

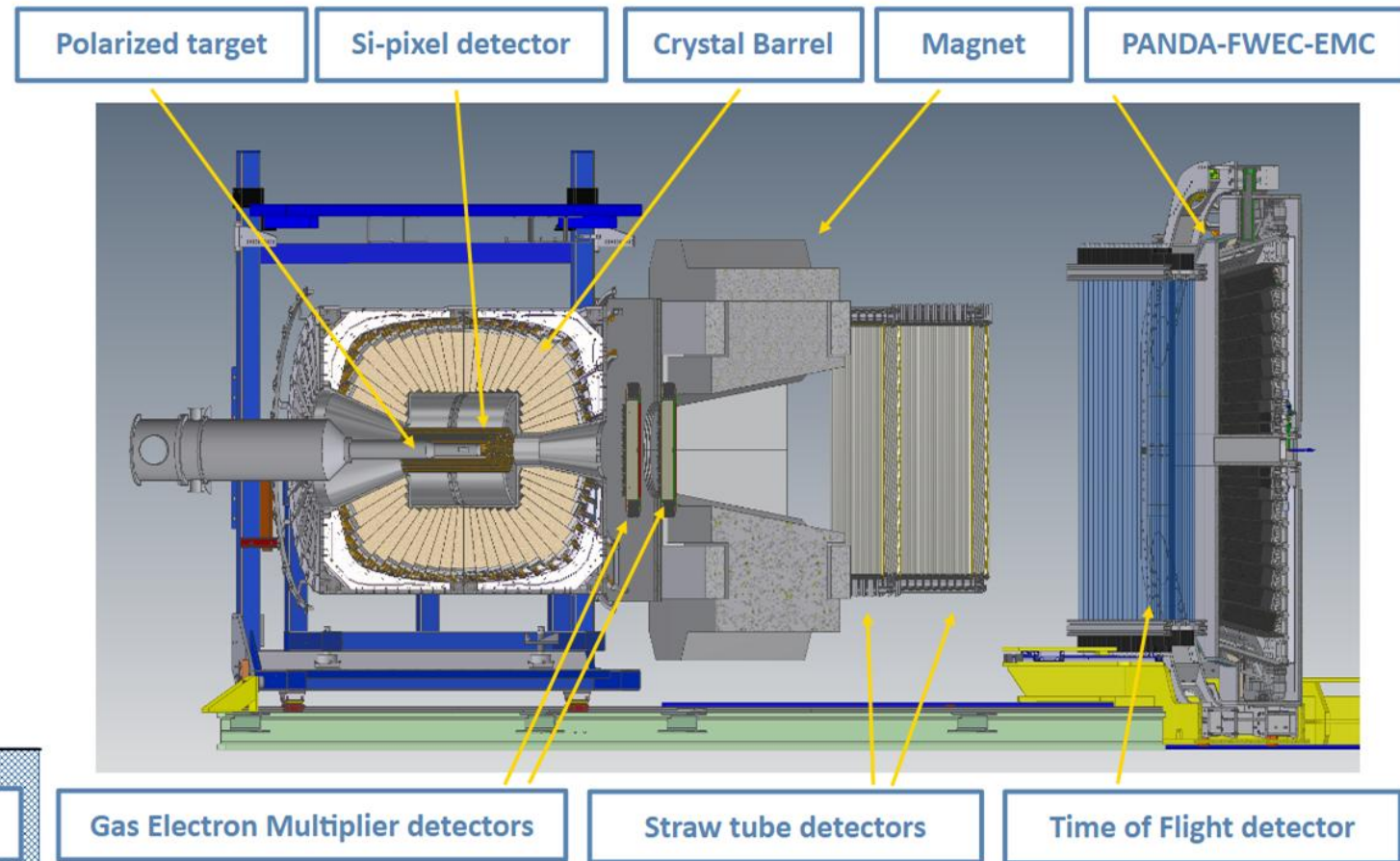
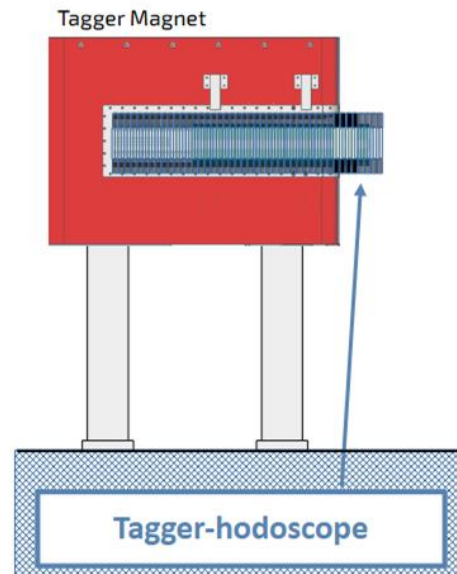
The new INSIGHT experiment @ELSA



U.Thoma, Bonn
for the INSIGHT collaboration

Contents:

- Introduction
- Open questions
- The future with INSIGHT at ELSA

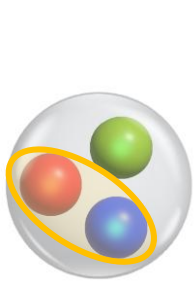


QCD in the non-perturbative regime:

⇔ One of the worst understood areas of the standard model = a challenge!

⇔ How does QCD produce its massive bound states from almost massless quarks?

- What are the relevant degrees of freedom?
- Effective forces between them?



$q\text{-(}qq\text{)}_{\text{stable}}$



qqq



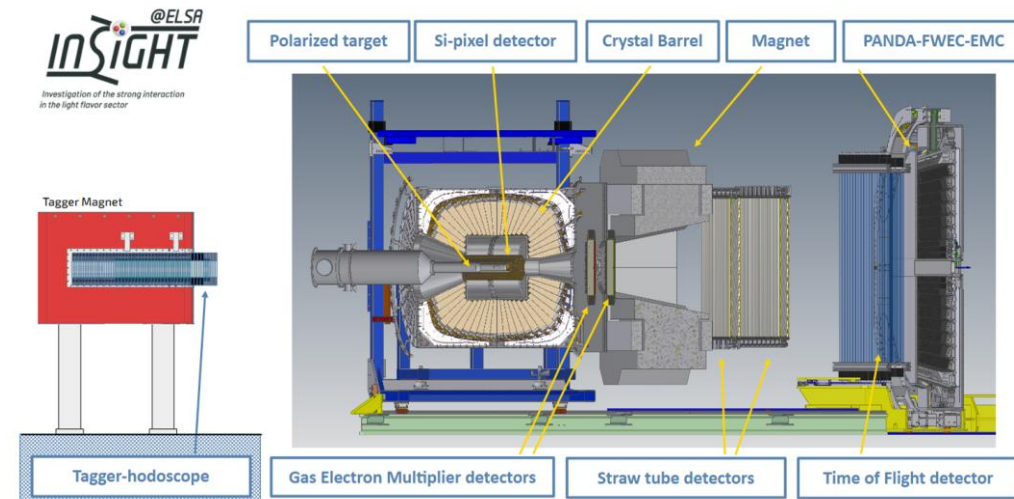
molecule



pentaquarks

⇔ **Nature of the complex bound states of QCD = ?**

u, d
 N^*, Δ^* $\Rightarrow$ u, d, s
 $N^*, \Delta^*, \underline{\Lambda^*}, \Sigma^*$ **important**



⇔ **Experimental spectrum of baryons and their properties**

⇔ **Search for exotic states**

Physics at ELSA - results on the baryon spectrum



Polarization as key to resolve the baryon spectrum

→ huge impact on knowledge of resonances in the second and third resonance region based on data from ELSA + experiments worldwide (Jlab, MAMI, Spring8, ...)

	RPP 2010	BnGa- PWA	RPP'25 (2018-25)
N(1710)1/2 ⁺	***	*****	*****
N(1860)5/2 ⁺		*	**
N(1875)3/2 ⁻		***	***
N(1880)1/2 ⁺		***	***
N(1895)1/2 ⁻		****	****
N(1900)3/2 ⁺	**	****	****
N(2060)5/2 ⁻		***	***
N(2100)1/2 ⁺	*	***	***
N(2120)3/2 ⁻		***	***
Δ(1600)3/2 ⁺	***	***	****
Δ(1900)1/2 ⁻	*	***	***
Δ(1940)3/2 ⁻	*	**	**
Δ(2200)7/2 ⁻	*	***	***

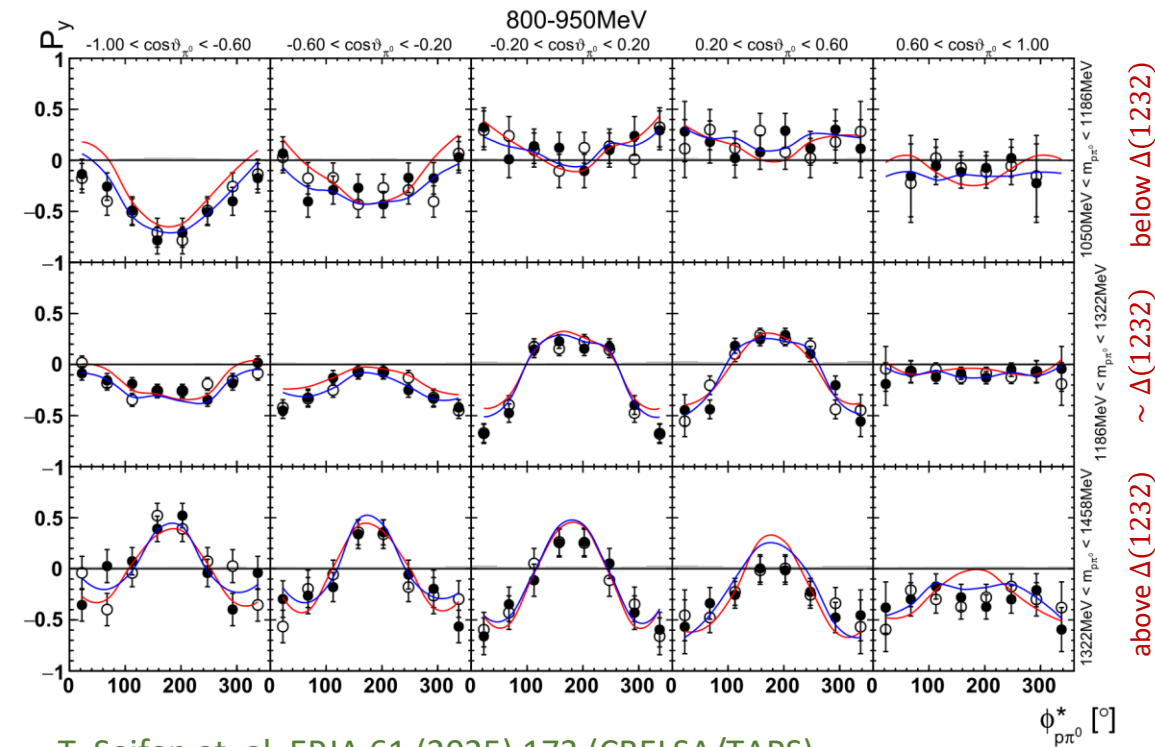
only examples shown

Up to 2.3 GeV:

- **6 new N*-resonances found** (25% of known N*-states)
- **7 N* + 2 Δ* new in the PDG summary tables** (30%)
- Many new resonance properties determined

$\gamma p \rightarrow p \pi^0 \pi^0$ (CBELSA/TAPS) - Target asymmetry data

(only one E-bin shown – 4 dimensional)



T. Seifen et. al. EPJA 61 (2025) 173 (CBELSA/TAPS)

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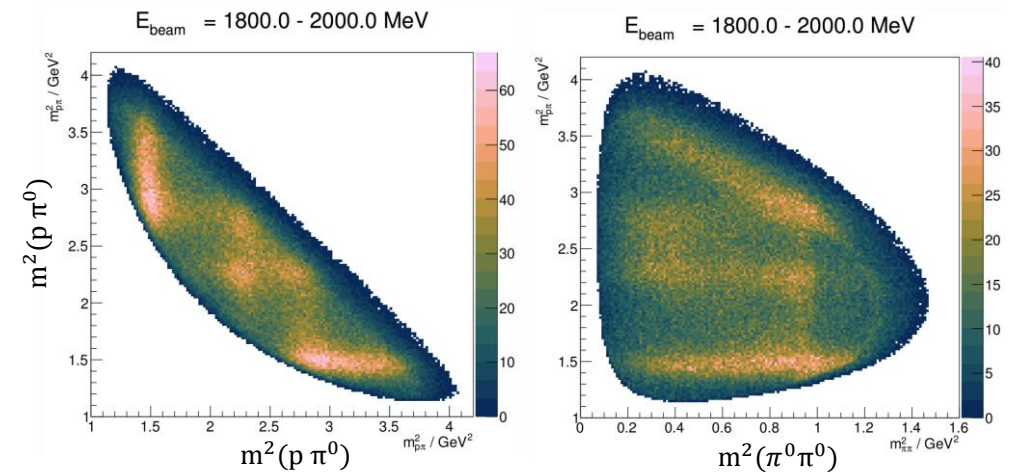
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N(1880)1/2 ⁺		***	***
N(1895)1/2 ⁻		****	****
N(1900)3/2 ⁺	**	****	****
N(2060)5/2 ⁻		***	***
N(2100)1/2 ⁺	*	***	***
N(2120)3/2 ⁻		***	***
Δ(1600)3/2 ⁺	***	***	****
Δ(1900)1/2 ⁻	*	***	***
Δ(1940)3/2 ⁻	*	**	**
Δ(2200)7/2 ⁻	*	***	***

only examples shown

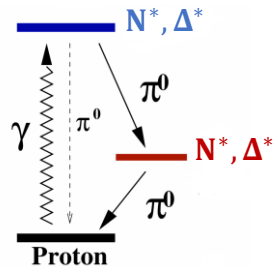
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$\gamma p \rightarrow p \pi^0 \pi^0$ (CBELSA/TAPS, P. Mahlberg et. al., in prep.)



$\gamma p \rightarrow N^*, \Delta^* \rightarrow \Delta(1232) \pi^0 \rightarrow p \pi^0 \pi^0$
 $\rightarrow N(1520) \pi^0 \rightarrow p \pi^0 \pi^0$
 $\rightarrow N(1680) \pi^0 \rightarrow p \pi^0 \pi^0$
 $\rightarrow \dots$
 $\rightarrow p f_0(980) \rightarrow p \pi^0 \pi^0$



Clear observation of cascading decays

⇔ Important: polarisation observables:

T, P, H, Σ, P_x, P_y, P_x^s, P_y^s, P_x^c, P_y^c, I_s, I_c
(published, in prep.)

Physics at ELSA - results on the baryon spectrum



Polarization as key to resolve the baryon spectrum

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N(1900)3/2⁺	**	*****	*****
N(2060)5/2⁻		***	***
N(2100)1/2 ⁺	*	***	***
N(2120)3/2⁻		***	***
Δ(1600)3/2⁺	***	***	*****
Δ(1900)1/2⁻	*	***	***
Δ(1940)3/2⁻	*	**	**
Δ(2200)7/2⁻	*	***	***

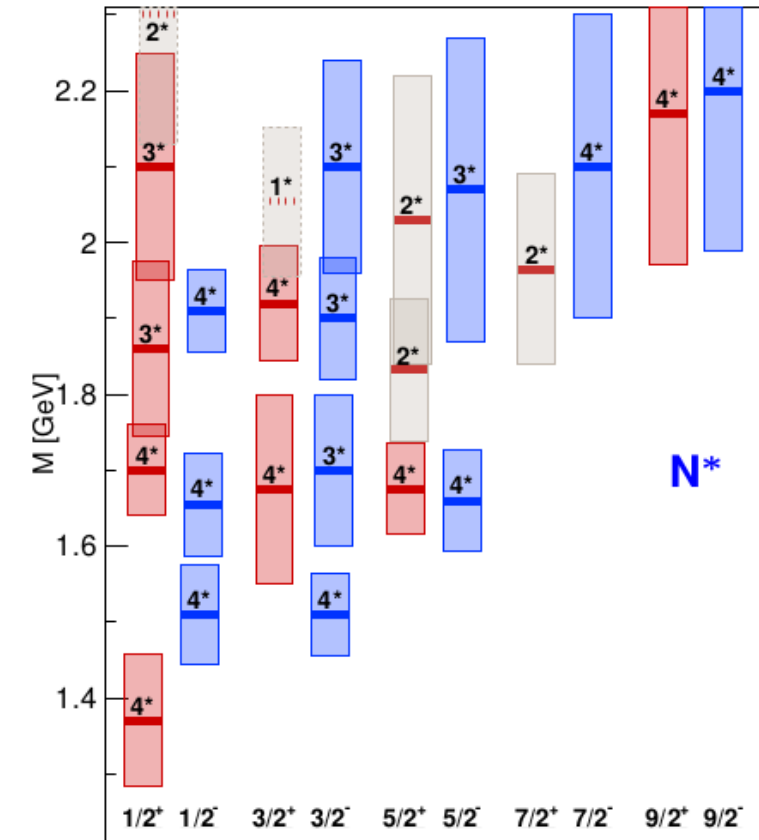
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N*-pole positions:

$(m, \pm \frac{r}{2})$



N*, Δ* - parity doublets observed (not for all states)

⇔ Not expected by present lattice calculations or constituent quark models

⇔ Not yet understood

Excited baryon spectrum – open questions

Open questions (examples):

⇔ **Do all the expected qqq -SU(6) $\times$ O(3)-states exist?**

- **Existing but experimentally not found yet?**

- ⇔ pol. photoproduction off the neutron (isospin dependence)

- ⇔ multi-meson photoproduction, further final states

continuation of the successful N^* , Δ^* -program

← Interesting results from CBELSA/TAPS
R. Beck (Tuesday), L. Reschke (Thursday)

⇔ **Certain resonances have „parity partners“ other's don't ⇔ Why?**

- **Needs to be explained by theory**

- ⇔ effective degrees of freedom / effective forces

- ⇔ meson-baryon or $3q$ or

... also relates to the first point ...

→ **Clarify the systematics in the spectrum !**

(SU(6): $u \uparrow\downarrow$ $d \uparrow\downarrow$ $s \uparrow\downarrow$)

⇔ **strange baryons of large interest**

- since decades: progress hampered by the lack of high quality data
not even the first excitation band completely know

⇔ **multiquark states? molecules? 2 pole-structures?**

← Hints for interesting structures BGOOD
T. Jude (Tuesday)

Excited baryon spectrum – open questions

$(D, L_N^P) S J^P$	Singlet	Octet			Decuplet	
$(56, 0_0^+) \frac{1}{2} \frac{1}{2}^+$		$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Delta(1232)$	$\Sigma(1385)$
$(70, 1_1^-) \frac{1}{2} \frac{1}{2}^-$	$\Lambda(1405)$ $\Lambda(1520)$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Delta(1620)$	$\Sigma(1900)^\dagger$
		$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Delta(1700)$	$\Sigma(1910)^\dagger$
		$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$		
		$N(1700)$	-	-		
		$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$		
$(56, 0_2^+) \frac{1}{2} \frac{1}{2}^+$		$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Delta(1600)$	$\Sigma(1780)$
$(70, 0_2^+) \frac{1}{2} \frac{1}{2}^+$	$\Lambda(1710)$	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Delta(1750)$	-
		-	-	-		
$(56, 2_2^+) \frac{1}{2} \frac{3}{2}^+$		$N(1720)$	$\Lambda(1890)$	$\Sigma(1940)$	$\Delta(1910)$	$\Sigma(2080)$
		$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Delta(1920)$	$\Sigma(2070)$
					$\Delta(1905)$	$\Sigma(2030)$
					$\Delta(1950)$	
$(70, 2_2^+) \frac{1}{2} \frac{3}{2}^+$	$\Lambda(2070)$ $\Lambda(2110)$	-	-	-	-	-
		$N(1860)$	-	-	$\Delta(2000)$	-
		$N(1880)$	-	-		
		$N(1900)$	-	-		
		$N(2000)$	-	-		
$(20, 1_2^+) \frac{1}{2} \frac{1}{2}^+$		$N(1990)$	$\Lambda(2085)$	-		
		-	-	-		
		-	-	-		
$(56, 1_3^-) \frac{1}{2} \frac{1}{2}^-$		$N(1895)$	$\Lambda(2000)$	$\Sigma(1900)^\dagger$	$\Delta(1900)$	$\Sigma(2110)$
		$N(1875)$	$\Lambda(2050)$	$\Sigma(1910)^\dagger$	$\Delta(1940)$	$\Sigma(2010)$
$(70, 3_3^-) \frac{1}{2} \frac{5}{2}^-$	$\Lambda(2080)$ $\Lambda(2100)$	$N(2060)$	-	-	$\Delta(1930)$	-
		$N(2190)$	-	$\Sigma(2100)$	-	-



⇐ First excitation band

Λ^*, Σ^* :

 Not known

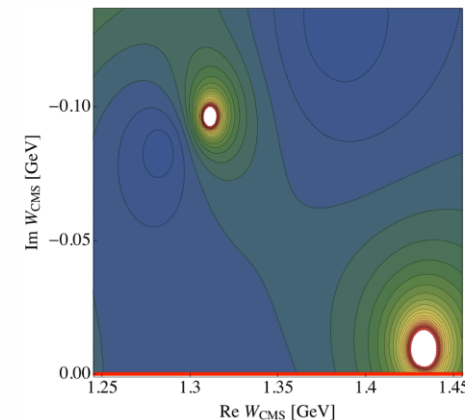
 $1^*, 2^*$ only

N^*, Δ^* :

 Not known

 $1^*, 2^*$ only

- $\Lambda(1405)$: 2 pole structure
- chiral unitary approach
- ↔ meson-baryon interaction



M. Mai EPJST (2021)
230:1593

$(m, \Gamma) = (1325 \pm 16, 180^{+24}_{-36}) \text{ MeV}$
 $(m, \Gamma) = (1429^{+8}_{-7}, 24^{+4}_{-6}) \text{ MeV}$

$\Lambda(1325)$: Singlet dom., $\Lambda(1405)$: Octet dom.

⇔ Destroys the symmetry of the 3-Quark -model

Important: Investigate the full SU(6)

$u \uparrow \downarrow, d \uparrow \downarrow, s \uparrow \downarrow$ space !

(INSIGHT: up to $m(\Lambda, \Sigma) = 2 \text{ GeV}$)

Lattice – C Morningstar this conf. ↔ 2 poles

Excited baryon spectrum – open questions



Open questions (examples):

⇔ **Do all the expected qqq -SU(6) $\times$ O(3)-states exist?**

- **Existing but experimentally not found yet?**

- ⇔ pol. photoproduction off the neutron (isospin dependence)

- ⇔ multi-meson photoproduction, further final states

⇔ **Gain a complete picture of the N^* , Δ^* -baryon spectrum**

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(SU(6): $u \uparrow \downarrow$ $d \uparrow \downarrow$ $s \uparrow \downarrow$)

⇔ **strange baryons of large interest**

- ⇔ not even the first excitation band completely know
since decades: progress hampered by the lack of high quality data

⇔ **multiquark states? molecules? 2 pole-structures?**

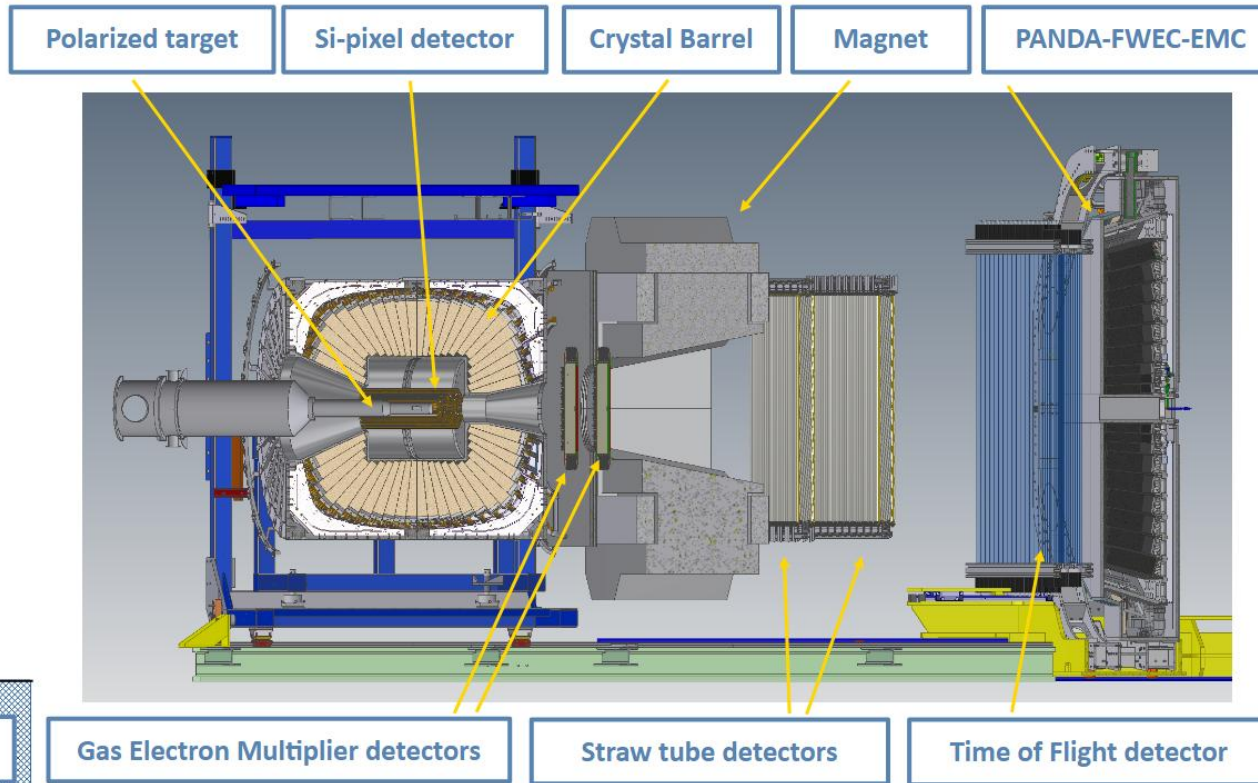
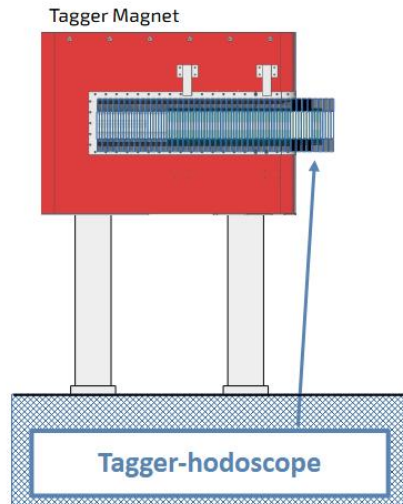
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R. Beck (Tuesday), L. Reschke (Thursday)



← Hints for interesting structures BGOOD
T. Jude (Tuesday)

Physics at ELSA - the future

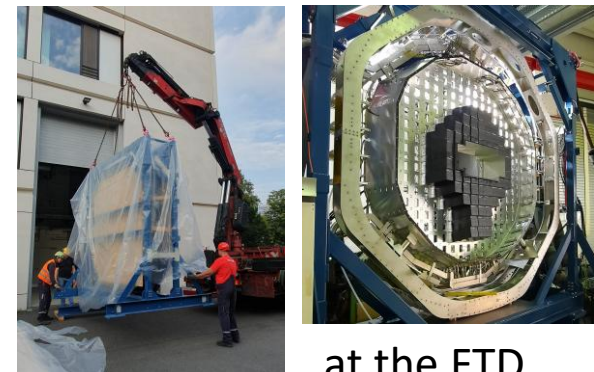
A new experiment ⇔ integral part of the new Cluster of Excellence „Color meets Flavor“:



- Over almost the entire 4π -solid angle:
- High resolution photon measurements
 - Precise charged particle detection
- Polarized beam and polarized target
- unique possibilities!



Arrival of the PANDA-FWEC
in Bonn:



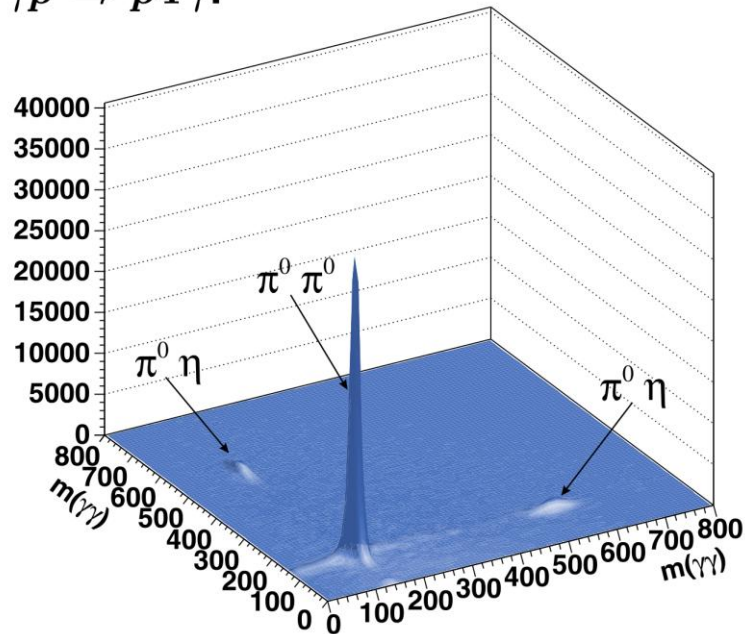
at the FTD

Performance: Photon-measurements and Charged particle identification

■ Photons from measurements:

Crystal Barrel:

$\gamma p \rightarrow p 4\gamma$:

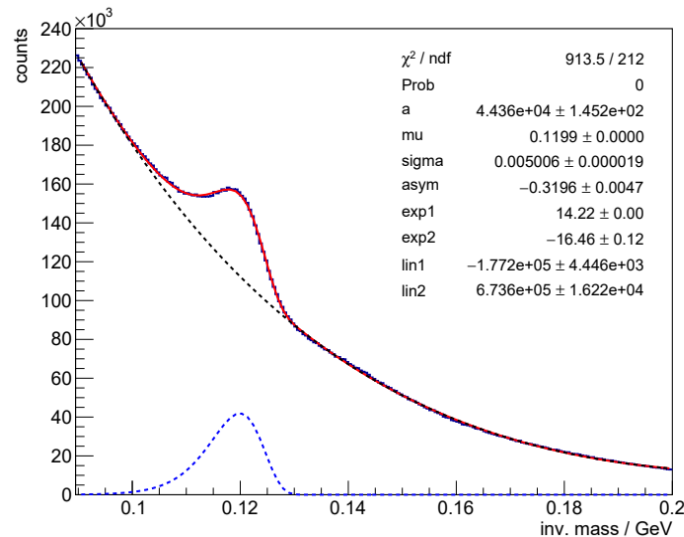


$\sigma(\pi^0) \approx 7 \text{ MeV}$

+ excellent signal to background ratio

PANDA-FWEC

@COSY testbeam (FZJ)



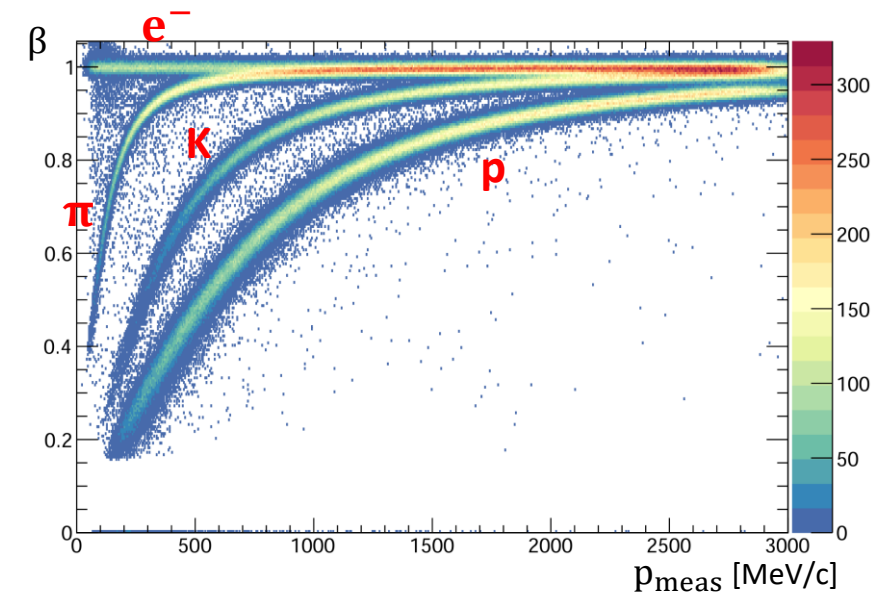
$\sigma(\pi^0) \approx 5 \text{ MeV}$

+ further improvements
to be expected

■ Charged particles:

Forward spectrometer

- from simulations



TOF @ 360cm , $\sigma = 100 \text{ ps}$

Strange baryons @INSIGHT



@ELSA, e.g.:



isospin selective

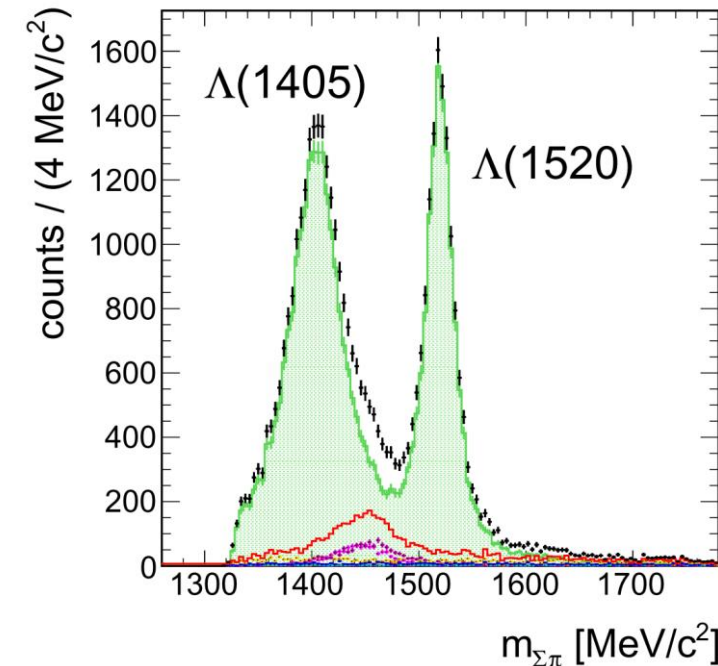
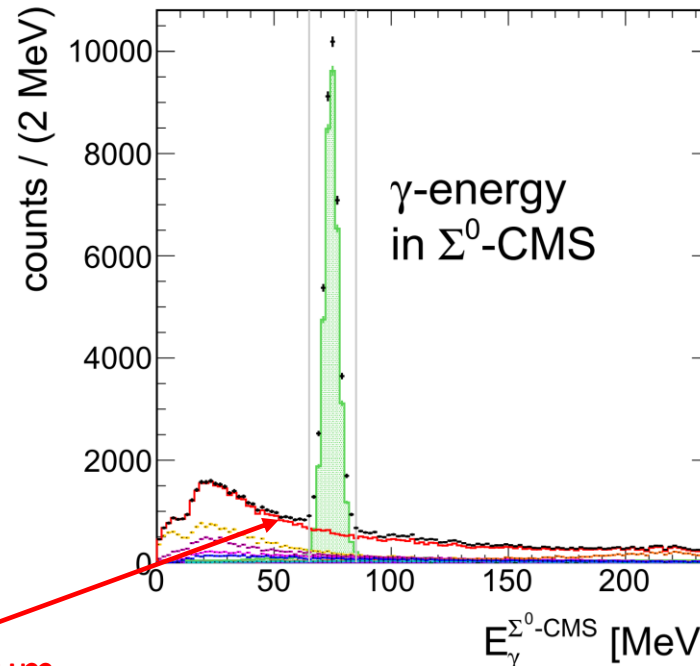
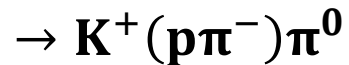


How well can we measure
strange baryons?

One example (simulations):



isospin selective



Simulated background channels:

- $K^+ \Sigma(1385): 0.8 \mu b$
- $K^0 \Sigma^+: 0.6 \mu b$
- $K^+ \Sigma^0: 1.8 \mu b$
- $p \pi^0 \eta: 3.5 \mu b$
- $p \pi^+ \pi^- \pi^0: 9 \mu b$
- $K^+ \Sigma(1385) \pi^0: 0.4 \mu b$
- $K^+ \Sigma^+ \pi^-: 1 \mu b$
- $K^+ \Lambda \pi^0: 1 \mu b$

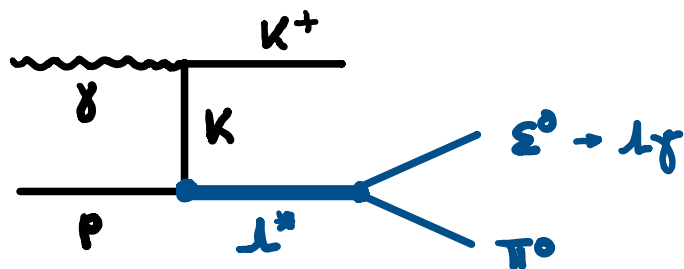
@ELSA: Advantage of polarization experiments

Several PWA groups have re-analysed the existing data (KN-scatt.) on strange baryon resonances

Almost the same data included in the fit, but quite different solutions

Use a PWA-solution toy model

⇔ calculation based on t-channel K-exchange only



Resonances based on

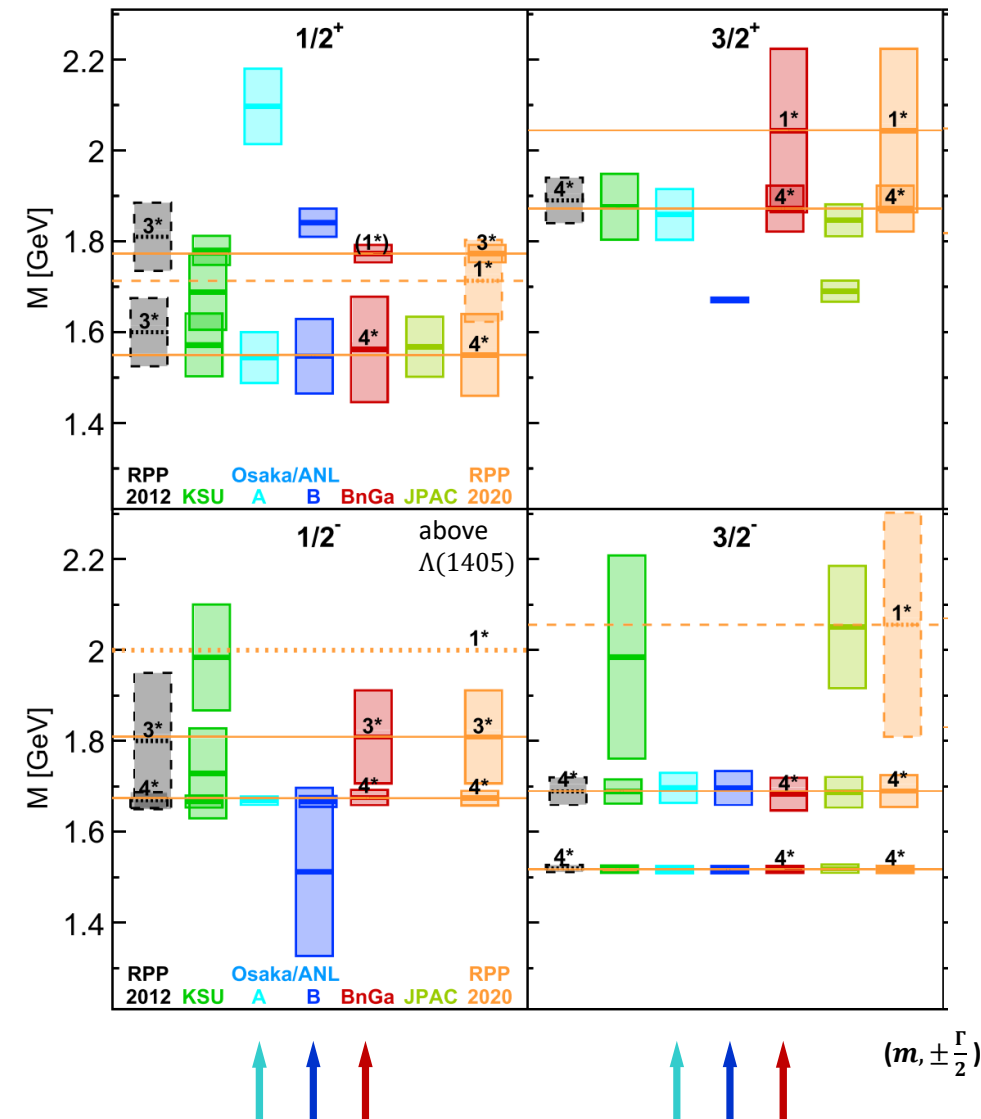
ANL/Osaka- and BnGa-PWA

Use resonance properties and $pK\Lambda^*$ couplings from BnGa

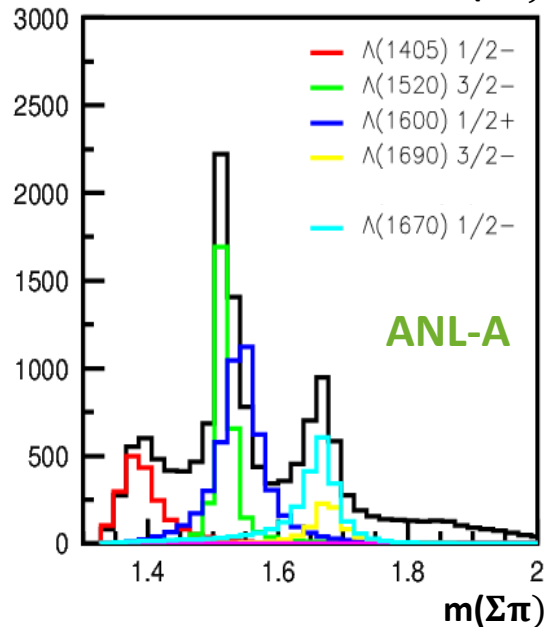
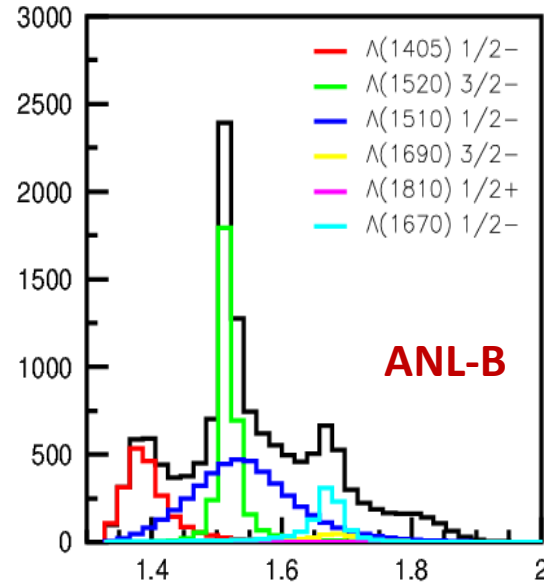
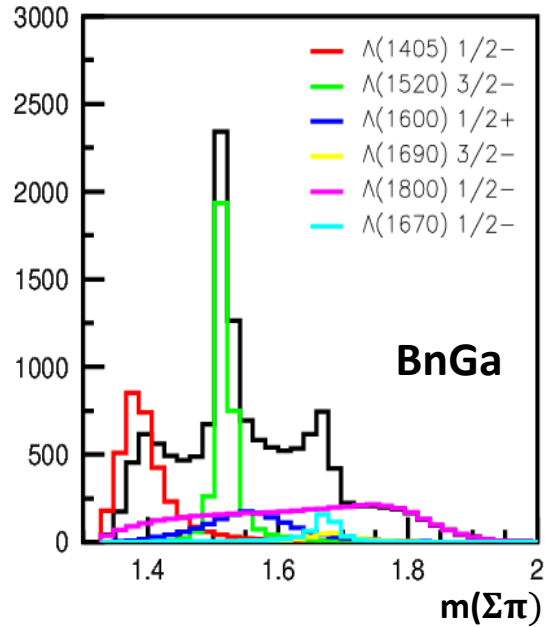
⇔ Predict solution

⇔ Fit to BnGa-“data” with ANL/Osaka pole positions

(only $J=1/2, 3/2$, $P=\pm$ shown, above $\Lambda(1405)$)



Strange baryons $\Leftrightarrow$ Predictions for $\gamma p \rightarrow \Lambda^* K^+ \rightarrow \Sigma^0 \pi^0 K^+$



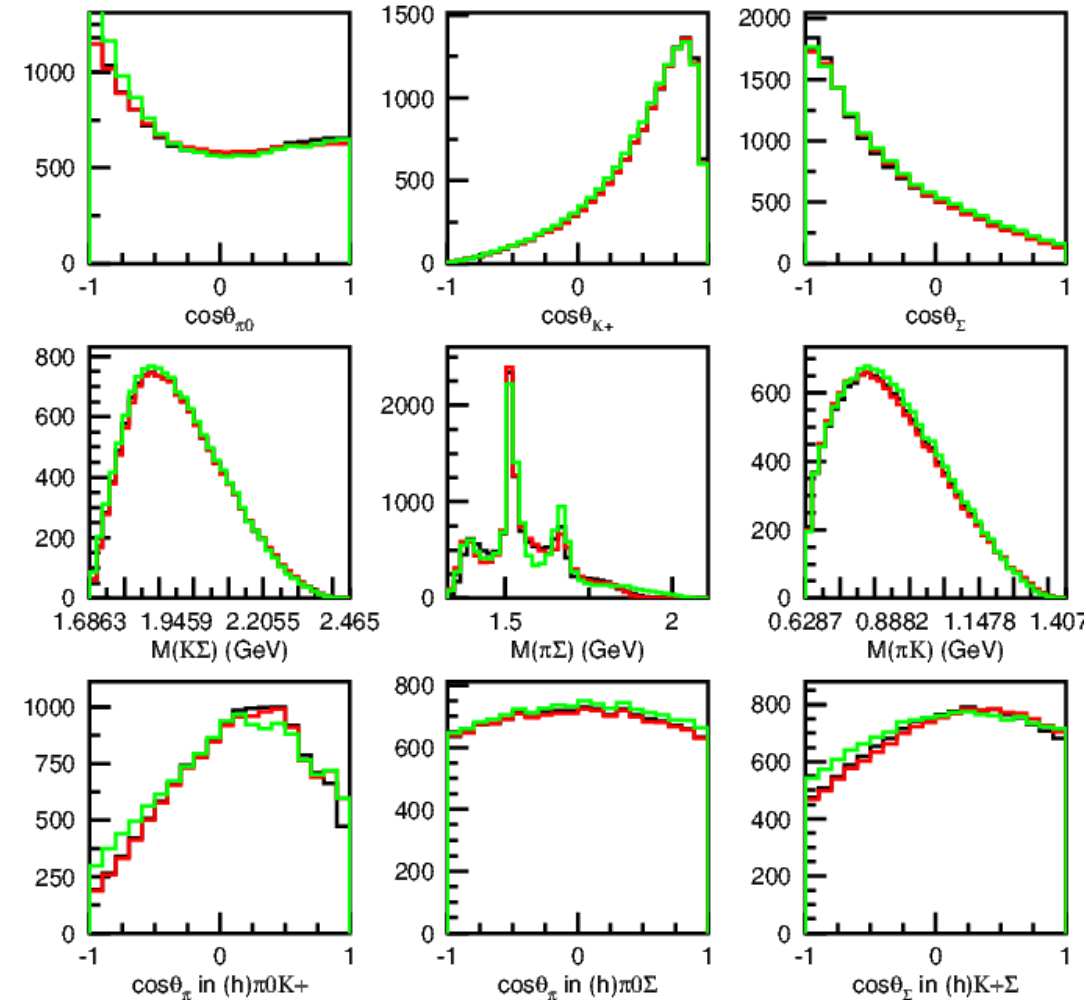
BnGa
 $\Lambda(1600)1/2^+$
 $\Lambda(1800)1/2^-$

ANL-B
 $\Lambda(1510)1/2^-$
 $\Lambda(1600)1/2^+$
 $\Lambda(1810)1/2^+$

ANL-A
 $\Lambda(1600)1/2^+$
 $\Lambda(2100)1/2^+$

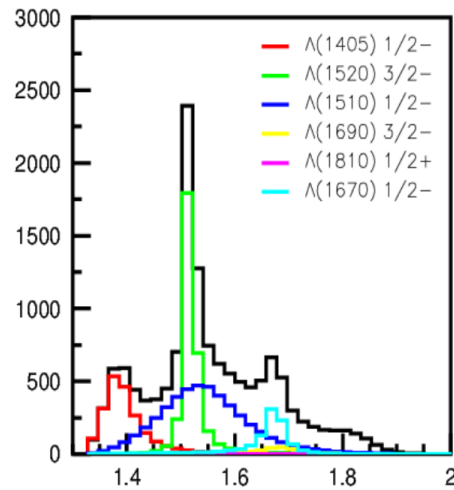
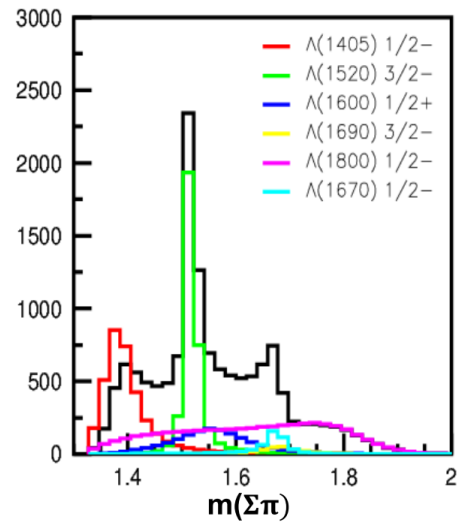
+ different resonance parameters

differential cross sections

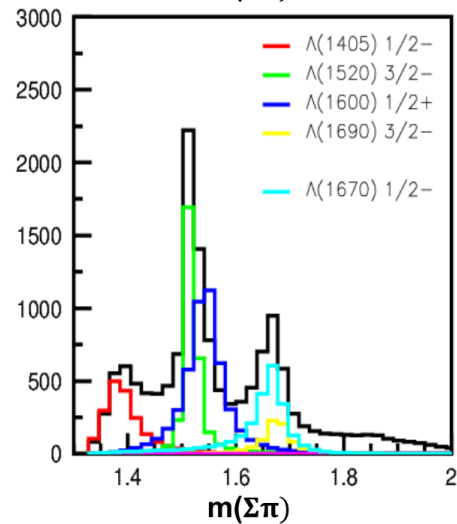


=> Almost identical distributions

Polarized target – strange baryons $\Leftrightarrow$ sensitivity studies



Measurement with
polarized target:
(1600h + 20% carbon)



BnGa

Λ(1600)1/2+
Λ(1800)1/2-

ANL-B

Λ(1510)1/2-
Λ(1600)1/2+
Λ(1810)1/2+

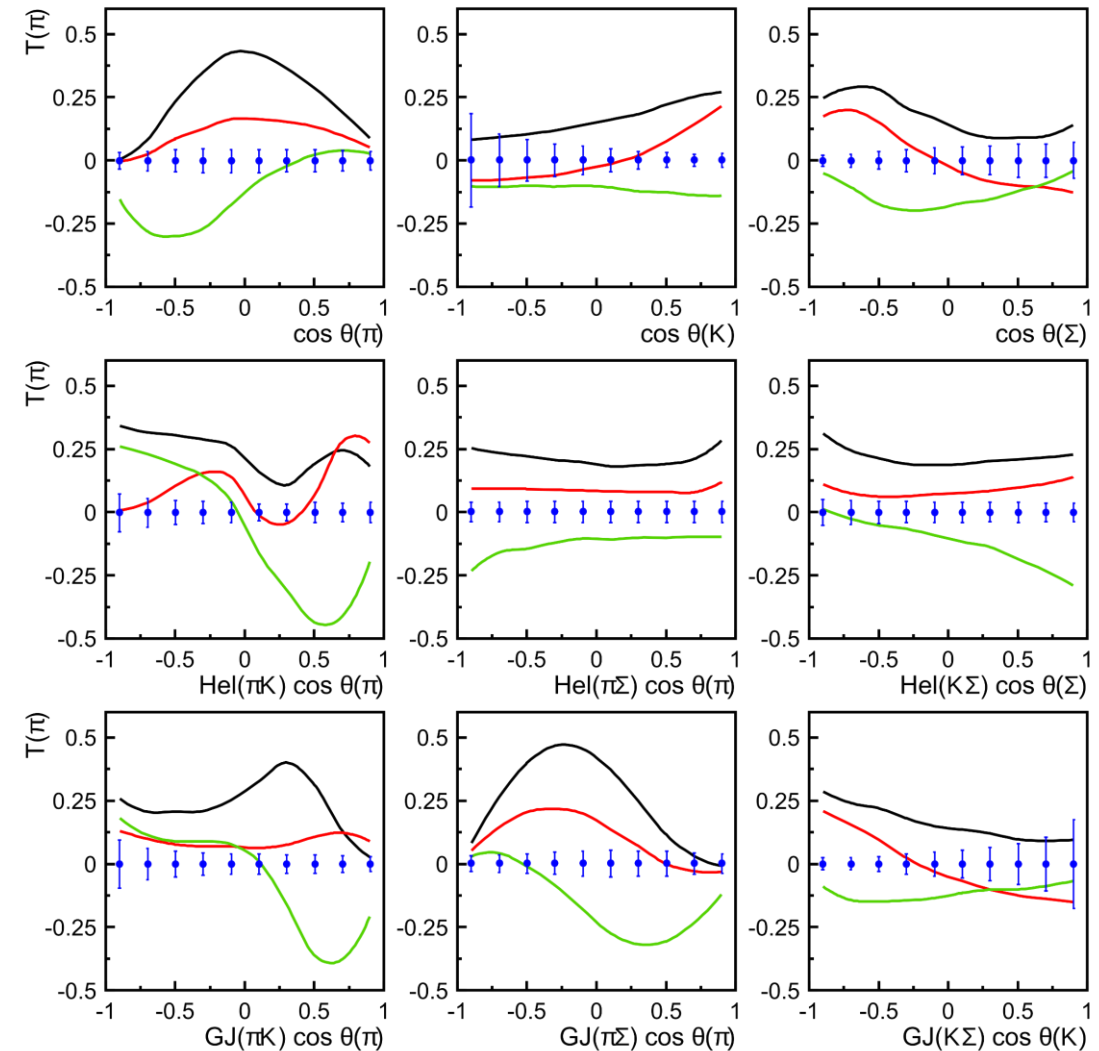
ANL-A

Λ(1600)1/2+
Λ(2100)1/2+

+ different resonance parameters

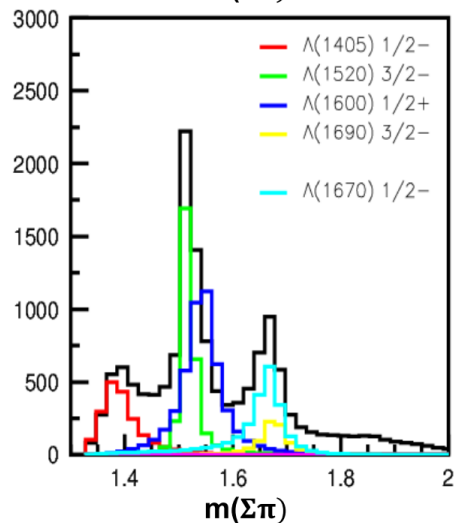
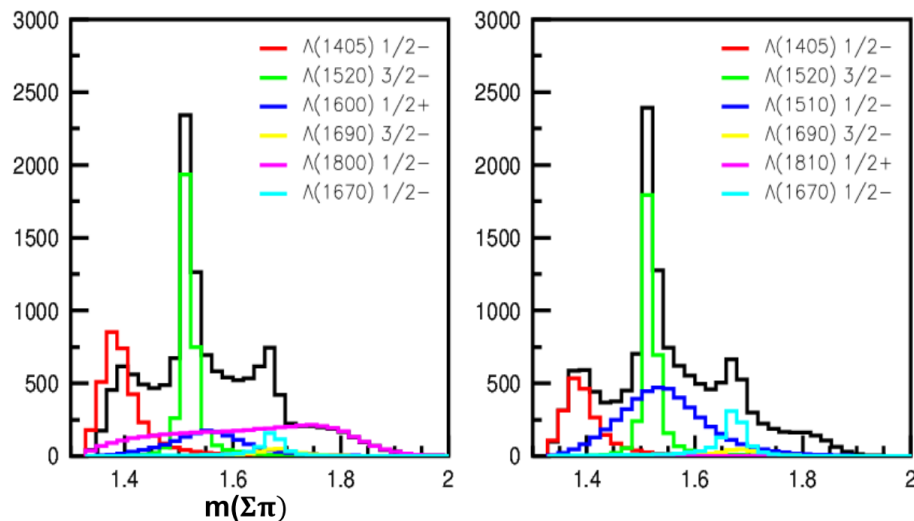
**Target asymmetry
(transv. pol.)**

W = 2.2-2.3 GeV



Target pol. 70%, dilution factor 0.7, [Acceptance from fast simulation](#)
PWA-distribution normalised to Λ(1520)-cross section at W=2.1 GeV (0.8μb)

Polarized target – strange baryons $\Leftrightarrow$ sensitivity studies



BnGa

$\Lambda(1600)1/2+$
 $\Lambda(1800)1/2-$

ANL-B

$\Lambda(1510)1/2-$
 $\Lambda(1600)1/2+$
 $\Lambda(1810)1/2+$

ANL-A

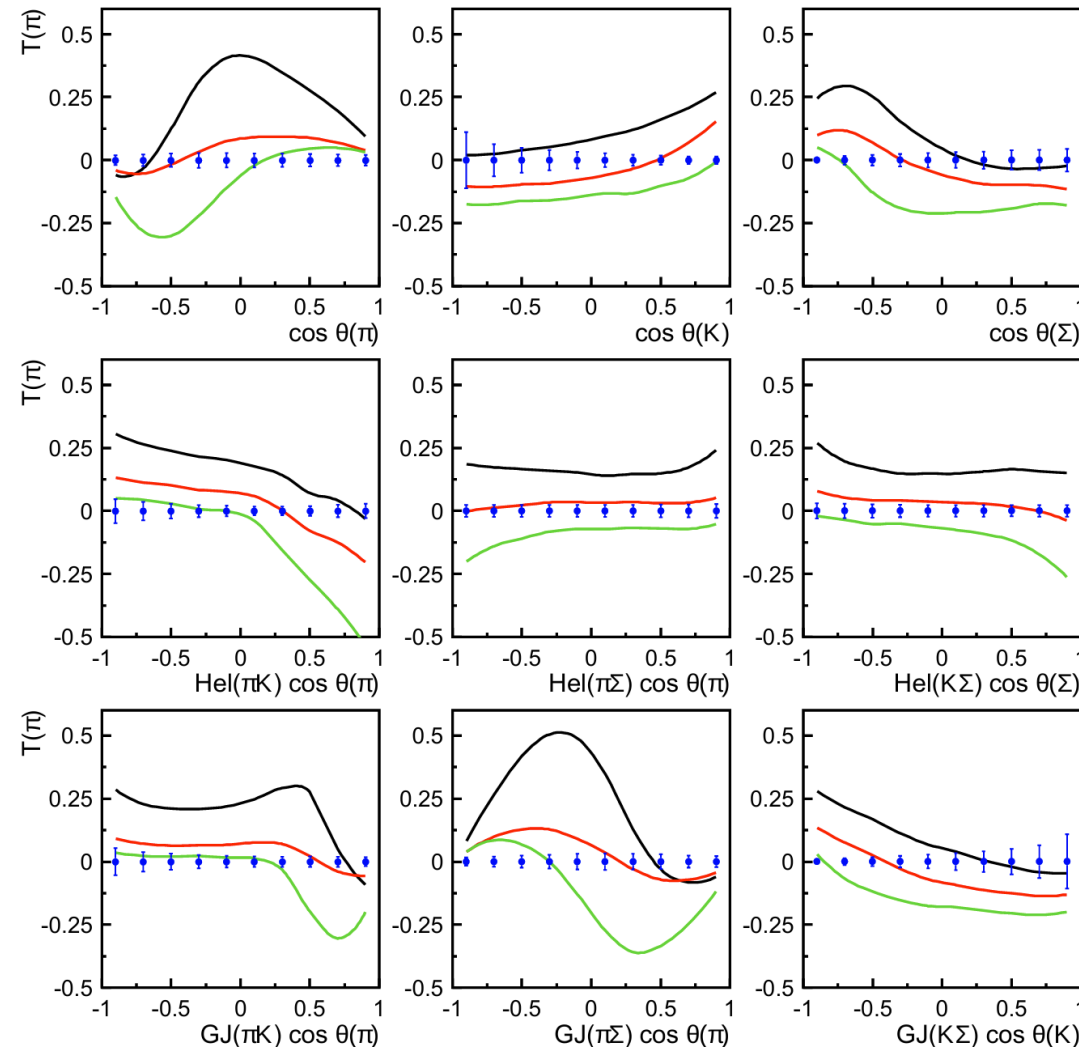
$\Lambda(1600)1/2+$
 $\Lambda(2100)1/2+$

+ different resonance parameters

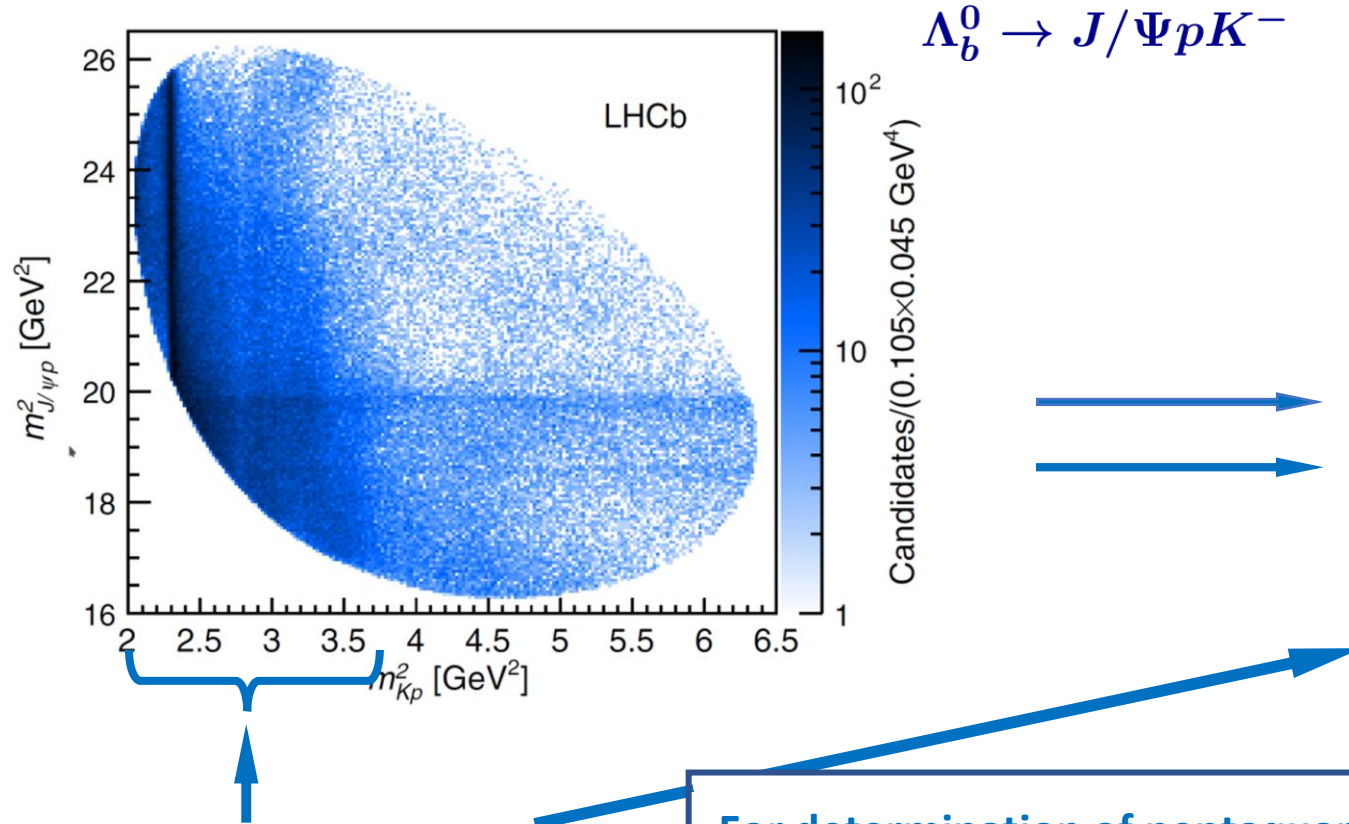
Measurement with polarized target:
(1600h + 20% carbon)

Target asymmetry
(transv. pol.)

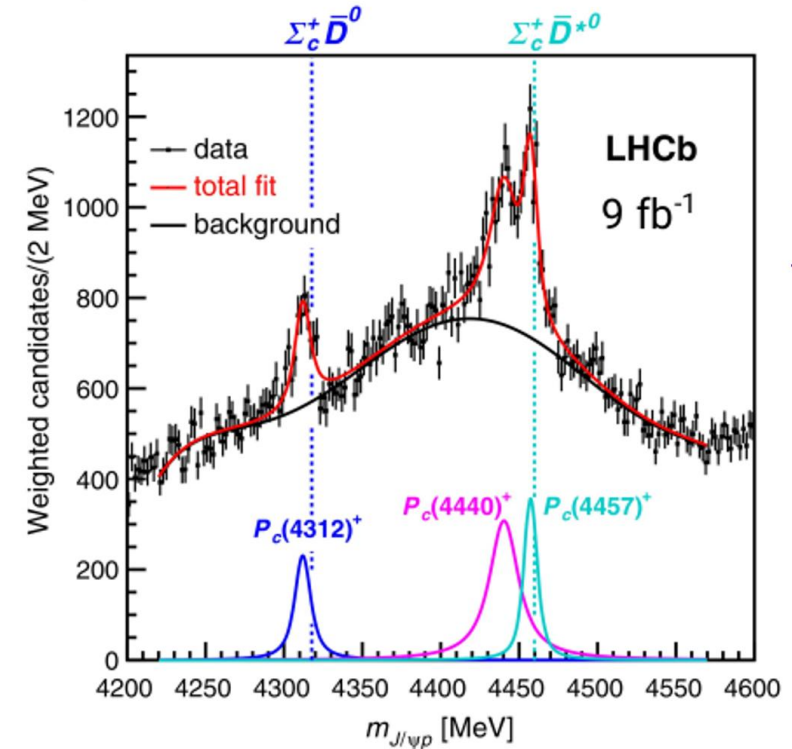
Cut on $m(\Sigma\pi) = 1.5-1.7$ GeV



Target pol. 70%, dilution factor 0.7, [Acceptance from fast simulation](#)
PWA-distribution normalised to $\Lambda(1520)$ -cross section at $W=2.1$ GeV ($0.8\mu\text{b}$)



Contribution of strange baryon resonances



For determination of pentaquark properties:

$\Leftrightarrow$ Strange baryon resonances and their properties important!

Polarisation experiments to avoid ambiguities!

$\Leftrightarrow$ Common analysis

INSIGHT@ELSA - Summary

Non-strange baryons:

Gain a complete picture of the N^* , Δ^* - baryon spectrum:

- Polarized photoproduction off the polarized proton and neutron!
- Multi-meson photoproduction

Strange baryons: (Λ^* , Σ^*):

„... the field is starved for data“ (PDG'2024)

Established resonances remained the same for more than 30 years!

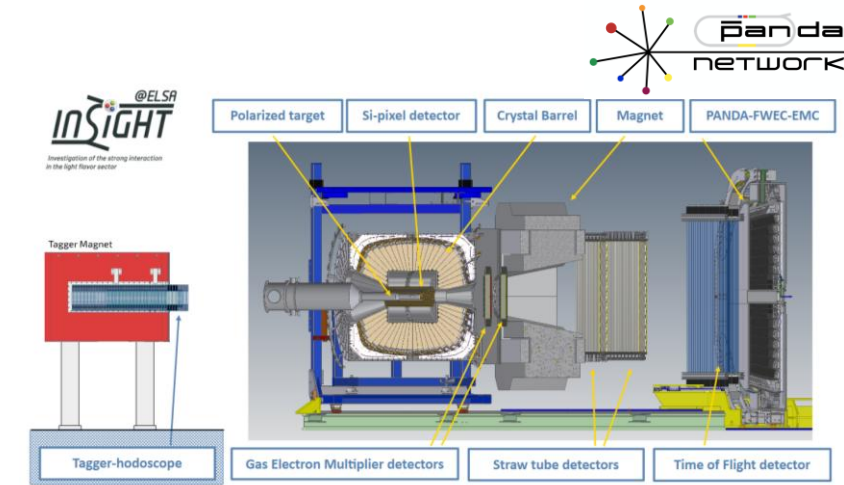
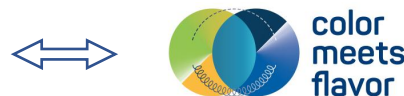
Interesting exception: Two pole structure of the (1405)

⇔ Not even all states of the first excitation band known!

- spectrum and properties of Λ^* , Σ^*
- multi-quark states? molecules? 2-pole structures?

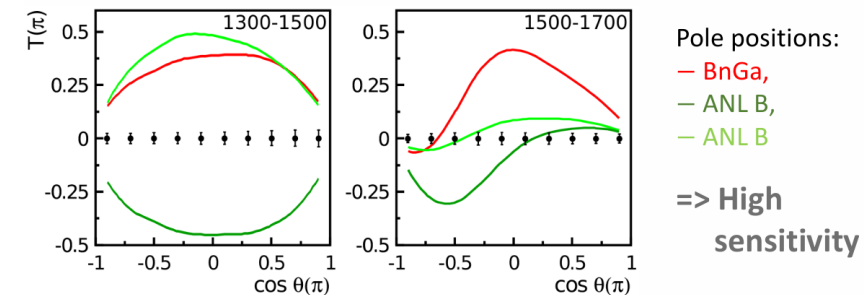
Combined PWA of LHCb and INSIGHT data: **large potential**

- Heavy hadron spectroscopy
- New phenomena in rare decays



Polarization measurements

→ unambiguous partial wave analysis



Pole positions:
— BnGa,
— ANL B,
— ANL B

=> High
sensitivity

(solutions indistinguishable in differential cross sections)

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Gain a complete picture of the N^* , Δ^* - baryon spectrum:

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„... the field is starved for data“ (PDG'2024)

Established resonances remained the same for more than 30 years!

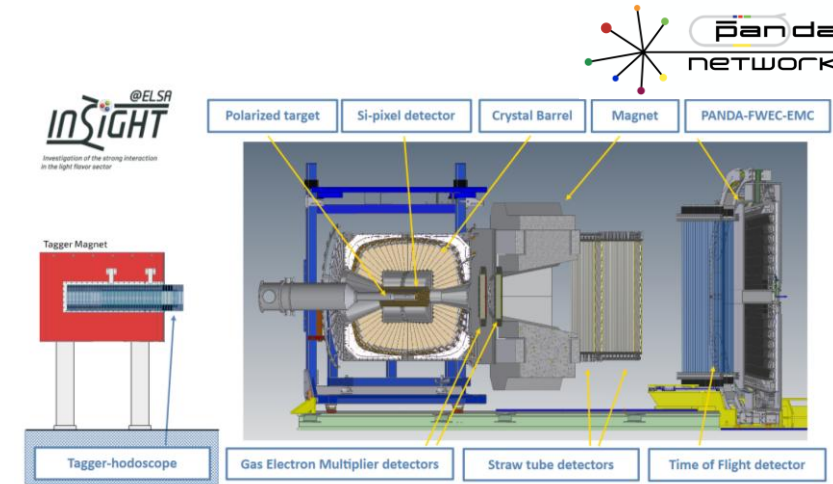
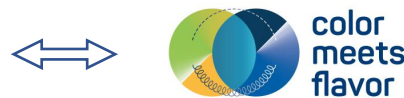
Interesting exception: Two pole structure of the (1405)

⇔ **Not even all states of the first excitation band known!**

- spectrum and properties of Λ^* , Σ^*
- multi-quark states? molecules? 2-pole structures?

Combined PWA of LHCb and INSIGHT data: **large potential**

- Heavy hadron spectroscopy
- New phenomena in rare decays



Thank you
for your attention!