Strangeness overview & perspectives

with the BGOOD photoproduction experiment

Review: TJ, Prog. Part. Nucl. Phys. 147 (2026) 1042245

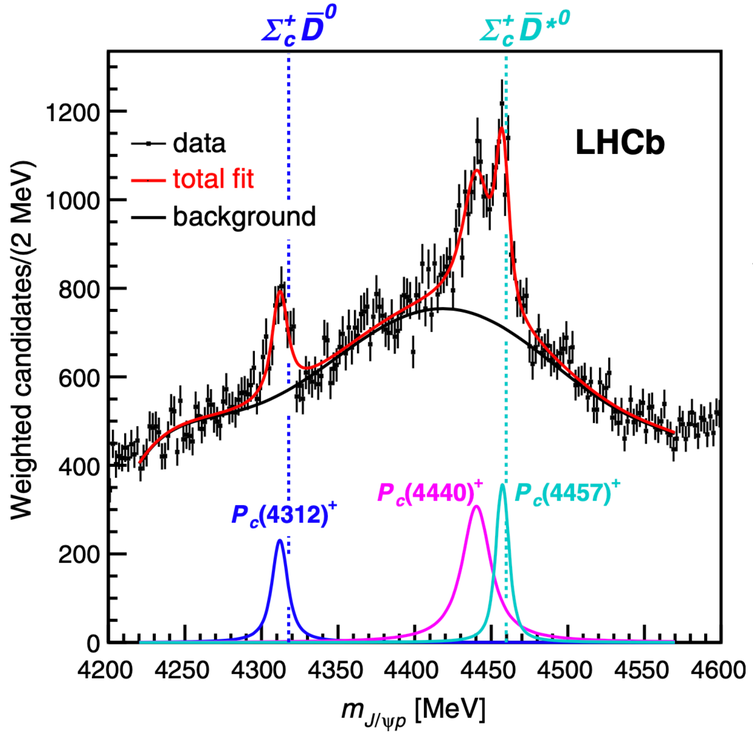
Tom Jude, 18th June 2026

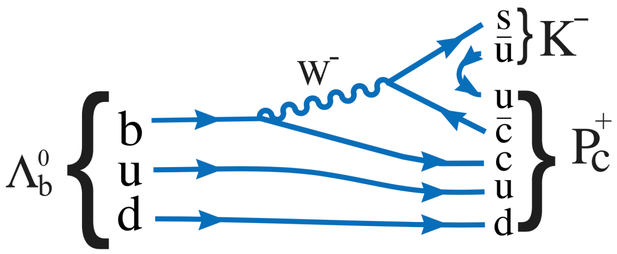
(Not what we measure at ELSA!)

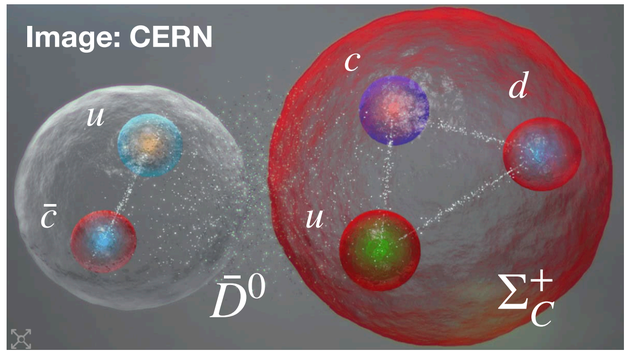
Exotic phenomena in the charmed sector

Pentaquarks at LHCb (P_c)

PRL 155, 072001 (2015), PRL 112, 222001 (2019)







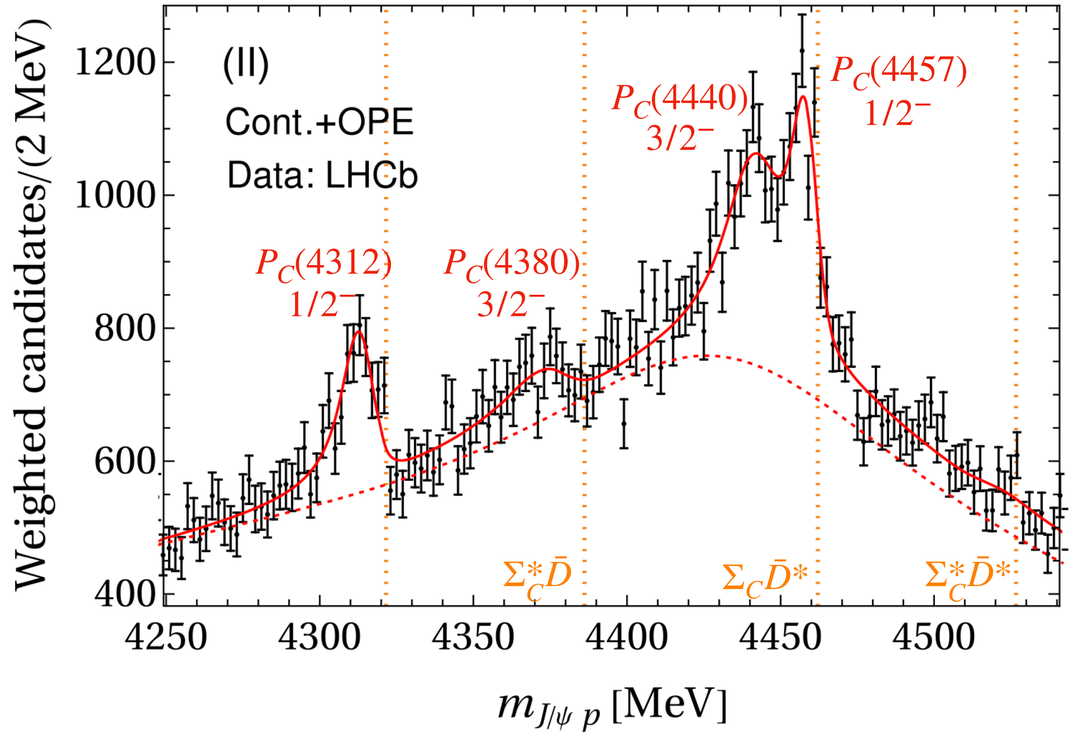
- Early predictions

  Wu *et al.*, PRL 105, 232001 (2010)
- Proposed molecular structure

  eg, Du *et al.* J. HEP. 08 (2021) 157

- Second data set fitted with (HQSS) model of hadronic molecules:

Du *et al.*, PRL 124, 072001 (2020)



F.-K. Guo et al., *Hadronic molecules*, Rev. Mod. Phys. 90 (2018) 015004

(Not what we measure at ELSA!)

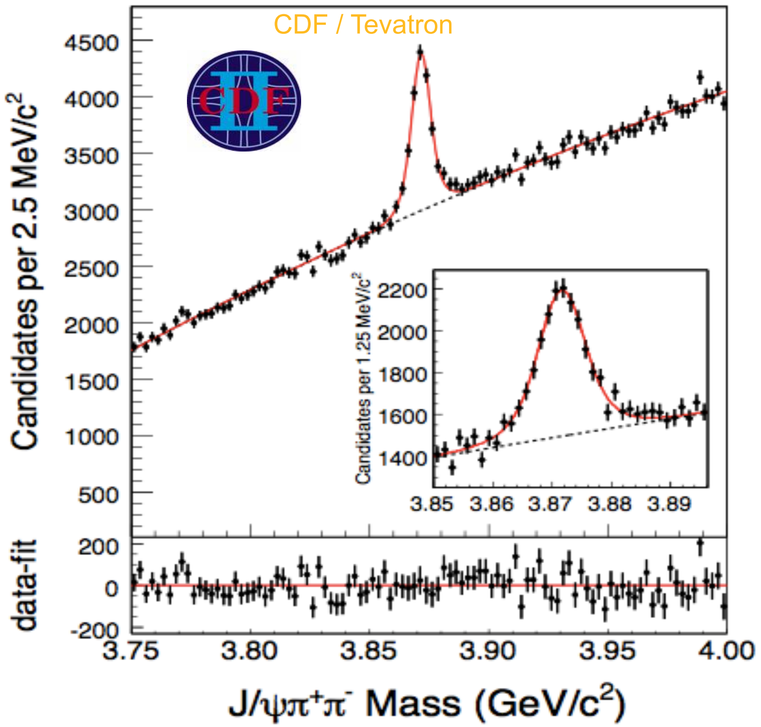
Exotic phenomena in the charmed sector

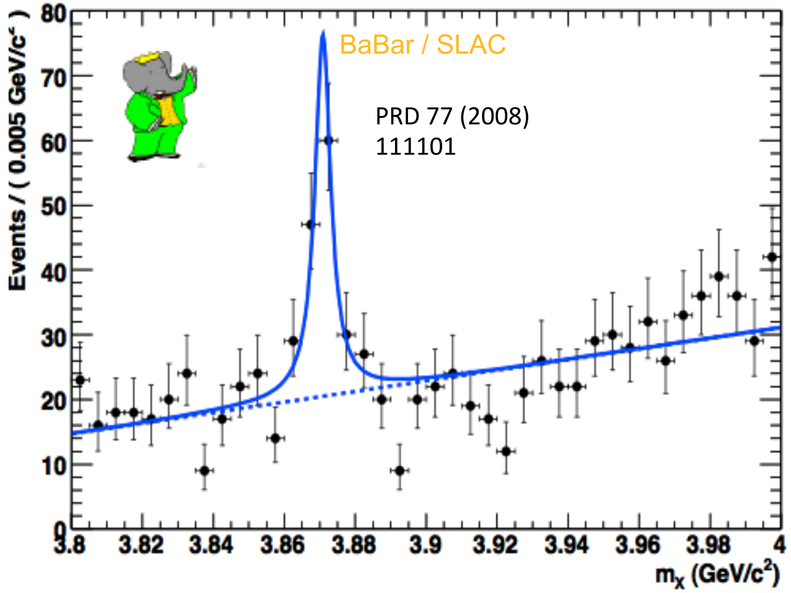
The X(3872) / $\chi_{c1}(3872)$ meson

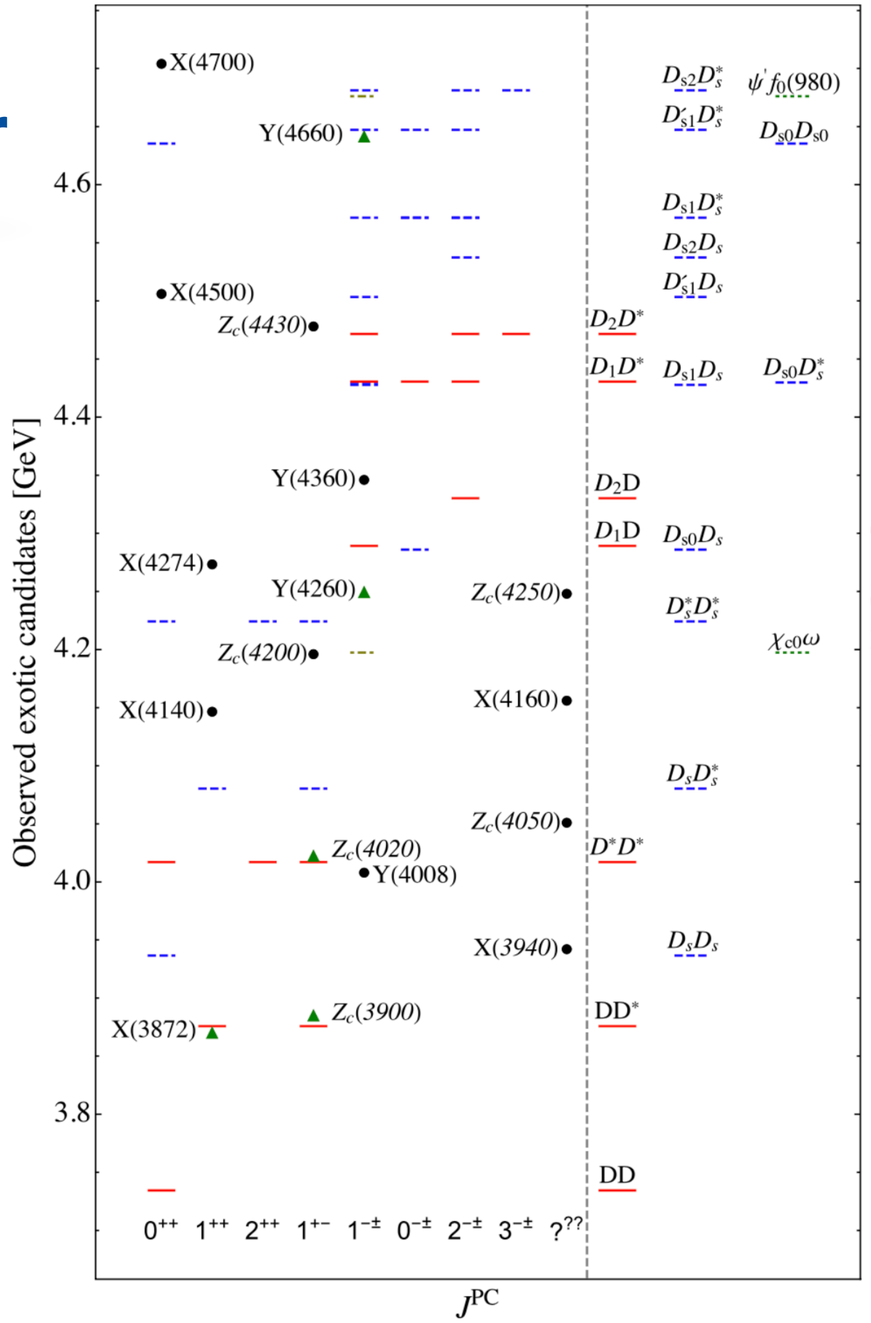
- Exotic state candidates with minimal $c\bar{c}$ configuration (2018):

F.-K. Guo et al., *Hadronic molecules*, Rev. Mod. Phys. 90 (2018) 015004

PRL 103 (2009) 152001







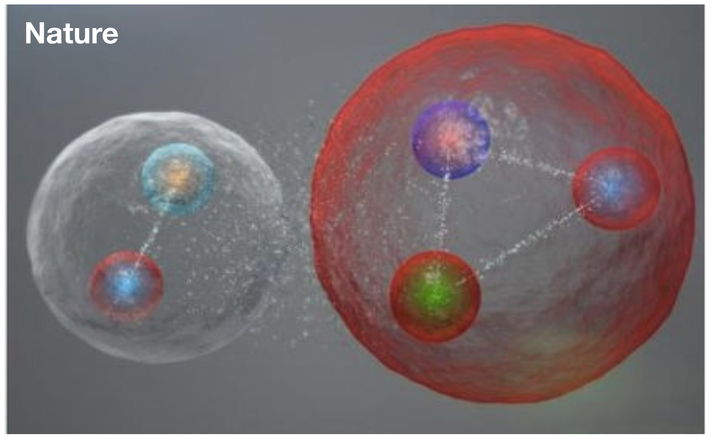
Molecular-like structure in the light sector?

- Molecular-like states, meson-baryon degrees of freedom in chiral perturbation theory based calculations

  ChPt introduction: V. Bernard, U.-G. Meißner, Annu. Rev. Nucl. Part. Sci.

- Improved success in describing N^*, Δ^*, Λ^* & Σ^* spectra

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



- Supported by electroproduction data (eg CLAS)
- Transition form factor measurements

$$\gamma^* N \rightarrow N(1440)$$

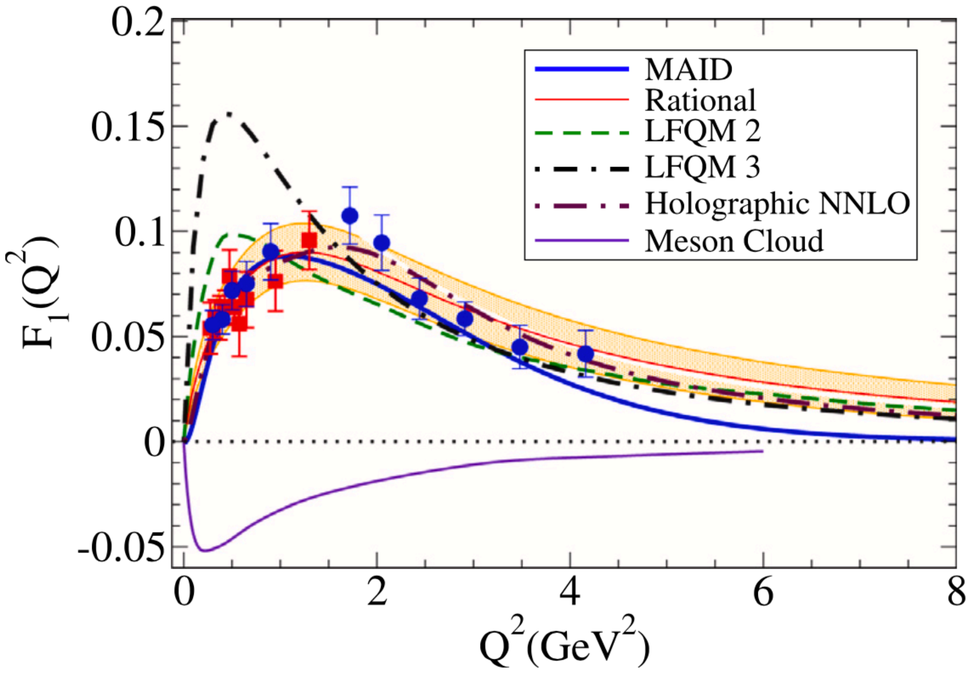
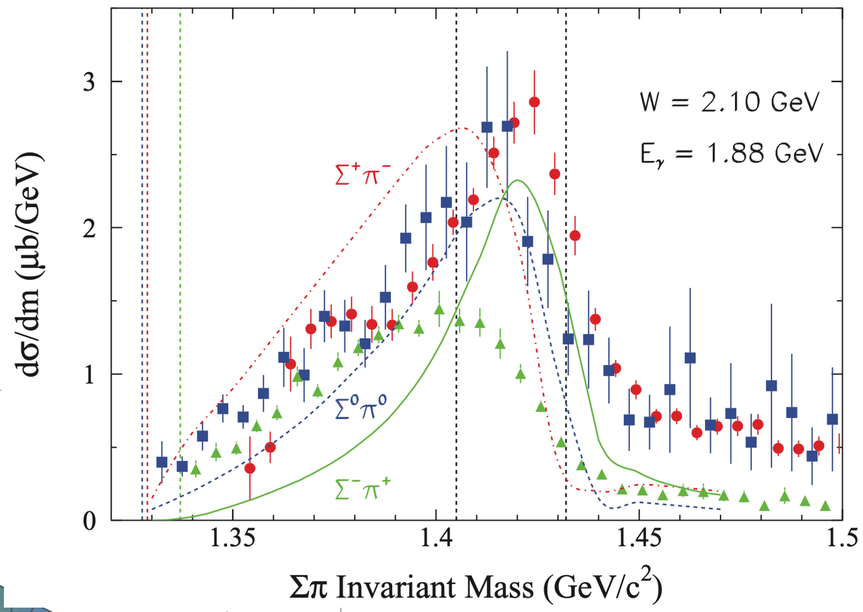


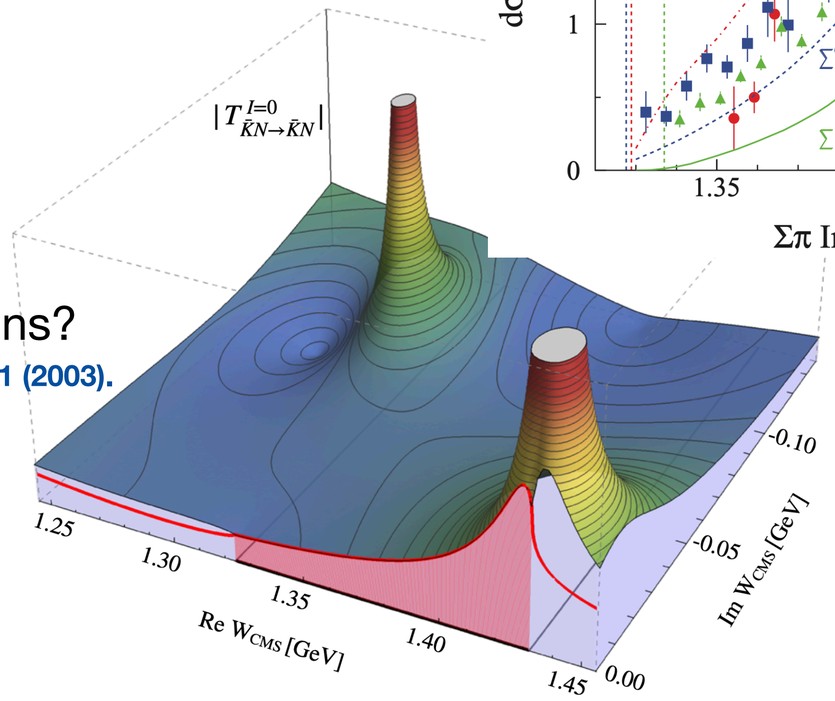
Figure from (and references in) G. Ramalho, M.T. Peña, PPNP 136 (2024) 104097

Motivation - structure of the $\Lambda(1405)$

- Constituent quark model - *uds*
- Considered a $\bar{K}N$ molecule prior to the quark model
  Dalitz & Tuan, PRL 2 (1959) 425
- Between $\pi\Sigma$ & $\bar{K}N$ thresholds & difficult to reconcile with a CQM:
  - Mass too low compared to $N^*(1535)$
  - Large spin orbit splitting to $\Lambda(1520)$
- Dynamically generated, meson-baryon interactions?
  D. Jido, J. A. Oller, E. Oset, A. Ramos, U.G. Meissner. Nucl Phys. A 725:181 (2003).
  Molina & Döring, PRD 94, 056010 & 079901 (2016)
- 2-pole structure in χPT based models
  M. Mai, EPJ Spec. Top. (2021) 230, 1593
  M. Mai, U.-G. Meißner, EPJA 51, 30 (2015)

Moriya et al., (CLAS) PRC 87, 035206 (2013)

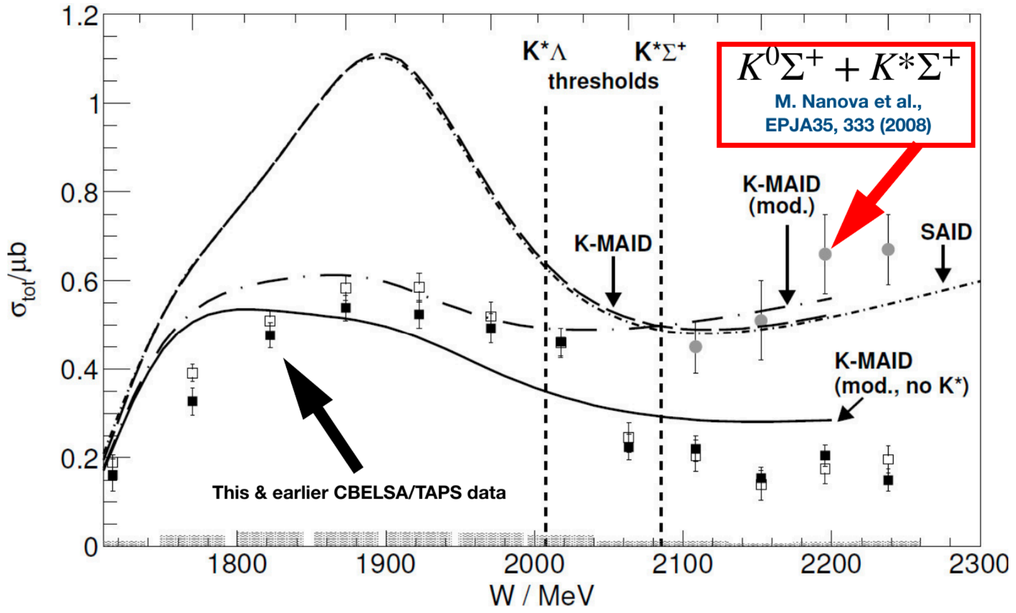


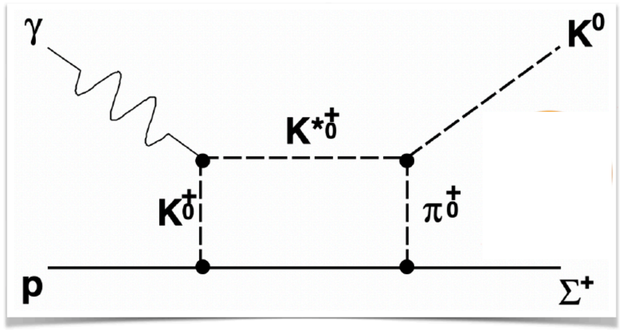


Motivation: Cusp in $\gamma p \rightarrow K^0\Sigma^+$ (CBELSA/TAPS)

- Cusp at K^*Y thresholds, pronounced at forward angles
- K^{*0} rescattering to π^0 & K^0?

R. Ewald *et al.*, PLB 713 (2012) 180



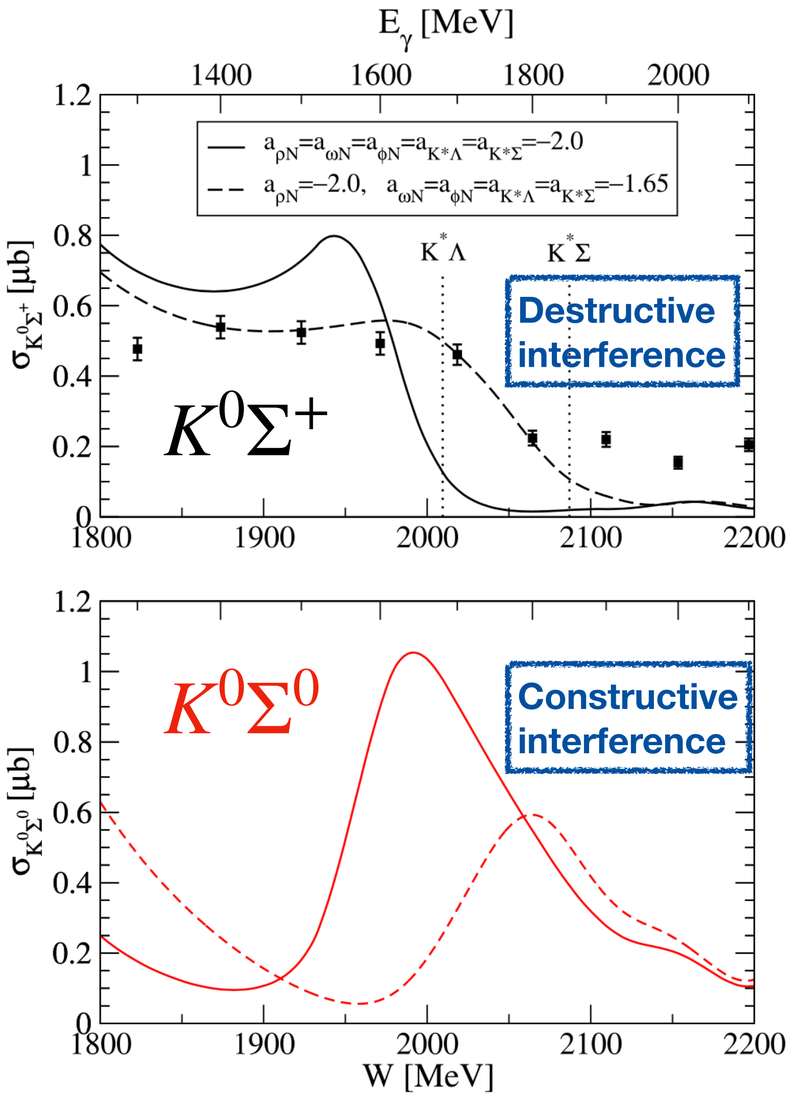


- Coupled channel model

  Ramos & Oset, PLB 727 (2013) 287
- Dynamically generated N^*s

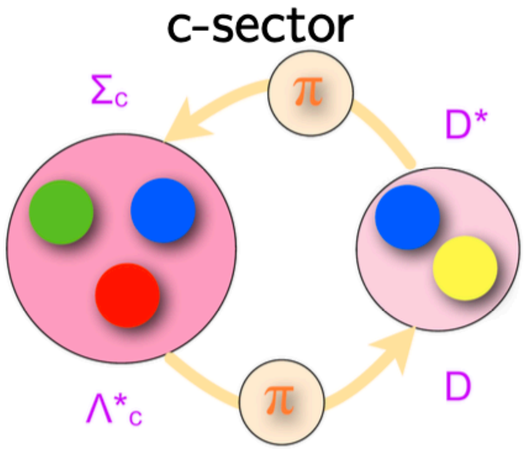
Equivalent model predicted P_C states

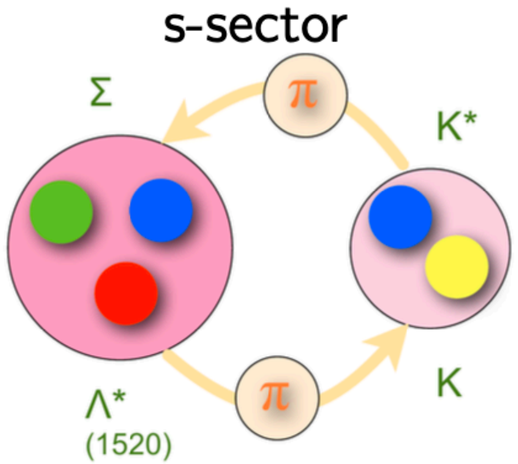
Wu *et al.*, PRL 105, 232001 (2010)



Parallels between the charm & light sectors?

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





Molecular-like structure - experimental requirements

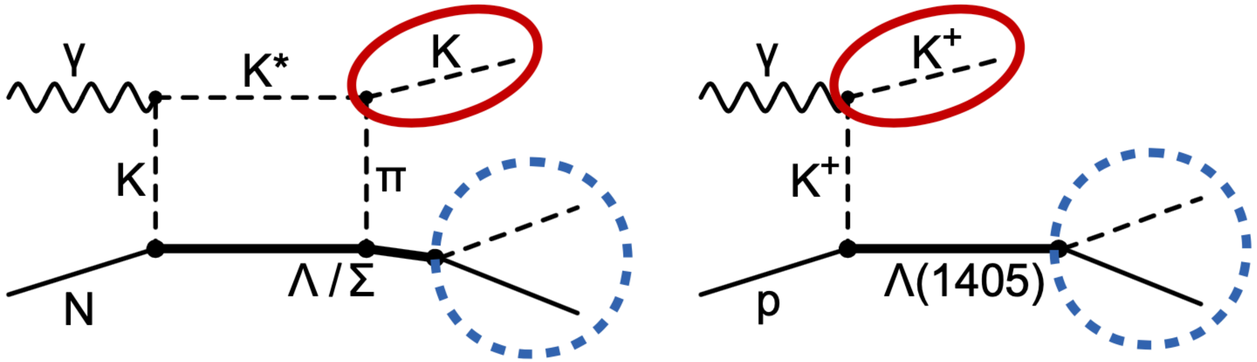
For strangeness photoproduction: $\gamma p \rightarrow K^+ Y$

$$s = (P_\gamma + P_{\text{Target}})^2 = (P_{K^+} + P_Y)^2$$

$$t = (P_\gamma - P_{K^+})^2 = (P_Y - P_{\text{Target}})^2$$

$$u = (P_\gamma - P_Y)^2 = (P_{K^+} - P_{\text{Target}})^2$$

- Charged particle identification at extremely forward angles
- Reaction dynamics at very low momentum exchange (low *t*)
- Reconstruction of complicated, mixed charge final states, eg $\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \pi^0\Sigma^0 \rightarrow \pi^0\gamma\Lambda \rightarrow 3\gamma p\pi^-)$



- **BGOOD**! Complementary to other facilities:
  - CBELSA-TAPS - 4π photon detection
  - CLAS - Charged particle identification

Overview

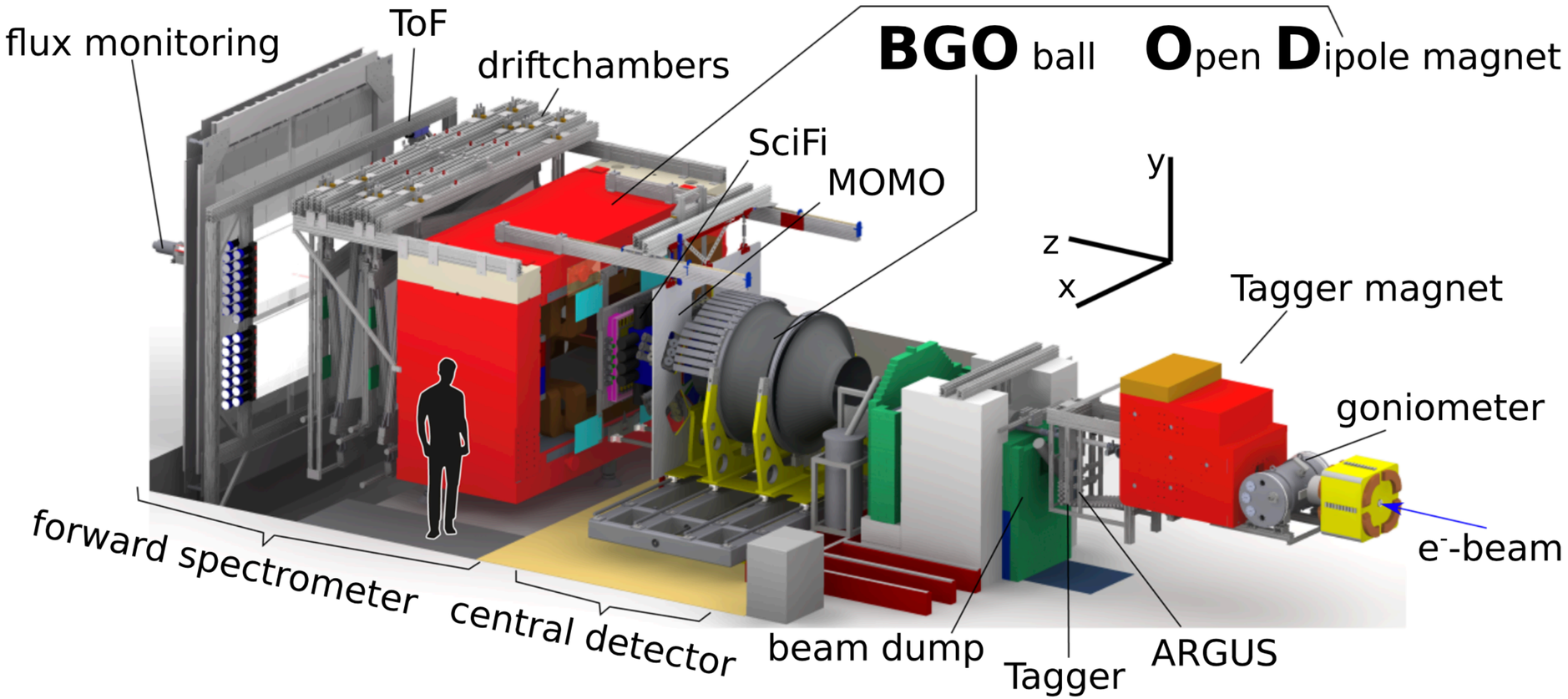
- **Motivation**
- **Low t acceptance at BGOOD**
- **Exotic structure in associated strangeness photoproduction**

Tom Jude, 18th June 2026

The BGOOD photoproduction experiment

BGO Calorimeter (central region) & Forward Spectrometer combination

Spokespersons: T.C. Jude (Bonn) & P. Levi Sandri (Frascati)

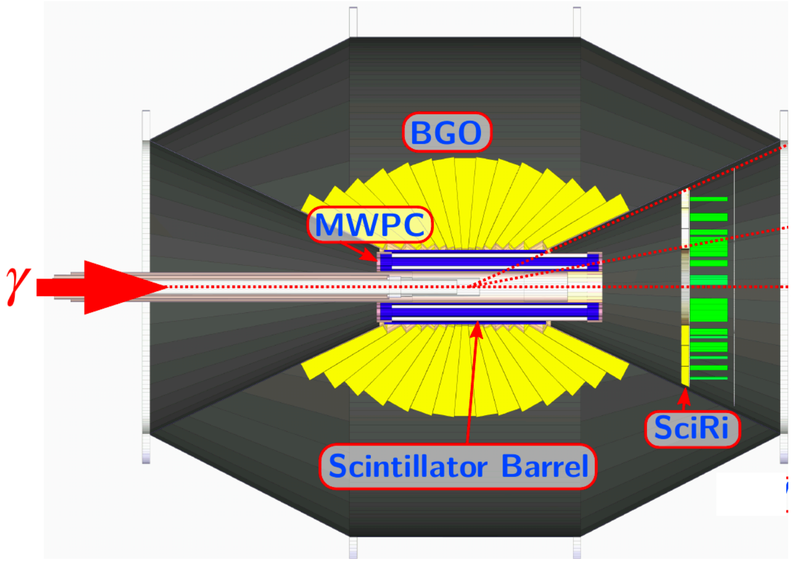


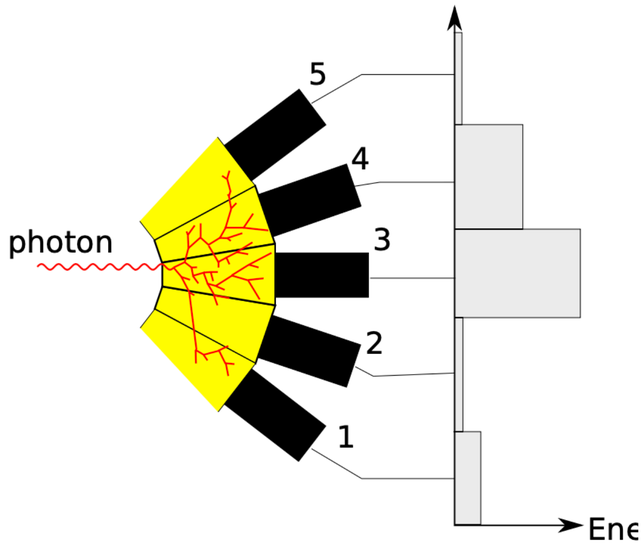
The BGOOD setup at ELSA, Eur. Phys. J. A 56 (2020) 104

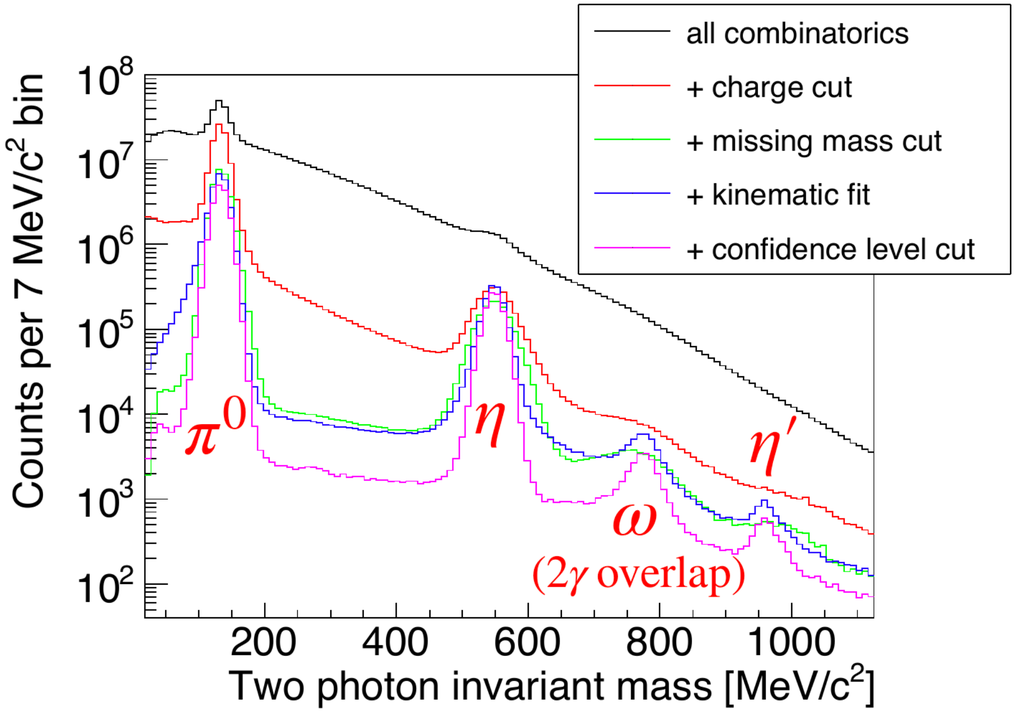
The BGOOD photoproduction experiment

Central region - neutral meson identification

$$P_{\text{Meson}} = P_{\gamma_1} + P_{\gamma_2}, \quad M_{\text{Meson}} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\alpha)}$$





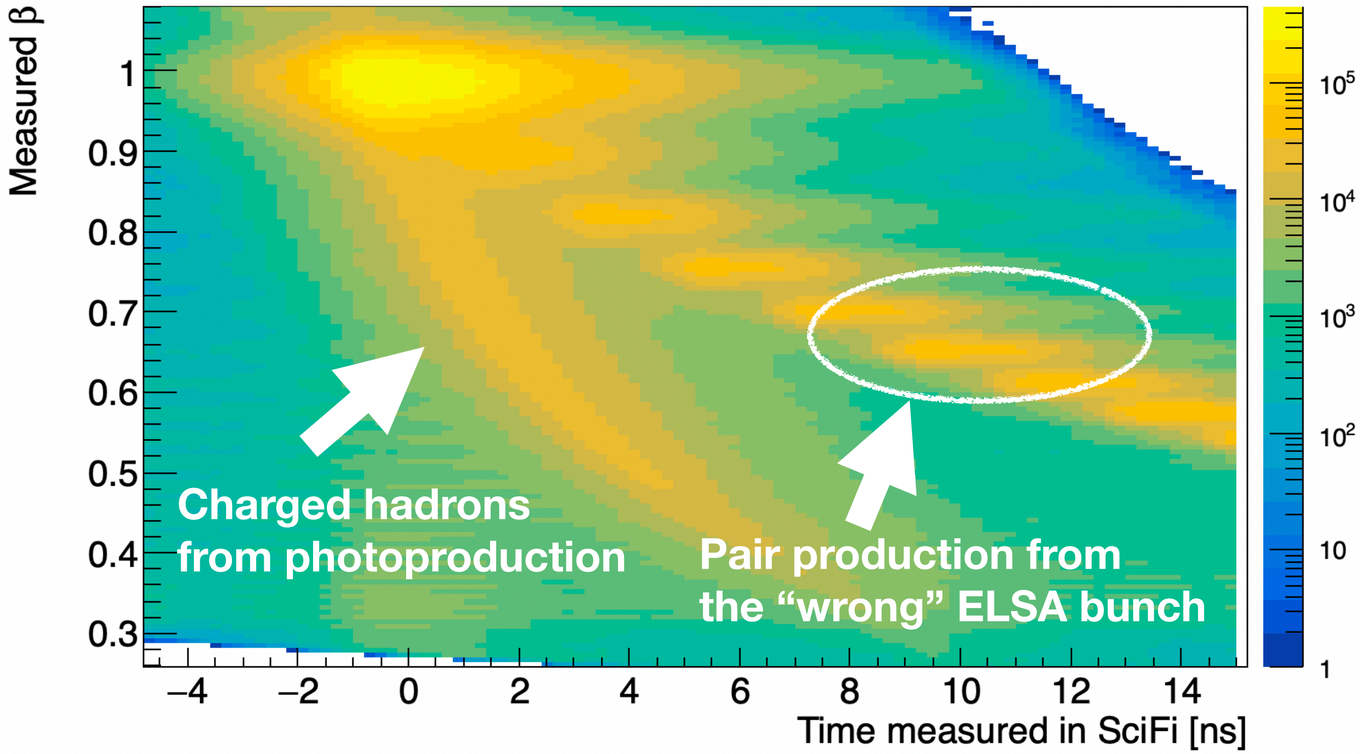


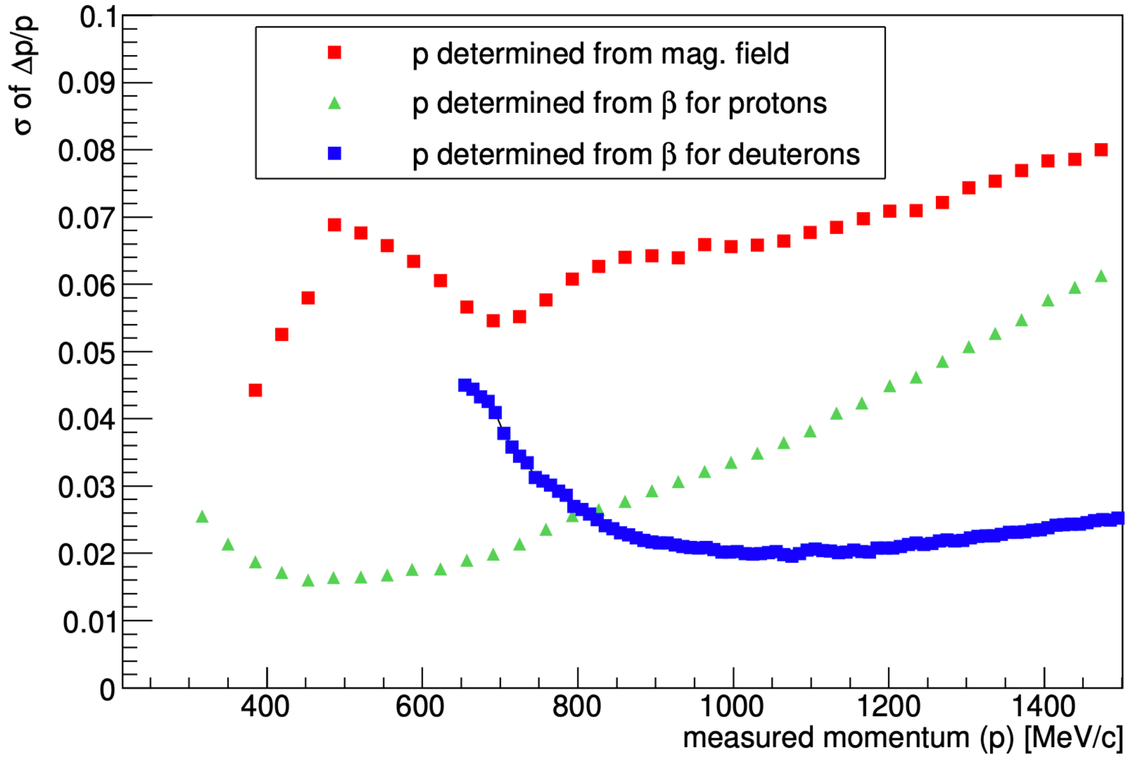
The BGOOD setup at ELSA, Eur. Phys. J. A 56 (2020) 104

The BGOOD photoproduction experiment

Forward spectrometer - A challenge at forward angles!

- Separating signal from e^+e^- background
- Momentum resolution improvement using β
- Only for protons & deuterons (not K^+)



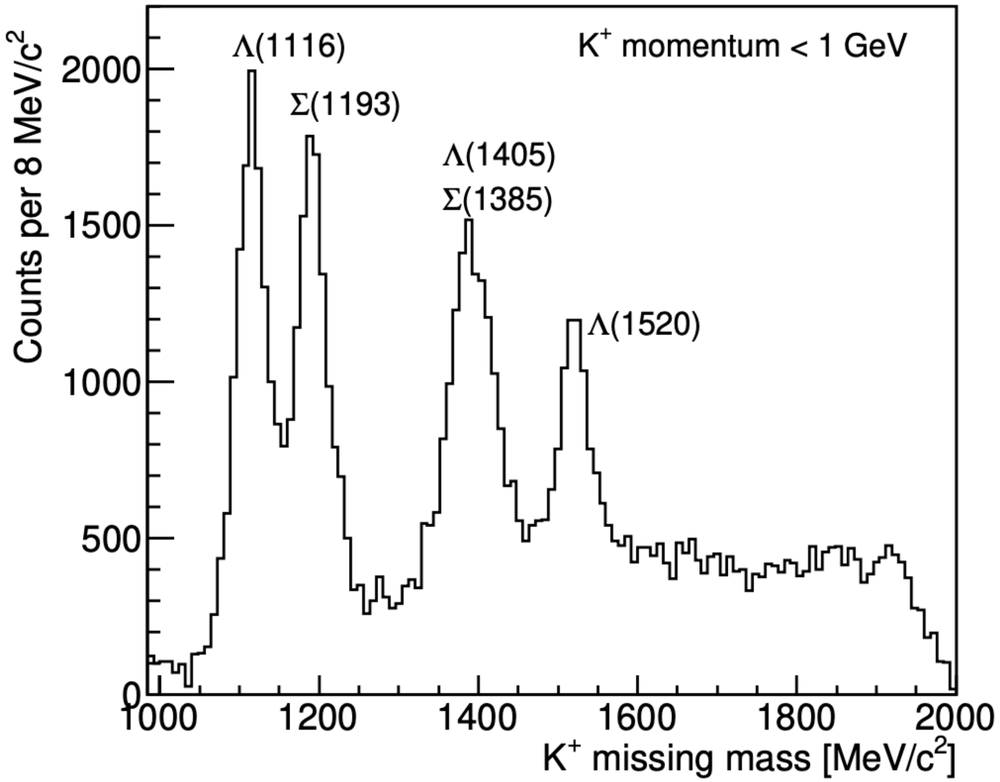


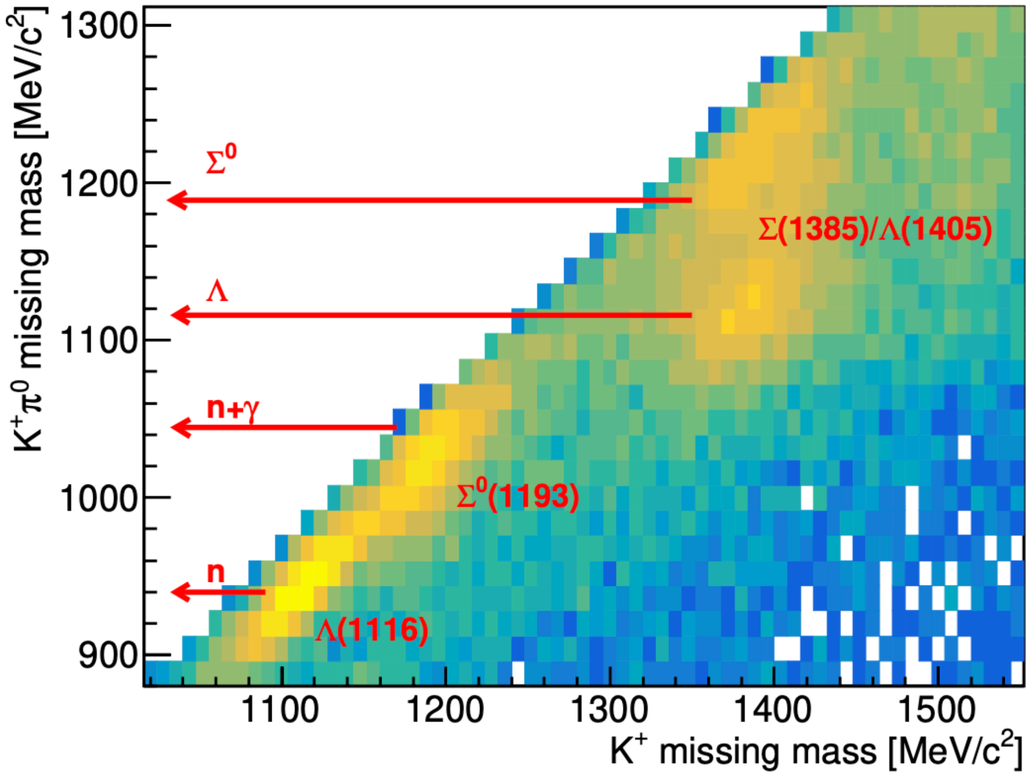
Identification of open strangeness final states

- K^+ identified in the forward spectrometer, $\cos\theta^K_{CM} > 0.9$
- The study of $Y*$ in an extremely low momentum transfer region

"Missing Mass"

$$P_{\text{Beam}} + P_{\text{Target}} = P_{K^+} + P_X$$





Identification of open strangeness final states

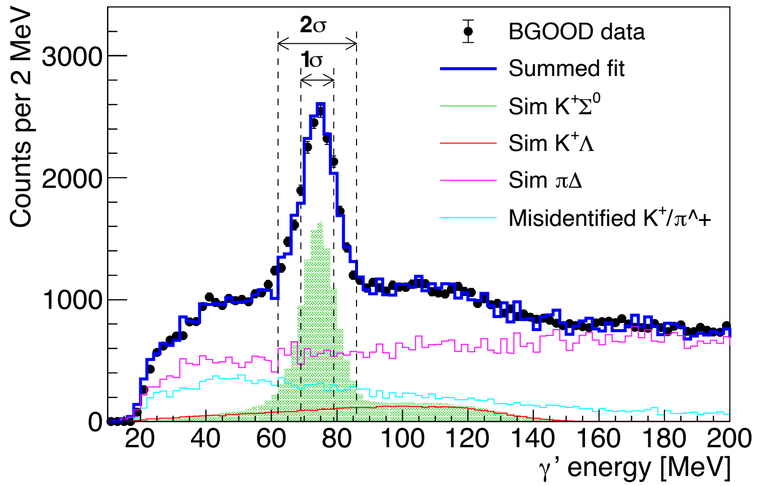
Examples of signal / background separation

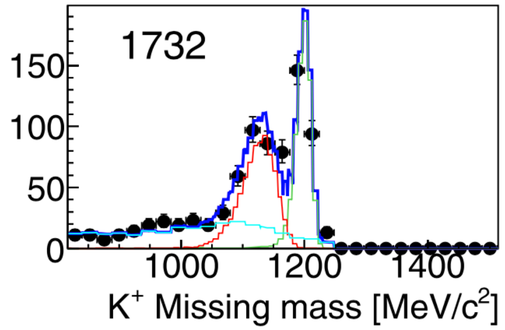
E. Rosanowski, T.C Jude *et al.*
Eur. Phys. J. A (2025) 61:147

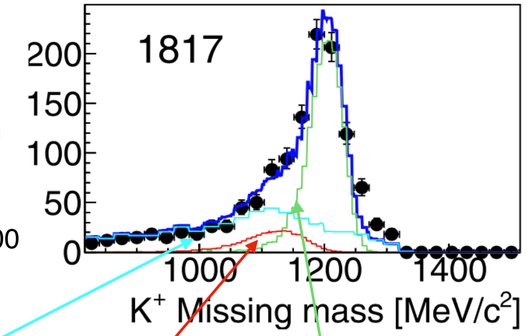
$\gamma p \to K^+\Sigma^0$

T.C. Jude *et al.*,
Phys. Lett. B 820 (2021) 136559

$\Lambda \leftarrow \Sigma^0 \to \gamma$







e⁺/π^+ modelled from real e⁻/π^- signal

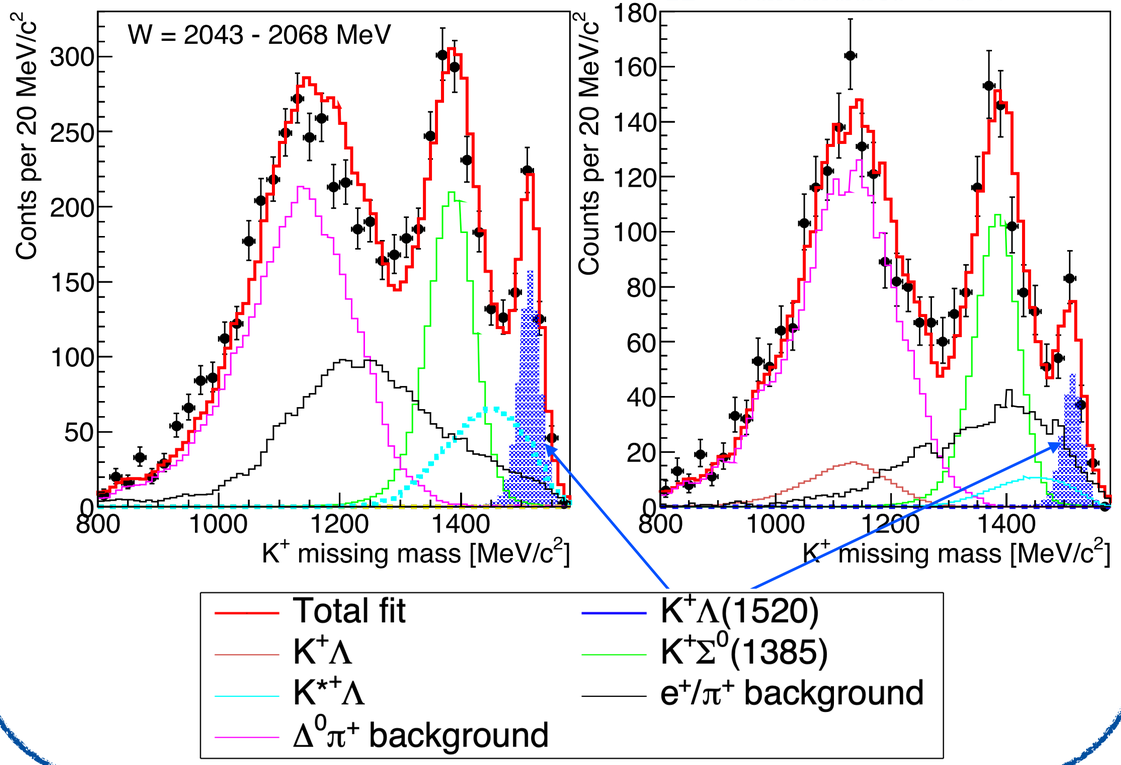
Sim $K^+\Lambda$

Sim $K^+\Sigma^0$

$\gamma p \to K^+\Lambda(1520)$

Just a forward K^+ candidate

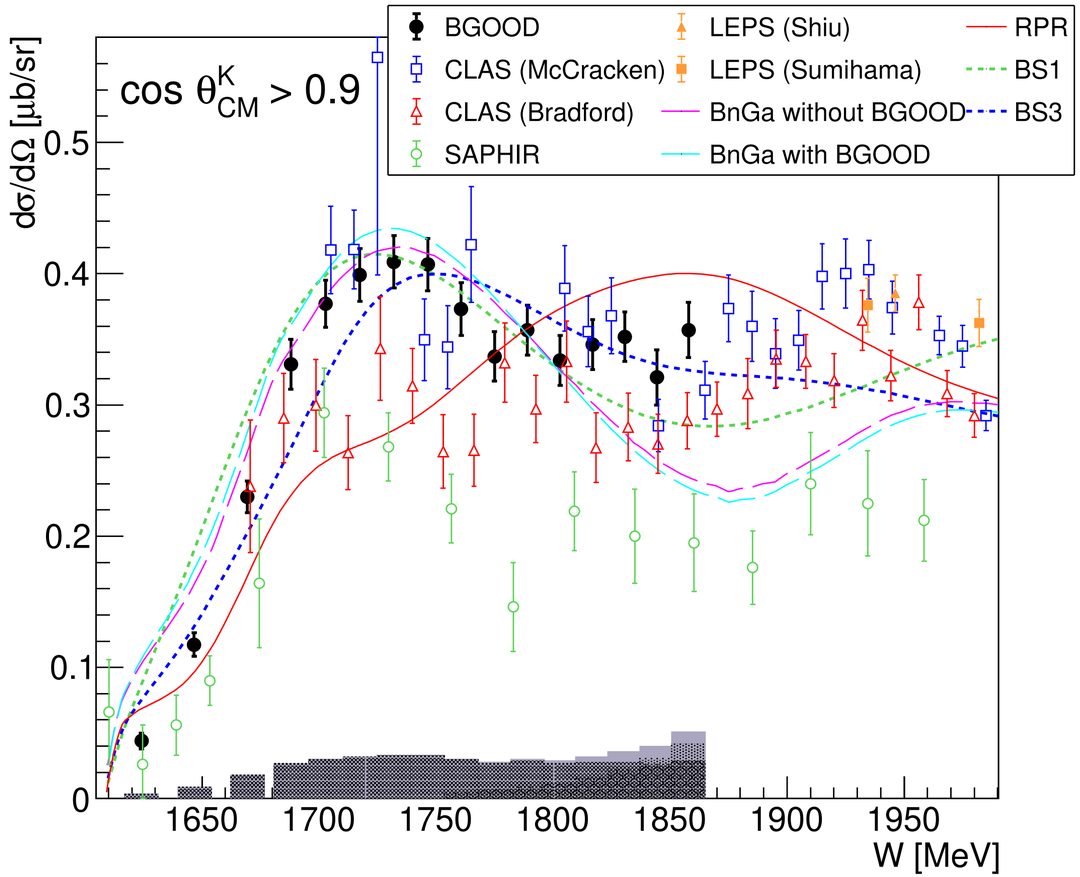
K^+ candidate + a π^0



Forward $K^+\Lambda$ and $K^+\Lambda(1520)$ photoproduction

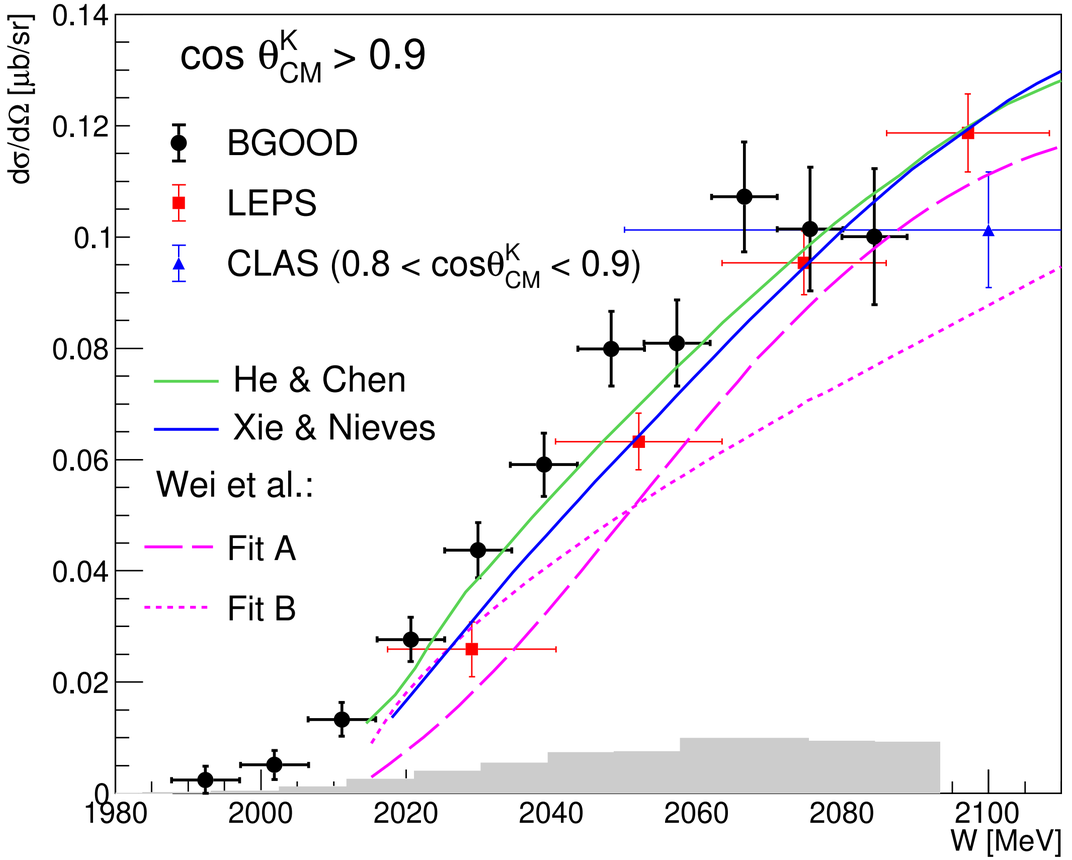
High statistical precision at forward angles & low *t* from threshold

$\gamma p \to K^+\Lambda$



Eur. Phys. J. A (2021) 57:80

$\gamma p \to K^+\Lambda(1520)$



E. Rosanowski, T.C Jude *et al.* Eur. Phys. J. A (2025) 61:147

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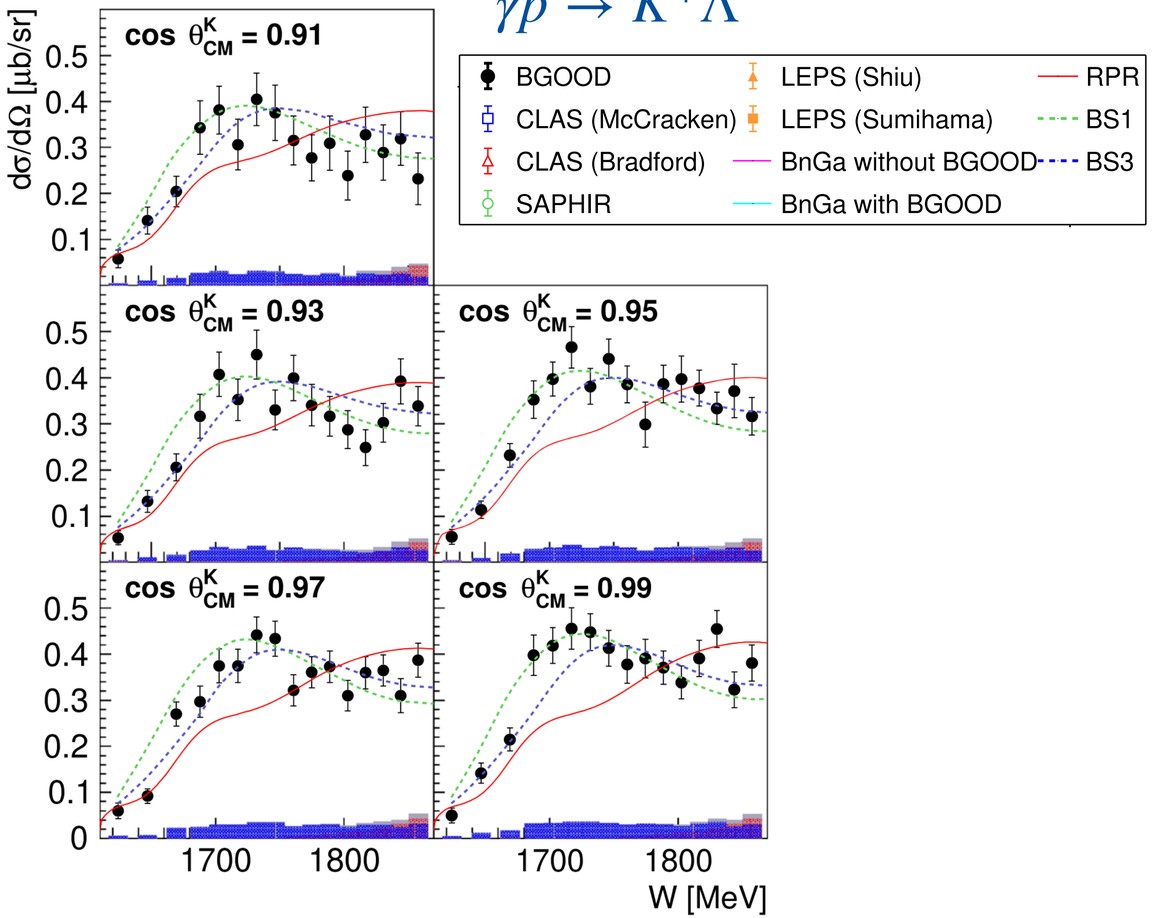

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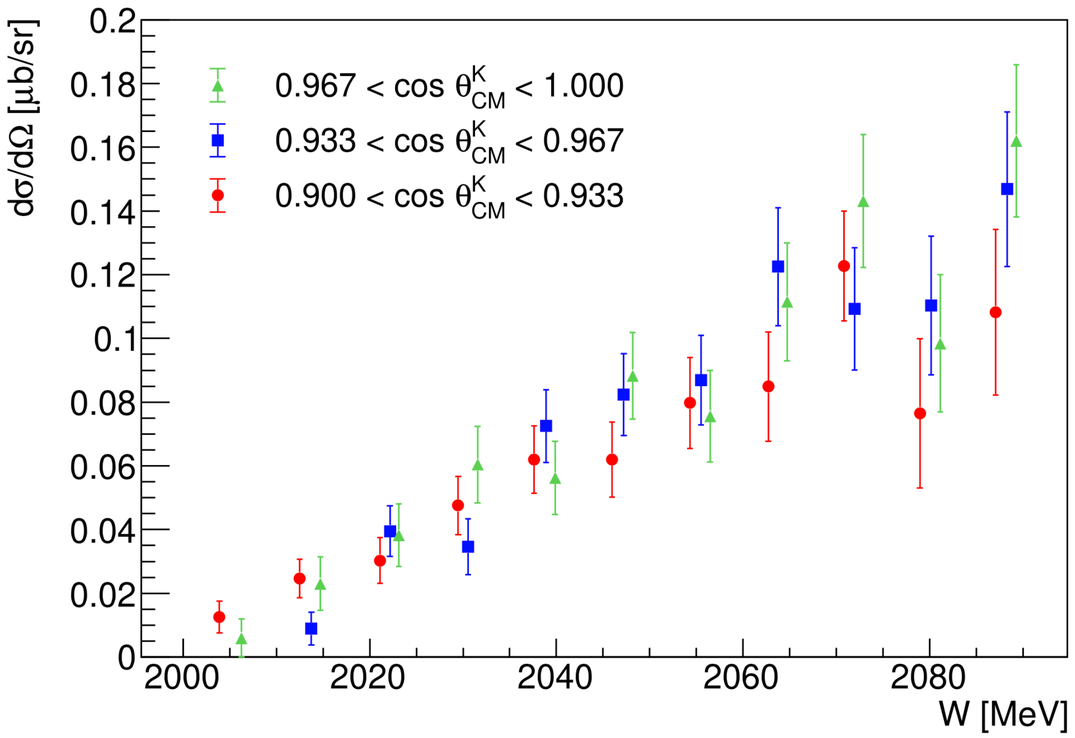
$\gamma p \to K^+\Lambda(1520)$



E. Rosanowski, T.C Jude *et al.* Eur. Phys. J. A (2025) 61:147

Overview

- **Motivation**
- **Low t acceptance at BGOOD**
- **Exotic structure in associated strangeness photoproduction**

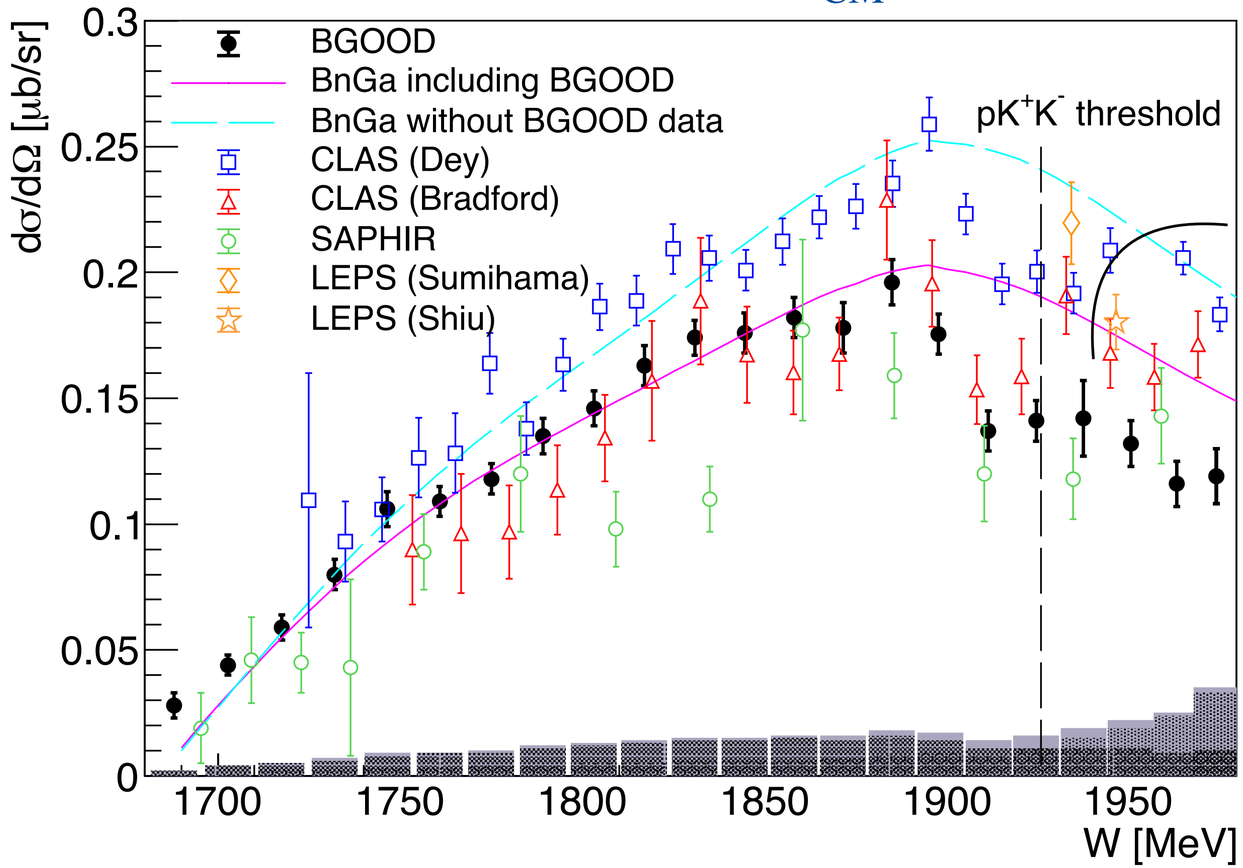
Tom Jude, 18th June 2026

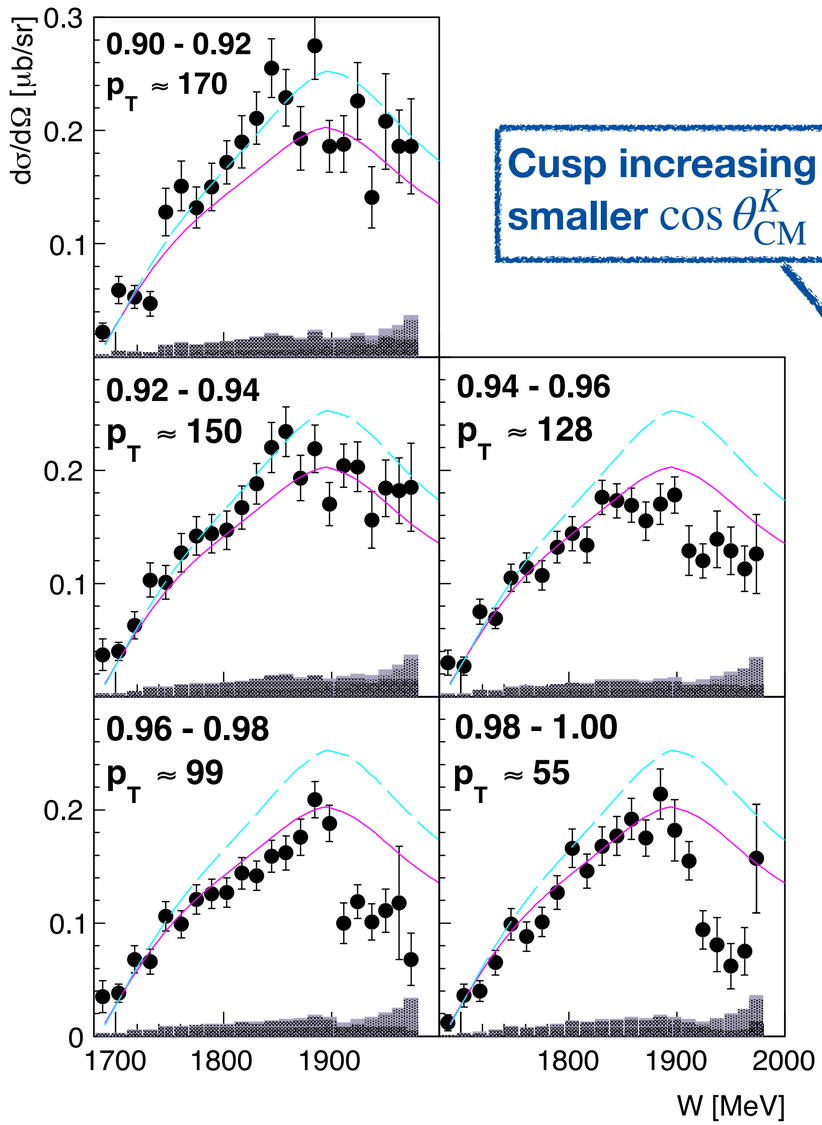
Forward $K^+\Sigma^0$ photoproduction

T.C. Jude *et al.*,
Phys. Lett. B 820 (2021) 136559

Cusp/peak resolved at W ~ 1900 MeV

$$\gamma p \to K^+\Sigma^0,\ \cos\theta^K_{\mathrm{CM}} > 0.9$$





Cusp increasing with smaller $\cos\theta^K_{\mathrm{CM}}$

Forward $K^+\Sigma^0$ photoproduction

T.C. Jude *et al.*,
Phys. Lett. B 820 (2021) 136559

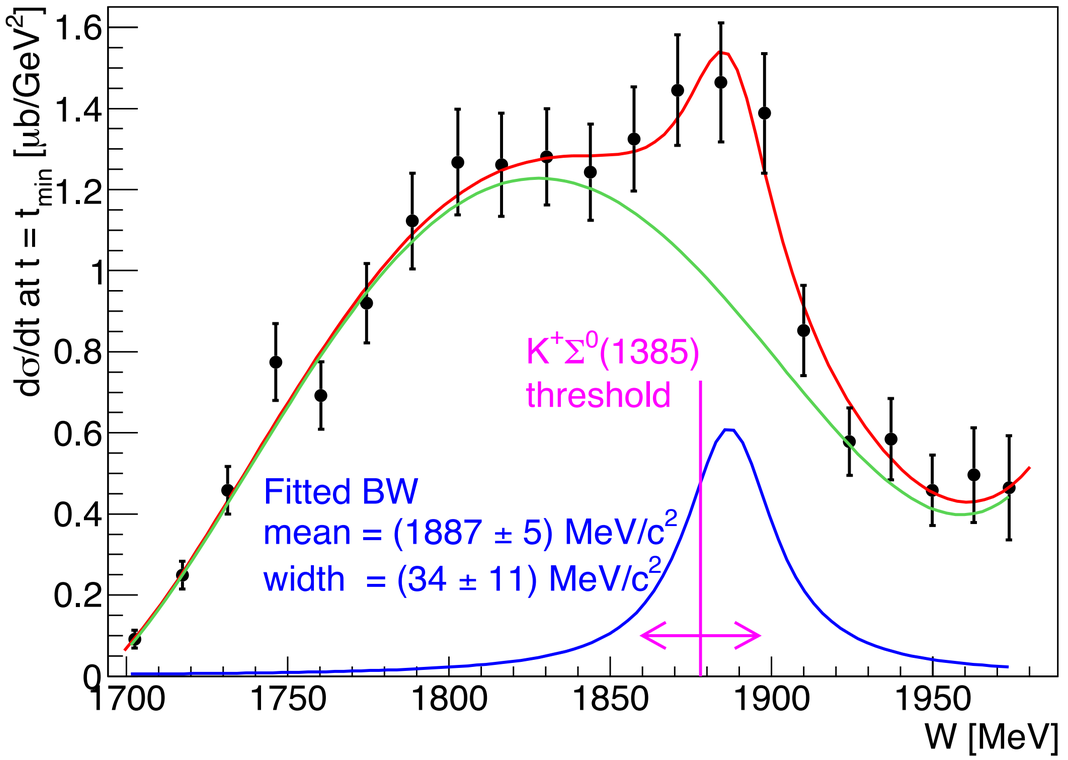
Cusp/peak resolved at 1900 MeV

$$t = (P_\gamma - P_K)^2$$

- A bound $K^+\Sigma(1385)$ system?
- Parallels to P_C states? $P_C(4382)$ at $\Sigma_C^* \bar{D}$ threshold
- Consistent with model calculations

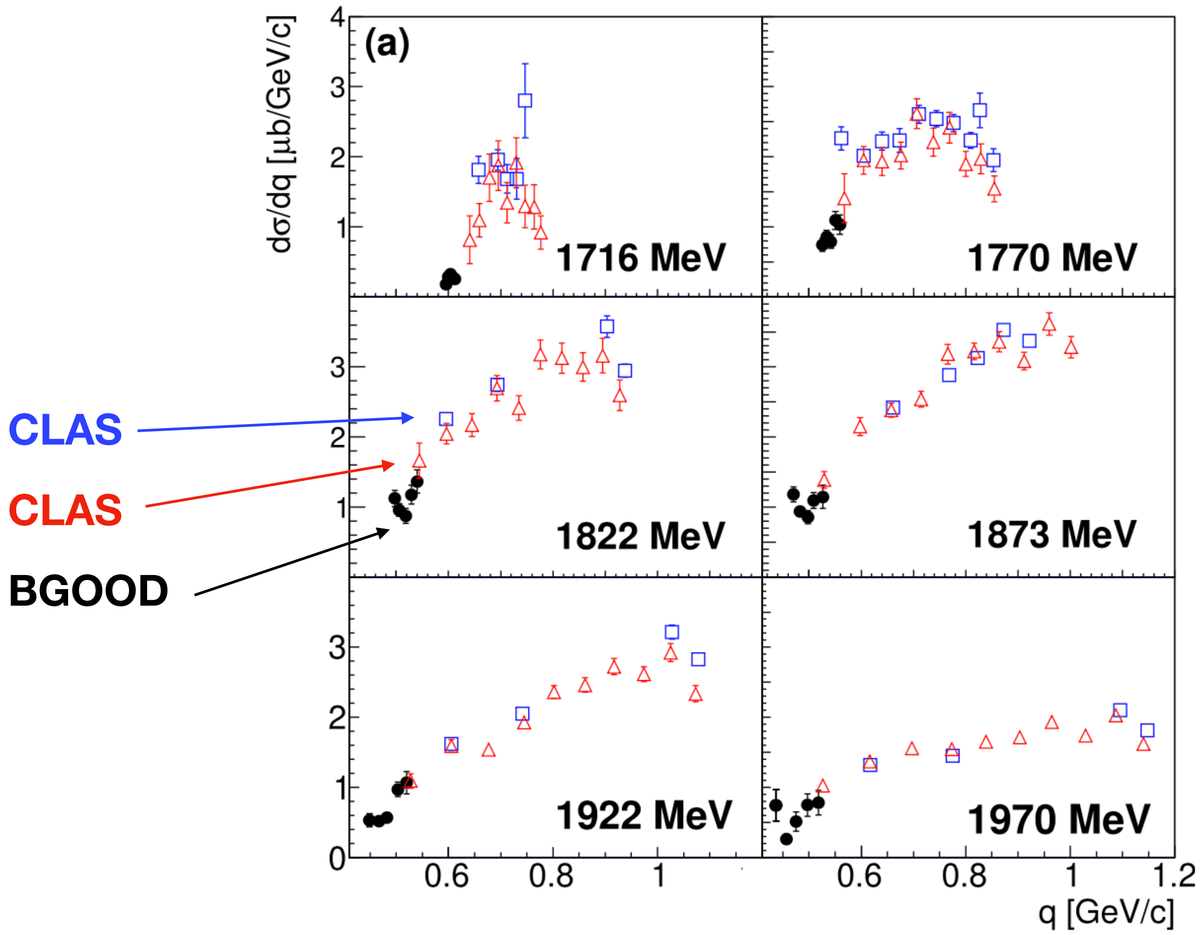
  P_C-like pentaquarks in a hidden strange sector
  Huang et al., PRD 97, 094019 (2018)

- Mandatory to study other $K^+\Sigma^\pm$ systems…

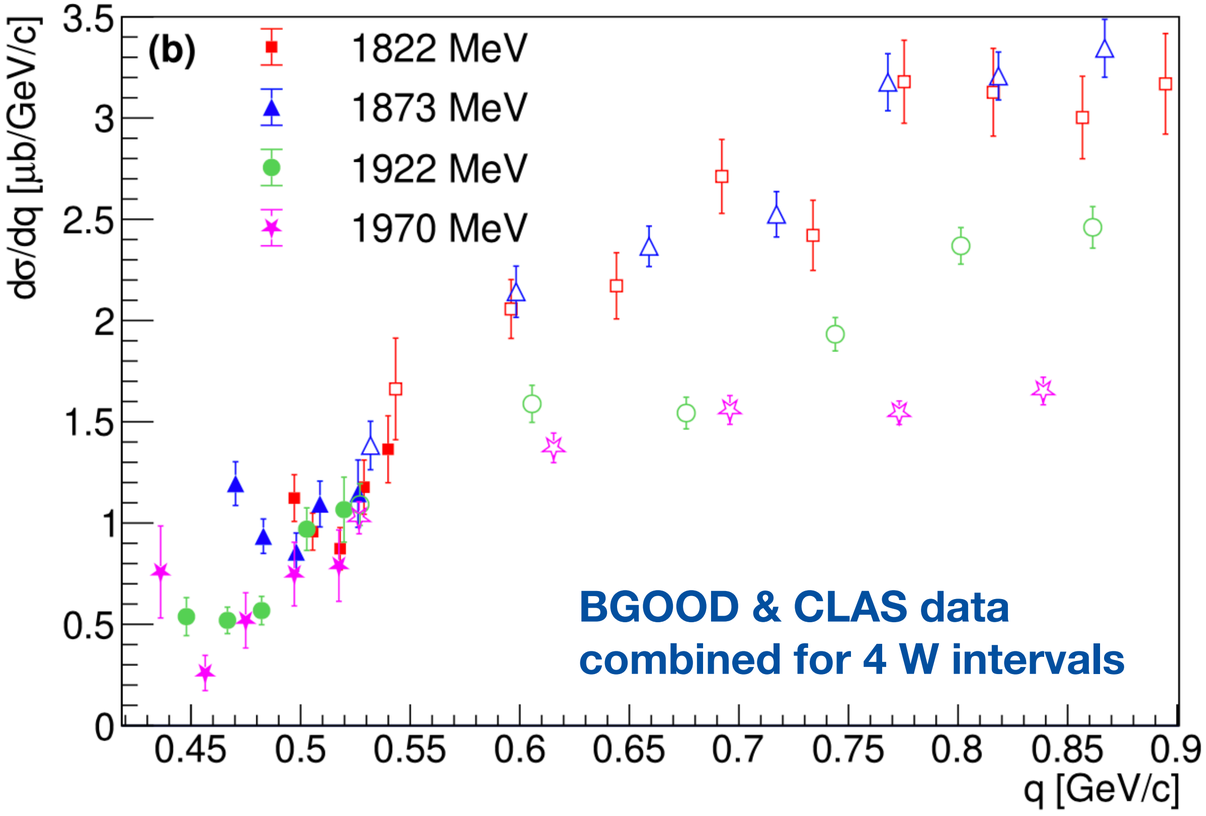


Forward $K^+\Sigma^0$ photoproduction

Differential with respect to 3-momentum transfer to Σ^0



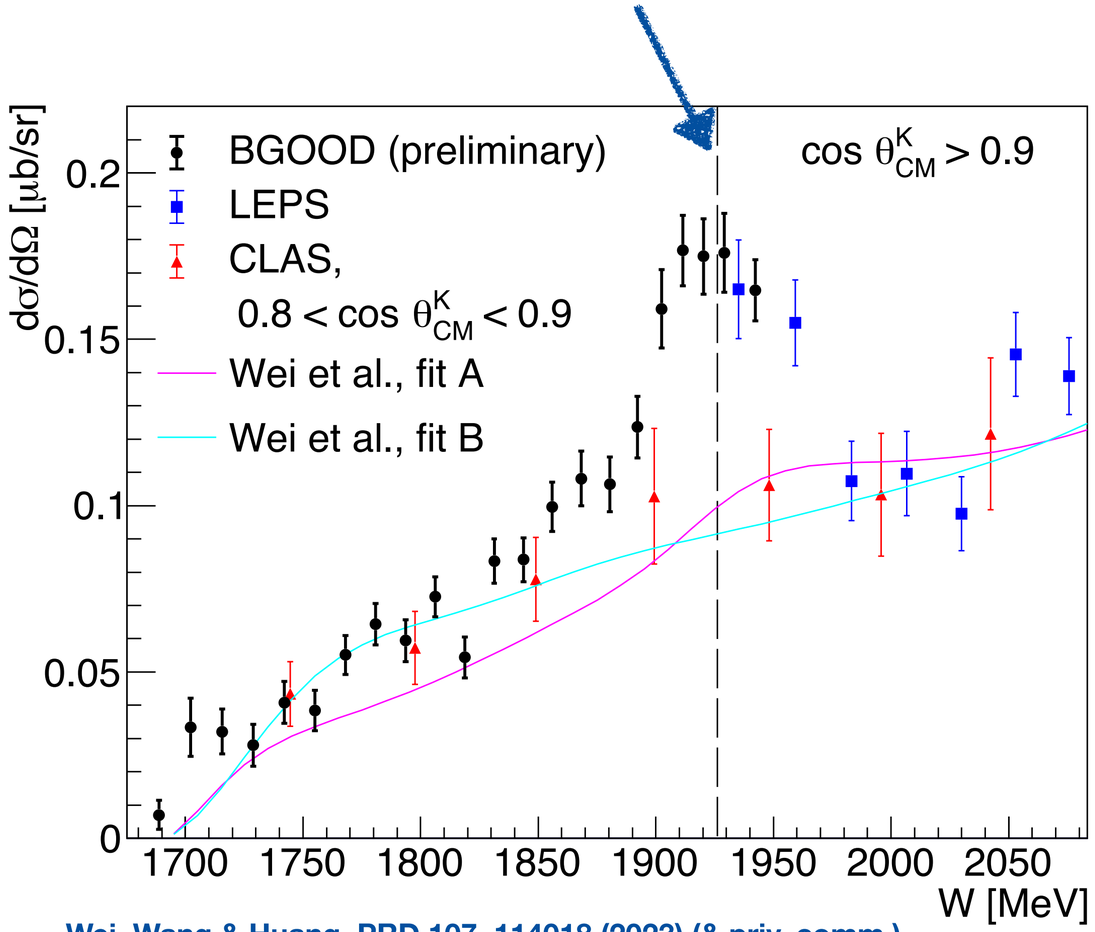
- At W ~ 1900, q ~ 0.5 - 0.55 GeV/c
- "Scaling effect" - mechanisms dependent only on q?



Forward $K^+\Sigma^-$ photoproduction

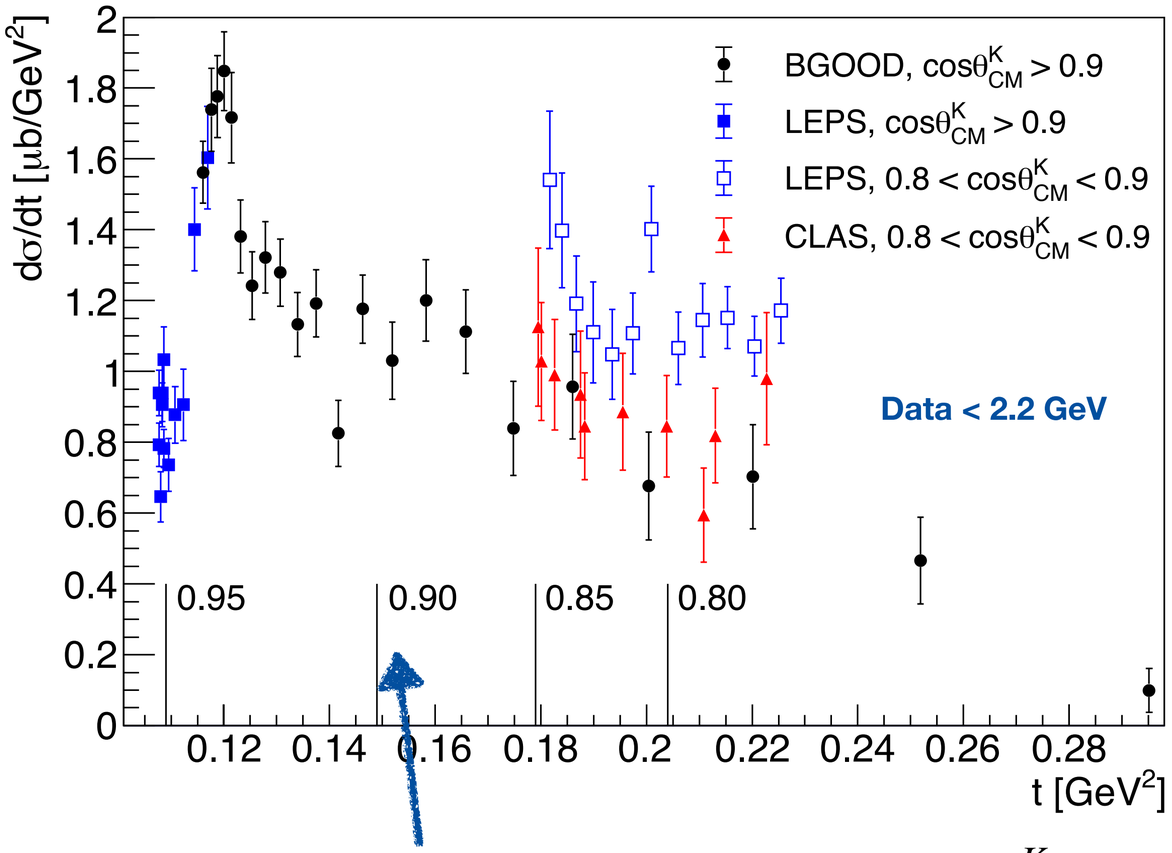
J. Gross, PhD thesis 2025, Uni Bonn
(See previous talk)

Structure close to K^+K^-p threshold?



Wei, Wang & Huang, PRD 107, 114018 (2023) (& priv. comm.)
CLAS: Pereira et al., PLB 688 (2010) 289
LEPS: H. Kohri et al., PRL 97 (8 2006) 082003

- The same data differential wrt *t*
- Agreement with more backward CLAS data

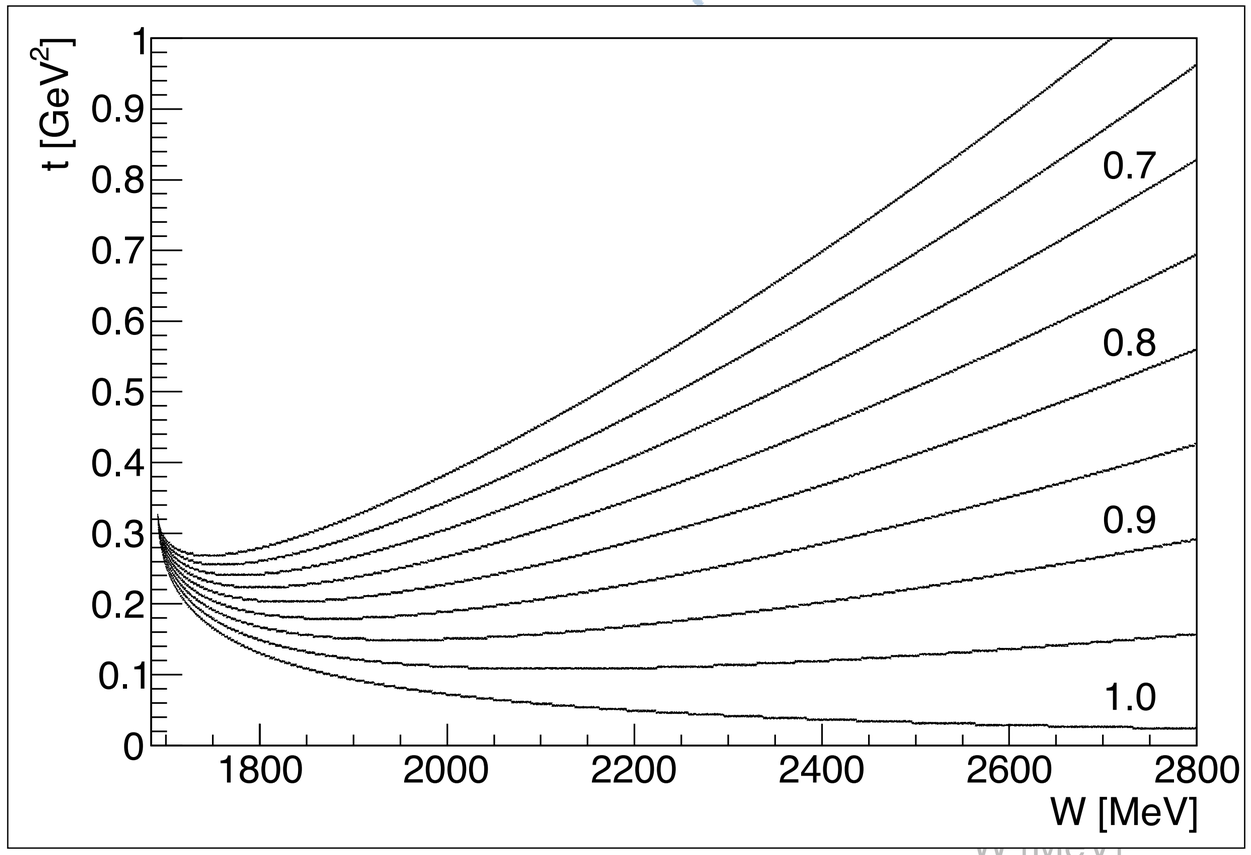


- Low *t* (with structure evident) only accessible for $\cos\theta^K_{\mathrm{CM}} > 0.9$

Forward $K^+\Sigma^-$ photoproduction

J. Gross, PhD thesis 2025, Uni Bonn

Structure close to K^+K^-p threshold?



Wei, Wang & Huang, PRD 107, 114018 (2023) (& priv. comm.)
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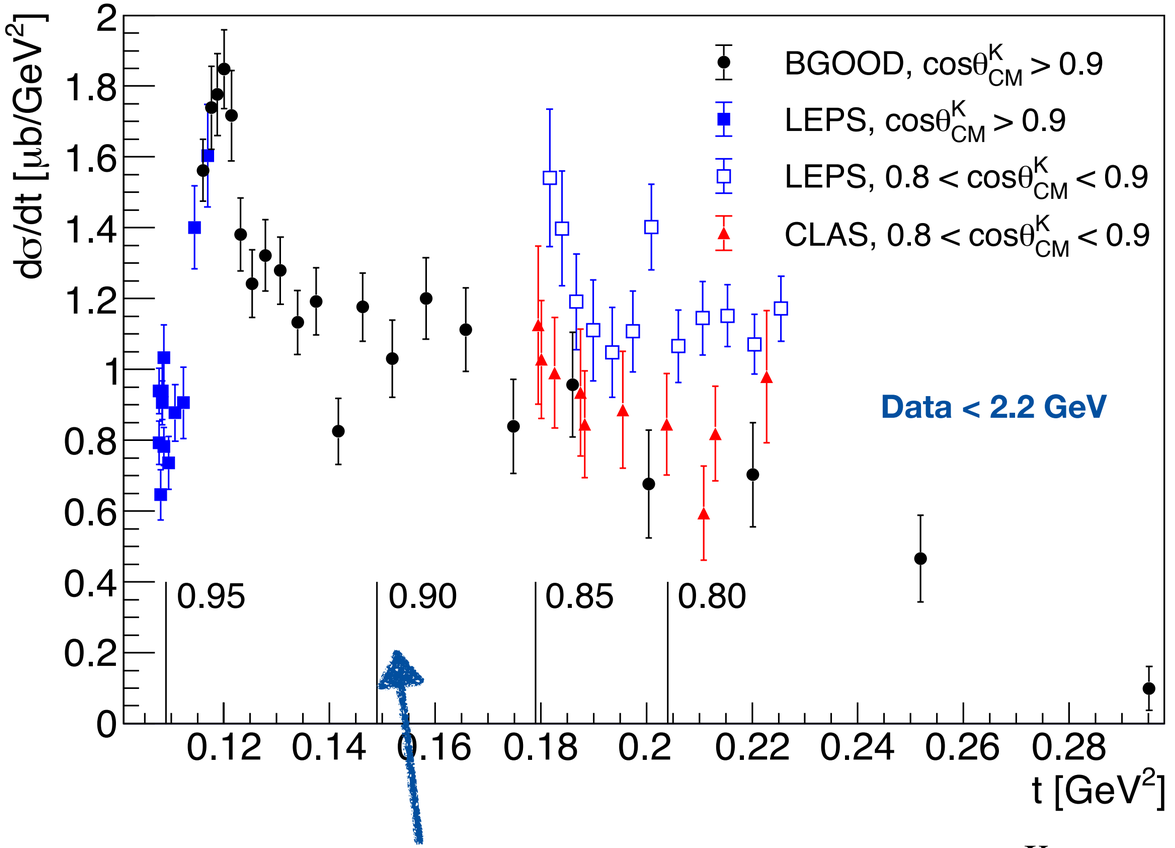
LEPS: H. Kohri et al., PRL 97 (8 2006) 082003

- The same data differential wrt *t*
- Agreement with more backward CLAS data



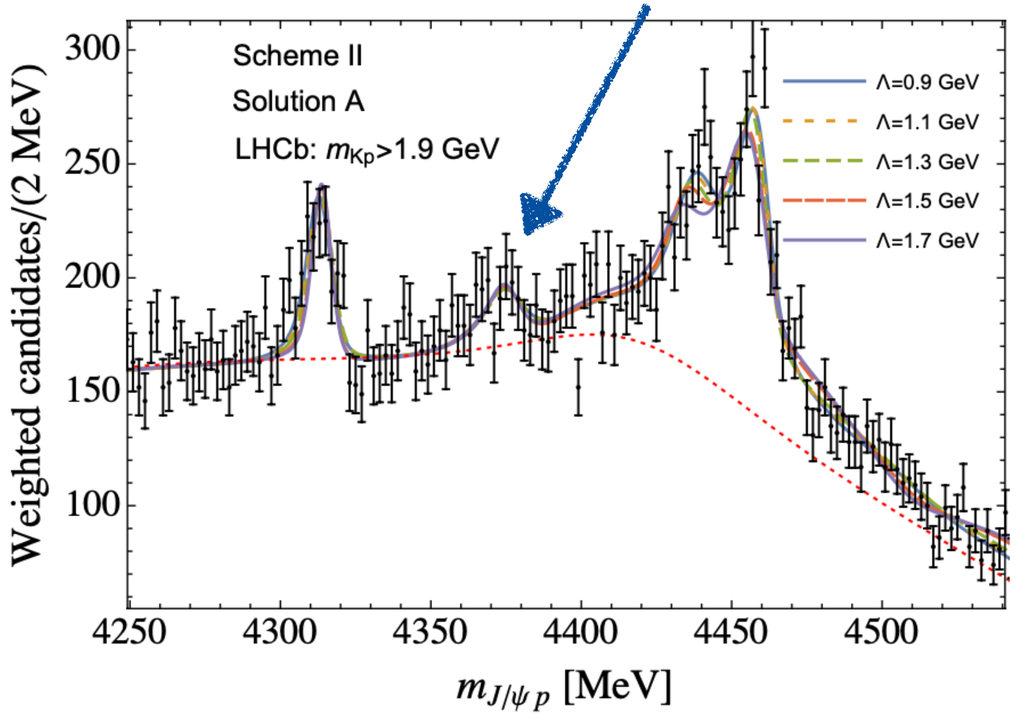
- Low *t* (with structure evident) only accessible for $\cos\theta^K_{\mathrm{CM}} > 0.9$

Some considerations from the charm sector…

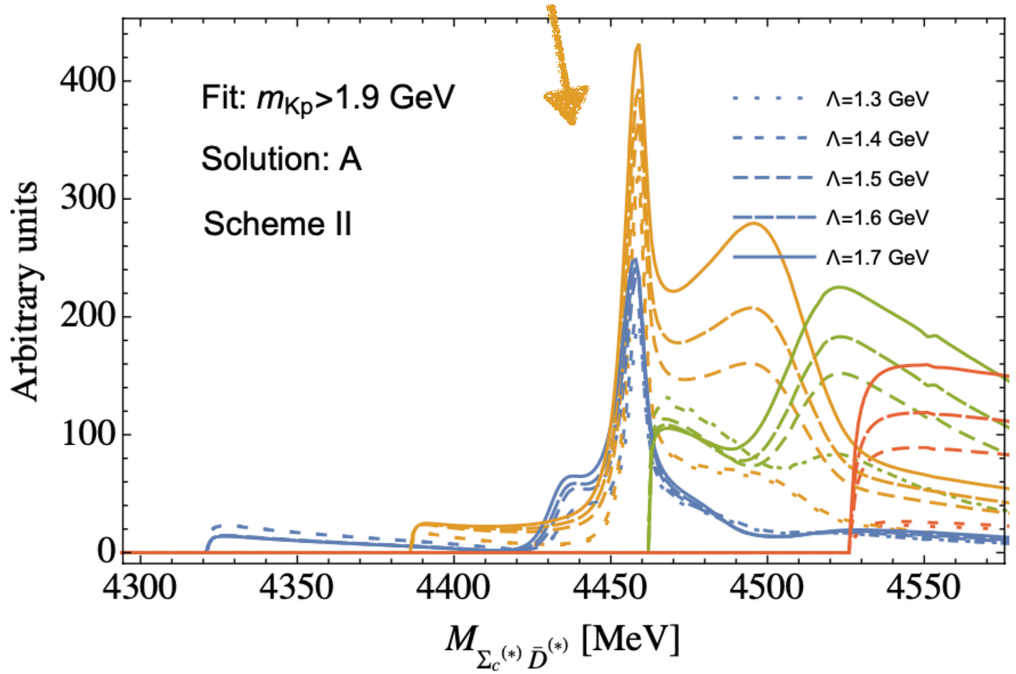
Du *et al.* J. HEP. 08 (2021) 157
Coupled channel model with HQSS

Structure in the "free" production of constituents?

Proposed PC(4380)



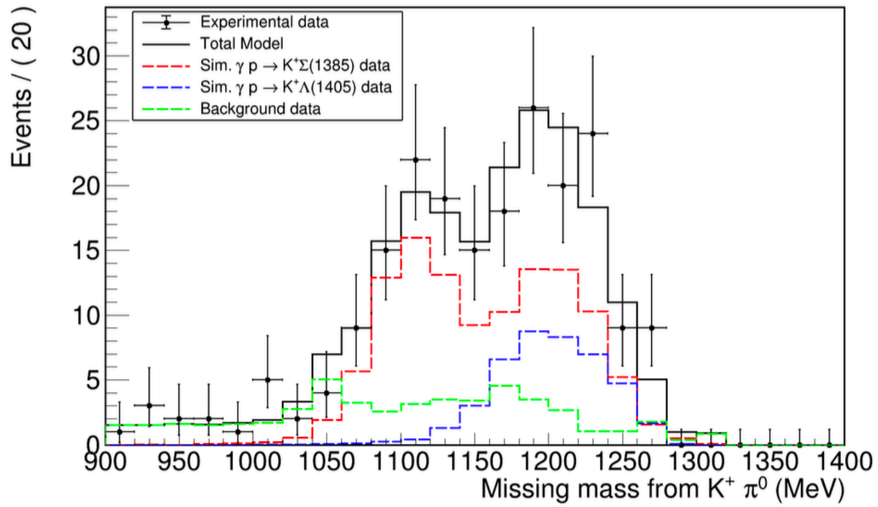
Predicted structure in the $\Sigma_C^* \bar{D}$ line shape

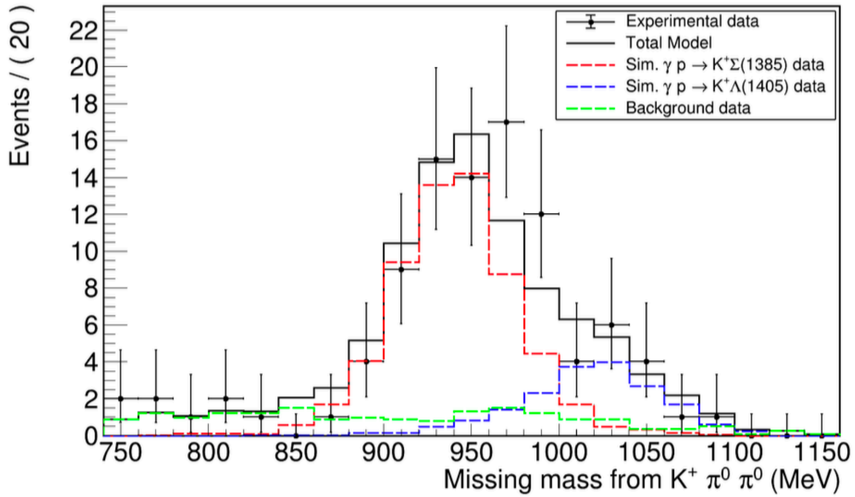


Forward $K^+\Sigma^0(1385)$

M. Jena, Masters thesis, Uni Bonn 2024
A. J. C. Figueiredo, PhD thesis (in preparation), Uni Bonn

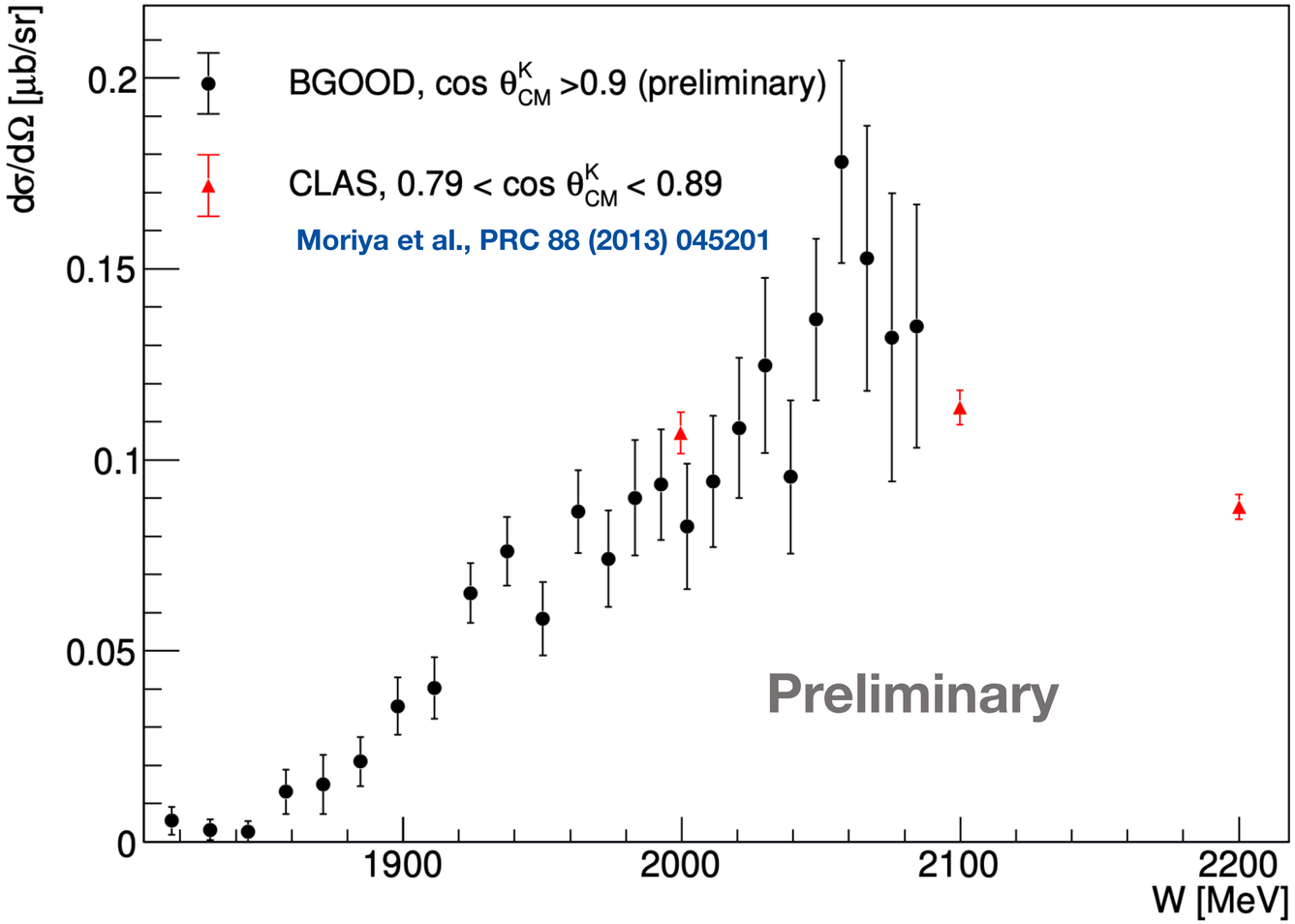
- Example separation of $\Sigma^0(1385)$ and $\Lambda(1405)$





Antonio's presentation today, 11:30

- First data at threshold & forward angles



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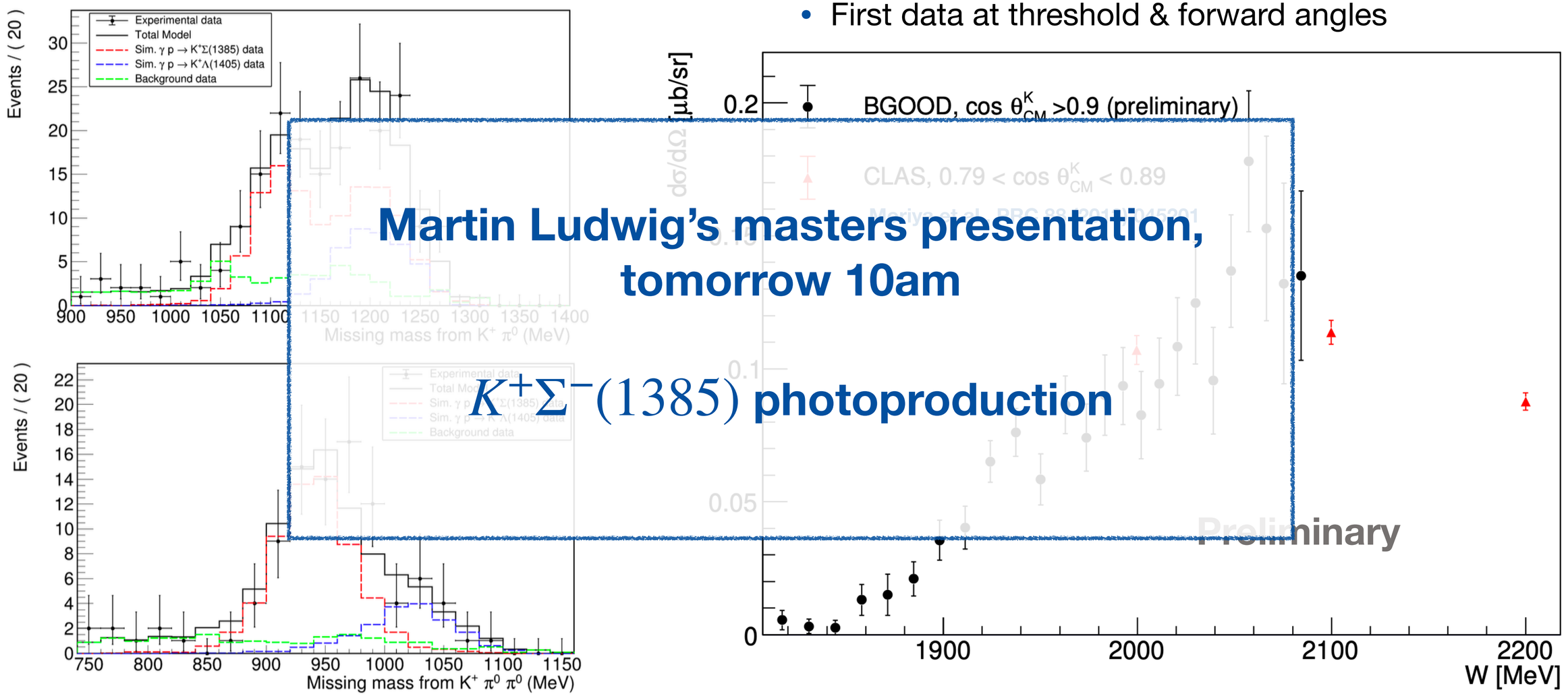


Martin Ludwig's masters presentation, tomorrow 10am

$K^+\Sigma^-(1385)$ photoproduction

$\gamma n \rightarrow K^0\Sigma^0$

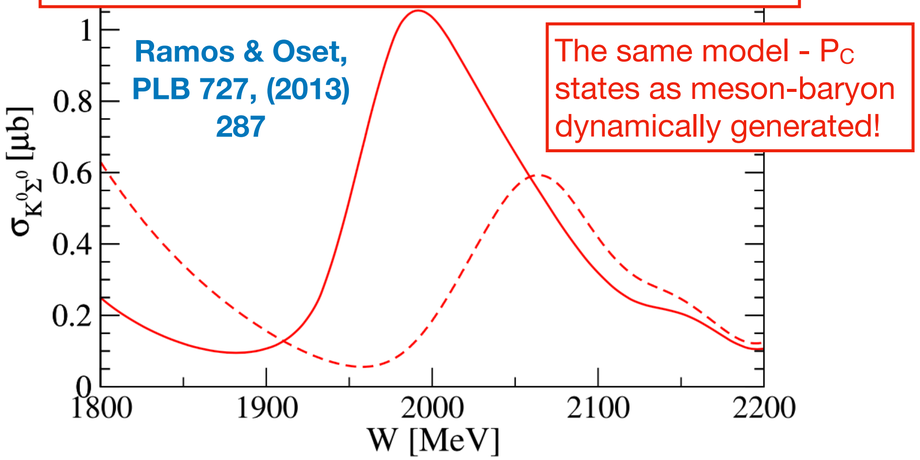
K. Kohl, T.C. Jude, *et al.*, EPJA 59 (2023)

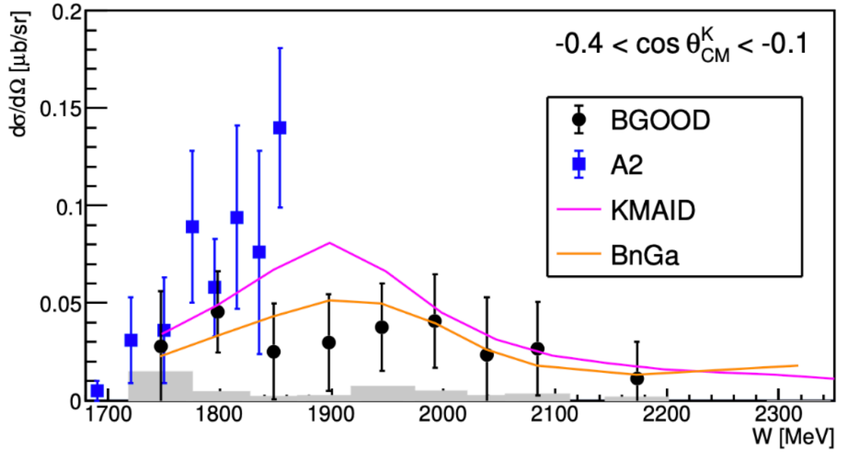
Predicted peak - *strange pentaquarks*?

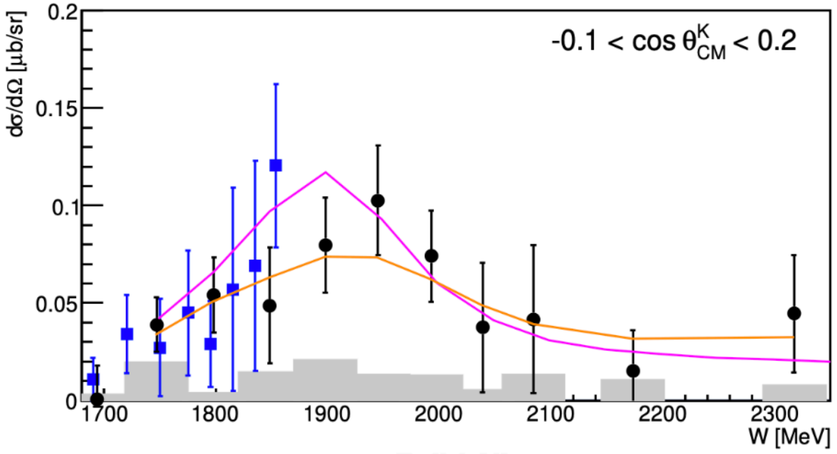
- Dynamically generated meson-baryon states? - $\Lambda^* K - \Sigma K^*$
- Identification via:
  - $K^0 \rightarrow \pi^0\pi^0$
  - $\Sigma^0 \rightarrow \gamma(\Lambda \rightarrow p\pi^-)$

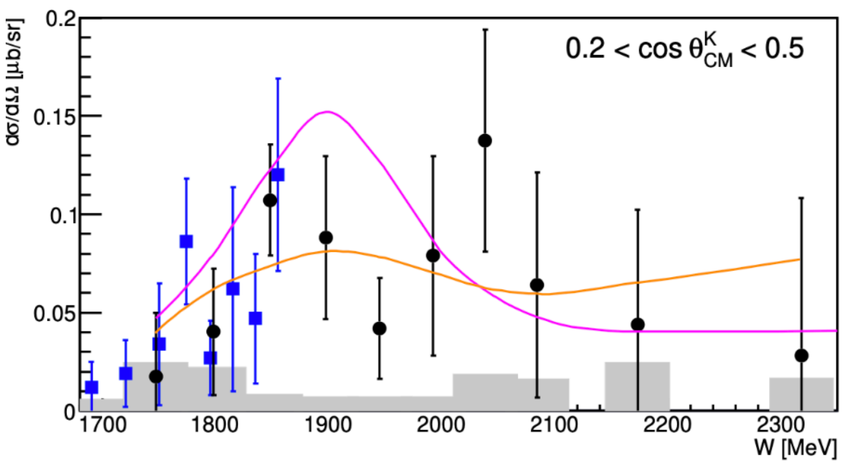
Integrated over all angles

Prediction off the neutron - **constructive** interference of dynamically generated N*s









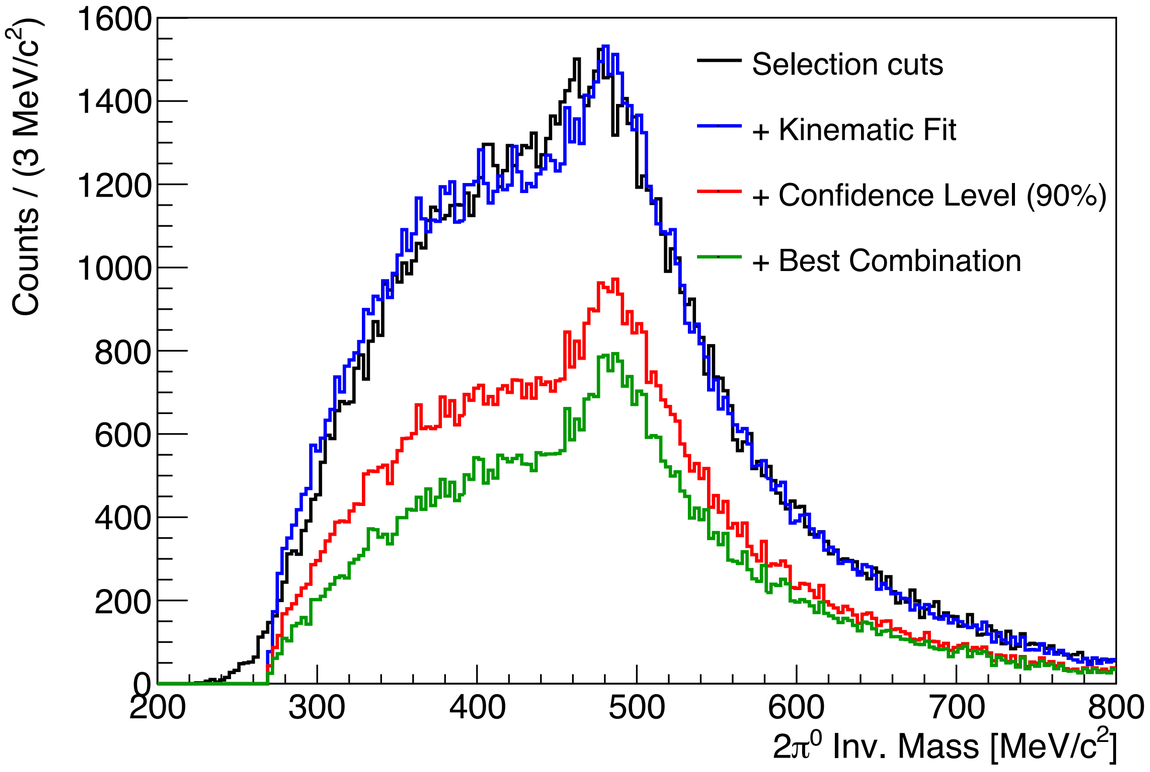
$\gamma n \rightarrow K^0\Sigma^0$

Predicted peak - strange pentaquarks?

- Dynamically g
- Identification
  - $K^0 \rightarrow \pi^0$
  - $\Sigma^0 \rightarrow \gamma(\Lambda$

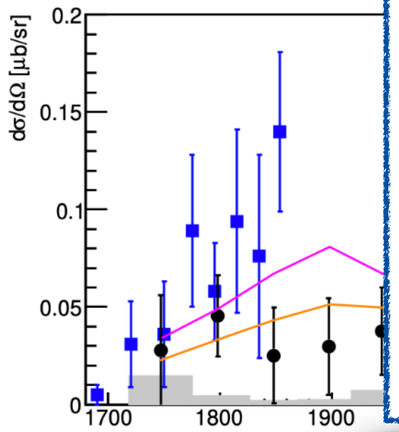
Integrated over all angles

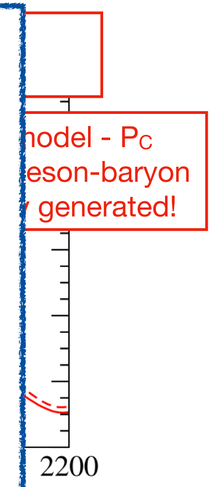
Analysis of further data & Kinematic fit

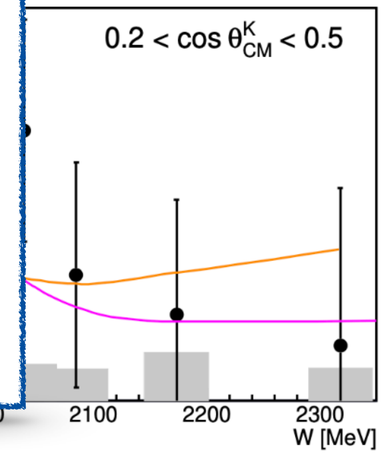


Adrian Sonnenschein, PhD thesis (in preparation)

Presentation today at 13:30







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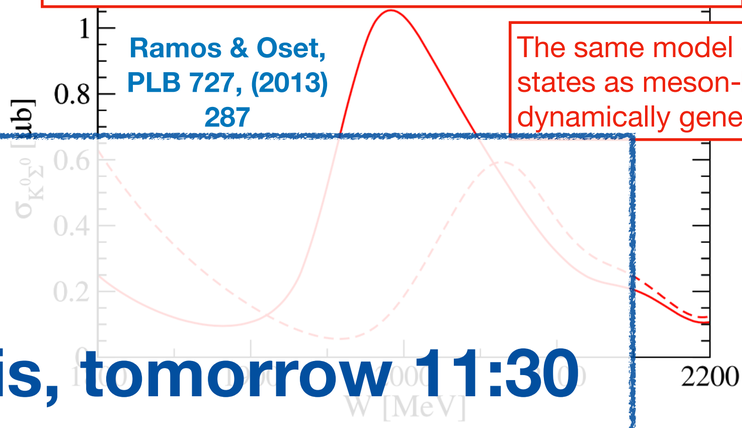
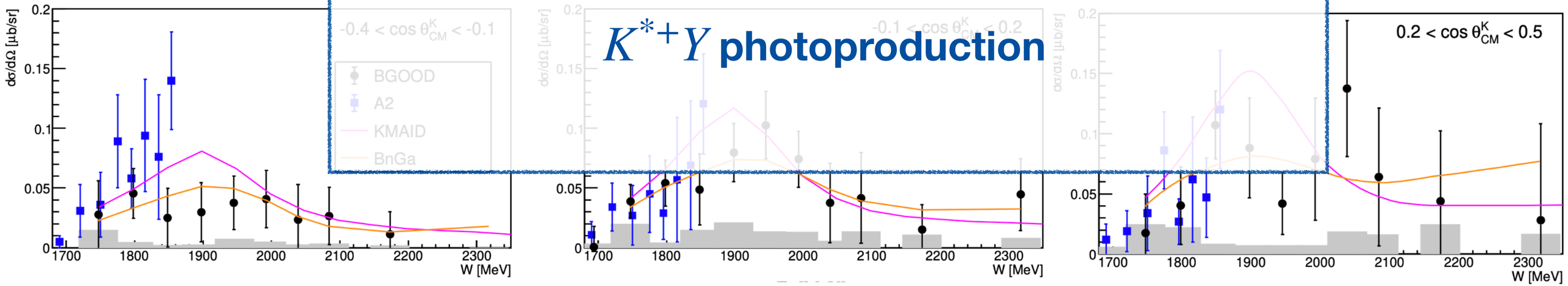


The same model - P_C states as meson-baryon dynamically generated!

Amelia de Lope Fend's analysis, tomorrow 11:30

K^*Y **photoproduction**

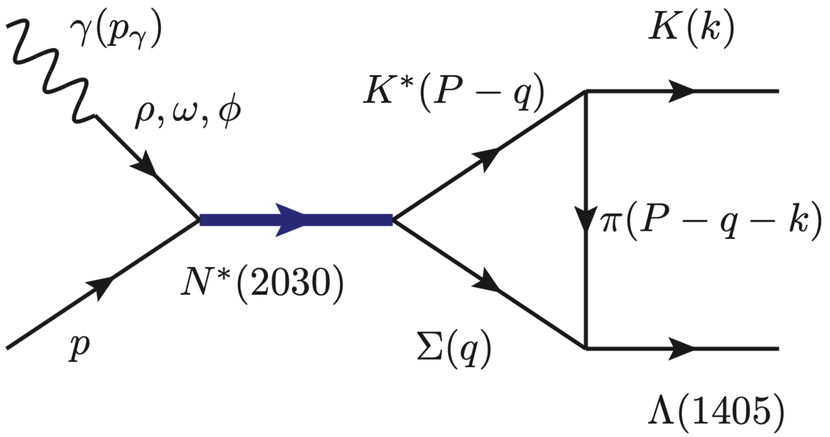


$\gamma p \to K^+\Lambda(1405) \to K^+(\Sigma^0\pi^0)$

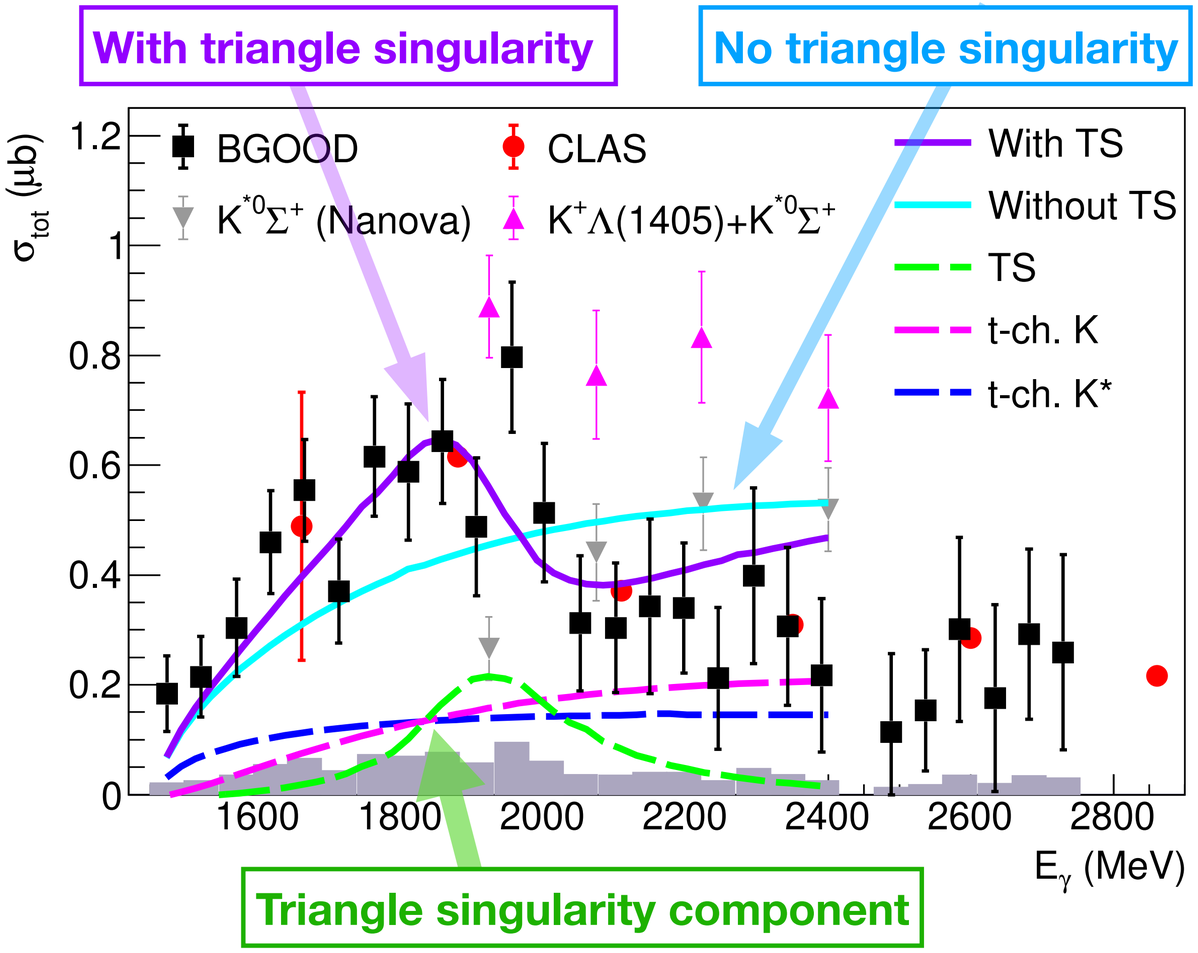
G. Scheluchin, T.C Jude *et al.*
PLB 833 (2022) 137375}

$\gamma p \to K^+\Lambda(1405) \to K^+\Sigma^0\pi^0 \to K^+3\gamma p\pi^-$ & kinematic fit

- Proposed triangle singularity:
- The same dynamically generated *N**(2030) proposed for cusp in $K^0\Sigma^+$



Wang *et al.*, PRC 95, 015205 (2017)

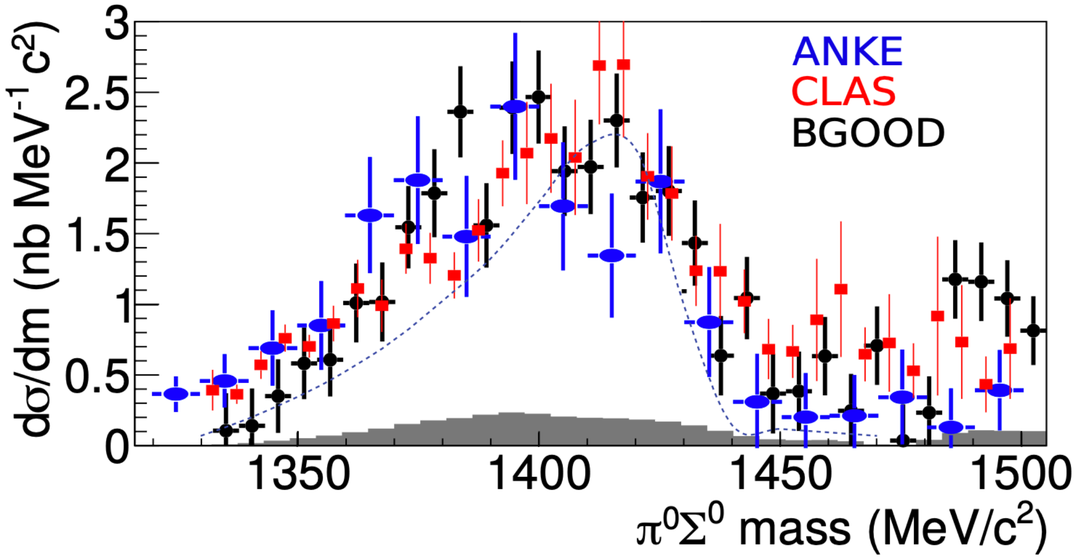


$\gamma p \to K^+\Lambda(1405) \to K^+(\Sigma^0\pi^0)$

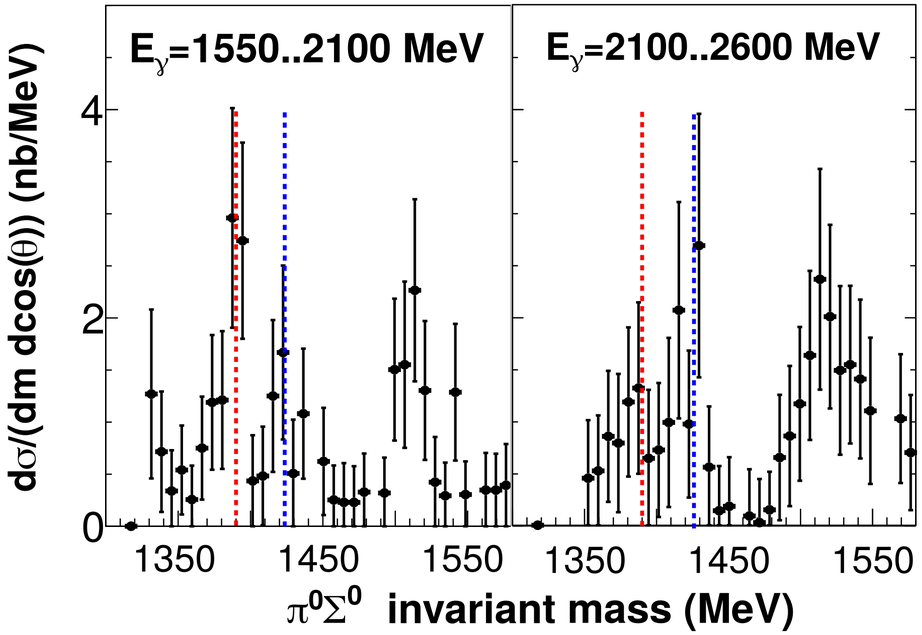
G. Scheluchin, T.C Jude *et al.*
PLB 833 (2022) 137375}

$\Lambda(1405)$ line shape measurements

- 2 peak structure at 1395 & 1425 MeV/c²?
- Similar to proposed 2-pole structure
  Oller & Meißner, PLB 500, 263 (2001)
- Integrated over all $\cos\theta^K_{\rm CM}$:



- At forward K^+ angles: $\cos\theta^K_{\rm CM} > 0.86$:

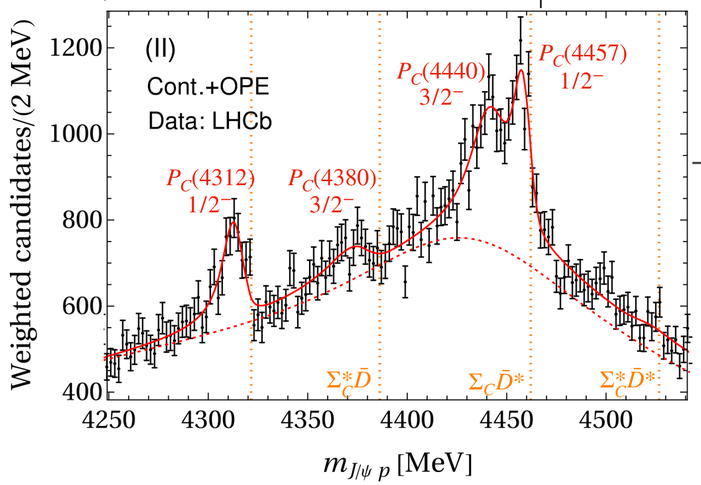


- Relative amplitudes of “poles” appear to vary
- Further data & analysis underway

New developments: Antonio’s presentation today, 11:30

Strange pentaquarks? Equivalence to P_C states?

Charm sector		Strange sector		
Threshold	State	Threshold	Evidence	
$\Sigma_c \bar{D}$	$P_C(4312)$	$\Sigma^0 K^+$ at 1687 MeV	$N(1535)$	
$\Sigma_c^* \bar{D}$	$P_C(4382)$	$\Sigma^0(1385) K^+$ at 1879 MeV	Peak in $K^+\Sigma^0$ at $t_{\min}$	TJ *et al.*, Phys. Lett. B 820 (2021) 136559
-	-	$K^+ K^- N$ at 1926 MeV	Structure in $K^+\Sigma^-$ at low t	J. Gross, PhD thesis 2025, Uni Bonn
$\Sigma_c \bar{D}^*$	$P_C(4457)$	$\Sigma^0 K^{*+}$ at 2085 MeV	Cusp in $K^0\Sigma^+$ CB/ELSA-TAPS	R. Ewald *et al.*, PLB 713 (2012) 180
			(Tentative) peak in $K^0\Sigma^0$	K. Kohl, TJ, *et al.*, EPJA 59 (2023)
			Triangle singularity in $K^+\Lambda(1405)$	G. Scheluchin, TJ *et al.* PLB 833 (2022) 137375



Du *et al.*, PRL 124, 072001 (2020)

Resolve the nature of structures via polarisation observables at INSIGHT

@ELSA INSIGHT

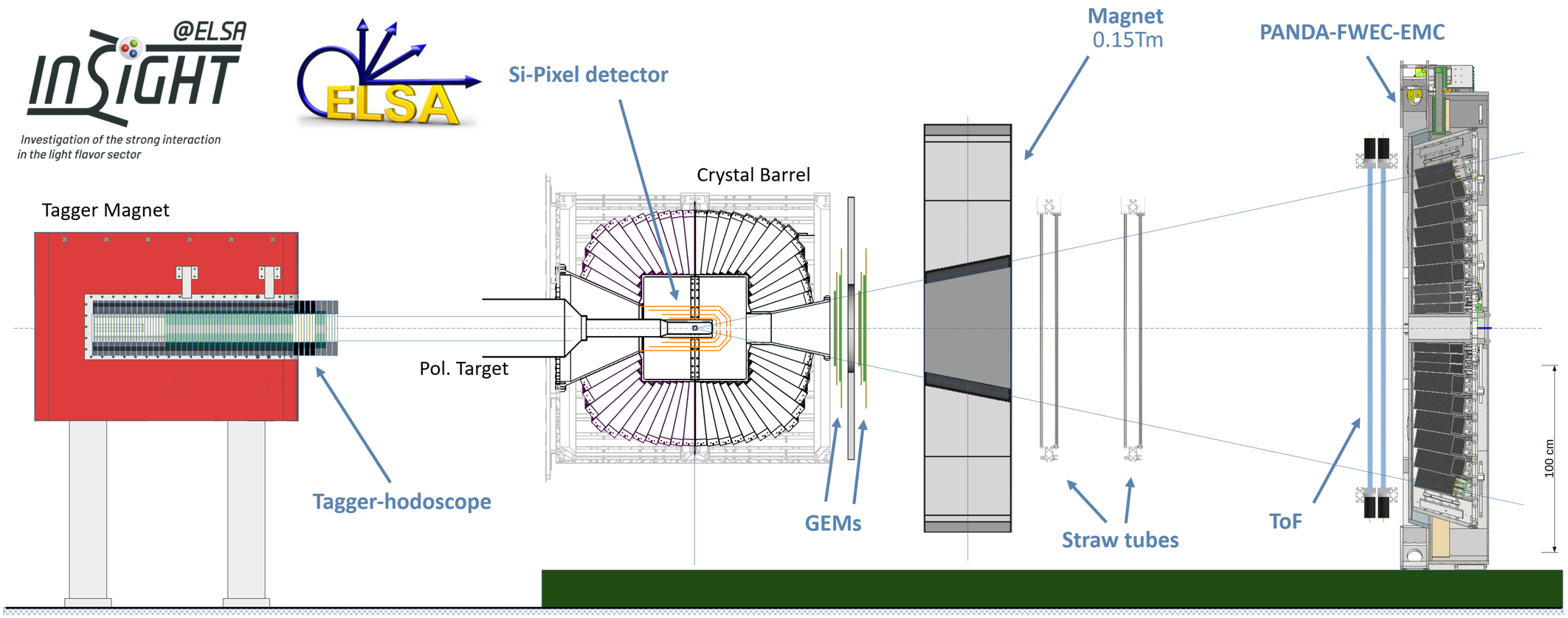
Investigation of the strong interaction in the light flavor sector

The Future: INSIGHT @ ELSA

color meets flavor

@ELSA INSIGHT
Investigation of the strong interaction in the light flavor sector

Unique possibilities in understanding strange and non-strange baryon resonance spectra & their properties



- ~ 4π solid angle: High resolution photon measurements, Precise charged particle detection
- Polarised beam & polarised target

The Future: INSIGHT @ ELSA

Investigation of the strong interaction in the light flavor sector

Unique possibilities in understanding strange and non-strange baryon resonance spectra & their properties

An integral part of the excellence cluster:

color meets flavor

UNIVERSITÄT BONN | technische universität dortmund | Universität Siegen | JÜLICH Forschungszentrum

https://www.color-meets-flavor.de

- ~ 4π solid a
- Polarised beam & polarised target

The Future: INSIGHT @ ELSA

Investigation of the strong interaction in the light flavor sector

Polarisation observables for $K^+\Sigma^0$ at $\cos\theta^K_{\mathrm{CM}} = 0.95$

Bonn-Gatchina PWA

K. Nikonov & A. Sarantsev, Priv. Comm.

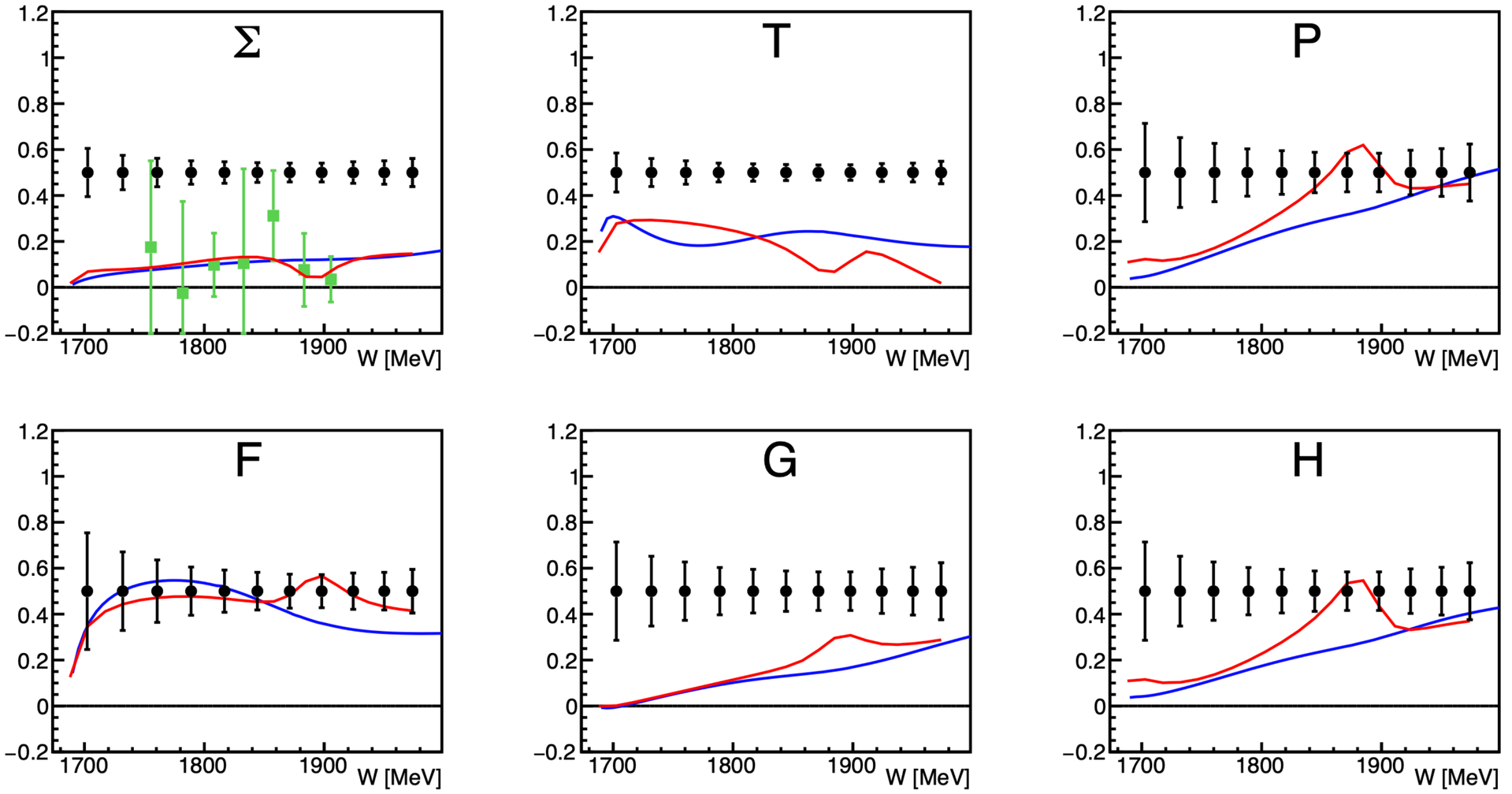
"Standard" calculation

With $N*(1896)\frac{3^-}{2}$ resonance, $\Gamma = 36$ MeV

Black circles - INSIGHT precision over 2 years

GRAAL

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



The Future: INSIGHT @ ELSA

INSIGHT @ELSA
Investigation of the strong interaction in the light flavor sector

- A good understanding of expected data taking parameters (from CBELSA/TAPS measurements)

	BGOOD 2017 504 hrs.	INSIGHT 2028 800 hrs.	INSIGHT 2029/2030 1600 hrs.
Flux rate (normalised to BGOOD)	1.00	1.64	3.28
Target	6 cm liquid H_2	5 cm liquid H_2	2.5 cm pol. butanol
Target area density	$2.53 \times 10^{-7}\,\mu\,\mathrm{b}^{-1}$	$2.11 \times 10^{-7}\,\mu\,\mathrm{b}^{-1}$	$9 \times 10^{-8}\,\mu\,\mathrm{b}^{-1}$
Linear beam polarisation	30 %	40 %	40 %
Circular beam polarisation	-	64 %	64 %
Target polarisation	-	-	70 %
Target dilution factor	-	-	0.7

Summary

UNIVERSITÄT BONN

FTD

- **BGOOD - photoproduction at forward angles & low *t***
- **Evidence of equivalent structure to P_C states?**
  - $K^+\Sigma^0$, $K^+\Sigma^-$, $K^+\Lambda(1405)$ & $K^0\Sigma^0$
- **Resolve with polarisation observables at INSIGHT**

Review: TJ, Prog. Part. Nucl. Phys. 147 (2026) 1042245

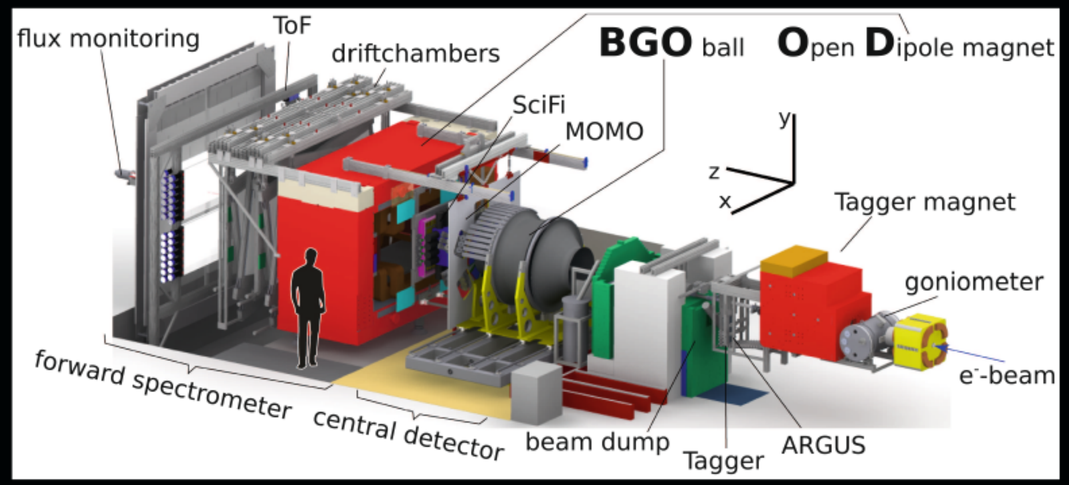
Tom Jude, 18th June 2026

The European Physical Journal volume 56 · number 4 · april · 2020

EPJ A

Recognized by European Physical Society

Hadrons and Nuclei



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

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

Società Italiana di Fisica

Springer

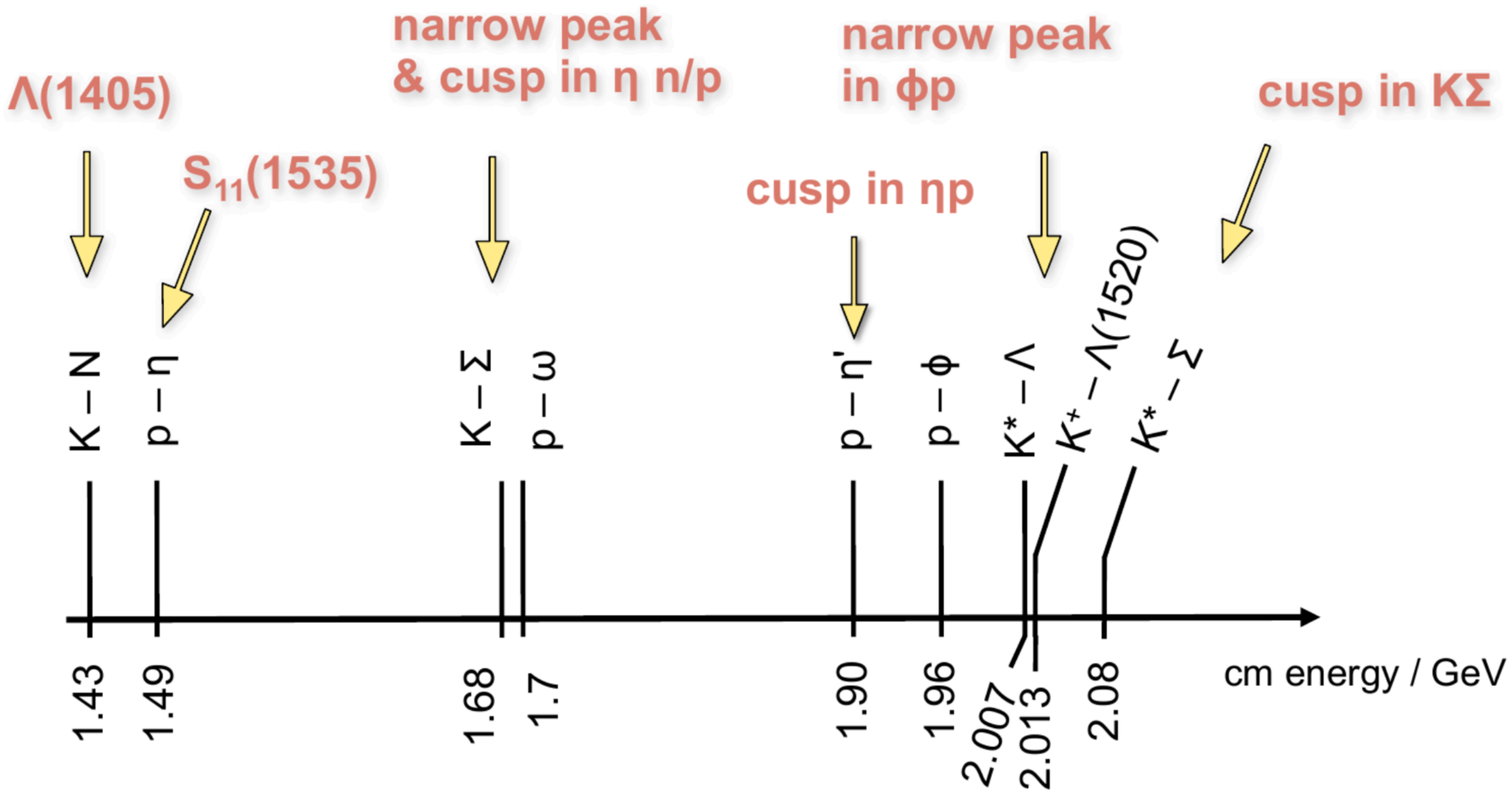
UNIVERSITÄT BONN

FTD

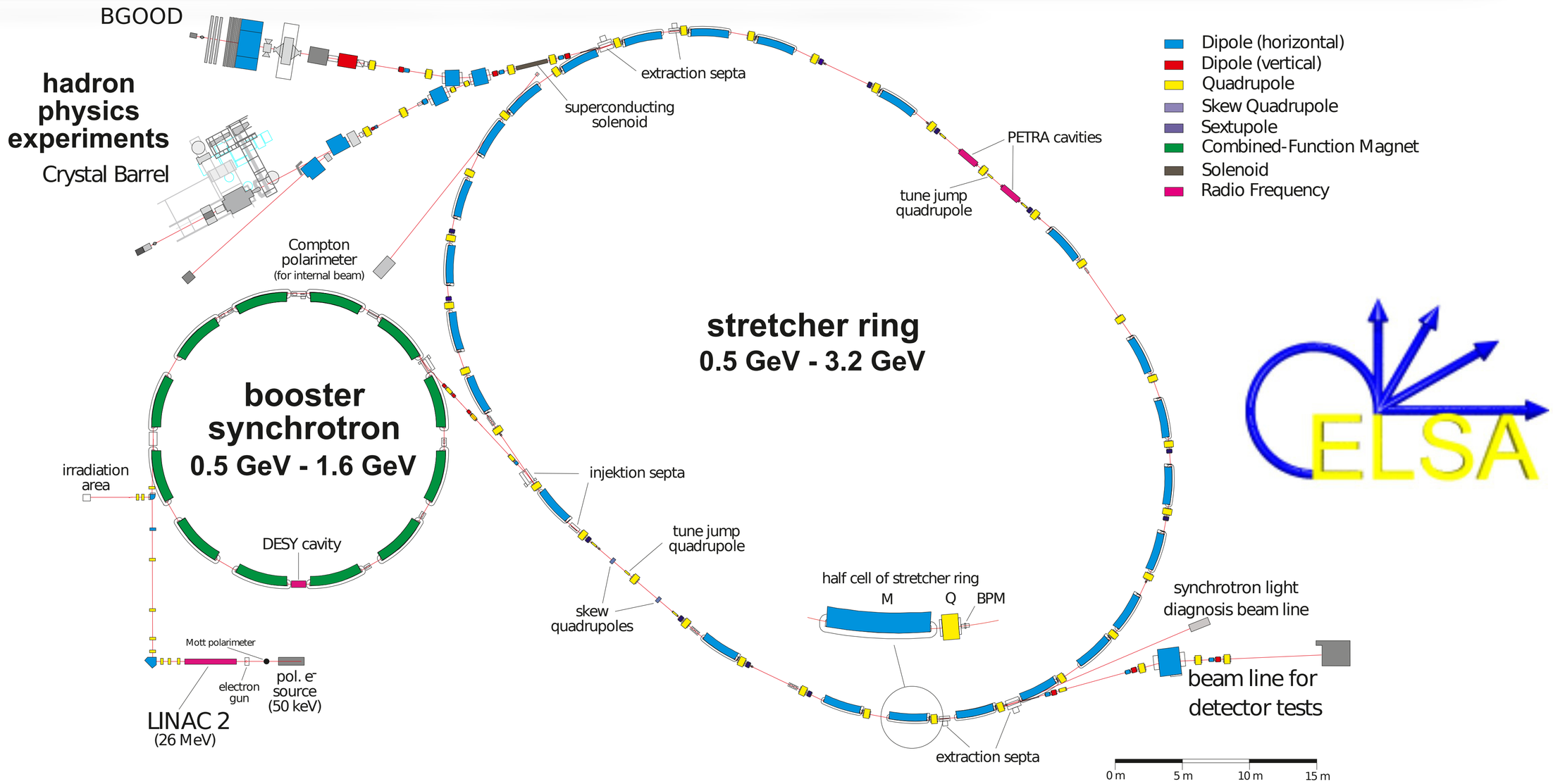
BGOOD

color meets flavor

Threshold effects in the light baryon sector?



The Electron Stretcher Accelerator (ELSA)

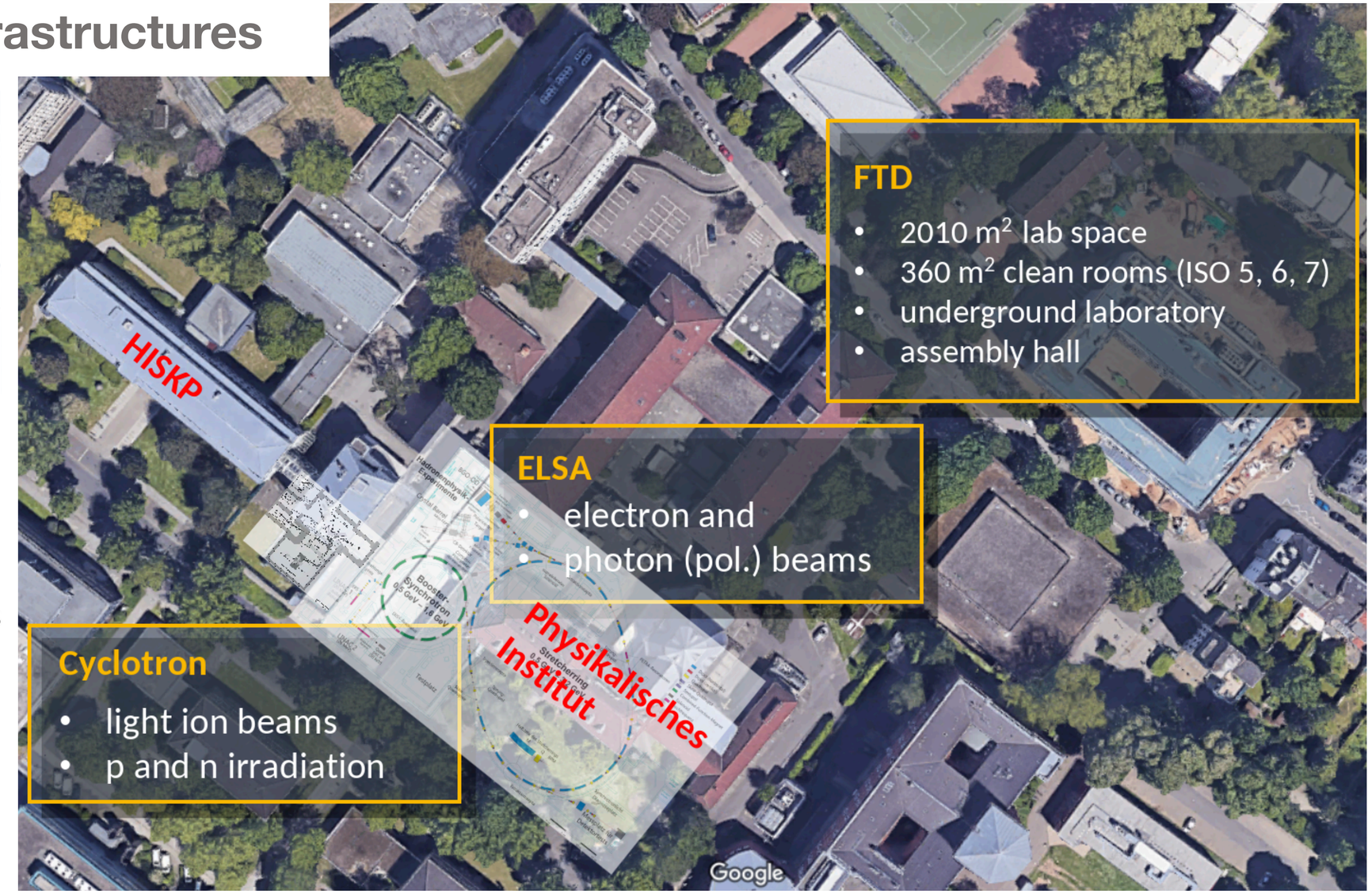


Centre for Detector & Accelerator Research at Bonn

Three large research infrastructures

- **FTD**
- **ELSA - Accelerator & hadron physics experiments**
- **Cyclotron**

- Development of detector & accelerator technologies for fundamental physics
- Local hadron physics experiments
- International collaborations
- **Open for external users via TNA**

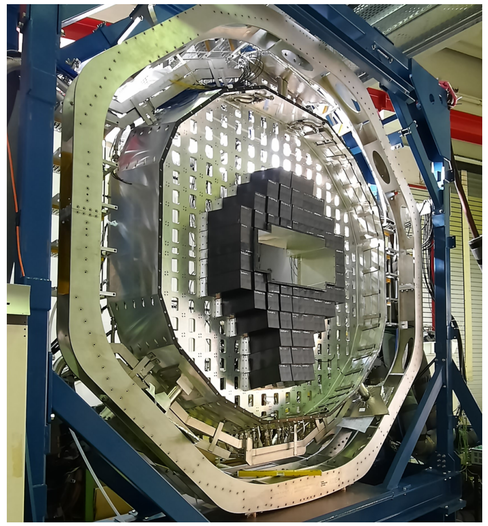


The Future: INSIGHT @ ELSA

INSIGHT @ELSA
Investigation of the strong interaction in the light flavor sector

Unique possibilities in understanding strange and non-strange baryon resonance spectra & their properties

- Arrival of the PANDA-FWEC in Bonn, Aug 2024



Non-strange baryons

- Complete picture of the N* & Δ* spectra
  - Polarised photoproduction off polarised protons & neutrons
  - Multi-meson photoproduction

Λ* & Σ* baryons

- Starved of data - research stagnated for ~ 30 years
  PDG 2025 (exception - Λ(1405))
- Not even all states of the 1st excitation band known
- Multi-quark states? molecular-like? 2-pole structures?