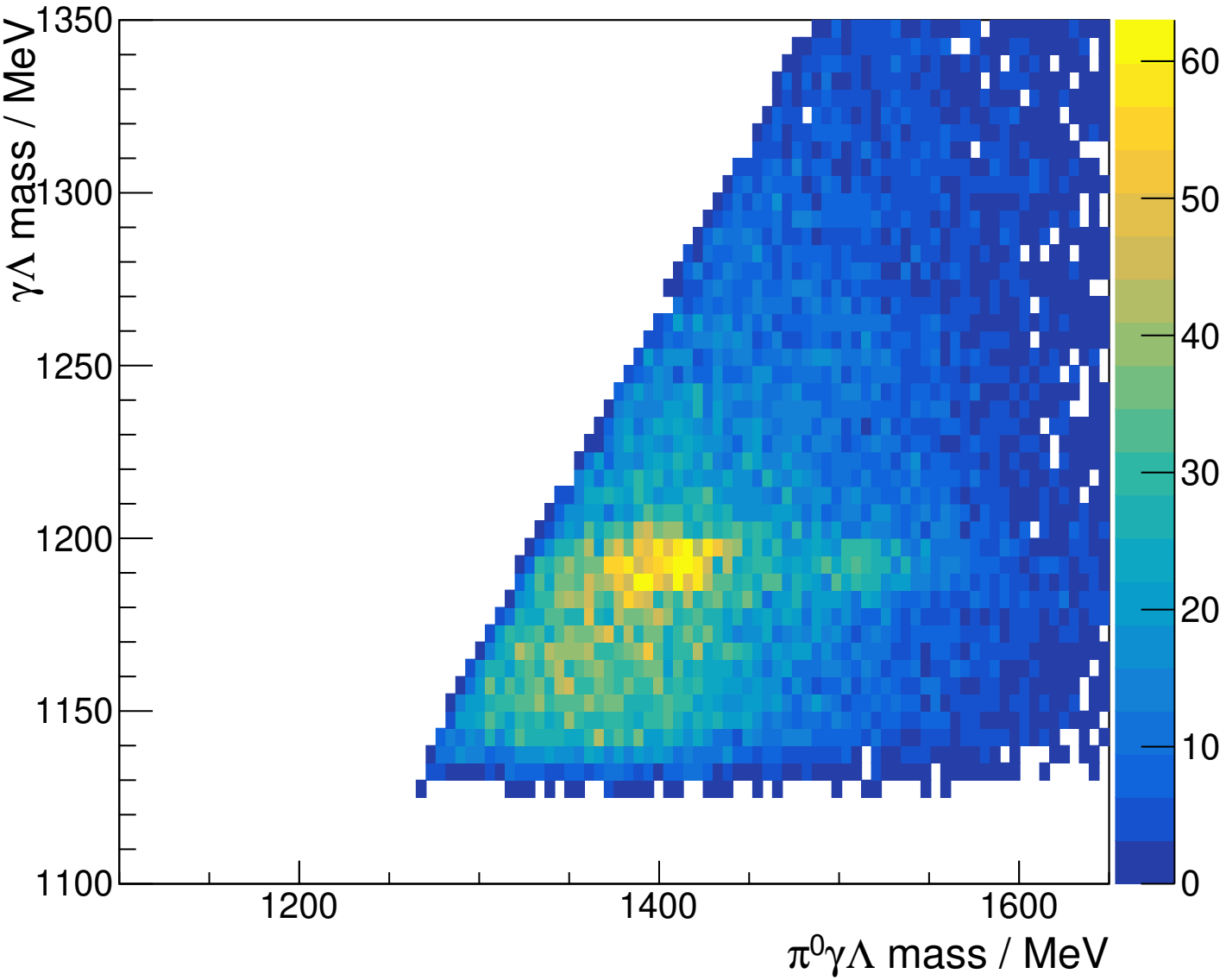
All θ allowed



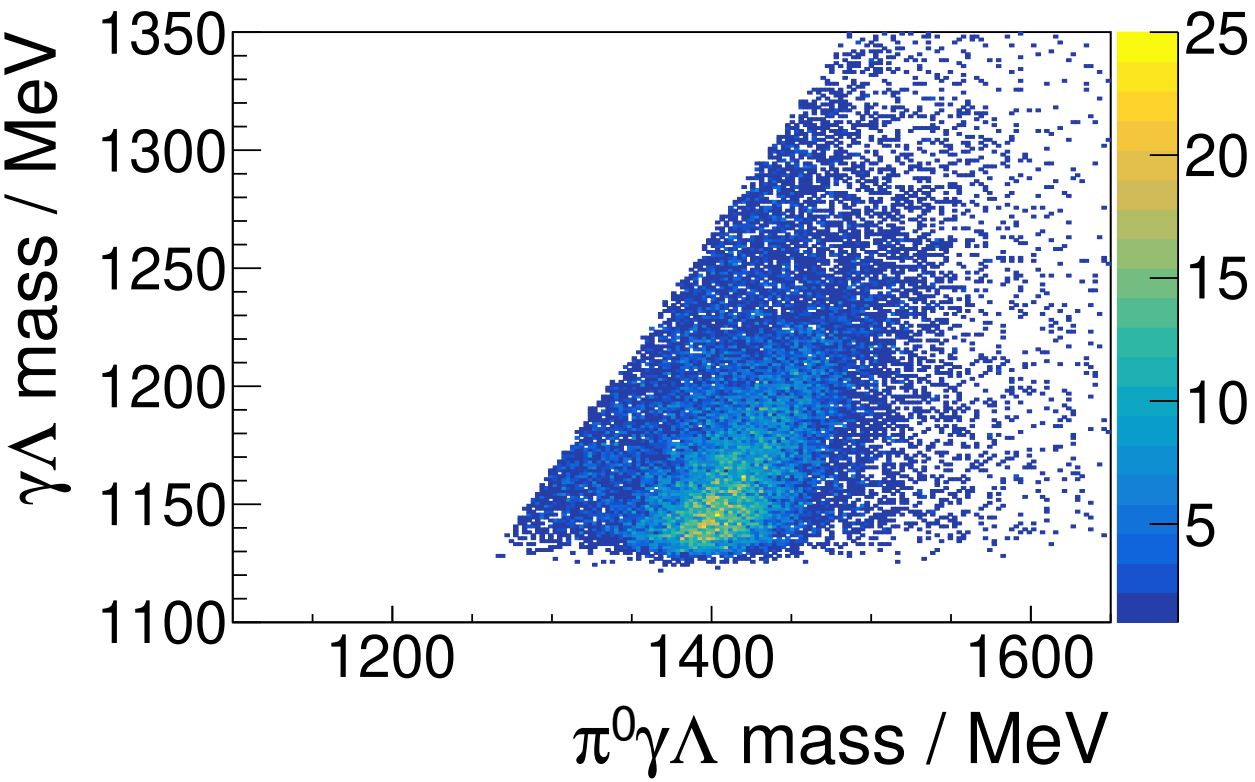
$\theta > 30°$



Real data $\gamma p \to K^+\Lambda(1405) \to K^+\Sigma^0\pi^0 \to K^+\gamma\Lambda^0\pi^0$

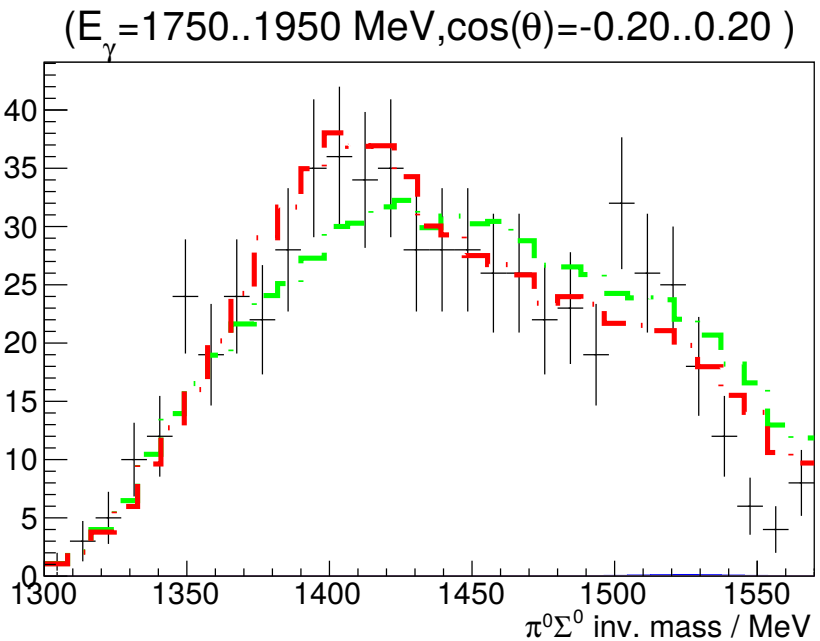


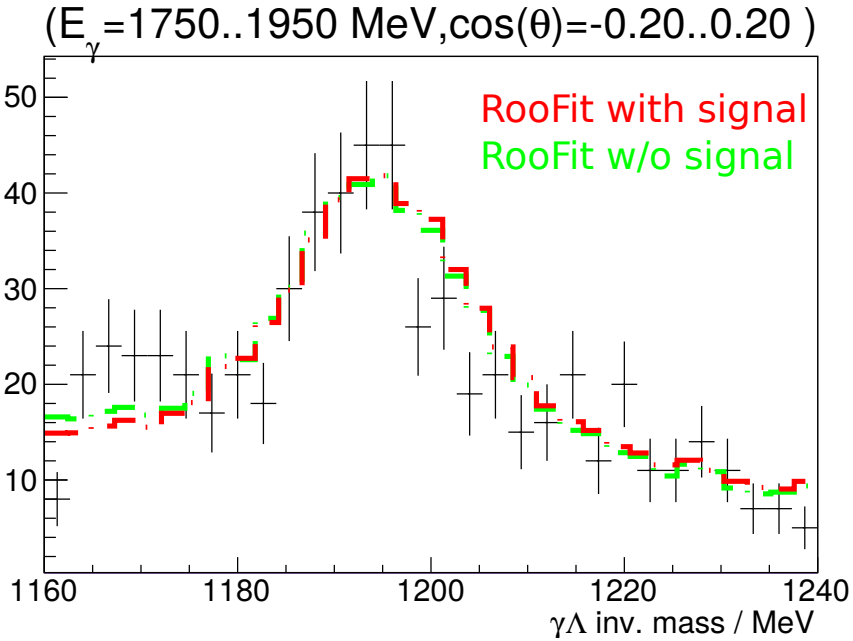
Simulation studies of background: $\Sigma(1385)$



$$\Sigma(1385) \to \pi^0\Lambda(87\%) \to \pi^0\pi^- p$$
$$\to \pi^-\Sigma^+(4\%) \to \pi^0\pi^- p$$

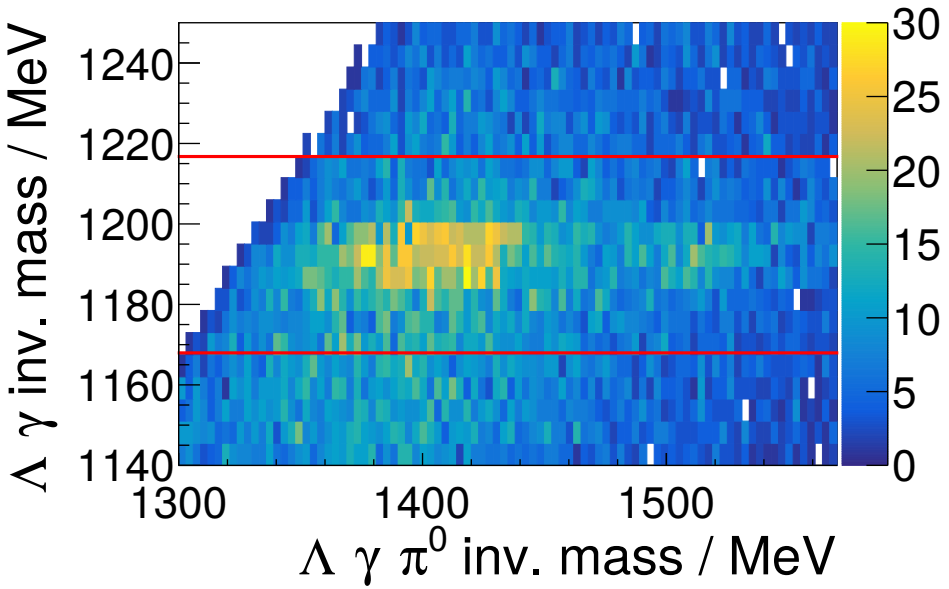
RooFit





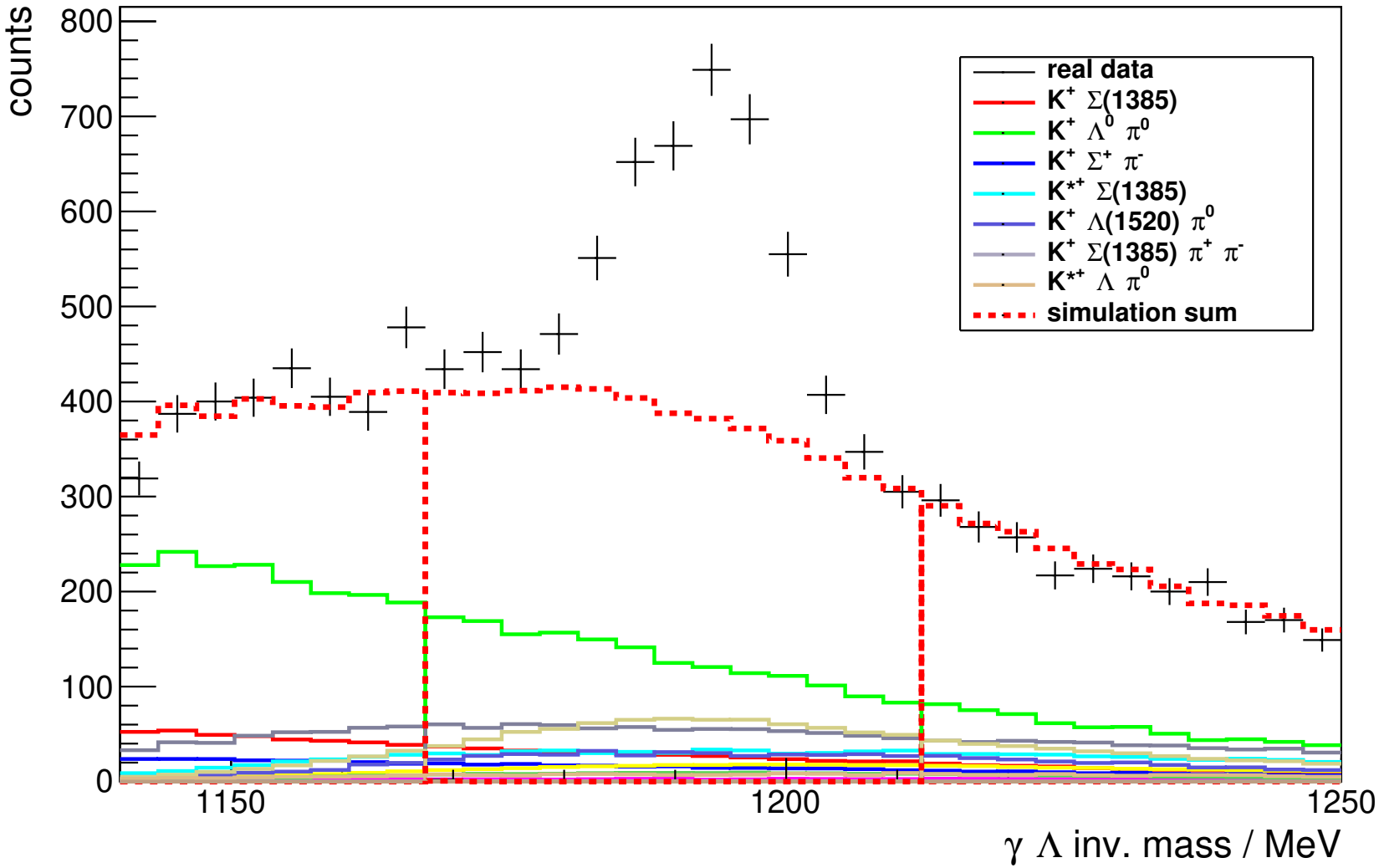
$K^+\Lambda(1405)$ events can be extracted with RooFit

Line shape extraction with RooFit



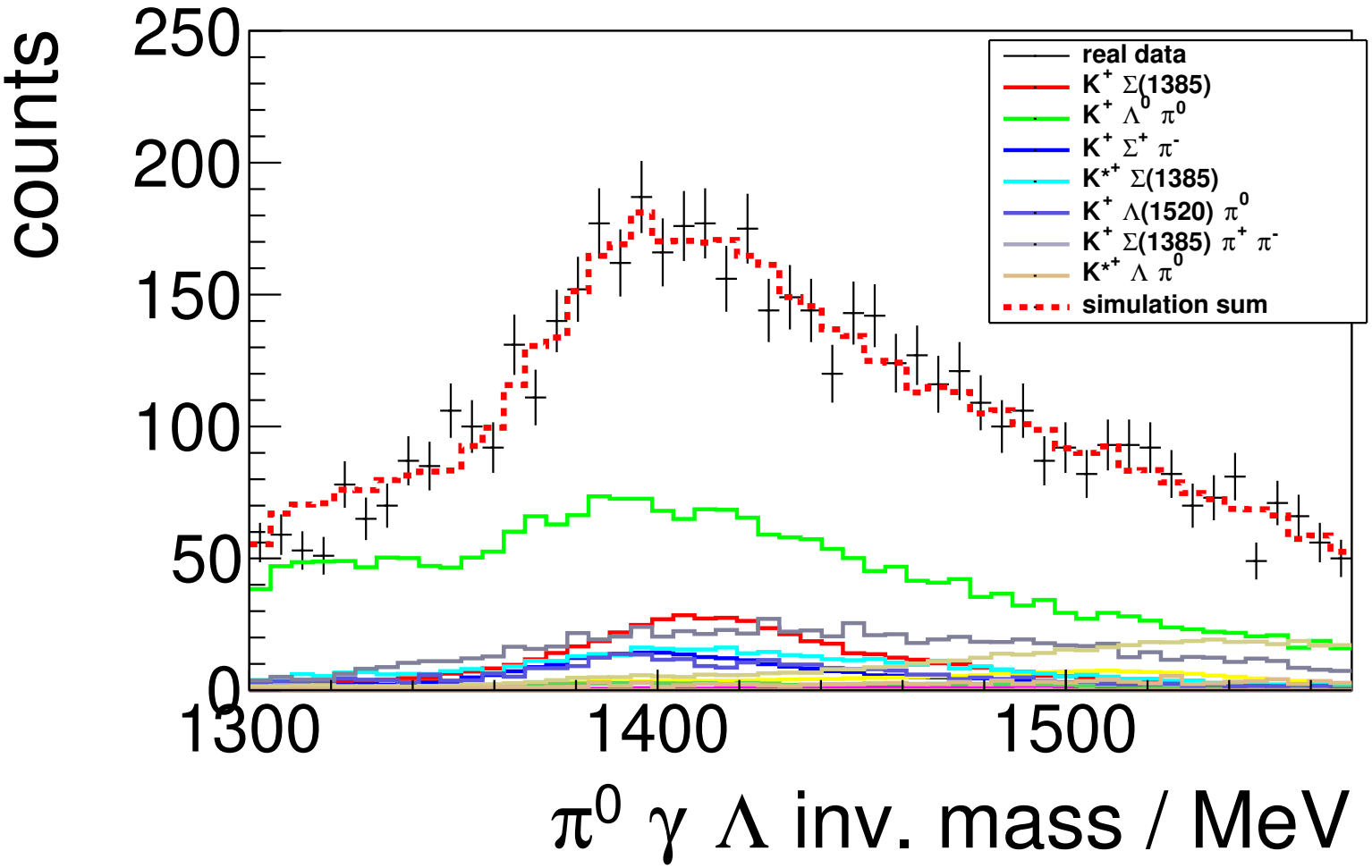
1. exclude events with $|\gamma\Lambda| \approx |\Sigma^0|$
2. fit background channels
   (excluding: $K^+\Sigma^0\pi^0, K^+\Lambda(1405/1520), K^{*+}\Sigma^0$)
3. subtract fitted background distribution from data

Line shape extraction, RooFit results, $\gamma\Lambda$ projection



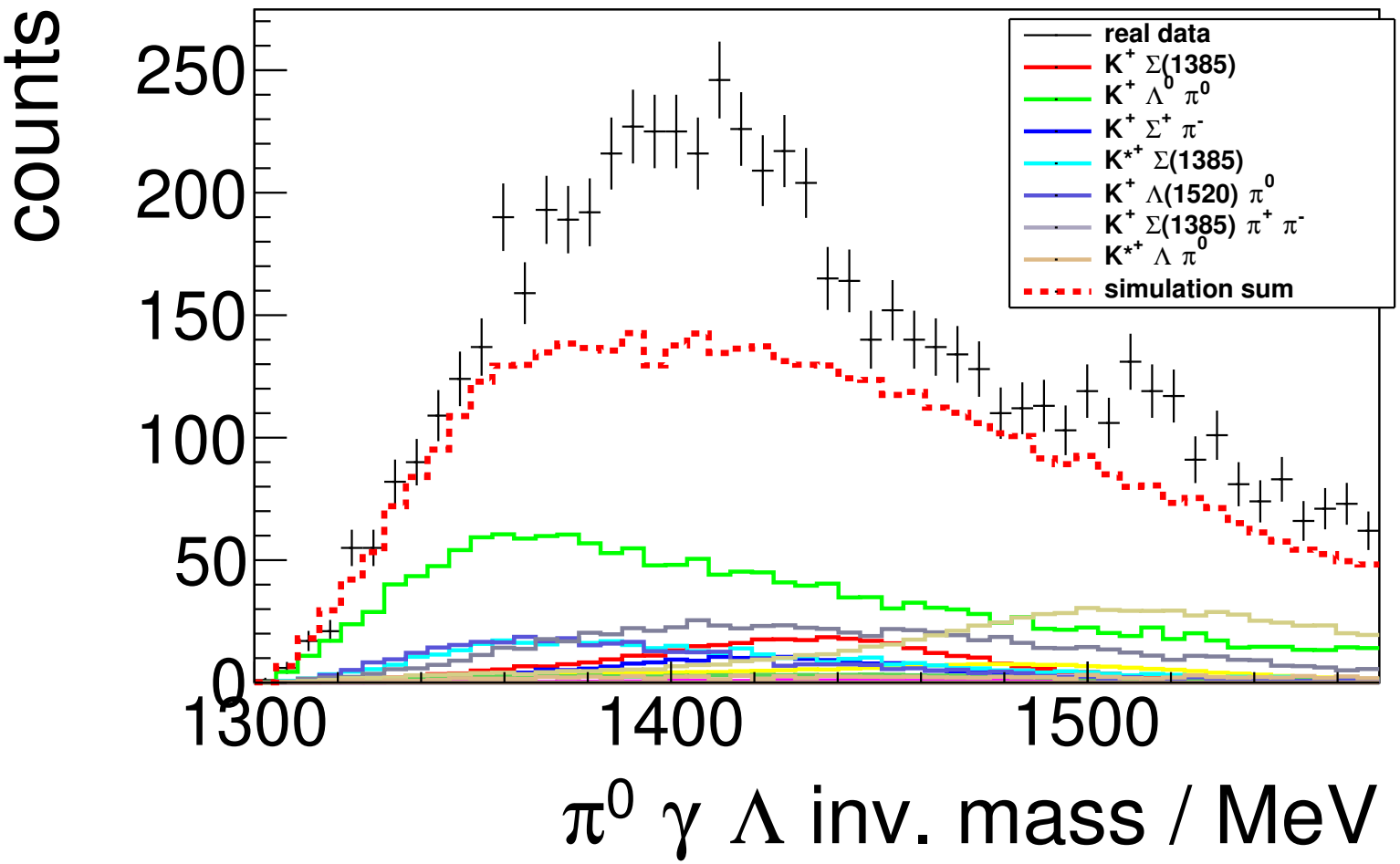
Line shape extraction, RooFit results, $\pi^0\gamma\Lambda$ projection

background region: $|\gamma\Lambda| < 1167$ MeV or $|\gamma\Lambda| > 1212$ MeV

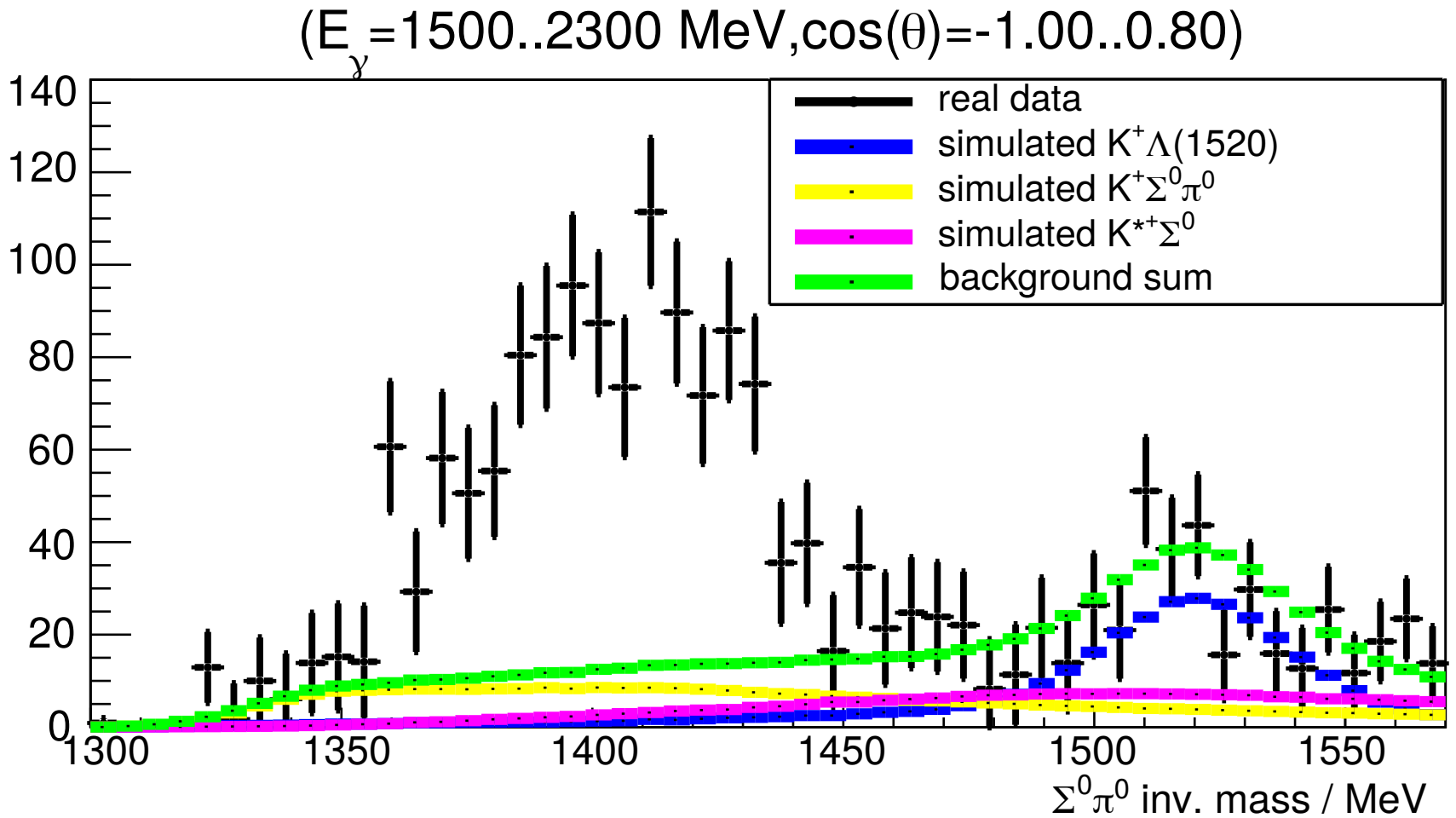


Line shape extraction, RooFit results, $\pi^0\gamma\Lambda$ projection

signal region: 1167 MeV $< |\gamma\Lambda| <$ 1212 MeV

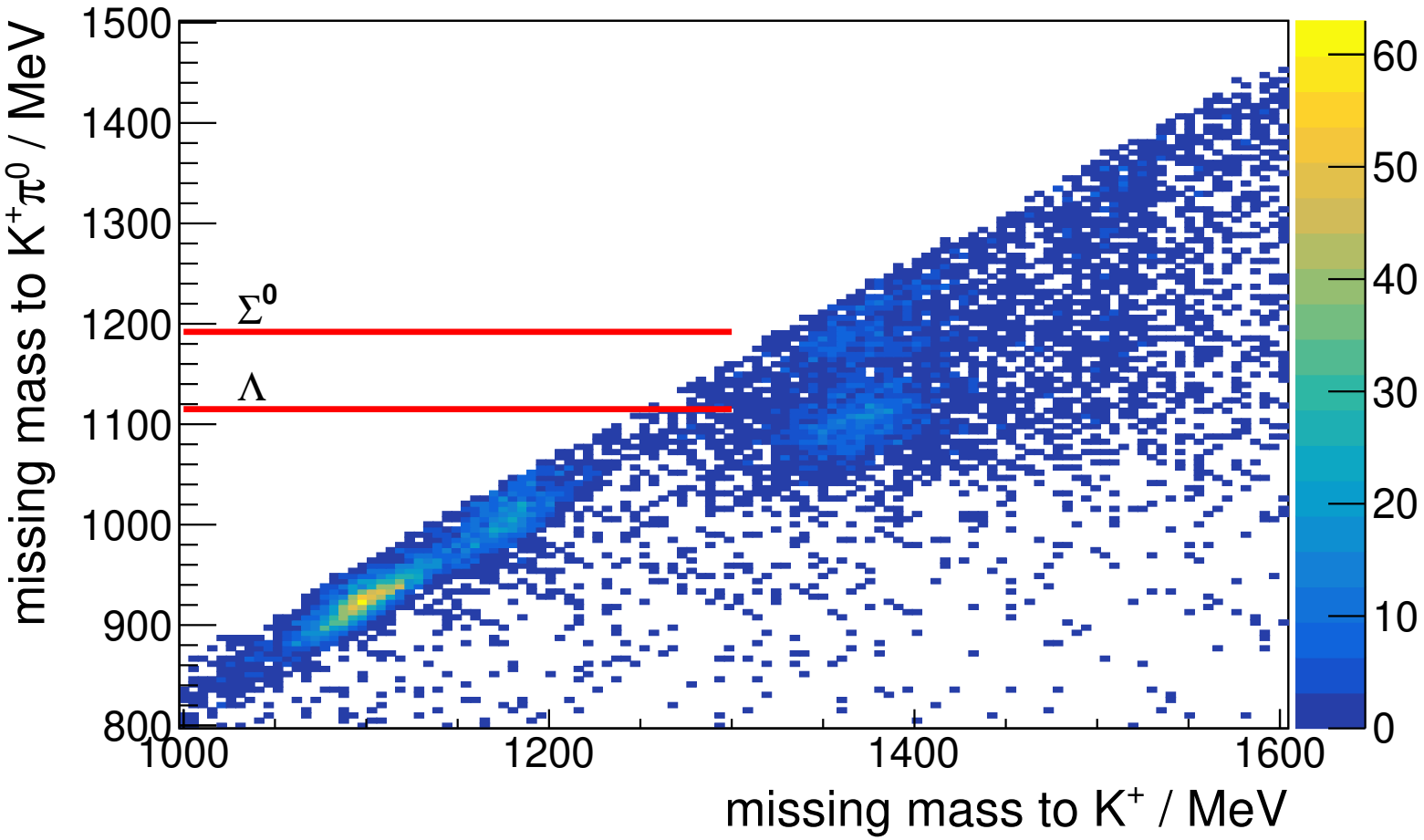


Line shape extracted



Mass resolution $\sigma = 13.0 \pm 0.1$MeV

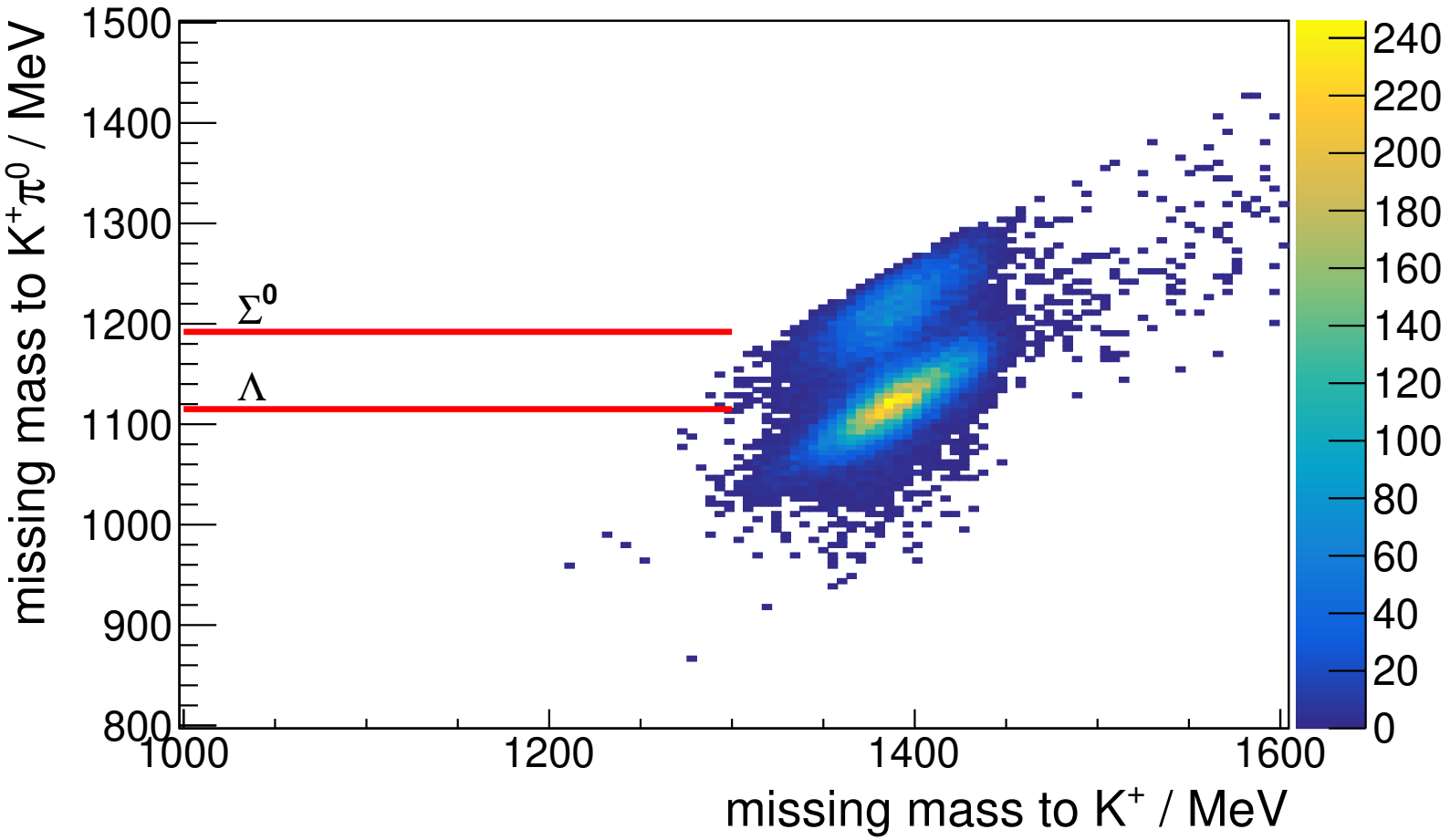
$K^+\Lambda(1405) \rightarrow K^+\pi^0 X$ (real data, K^+ forward)



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

$K^+\Sigma(1385) \rightarrow K^+\pi^0\Lambda$

$K^+\Lambda(1405) \rightarrow K^+\pi^0 X$ (sim. $\Sigma(1385)$, K^+ forward)



$K^+\Sigma(1385) \rightarrow K^+\pi^0\Lambda$

$K^+\Sigma(1385) \rightarrow K^+\pi^-\Sigma^+ \rightarrow K^+\pi^0\pi^- p$