

The BGOOD experiment at ELSA - Multi quark structures in the light quark sector

Katrin Kohl

on behalf of the BGOOD collaboration

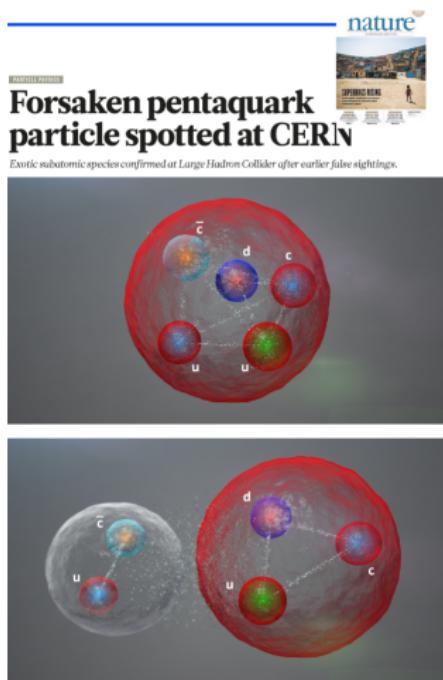
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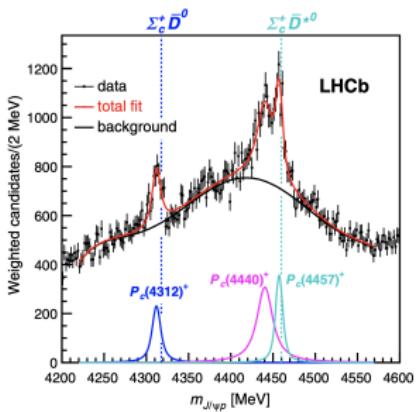
supported by DFG (PN 388979758/405882627)
and European Union's Horizon 2020 programme, grant 824093



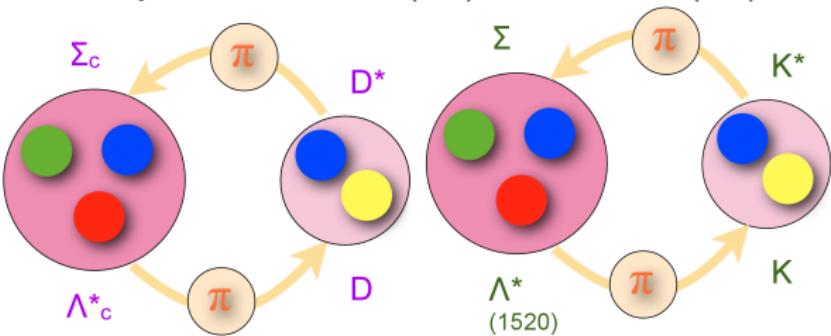
Multi-quark states beyond the conventional quark model



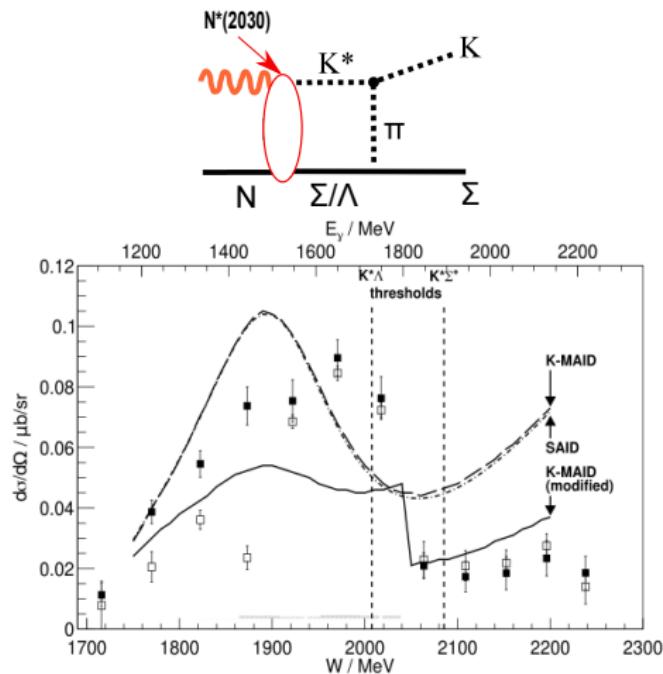
Nature 523, 267–268 (2015)



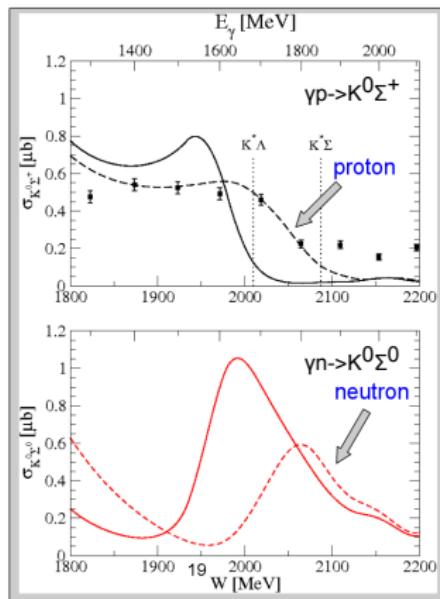
R. Aaij, et al., PRL 115, 072001 (2015) & PRL 122, 222001 (2019)



Cusp in $K^0\Sigma^+$ photoproduction



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



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

Same model of vector meson-baryon interaction that predicted the LHCb pentaquark

Structure of the $\Lambda(1405)$

- Well established since the 1960's - considered a $\bar{K}N$ molecule prior to the quark model

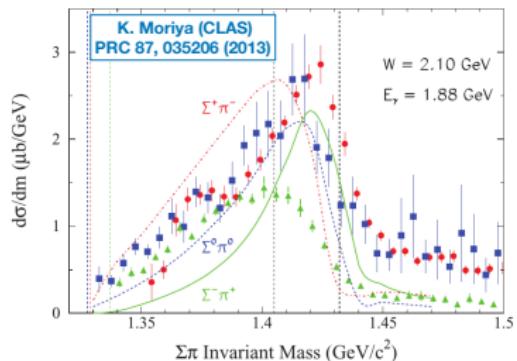
Dalitz & Tuan, PRL 2 (1959) 425

- 2010: after long discussion
PDG: It's a 3-quark state

K. Nakamura et al. (Particle Data Group), JPG 37, 075021 (2010)

- 2015: now a $\bar{K}N$ molecule most probable
"It is the archetype of what is called a dynamically generated resonance"

Ulf-G. Meißner and Tetsuo Hyodo, 2015



- Lies between the $\pi\Sigma$ & $\bar{K}N$ thresholds
- $\Lambda(1405)$ - dynamically generated by meson-baryon interactions?

Nacher, Oset, Toki, Ramos, & Meißner, NPA725 (2003) 181

Multi-quark structures in the light quark sector?

Recent highlights:

- K^0 photoproduction off the neutron

[K. Kohl et al. arXiv:2108.13319 \(2021\), submitted to EPJA](#)

- $K^+\Lambda(1405)$

[G. Scheluchin et al. Phys. Lett. B, 833 \(2022\)](#)

- $K^+\Sigma^0$ photoproduction, cusp at the $K\bar{K}p$ threshold

[T.C. Jude et al. Phys. Lett. B, 820 \(2021\)](#)

(→Johannes Groß, Wednesday 15:40, P2)

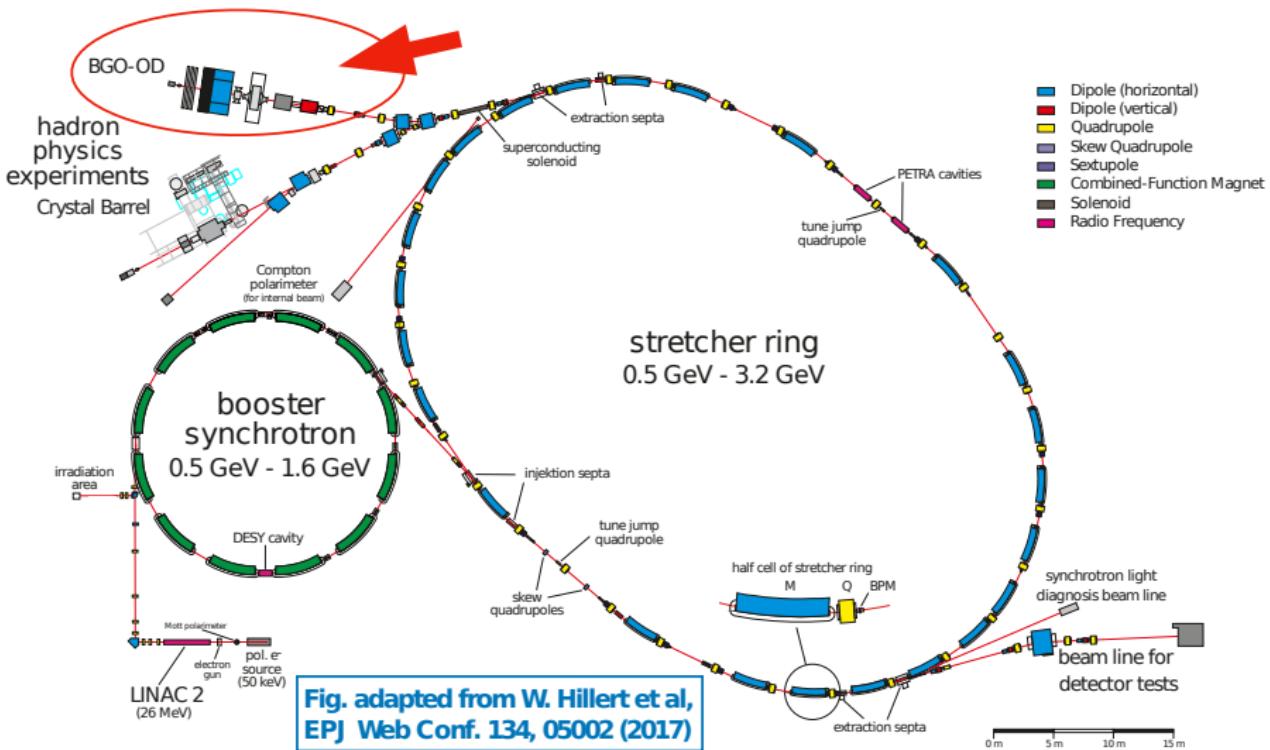
Experimental requirements

- Reconstruction of complicated, mixed charge final states -
eg $K^+ \Lambda(1405) \rightarrow K^+(\pi^0 \Sigma^0) \rightarrow K^+ \pi^0 \gamma p \pi^-$
or $K^0 \Sigma^0 \rightarrow (2\pi^0)(\gamma \Lambda) \rightarrow 5\gamma p \pi^-$
 - Charged particle identification at extremely forward angles -
reaction dynamics at very low momentum exchange
 - Neutral meson reconstruction in 4π
 - Unique & complementary to existing experiments (eg CBELSA-TAPS neutral particle reconstruction, CLAS charged particle reconstruction).
-

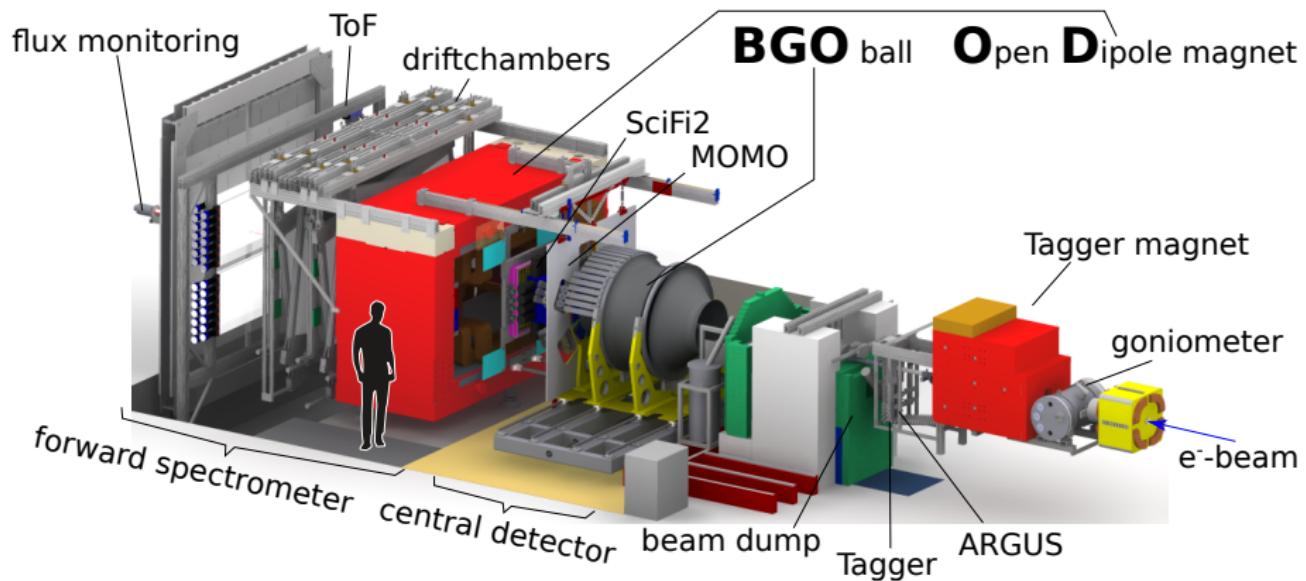
BGOOD at the ELSA facility, Bonn

Overview Thursday 11:50 Rachele Di Salvo

ELSA

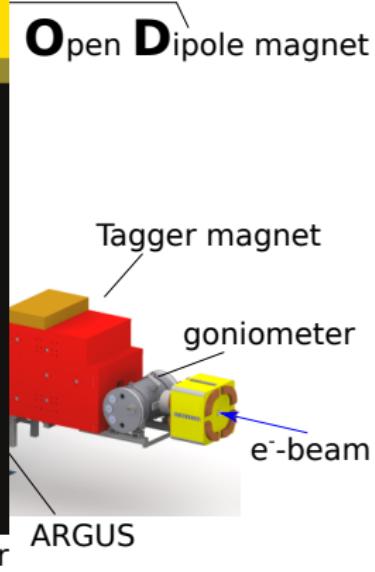
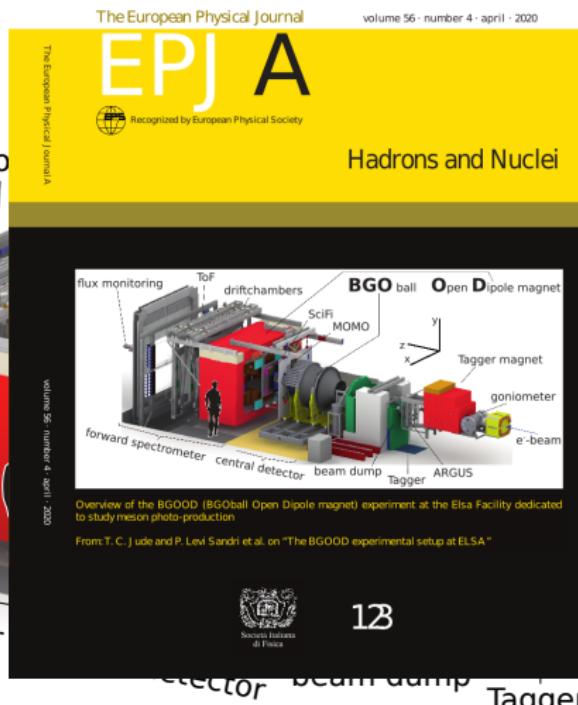
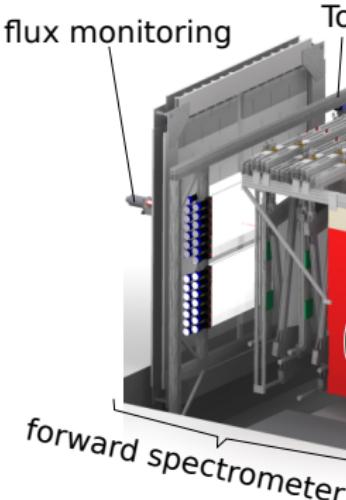


BGOOD experiment at ELSA



S. Alef, et al., Eur. Phys. J. A 56, 104 (2020)

BGOOD experiment at ELSA



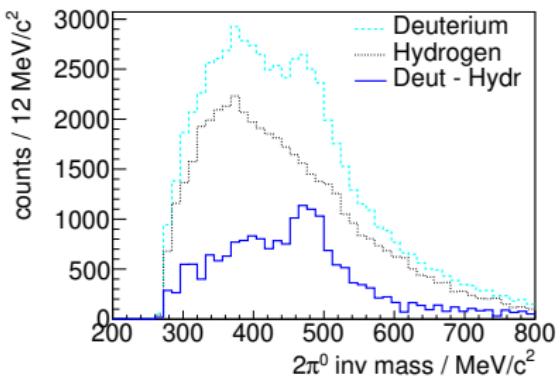
S. Alef, et al., Eur. Phys. J. A 56, 104 (2020)

$$\gamma n \rightarrow K^0 \Sigma^0 \rightarrow (2\pi^0)(\gamma\Lambda) \rightarrow (\gamma\gamma)(\gamma\gamma)\gamma(p\pi^-)$$

K.K. PhD thesis, arXiv:2108.13319 (2021), submitted to EPJA

reconstruction

- combine 4γ to $2\pi^0$, select missing mass to $2\pi^0$ to agree with Σ^0 mass
- identify 5th γ to be consistent with $\Sigma^0 \rightarrow \Lambda\gamma$
- identify charged particles to be compatible with $\Lambda \rightarrow p\pi^-$

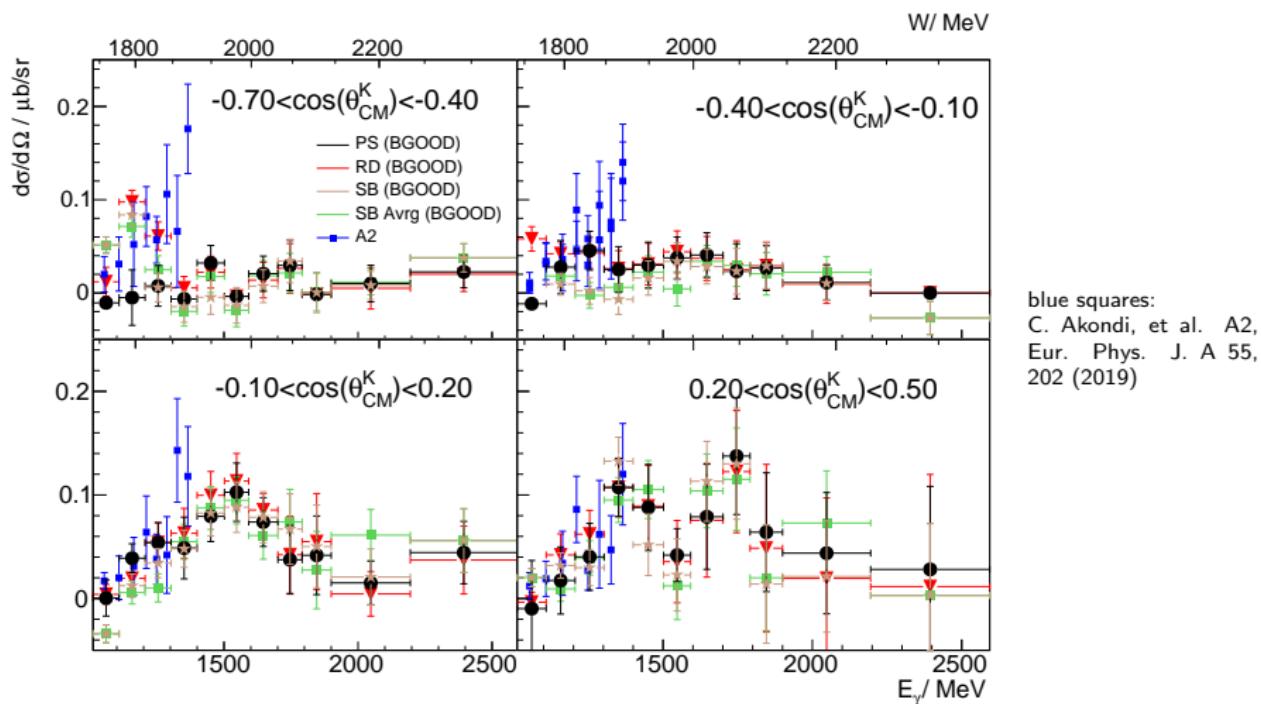


Proton background

- repeat analysis with hydrogen data set
- account for Fermi motion
- scale by luminosity
- subtract proton contribution

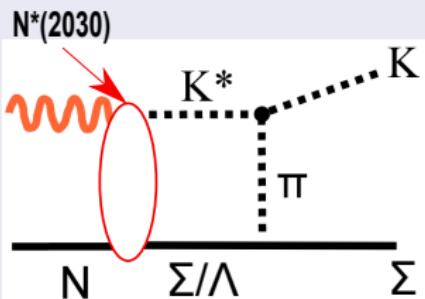
$\gamma n \rightarrow K^0\Sigma^0$ differential cross section

K.K. PhD thesis, arXiv:2108.13319 (2021), submitted to EPJA

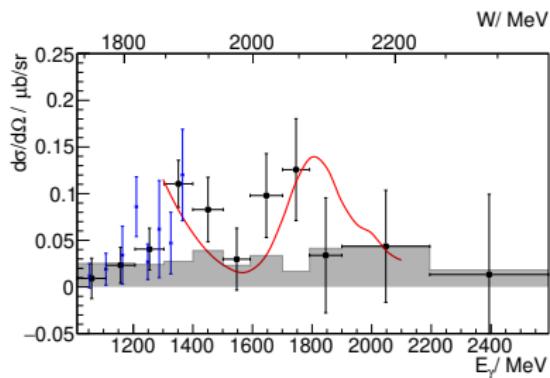


Possible role of $K^*\Sigma$ pentaquark state

K.K. PhD thesis, arXiv:2108.13319 (2021), submitted to EPJA



- interference with intermediate $K^*\Sigma/\Lambda$ predicted to cause peak
- peak consistent with prediction
- indication for $K^*\Sigma/\Lambda$ type resonance $N^*(2030)$, analogue to $P_c D^*\Sigma_c/\Lambda_c$ type states at LHCb?
- BUT: need more data! 2x more on tape

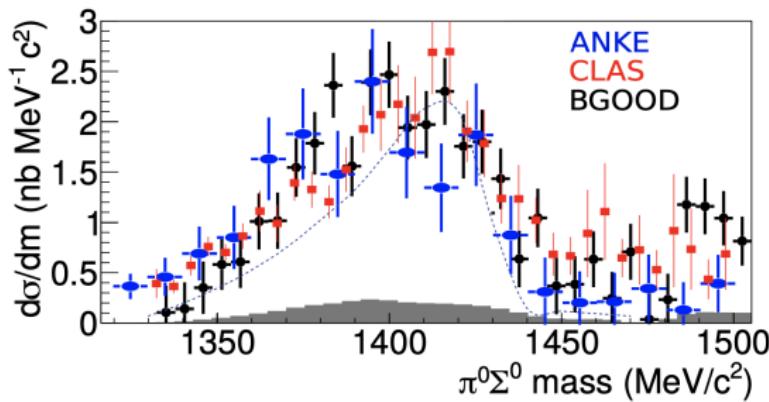


C. Akondi, et al A2., Eur. Phys. J. A 55, 202 (2019)
A. Ramos and E. Oset, Phys. Lett. B 727, (2013) 287 scaled to approx. fit the height

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

G. Scheluchin PhD thesis, Phys. Lett. B, 833 (2022)

- $\Lambda(1405) \rightarrow \pi^0 \Sigma^0$ - Clean identification: $\Sigma(1385) \rightarrow \Sigma^0 \pi^0$ isospin forbidden
- Full reconstruction & kinematic fit:
 $K^+ \Lambda(1405) \rightarrow K^+ \Sigma^0 \pi^0 \rightarrow K^+ \gamma \Lambda \pi^0 \rightarrow K^+ 3\gamma p \pi^-$
- Line shape - good agreement with previous data



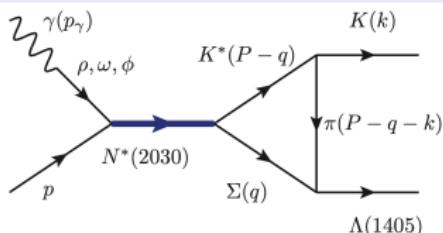
CLAS: Moriya, et al PRC 87, 035206 (2013)
ANKE: Zychor et al, PLB 660, 167 (2008)
Dashed line: Nacher et al, PLB 455, 55 (1999)

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

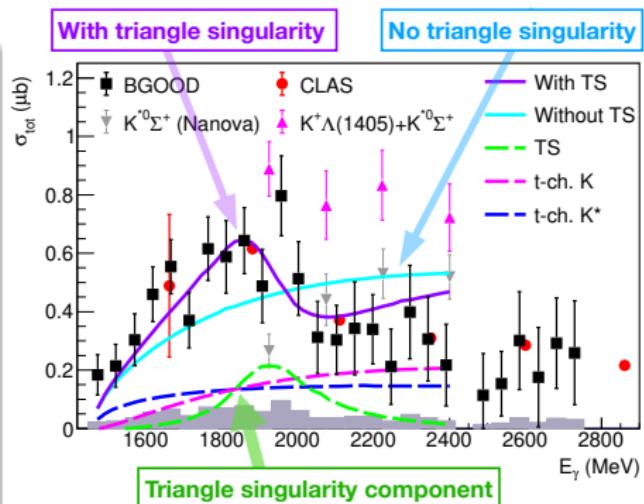
G. Scheluchin PhD thesis, Phys. Lett. B, 833 (2022)

Triangle singularity in $\gamma p \rightarrow K^+ \Lambda(1405)$

Wang et al. PRC 95, 015205 (2017)



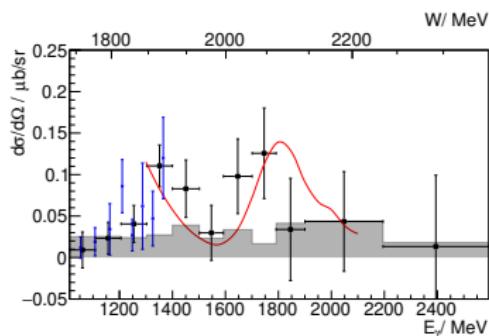
- $N^*(2030)$ close in mass & strong coupling to $K^*\Sigma$
- $K^*\Sigma$ molecular component?



[CLAS: Moriya, PRC 87, 035206 (2013)]

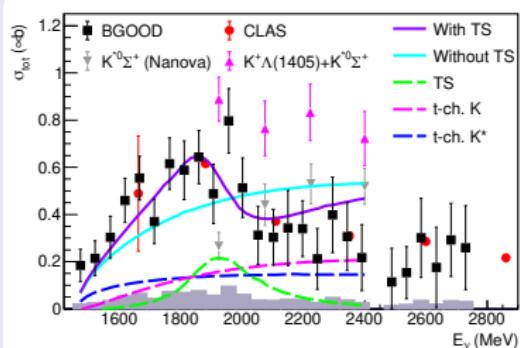
[M. Nanova et al., EPJA 35 (2008) 333]

Possible role of $K^*\Sigma$ pentaquark state

 $K^0\Sigma^0$ 

C. Akondi, et al A2., Eur. Phys. J. A 55, 202 (2019)

A. Ramos and E. Oset, Phys. Lett. B 727, (2013) 287 scaled to approx. fit the height

 $K^+\Lambda(1405)$ 

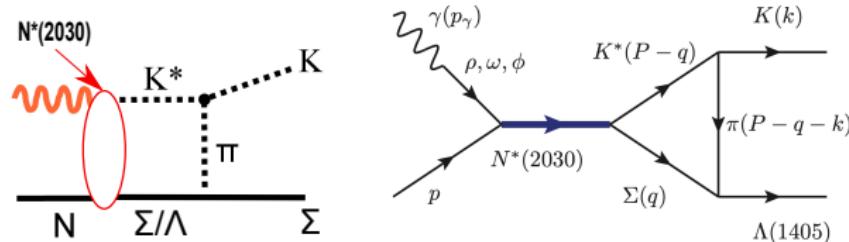
[CLAS: Moriya, PRC 87, 035206 (2013)]

[M. Nanova et al., EPJ A 35 (2008) 333]

- same resonance $N^*(2030)$ explains cusp in $\gamma p \rightarrow K^+\Lambda(1405)$ cross section

Summary and Outlook

- multi-quark states observed in heavy quark sector
- meson-baryon molecule like state general feature of QCD?
- same mechanism possible in strange quark sector
- $K^0\Sigma^0$ differential cross section: peak consistent with prediction
- $K^+\Lambda(1405)$ cross section: cusp explained by triangle singularity
- both effects described by $N^*(2030) K^*\Sigma$ molecule-like state



T. Jude, Evidence of a dibaryon spectrum in coherent $\pi^0\pi^0d$ photoproduction, Today 15:40 P1

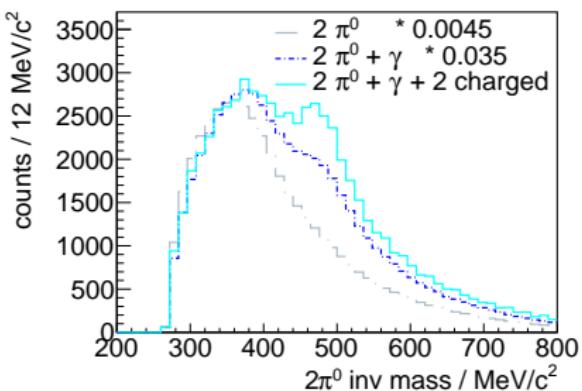
J. Groß, Differential Cross Section of $\gamma p \rightarrow K^+\Sigma^0$ at the BGOOD Experiment,

Wednesday 15:40 P2

R. Di Salvo, Recent results from BGOOD, Thursday 11:50 Plenary

Backup

$2\pi^0$ invariant mass



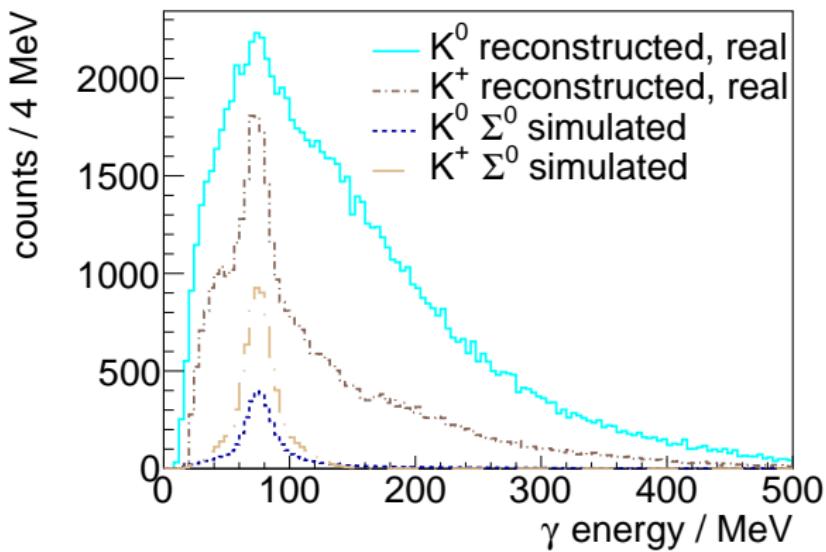
Tagging Σ^0 decay γ

- $\Sigma^0 \rightarrow \Lambda\gamma$ BR:100%
- in Σ^0 rest frame γ energy ≈ 74 MeV

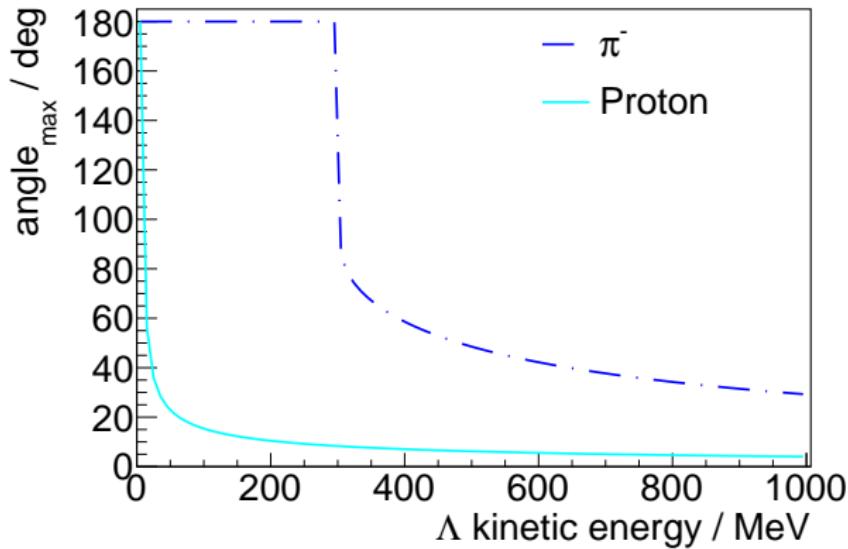
Identifying Λ decay particles

- angles of decay particles kinematically limited
- select any two charged particles within the limits

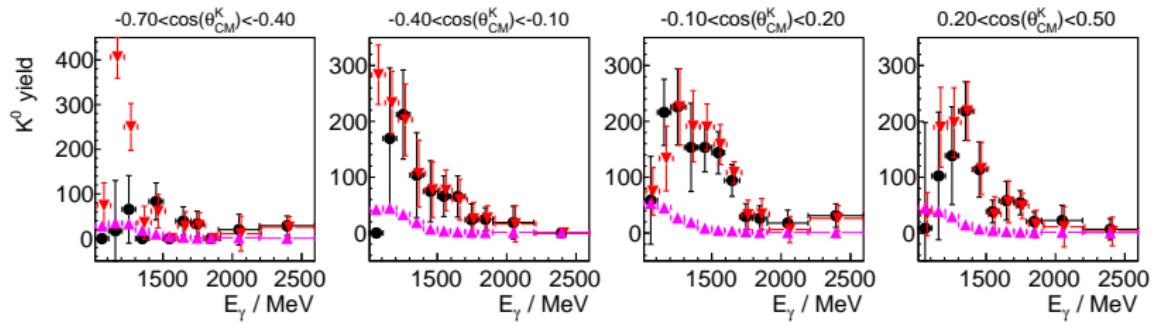
Σ^0 Decay Photon



Lambda Decay Particles



contamination from $K^0\Lambda$



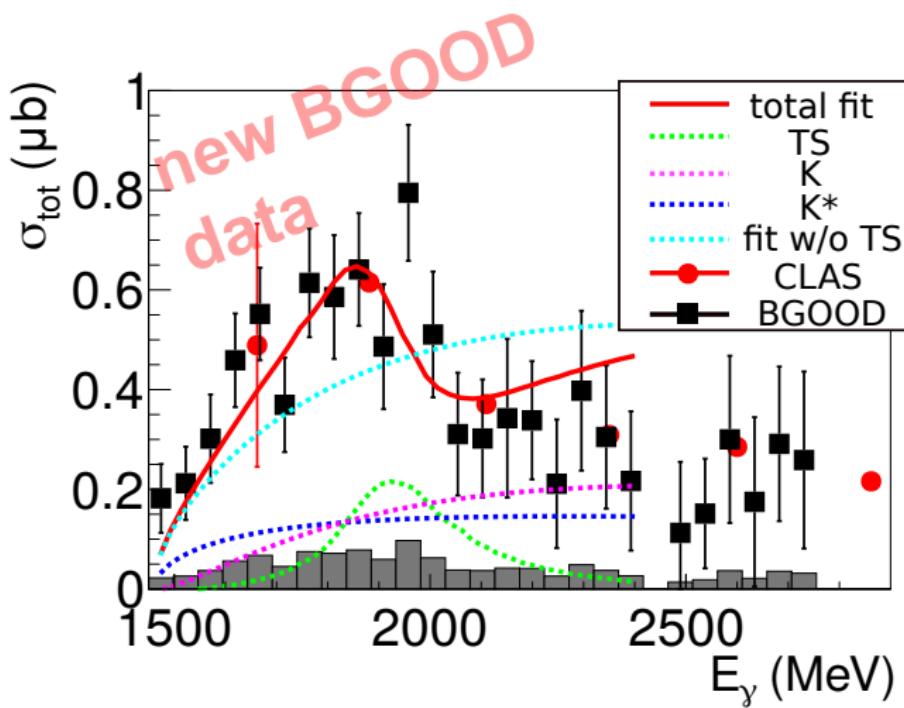
black: PS, red: RD, pink: $K^0\Lambda$ contribution determined from N. Compton, et al., Phys. Rev. C 96, 065201 (2017)

- fit can't differentiate between different sources of K^0
- previous selection cuts suppressed contribution of $K^0\Lambda$
- remaining contribution of $K^0\Lambda$ is determined from known cross section and subtracted

$K^0\Lambda$ contamination

$$\text{yield}_{K^0\Lambda} = \frac{d\sigma_{K^0\Lambda}}{d\Omega} \cdot RE_{K^0\Lambda} \cdot F \cdot \rho \cdot \Delta\Omega \quad (1)$$

$$\text{yield}_{K^0\Sigma^0} = \text{yield}_{K^0X} - \text{yield}_{K^0\Lambda}. \quad (2)$$

$K^0\Lambda$ contamination

Reconstruction Efficiency

