Λ(1405) ‘golden channel’ measured in p+p at HADES

Seminarium Fizyki Jądra Atomowego, UW

14.05.2026

Anna Władyszewska

HADES

JAGIELLONIAN UNIVERSITY IN KRAKÓW

FAIR

GSI

PLAN

- Hypotheses and studies on Λ(1405) (constituent quark model, N$\overline{K}$ quasi-bond state, two-pole structure, kaonic hydrogen, lQCD)

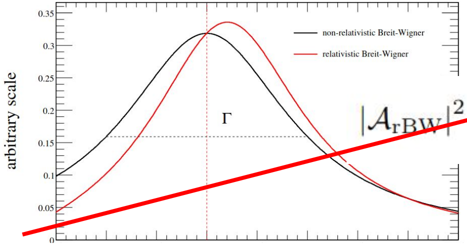
- Previous HADES measurements @ p(3.5 GeV)+p
  $p^{+}K^{+}\Lambda(1405)\to(\Sigma^{+/-}(n\pi^{+/-})\pi^{-/+})$

- Analysis of exclusive channel @ p(4.5 GeV)+p
  $p^{+}K^{+}\Lambda(1405)\to(\Sigma^{0}(\Lambda(\to p\pi^{-})\gamma)\pi^{0}(\to\gamma\gamma))$
    - particles selection
    - kinematic fitting (M_{inv}, MM constraints)
    - side-band analysis
    - preliminary results

- Perspectives
    - Invariant mass analysis in Mandelstam term bins
    - Joint analysis of $\Lambda(1405)\to\Sigma^{0}\pi^{0}$ and $\Lambda(1520)\to p\,K^{-}$ invariant mass spectra with K-matrix

Λ(1405)

- S = −1
- decays to:
  - $\Sigma^+\pi^-$
  - $\Sigma^-\pi^+$
  - $\Sigma^0\pi^0$
- decays right below $N\bar{K}$ threshold (1433 MeV)
- observed line shape is not a Breit-Wigner



$$|\mathcal{A}_{\rm rBW}|^2 = \frac{1}{2\pi}\frac{4\Gamma M M_0}{(M^2 - M_0^2)^2 + M_0^2\Gamma^2},$$

K. Moriya, *Measurement of the Lineshape, Differential Cross Sections, and Spin-Parity of the Λ(1405)*, Ph.D. Thesis, Indiana University / Jefferson Lab (2010).

Properties of Λ(1405) - PDG

Citation: S. Navas *et al.* (Particle Data Group), Phys. Rev. D **110**, 030001 (2024) and 2025 update

Λ(1405) 1/2⁻ $I(J^P) = 0(\frac{1}{2}^-)$ Status: ∗∗∗∗

Λ(1405) MASS

PRODUCTION EXPERIMENTS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
$1405.1^{+1.3}_{-1.0}$ OUR AVERAGE				

Λ(1405) WIDTH

PRODUCTION EXPERIMENTS

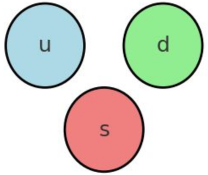
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
50.5 ± 2.0 OUR AVERAGE				

Λ(1405) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\Sigma\pi$	100 %
Γ_2	$\Lambda\gamma$	
Γ_3	$\Sigma^0\gamma$	
Γ_4	$N\bar{K}$	

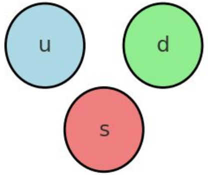
Λ(1405) as a 3-quark orbital excitation of Λ(1115)

Λ(1115)
Ground state
$J^P = 1/2^+$



Λ(1405)
Excited state
$J^P = 1/2^-$

Orbital excitation
L=1 (P-wave)



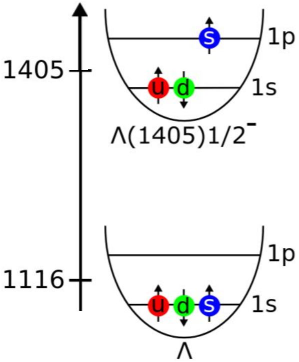


Figure adapted from: D. Werthmüller & R. A. Schumacher, *Photoproduction of the Λ(1405) Hyperon*, arXiv:1802.01720 [nucl-ex] (2018).

qqq model

Nathan Isgur i Gabriel Karl, *"P-Wave Baryons in the Quark Model"*, Physical Review D 18, 4187 (1978).

experiment
(average)

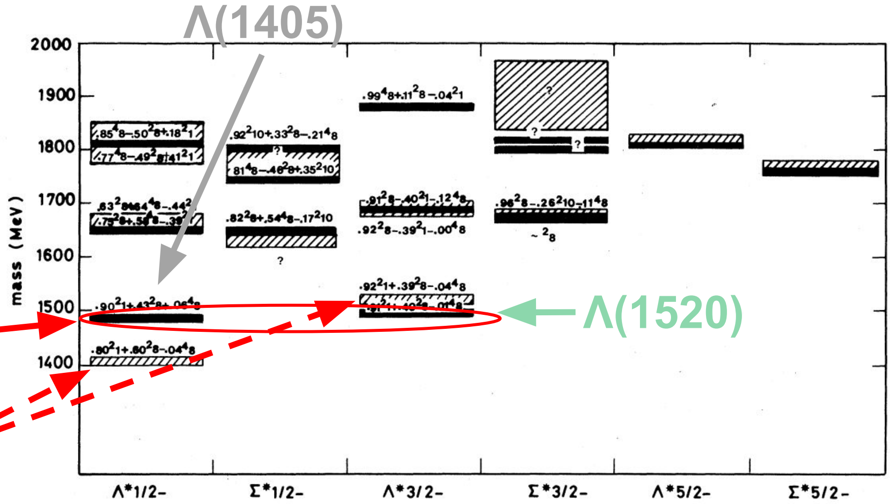


Figure 1.10: The masses of the strangeness $S = -1$ baryons predicted by Isgur and Karl [38]. The shaded boxes show the experimentally observed masses, and the black bars show the predictions of the model. The $\Lambda(1405)$ $(\Lambda^*\frac{1}{2}^-)$ mass is predicted about 80 MeV higher than its experimental value.

Source: K. Moriya, *Measurement of the Lineshape, Differential Cross Sections, and Spin-Parity of the Λ(1405)*, Ph.D. Thesis, Indiana University / Jefferson Lab (2010).

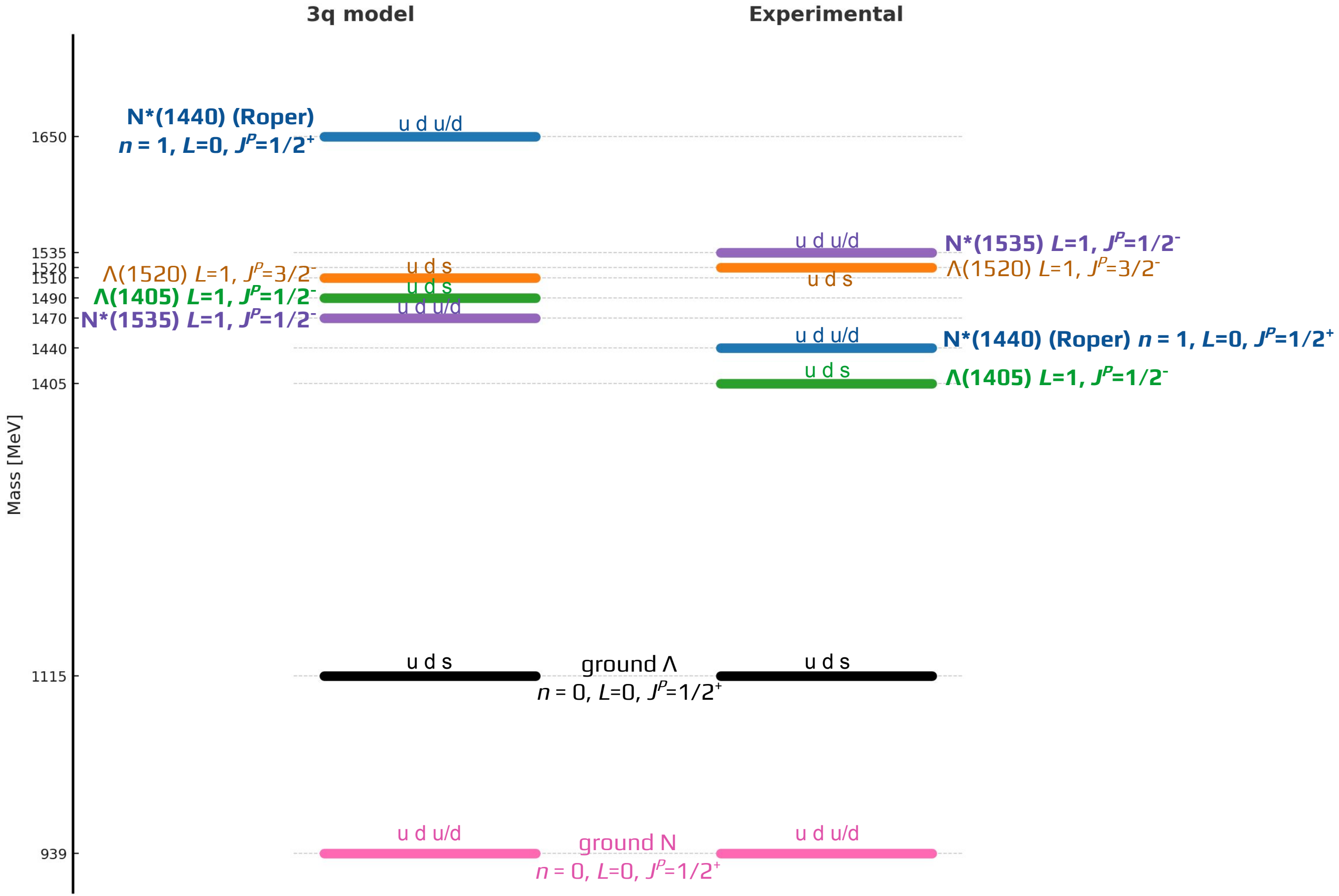
Λ(1405) not compatible with quark model predictions

Λ(1405) as a 3-quark orbital excitation of Λ(1115)

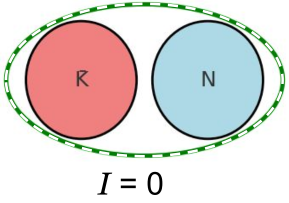
Burkert & Roberts (2019, Rev. Mod. Phys. 91, 011003)

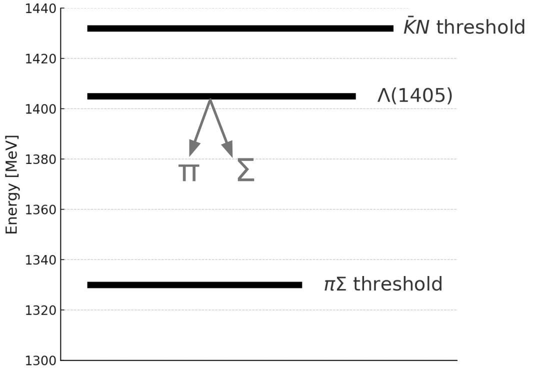
Zhong et al. (2024, arXiv:2409.07998)

Nathan Isgur i Gabriel Karl, *“P-Wave Baryons in the Quark Model”*, Physical Review D 18, 4187 (1978).



Λ(1405) as a $\bar{K}N$ quasi-bound state





Predicted by Dalitz & Tuan (1960s) examining low energy reaction of K^- + p
No data on the final Σπ state available back then

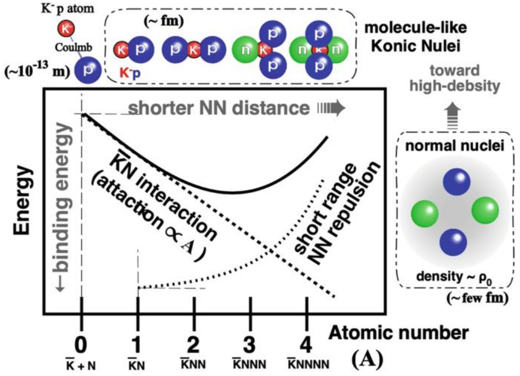
From analysis of above-threshold behaviour of K^- + p in unphysical region below p_{K-} = 0 the below threshold Σπ could be predicted

Resonance that happens in Σπ system explained as a result of an unstable bound state

NK channel plays an important role in the nature of the Λ(1405)

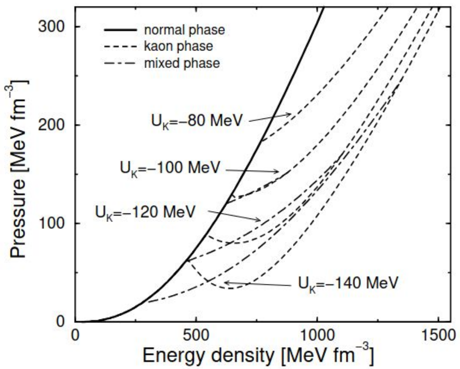
Λ(1405) as a potential doorway state" for forming K^-N bound systems K−pp ~ Λ(1405) p

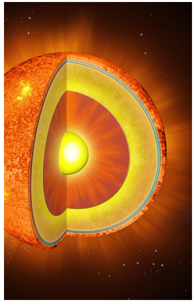
kaonic nuclei



Source: T. Yamazaki & Y. Akaishi, *Nuclear K bound states in light nuclei*, Phys. Lett. B 535, 70 (2002)

softening the EoS of the neutron star

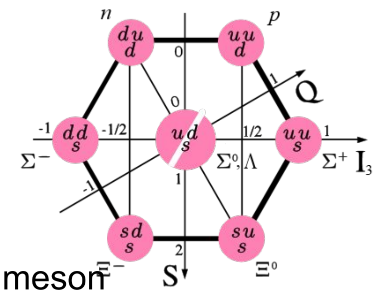


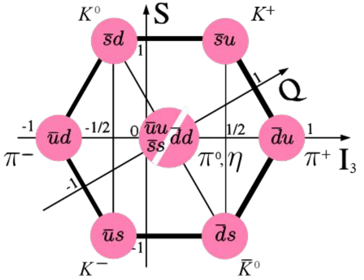


Ramos, A., Schaffner-Bielich, J., & Wambach, J., *Kaon Condensation in Neutron Stars*, arXiv:nucl-th/0011003v3 (2001)

Λ(1405) as a two-pole structure

Two nearby poles from coupled-channel dynamics



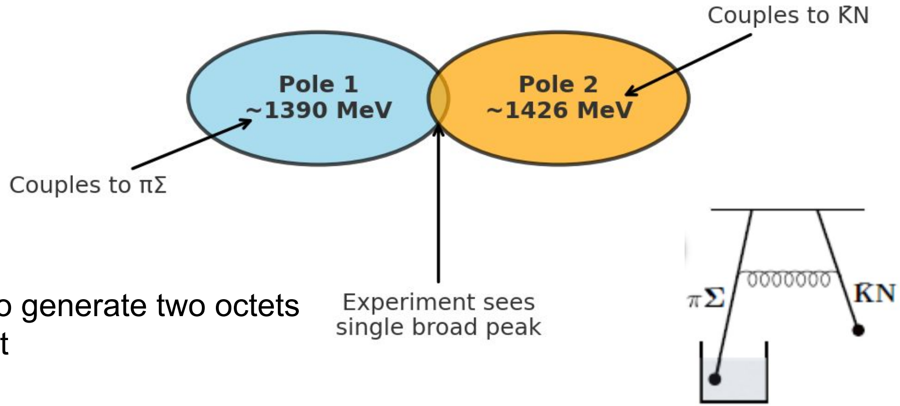


Chiral unitary approach - A.Ramos, E. Oset (2003)

- Interaction of the baryon ground-state octet with the pseudoscalar meson octet
- Effective Lagrangian constrained by chiral symmetry and flavor SU(3)
- Pseudoscalar mesons treated as pseudo-Goldstone bosons
- Unitarity and analyticity of scattering amplitudes implemented in coupled-channel dynamics
- Low-energy constants constrained by experimental data
- Multiple meson–baryon rescattering dynamically generates resonances

Λ(1405) as a two-pole structure

Two nearby poles from coupled-channel dynamics

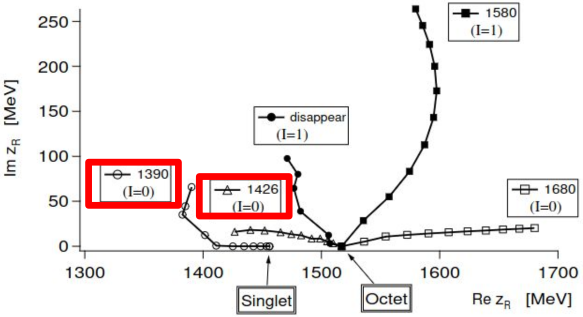


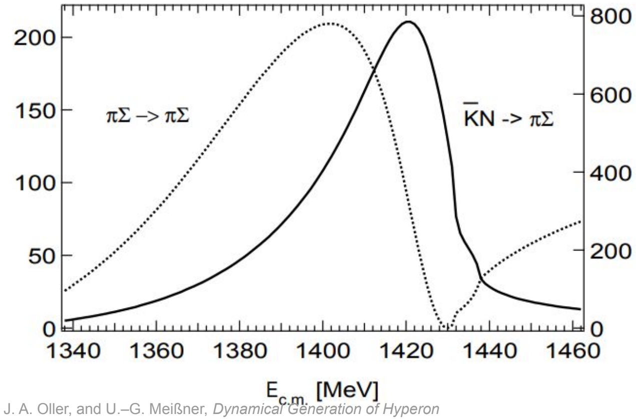
Graphic: W. Weise

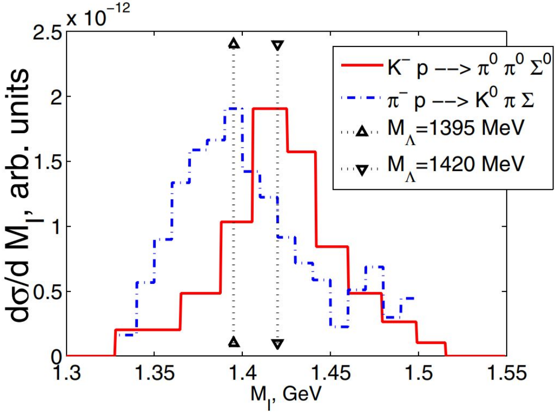
$$8 \otimes 8 = 1 \oplus 8_s \oplus 8_a \oplus 10 \oplus \overline{10} \oplus 27$$

SU(3) baryons irreps 1+8s+8a combine with 0- Goldstone bosons to generate two octets and a singlet of ½- baryons dynamically generated in the SU(3) limit

SU(3) breaking leads to two S = -1, I = 0 poles near 1405 MeV
Possible weak I=1 pole also predicted







Other poles correspond to the Σ and Λ (1670) resonances

A. Ramos, E. Oset, C. Bennhold, D. Jido, J. A. Oller, and U.–G. Meißner, *Dynamical Generation of Hyperon Resonances*, Nucl. Phys. A 754, 202–211 (2005) (originally arXiv:nucl-th/0312013, 2003).

V. K. Magas, E. Oset, and A. Ramos, *Evidence for the two pole structure of the Λ (1405) resonance*, Phys. Rev. Lett. 95, 052301 (2005), arXiv:hep-ph/0503043.

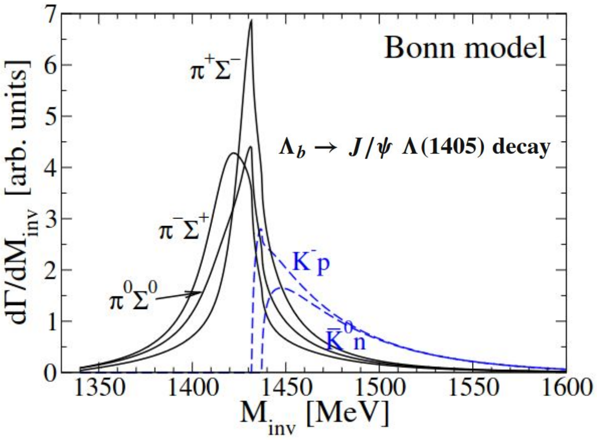
Λ(1405) line-shape depend on the decay and production channel

Isospin decomposition of πΣ channels

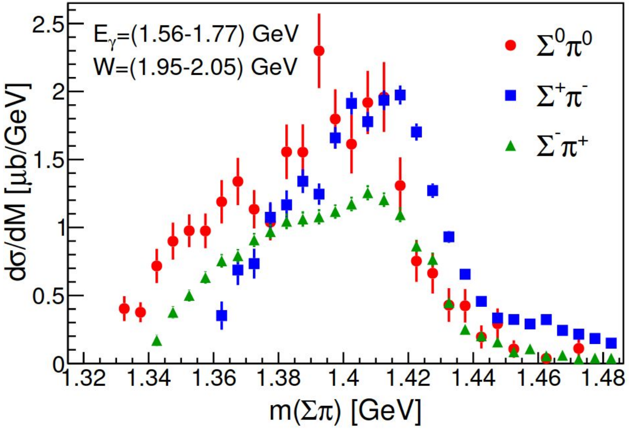
The I = 1 component might influence the line shape between decay channels

$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}\,(T^{(0)}T^{(1)*}),$$
$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\,(T^{(0)}T^{(1)*}),$$
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2,$$

Photoproduction

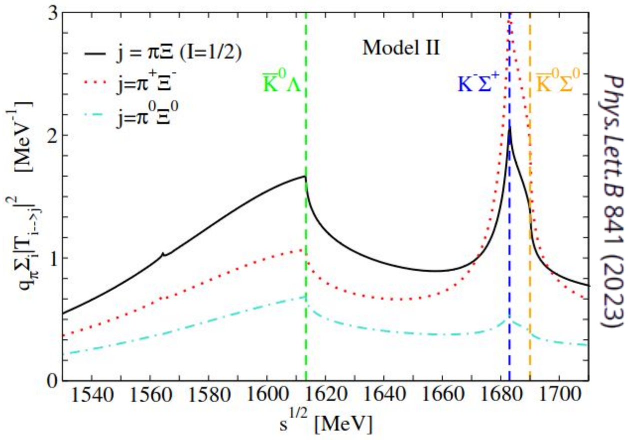


Eur. Phys. J. C75 (2015) 5, 218



D. Werthmüller & R. A. Schumacher, *Photoproduction of the Λ(1405) Hyperon*, arXiv:1802.01720 (2018)

Are there any similar structures?



S = -2

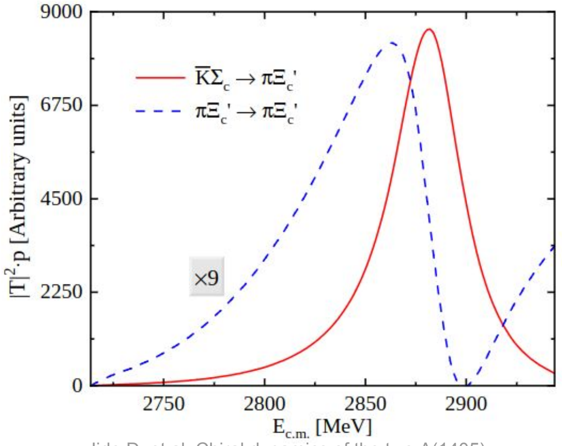
Ξ(1620), Ξ(1690) in coupled channels πΞ, Λ /Σ K

Ξ(1620) molecular state?

Ξ(1690) quasi bound state Σ $\bar{K}$?

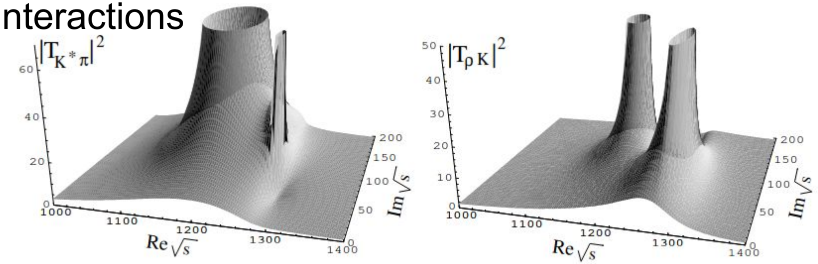
Thresholds close to Ω mass

charmed baryon sector



Jido D. et al. Chiral dynamics of the two Λ(1405) states. Nucl. Phys., A725:181–200, 2003.

K1(1270) in pseudoscalar meson – vector meson interactions



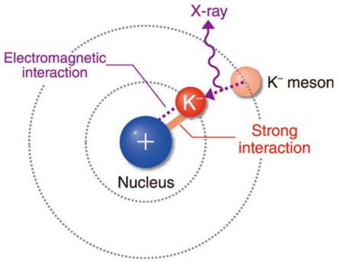
L. S. Geng, E. Oset, L. Roca, and J. A. Oller, Phys. Rev. D 75, 014017 (2007), arXiv:hep-ph/0610217.

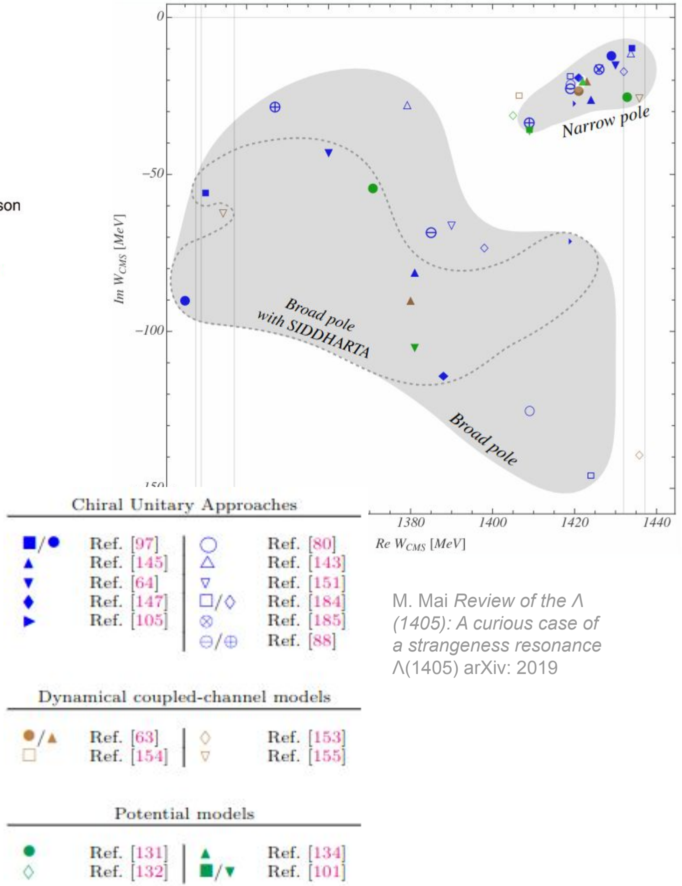
poles below the ρK and above the K*π

Kaonic hydrogen measurements

Energy shift and width of the 1s atomic state related to the complex-valued K⁻p (strong) scattering length a_{K-p}

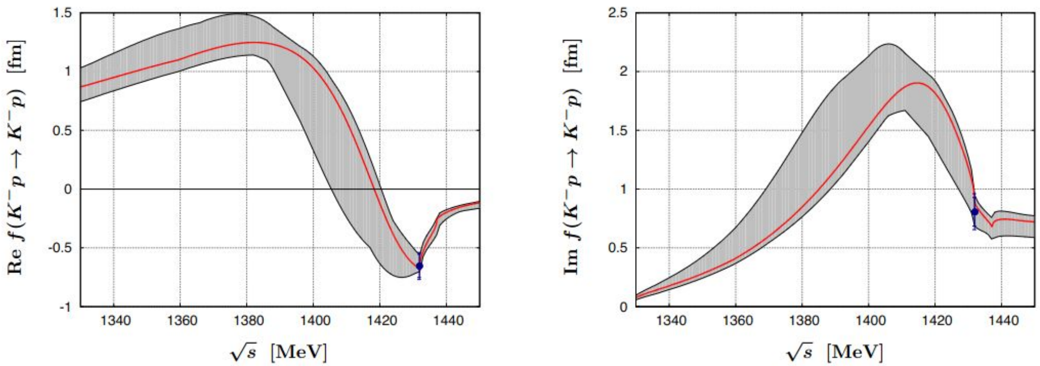
$$\Delta E - i\Gamma/2 = -2\alpha^3\mu_c^2 a_{K^-p}\left(1 - 2a_{K^-p}\alpha\mu_c(\ln\alpha - 1)\right)$$





M. Mai *Review of the Λ (1405): A curious case of a strangeness resonance* Λ(1405) arXiv: 2019

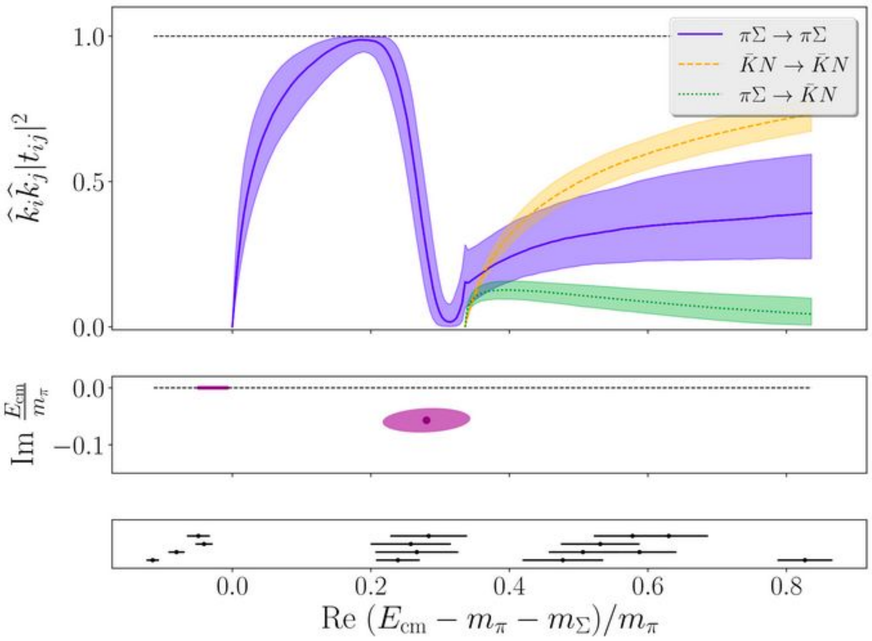
meson–baryon scattering amplitude in the K⁻N system



Y. Ikeda, T. Hyodo, W. Weise, Chiral SU(3) theory of antikaon–nucleon interactions with improved threshold constraints, Nucl. Phys. A 881 (2012) 98–114

Most data from low-energy NK scattering, kaonic atoms – not very sensitive to lower (Σπ) pole position

Lattice QCD studies



$$E_1 = 1392(9)_{\text{stat}}(2)_{\text{model}}(16)_a \text{ MeV}$$

$$\left| \frac{c^{(1)}_{\pi\Sigma}}{c^{(1)}_{\bar{K}N}} \right| = 1.9(4)_{\text{stat}}(6)_{\text{model}}$$

Stronger coupling to $\pi\Sigma$

Resonance pole

$$E_2 = [1455(13)_{\text{stat}}(2)_{\text{model}}(17)_a - i \times 11.5(4.4)_{\text{stat}}(4.0)_{\text{model}}(0.1)_a] \text{ MeV}$$

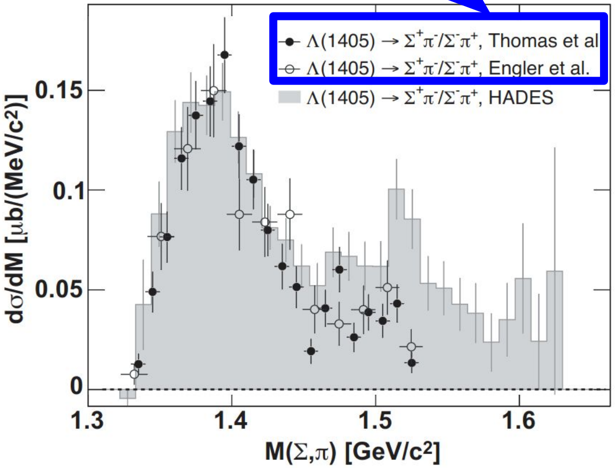
$$\left| \frac{c^{(2)}_{\pi\Sigma}}{c^{(2)}_{\bar{K}N}} \right| = 0.53(9)_{\text{stat}}(10)_{\text{model}}$$

Stronger coupling to KN

Bulava, Cid Mora, Hanlon, Hörz, Mohler, Morningstar, Moscoso, Nicholson, FRL, Skinner, Walker-Loud, 2307.13471 & 2307.10413]

Λ(1405) in proton-proton collisions @ 3.5 GeV - HADES measurements

Visible shift towards lower masses similarly to the data obtained in π^-p collisions



J. Siebenson, L. Fabbietti
Investigation of the Λ(1405) line shape observed in pp collisions
American Physical Society, *Physical Review C*, Vol. 88, No. 5, 055201 (2013).

Model with one pole:
m = 1385 MeV/c² Γ = 50 MeV/c²

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^{\pm} + \pi^{\mp}$$
$$\hookrightarrow \pi^{\pm} + n$$

$$\Sigma(1385)^0 + p + K^+ \xrightarrow{12\%} \Sigma^{\pm} + \pi^{\mp} + p + K^+,$$

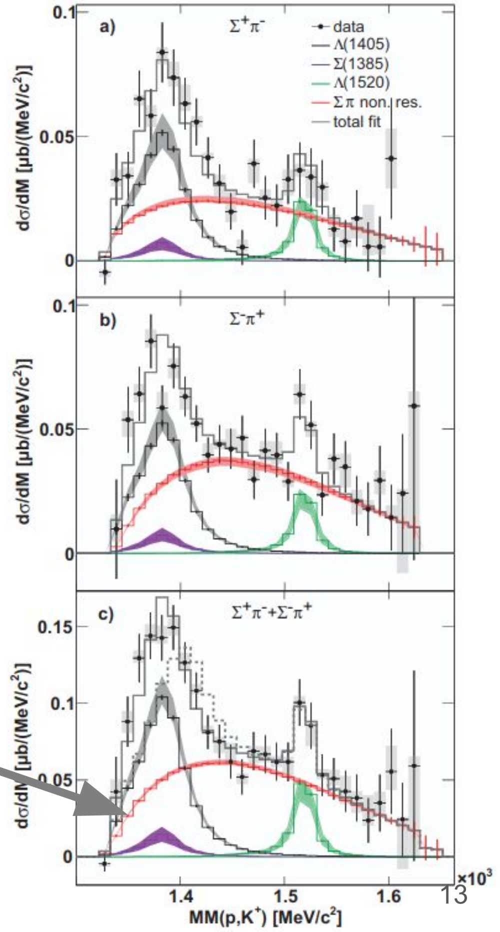
$$\Lambda(1520) + p + K^+ \xrightarrow{28\%} \Sigma^{\pm} + \pi^{\mp} + p + K^+,$$

$$\Sigma^+ + \pi^- + p + K^+,$$

Dotted line – sim sum if Λ(1405) simulated with mass 1405 MeV/c²

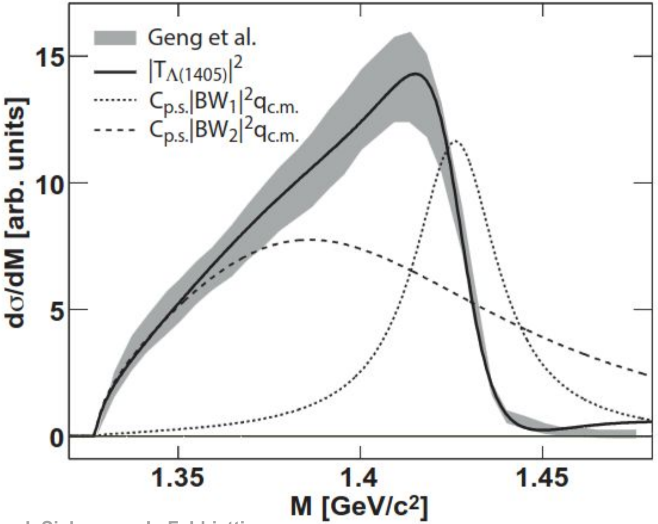
Λ(1405) overlap with **Σ(1385)**

HADES Collaboration, *Baryonic Resonances Close to the K̄N Threshold: The Case of Λ(1405) in pp Collisions*, Physics Letters B 742 (2015) 242–248.



Λ(1405) in proton-proton collisions - two-pole UχPT approach

Spectrum obtained with unitarized coupled channel calculations reconstructed with coherent sum of two Breit-Wigner functions (two Λ(1405) poles)



J. Siebenson, L. Fabbietti
Investigation of the Λ(1405) line shape observed in pp collisions
American Physical Society, *Physical Review C*, Vol. 88, No. 5, 055201 (2013).

$$BW_i = A_i \frac{1}{(m - m_{0,i})^2 + i m_{0,i}\Gamma_{0,i}}$$

$$\frac{d\sigma}{dm} = \left|T_{\Lambda(1405)}\right|^2 =$$

$$= C_{\mathrm{p.s.}}(m)\left|BW_1(m)e^{i\varphi_1} + BW_2(m)\right|^2 q_{\mathrm{c.m.}}$$

$C_{p.s.}(m)$ - dimensionless weight function, normalized to unity in the mass range of 1280-1730 MeV/c^2

BW parameters varied within ranges:

$$z_1 = 1424^{+7}_{-23} + i26^{+3}_{-14}\ \mathrm{MeV}$$

$$z_2 = 1381^{+18}_{-6} + i81^{+19}_{-8}$$

SIDDARTHA data on kaonic hydrogen

Λ(1405) in proton-proton collisions - two-pole UχPT approach

Considering the interference with the non−resonant background:

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^+\pi^-} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\alpha}A_{\Sigma^+\pi^-}T_{\Sigma^+\pi^-}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^-\pi^+} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\beta}A_{\Sigma^-\pi^+}T_{\Sigma^-\pi^+}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

m_1	Γ_1	m_2	Γ_2	A_1/A_2	φ_1
1426	28	1375	147	0.23	205°

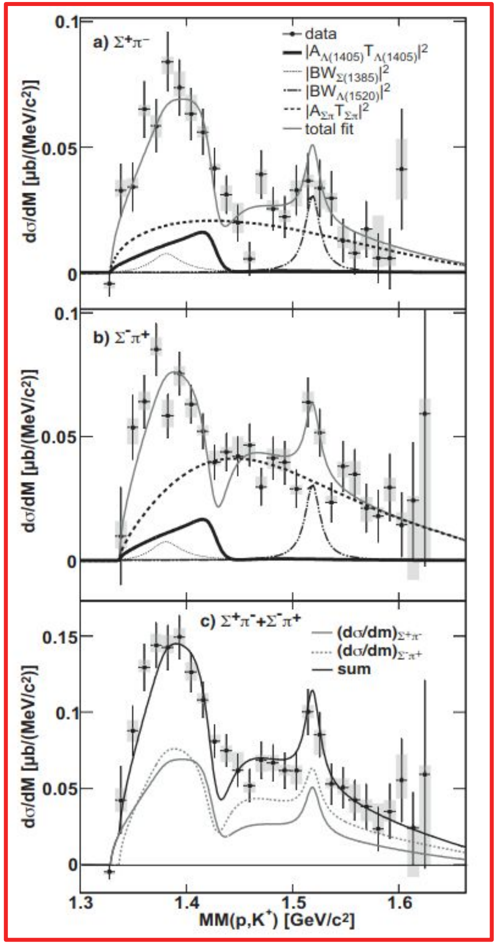
Neglecting interference with the non−resonant background:

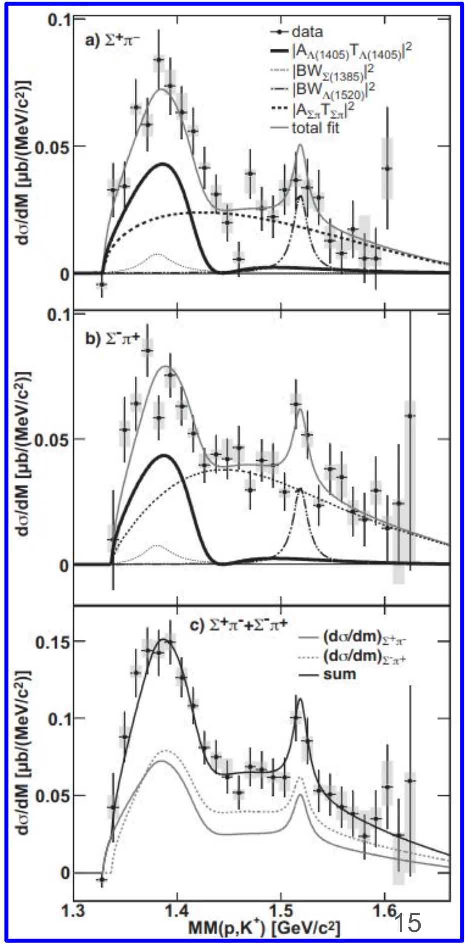
$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^+\pi^-} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)}\right|^2 + \left|A_{\Sigma^+\pi^-}T_{\Sigma^+\pi^-}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2 ,$$

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^-\pi^+} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)}\right|^2 + \left|A_{\Sigma^-\pi^+}T_{\Sigma^-\pi^+}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

$m_{0,1}$	$\Gamma_{0,1}$	$m_{0,2}$	$\Gamma_{0,2}$	A_1/A_2	φ_1
1418	58	1375	146	0.395	178°

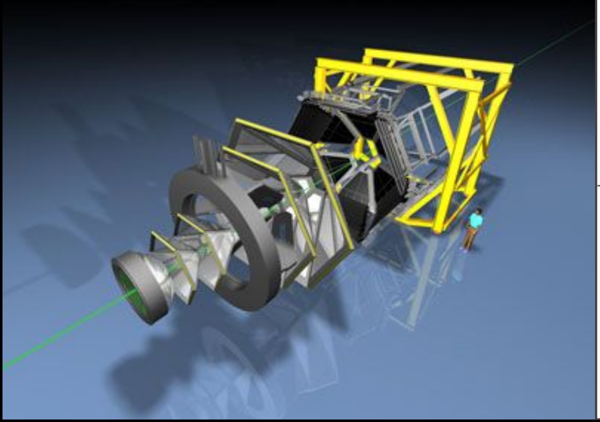
$m_{0,1}$	$\Gamma_{0,1}$	$m_{0,2}$	$\Gamma_{0,2}$	A_1/A_2	φ_1	$A_{\Sigma^+\pi^-}$	$A_{\Sigma^-\pi^+}$
1431	58	1375	146	0.204	164°	0.857	0.887





J. Siebenson, L. Fabbietti *Investigation of the Λ(1405) line shape observed in pp collisions*, *Physical Review C*, Vol. 88, No. 5, 055201 (2013).

High Acceptance DiElectron Spectrometer - HADES



https://hades.gsi.de/

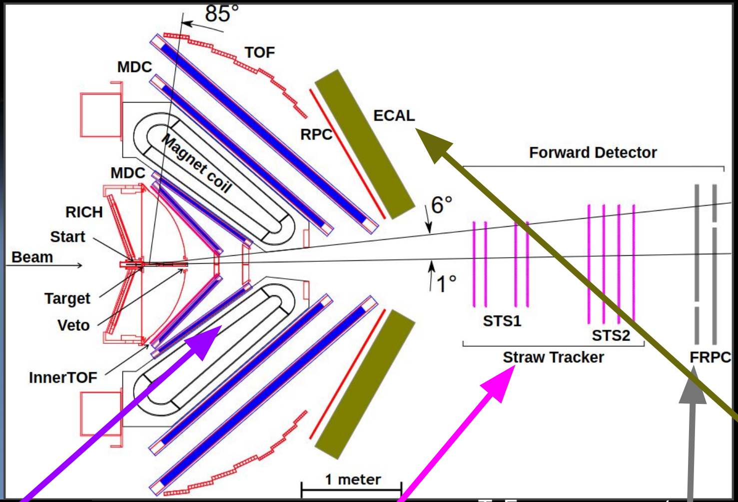
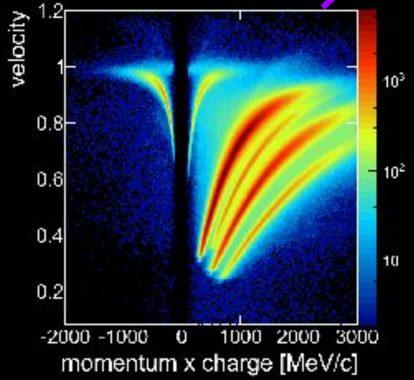


Image: Visualization of the FAIR facility, © GSI/FAIR



Source: HADES Collaboration, GSI Helmholtzzentrum für Schwerionenforschung, https://hades.gsi.de/

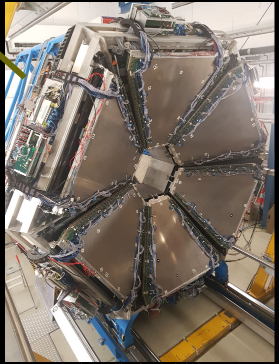
track reconstruction

increased hyperons acceptance!

J. Adamczewski-Musch et al. (HADES and PANDA@HADES Collaboration), Production and Electromagnetic Decay of Hyperons: A Feasibility Study with HADES as a Phase-0 Experiment at FAIR, arXiv:2010.06961, July (2021)

ToF measurements

Source: A. Blanco, P. Fonte, L. Lopes, J. Saraiva (for the HADES Collaboration), *The new HADES ToF Forward Detector*, arXiv:2212.02621, (2022)



https://hades.gsi.de/

$$\Sigma^0 \rightarrow \Lambda\gamma$$

$$\pi^0 \rightarrow \gamma\gamma$$

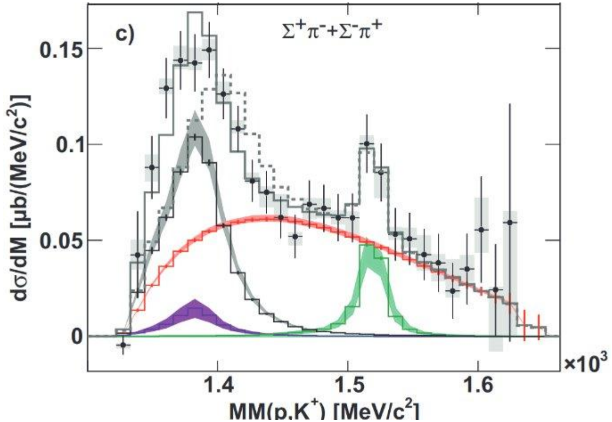
$$\Lambda(1405) \rightarrow \Sigma^0\pi^0$$

now available with significant statistics!

Of interest - ‘golden’ channel with decay to $\Sigma^0\pi^0$

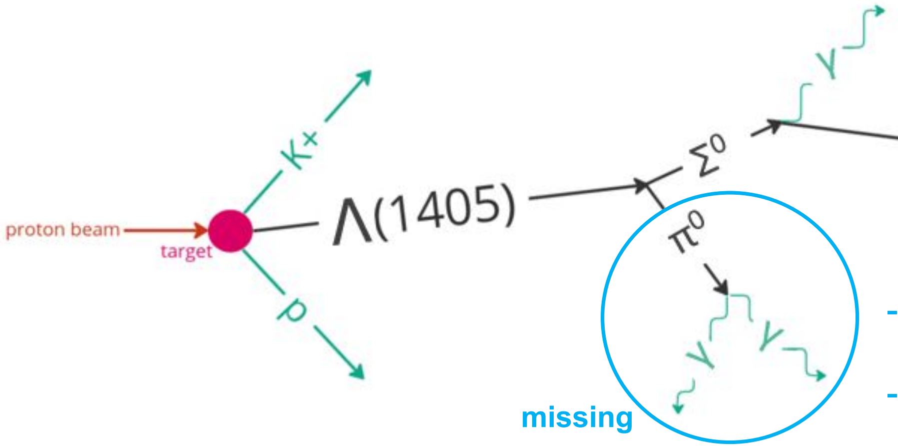
I = 0	$\Lambda(1405) \rightarrow \Sigma^0\pi^0 \rightarrow \Lambda\gamma\pi^0$
I = 1	$\Sigma(1385)^0 \rightarrow \Lambda\pi^0$

Λ(1405) overlap with **Σ(1385)** for $\Sigma^{-/+}\pi^{+/-}$ channels



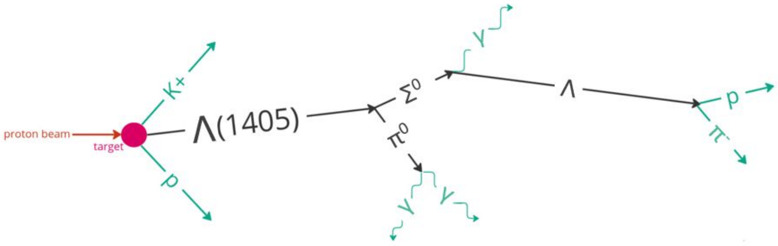
Source: G. Agakishiev *et al.*, “Baryonic resonances close to the K̄N threshold: the case of Λ(1405) in pp collisions,” *Physics Letters B* **742** (2015) 242–248.

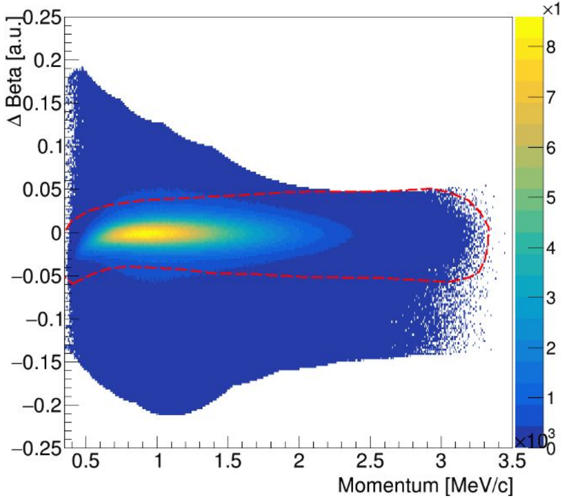
Possibility to disantangle Λ(1405) from Σ(1385)



- better sensibility to the line shape within exclusive channel reconstruction
- MM technique without requirement of direct detection of π0->γγ => prominent acceptance

Particles identification





p and π⁻ in main HADES module (magnetic spectrometer)

1) graphical cuts on velocity (β) vs. momentum
2) Λ->pπ⁻ preselection - topology and MM cuts
3) 3.5σ criteria in β-β$_{th}$ vs. momentum slices

$$\Delta\beta = \beta_{exp} - \beta_{theor}(p)$$

$$\beta_{theor} = \sqrt{1 - \frac{m^2}{p^2+m^2}}$$

K⁺ in main HADES

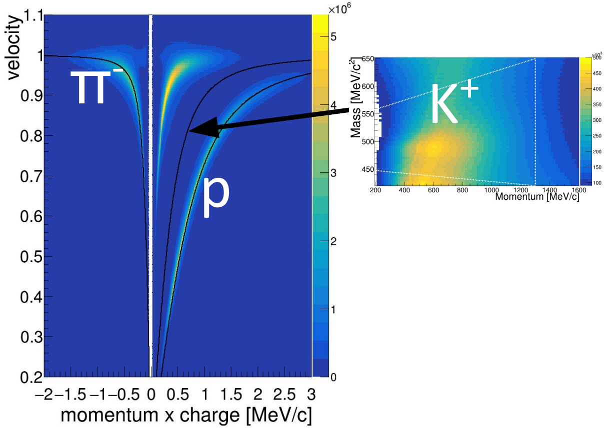
- cut on mass vs. momentum

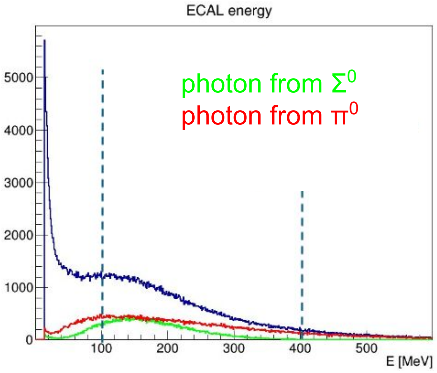
p in Forward Tracker

- majority are protons (based on MC SIM)

γ in ECAL

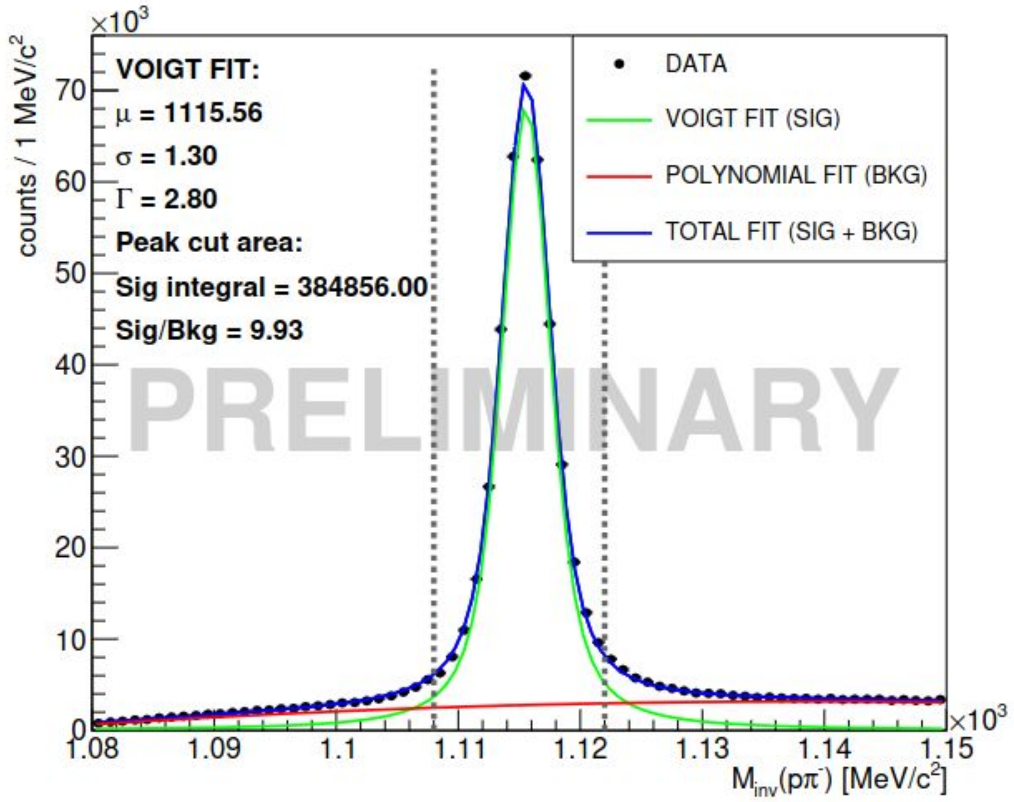
- 100 MeV < energy$_\gamma$ < 400 MeV
- 0.8 < β_γ < 1.2

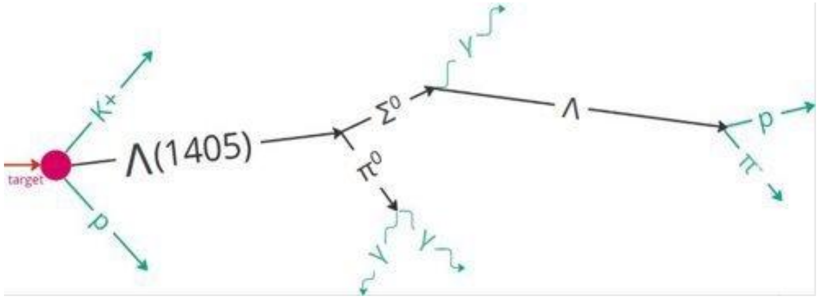




Λ selection

>=1 π-, >=1 K+, >=1 γ, >=2 p



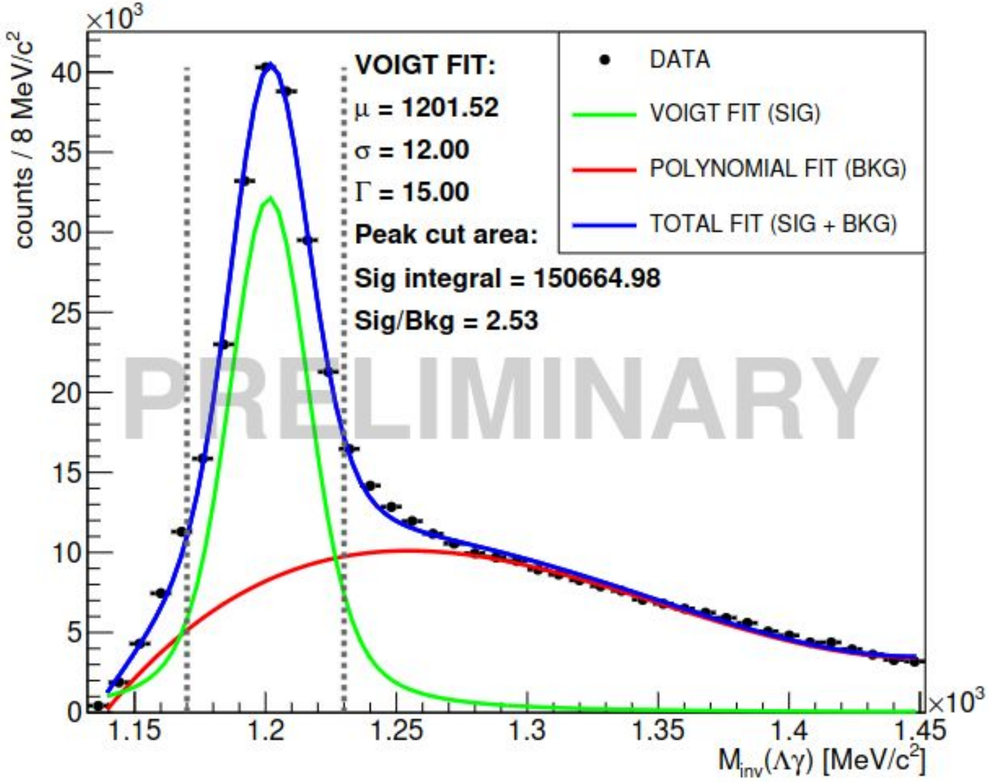


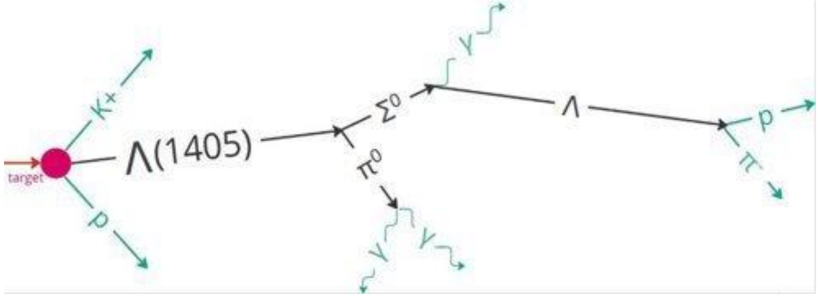
PDG: 1115.683 ± 0.006

Protons that did not fall into the Λ mass cut region are from now on marked as protons coming from event vertex (spectators)

Σ^0 selection

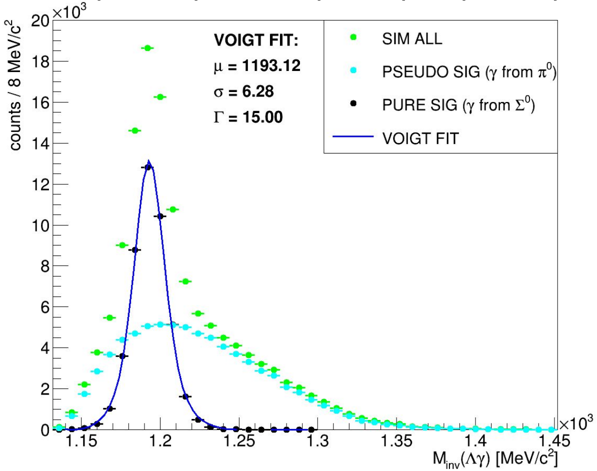
>=1 Λ, >=1 proton spectator





SIMULATION

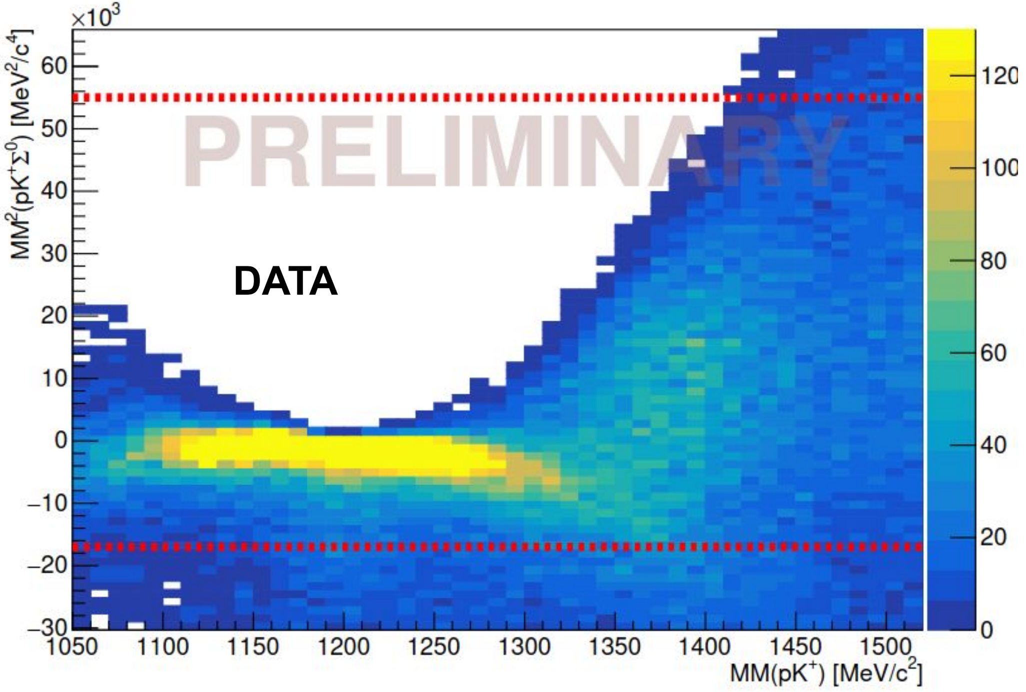
$pK^+\Lambda(1405)$ [->π^0(->γγ)Σ^0(->Λγ)]

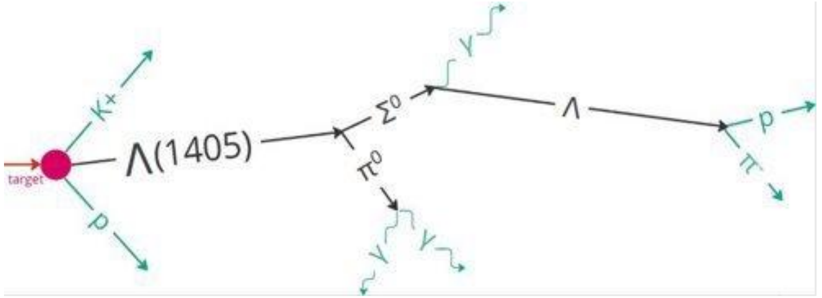


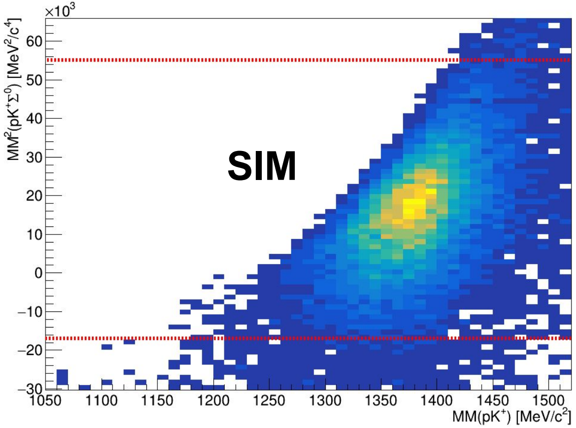
Σ^0 PDG:

Mass $m = 1192.642 \pm 0.024$ MeV

π^0 vs. $\Lambda(1405)$ expected signal







Kinemating fitting

WHY?

- to reduce measurement uncertainties => improve the resolution
- basic of event selection => improve signal to background

HOW?

- imposing specific conditions (kinematic / geometric constraints)
- solving mathematical minimization problem (e.g. the Lagrange multiplier technique)

=> Improved set of parameters

Errors parametrization is crucial!

Kinemating fitting

$$\chi^2\left(\overrightarrow{x}\right) = \left(\overrightarrow{y} - \overrightarrow{x}\right)^T V^{-1}\left(\overrightarrow{y} - \overrightarrow{x}\right)$$

x – measured
y – estimated
V – covariance matrix

$$f\left(\overrightarrow{x}, \overrightarrow{\xi}\right) = 0$$

f - constraint
ξ - unmeasured

$$\chi^2\left(\overrightarrow{x}, \overrightarrow{\xi}, \overrightarrow{\lambda}\right) = \left(\overrightarrow{y} - \overrightarrow{x}\right)^T V^{-1}\left(\overrightarrow{y} - \overrightarrow{x}\right) + 2\lambda^T f\left(\overrightarrow{x}, \overrightarrow{\xi}\right)$$

Minimization:

$$\nabla_x \chi^2 = -2V^{-1}\left(\overrightarrow{y} - \overrightarrow{x}\right) + 2D_x^T \overrightarrow{\lambda} = 0$$

$$\nabla_\xi \chi^2 = 2D_\chi^T \overrightarrow{\lambda} = 0,$$

$$\nabla_\lambda \chi^2 = 2\overrightarrow{f}^T = 0.$$

λ - Lagrange parameters

D - derivative matrix of constraint equation

Computing and Software for Big Science (2024) 8:3
https://doi.org/10.1007/s41781-023-00112-x

RESEARCH

KinFit: A Kinematic Fitting Package for Hadron Physics Experiments

Waleed Esmail[1] · Jana Rieger[2] · Jenny Taylor[1,2] · Malin Bohman[2] · Karin Schönning[2]

Received: 7 September 2023 / Accepted: 20 December 2023

The iterative procedure is obtained changing the parameters and errors values.

Stopped when convergence is reached based on one of criteria: change in χ^2, constraint equation norm, or change in track parameters (Default threshold: 10^{-4}, with a maximum of 20 iterations)

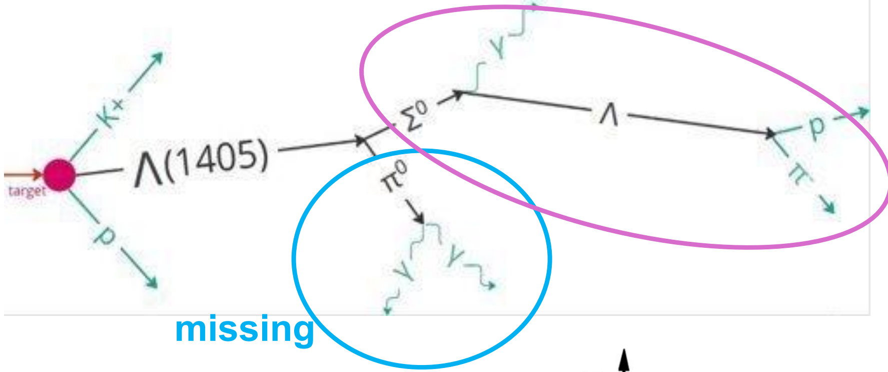
Constraints examples (1C)

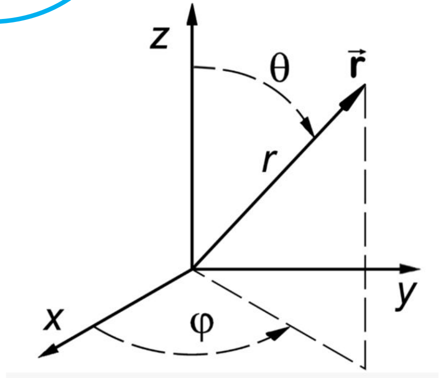
1C: Invariant mass constraint:

$$f = \sqrt{\left(\sum_{i=1}^{N} E_i\right)^2 - \left(\sum_{i=1}^{N} \vec{p}_i\right)^2} - m_{\text{mother}} = 0$$

1C: Misssing mass constraint:

$$f = \sqrt{\left(E_{\text{ini}} - \sum_{i=1}^{N} E_i\right)^2 - \left(\vec{p}_{\text{ini}} - \sum_{i=1}^{N} \vec{p}_i\right)^2} - m_{\text{miss}} = 0$$





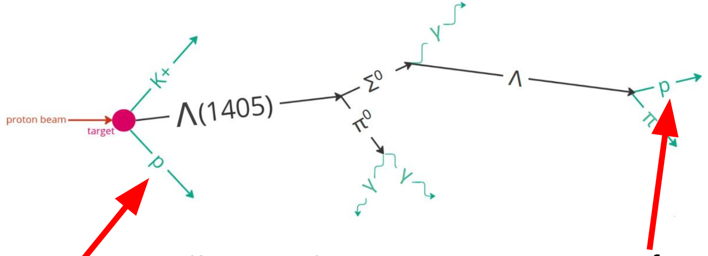
Input – measured parameters (pure kinematic fit):

- inverse momentum 1/p [MeV^{-1}/c]
- polar angle θ [radians] defined from 0 to π
- azimuthal angle ϕ [radians] defined from $-\pi$ to π relative to the beam (z) axis

Verification of the method: P(χ^2)

$$pull_i = \frac{y_i - \eta_i}{\sqrt{\sigma^2(y_i) - \sigma^2(\eta_i)}}$$

should be centered around 0
with a variance = 1



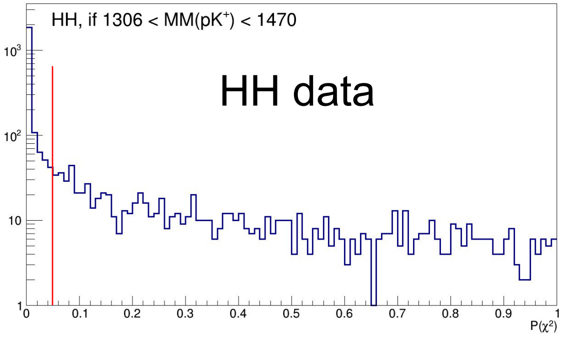
proton spectator (first letter)

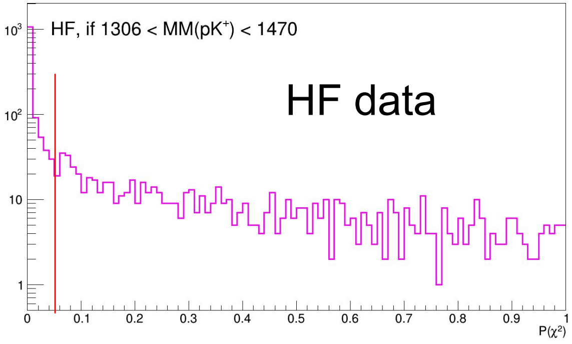
p from Λ decay (second letter)

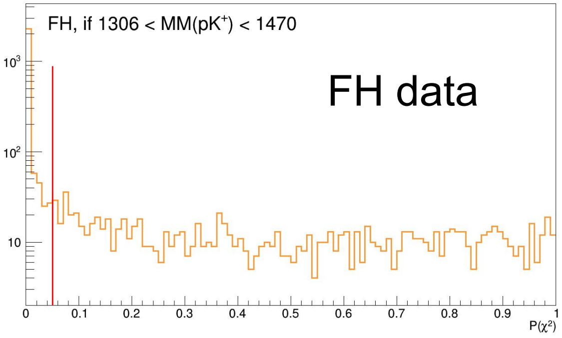
H – detected in HADES F – detected in Forward Tracker

$$p = \int_{\chi^2}^{\infty} f_{\mathrm{NDF}}(z)\, dz$$

Overestimation of errors → p-distribution pulled to higher values
Underestimation of errors → p-distribution pulled to lower values





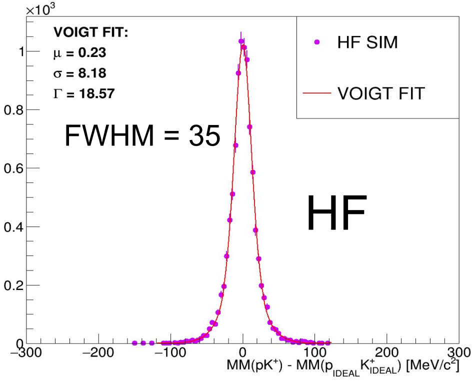


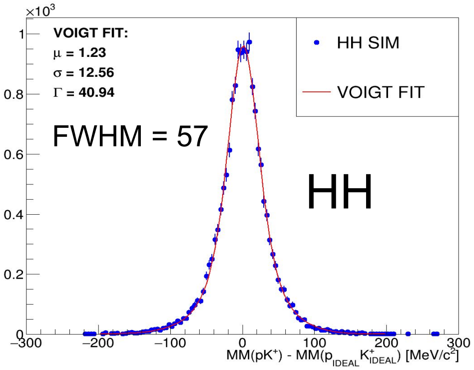
p > 0.05 cut is performed

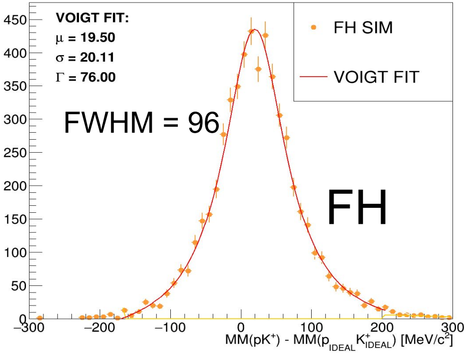
Λ(1405) mass resolution from simulation: $MM(p_{RECO}K^{+}_{RECO})$ - $MM(p_{TRUE}K^{+}_{TRUE})$

Λ(1405) natural width (PDG): 50.5± 2.0

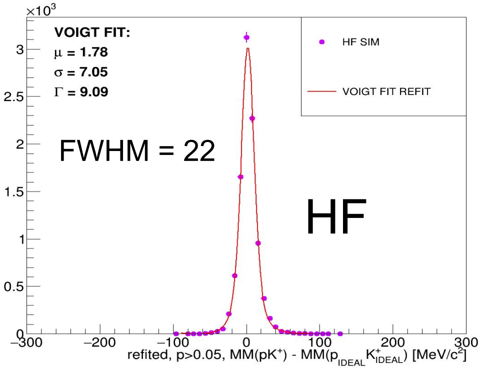
BEFORE THE REFIT:

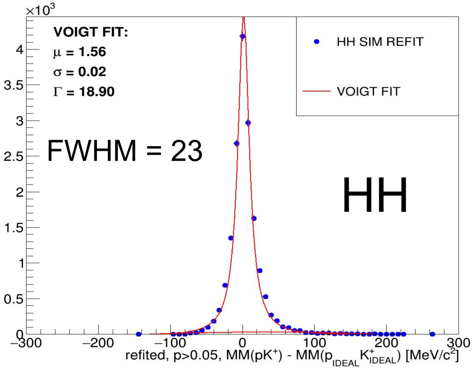


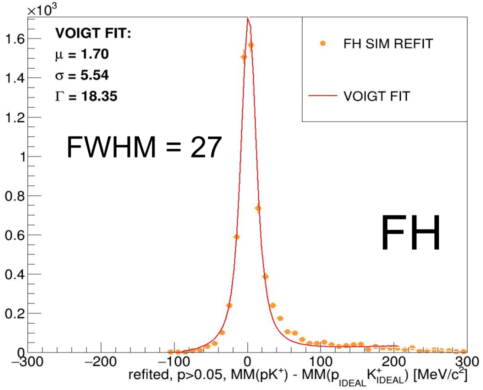




AFTER THE REFIT:

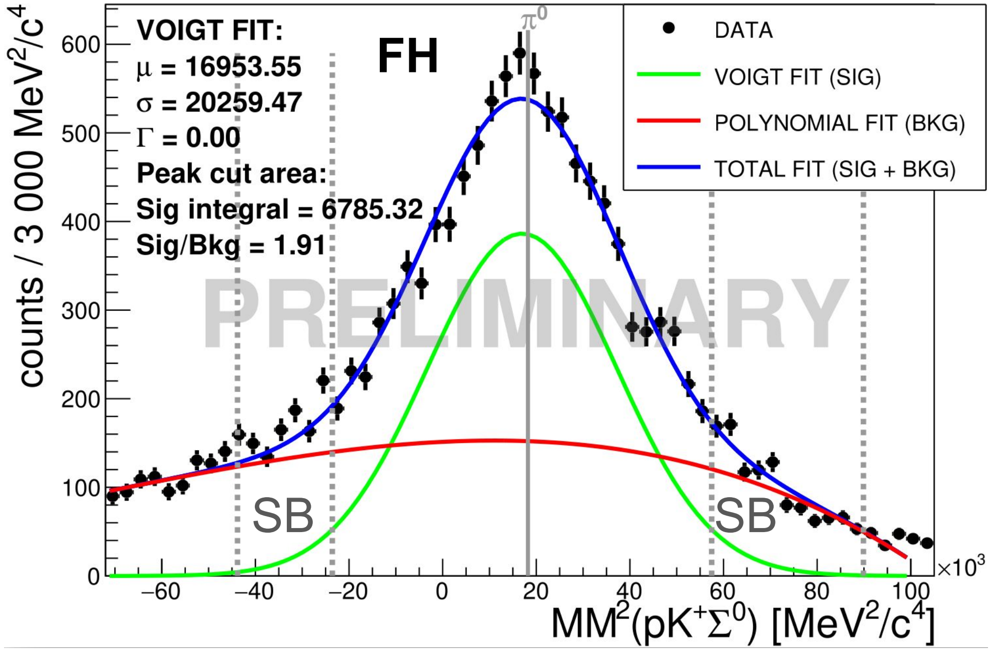






Obtained sensitivity to the line shape and peak position by improvement of the mass resolution with kinematic fitting

Sideband analysis on π^0



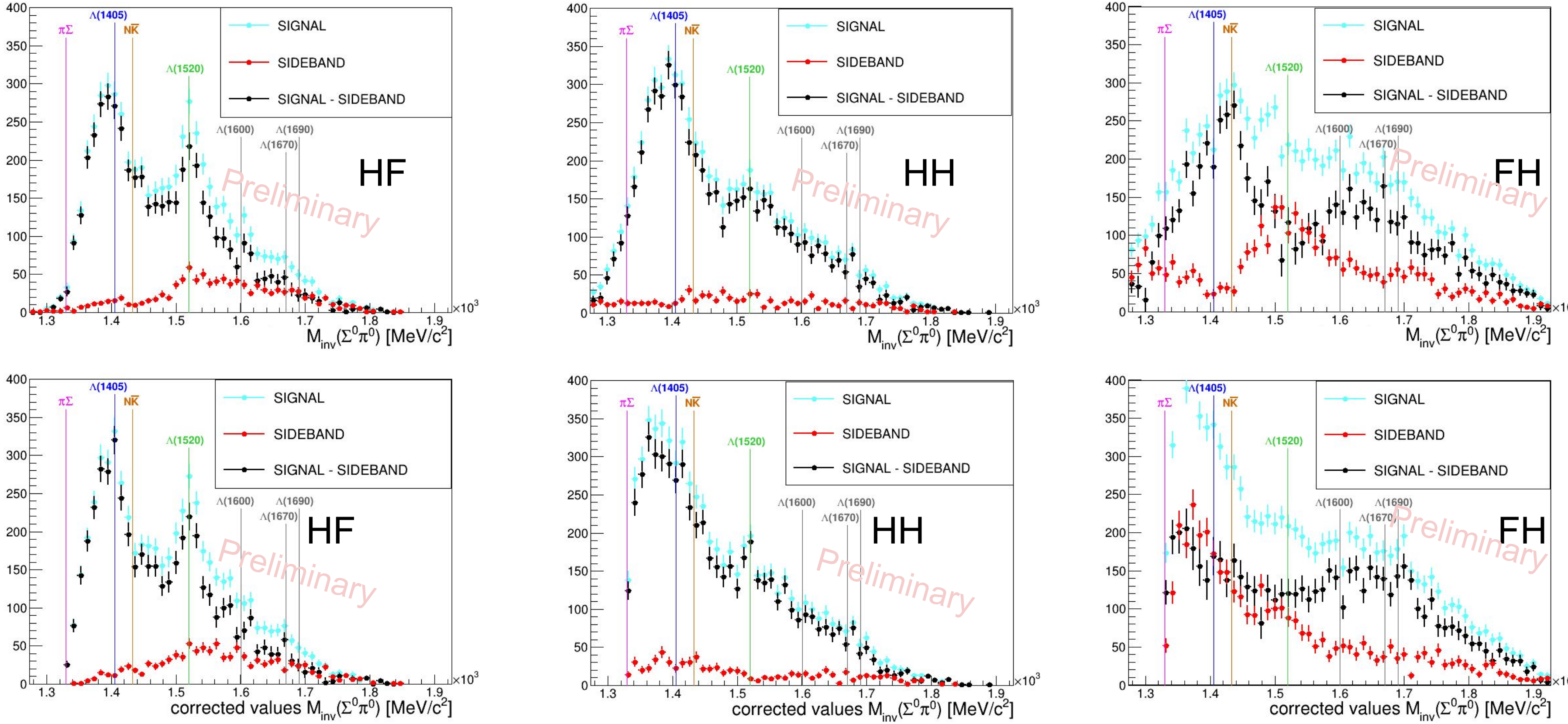
Signal of Λ(1405) reconstructed with events from the peak area

Pseudo-signal reconstructed with events from outside the peak area but close (SB)

This pseudo-signal scaled to the same integral as the BKG underneath peak cut region

Than subtracted

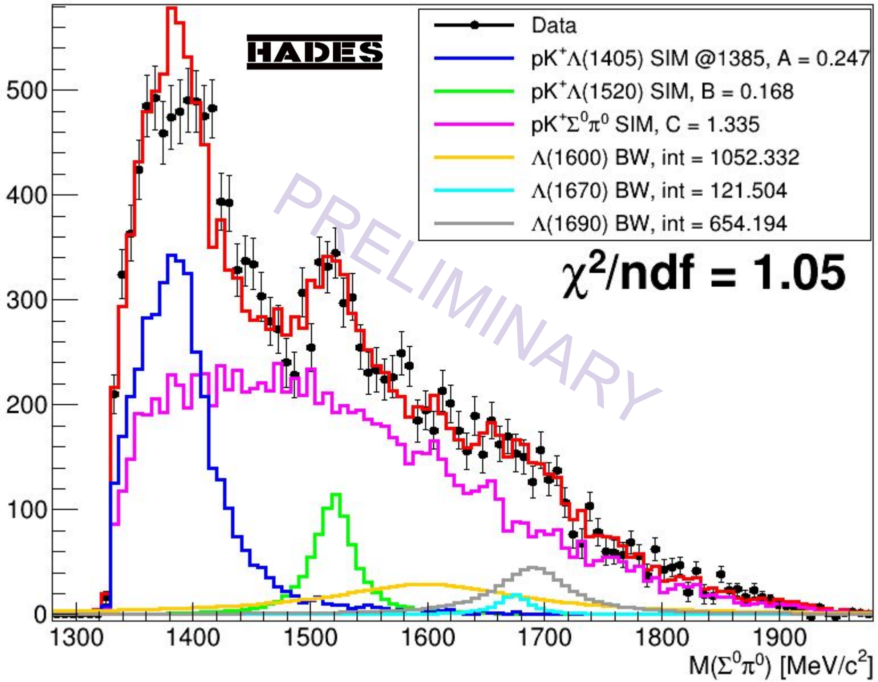
$M_{inv}(\Sigma^0\pi^0)$ comparison between values uncorrected and corrected by kinematic fitting



Data vs. simulations - incoherent model

Visible bump at around 1600–1700 MeV/c² may indicate contributions from three higher resonances:

PDG:
Λ(1600) ****: Γ ≈ 200 MeV
Λ(1670) ****: Γ ≈ 30 MeV
Λ(1690) ****: Γ ≈ 70 MeV



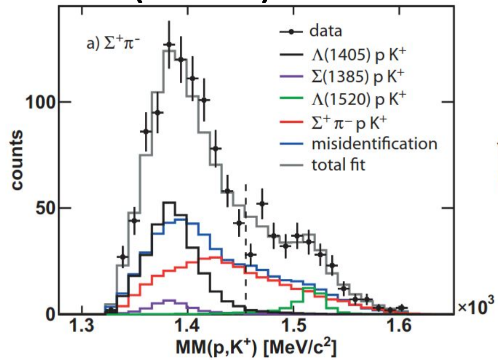
Λ(1405) - PLUTO SIM
Λ(1520) - PLUTO SIM
$\Sigma^0\pi^0$- PLUTO SIM
Λ(1600) - BW function
Λ(1670) - BW function
Λ(1690) - BW function

$d\sigma/dM_{tot}$ =

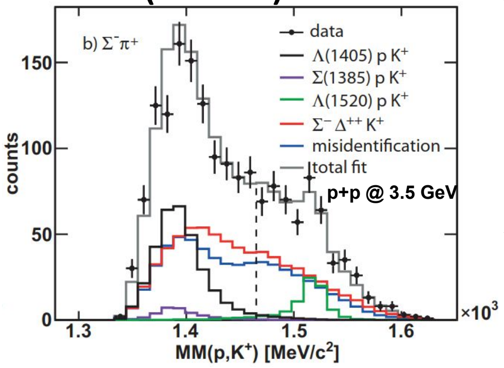
A · dσ/dM (Λ(1405)) +
B · dσ/dM (Λ(1520)) +
C · dσ/dM ($\Sigma^0\pi^0$) + ...

Comparison with previous HADES results at 3.5 GeV

$\Lambda(1405) \to \Sigma^+\pi^-$

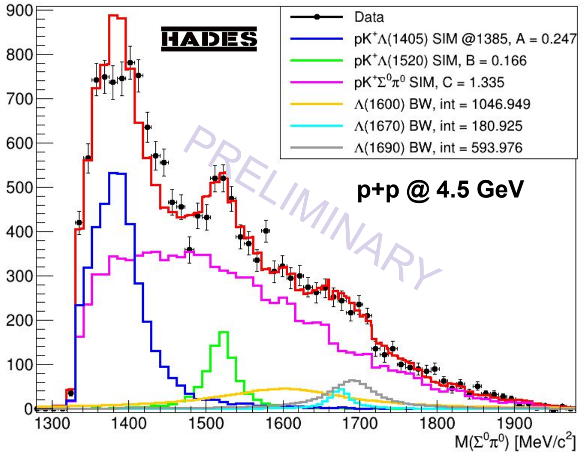


$\Lambda(1405) \to \Sigma^-\pi^+$



Source: J.S. Siebenson, "Exclusive analysis of the Λ(1405) resonance in the charged Σπ decay channels in proton–proton reactions with HADES," Diploma thesis, Technische Universität München, April 25, 2010.

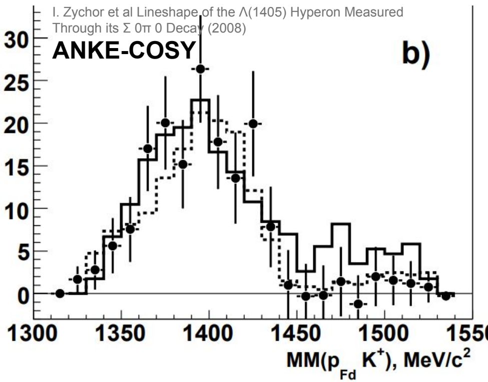
$\Lambda(1405) \to \Sigma^0\pi^0$



same binnig

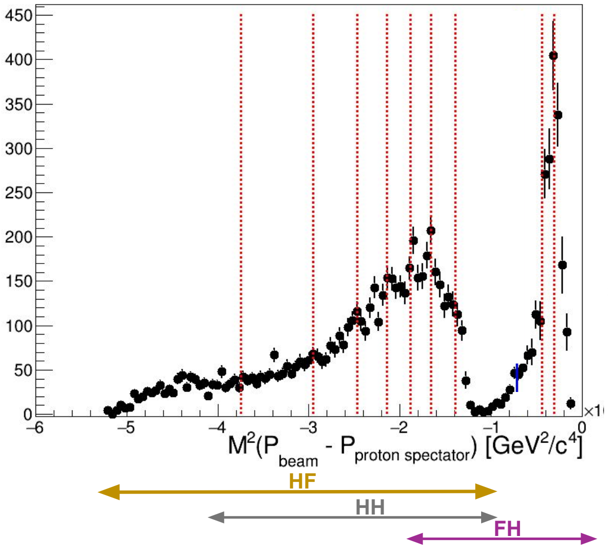
An order-of-magnitude improvement in statistics

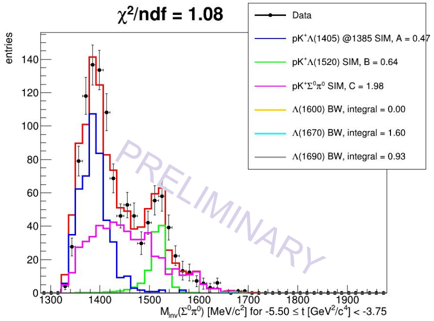
$pp \to pK^+\Lambda(1405) \to pK^+\Sigma^0\pi^0$

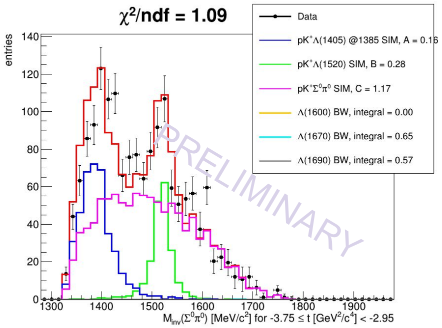


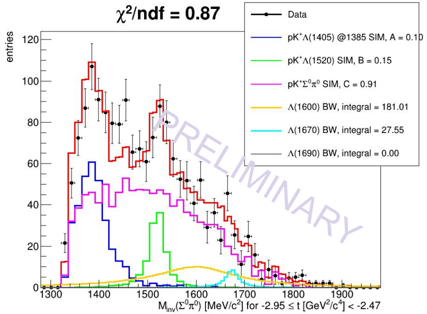
Differential analysis in *t* bins

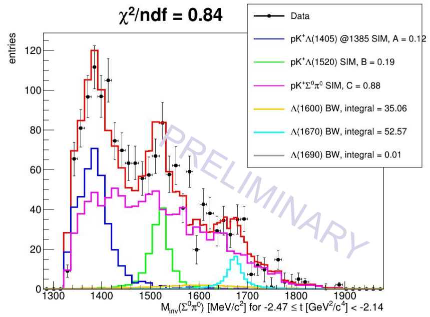
Mandelstam term *t* as the four-momentum transfer between the incoming proton and the spectator proton

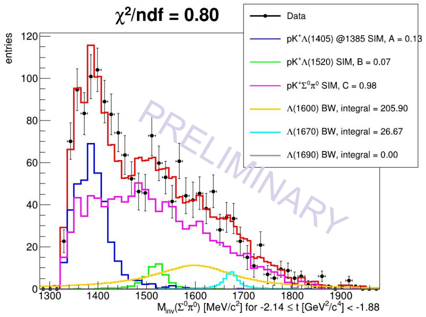


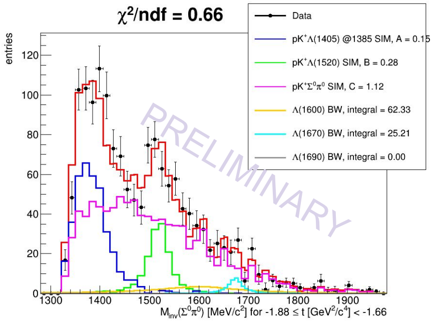


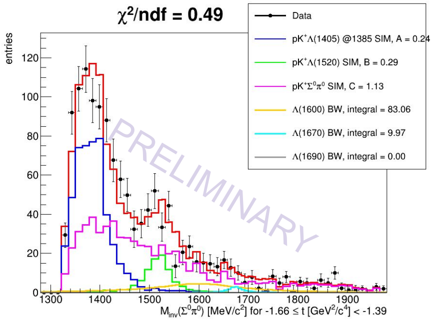












K-matrix approach

S.U. Chung et al., Ann.Physik 4,404 (1995)

Unitary framework used to describe scattering and production with coupled channels

Lorentz-invariant 2x2 T-matrix, ensures unitarity

$$\hat{T} = \left(I - i\hat{K}\rho\right)^{-1}\hat{K}$$

Sum over resonances (both poles)

$$K = \sum_{\alpha} \frac{m_\alpha \Gamma_\alpha(m)}{m_\alpha^2 - m^2}$$

Each resonance characterized by its mass, width, and couplings to different decay channels

Invariant K-matrix for available decay modes i, j = {$\Sigma^0\pi^0$, pK-}

$$\hat{K}_{ij} = \sum_{\alpha} \frac{\gamma_{\alpha i}\gamma_{\alpha j} m_\alpha \Gamma_\alpha^0}{m_\alpha^2 - m^2} B_{\alpha i}^{\ell} B_{\alpha j}^{\ell}$$

Production vector introduced and modified by final-state interactions

Production vector

$$\hat{P}_i = \sum_{\alpha} \frac{\beta_\alpha \gamma_{\alpha i} m_\alpha \Gamma_\alpha^0}{m_\alpha^2 - m^2}$$

Production amplitude

$$\hat{F}_i = \left(I - i\hat{K}\rho\right)^{-1}\hat{P}_i$$

Observable mass distributions are proportional to the phase space times the squared amplitude

Fit to the data

$$\frac{d\sigma_i(m)}{dm} \sim \rho_i \left|\hat{F}_i(m)\right|^2$$

Example observable

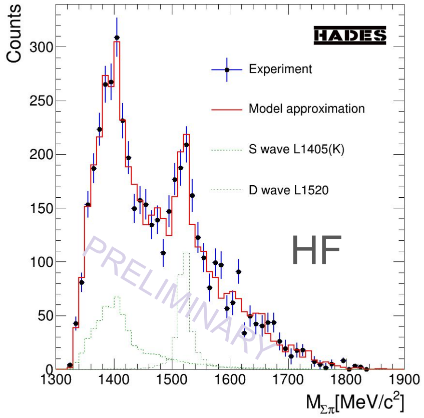
$$T_{11}(m) = \rho_{\Sigma^0\pi^0}(m)\,\hat{T}_{11}(m)$$

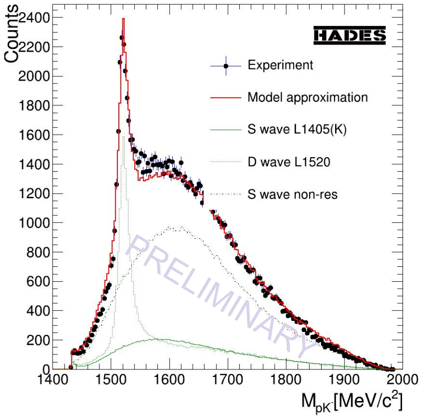
-> test for unitarity (Argand plot)
-> obtain poles positions

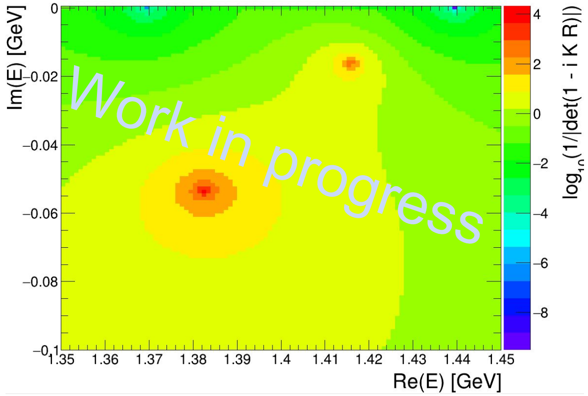
Obtaining the poles positions with K-matrix

S.U. Chung et al.,
Ann.Physik 4,404 (1995)

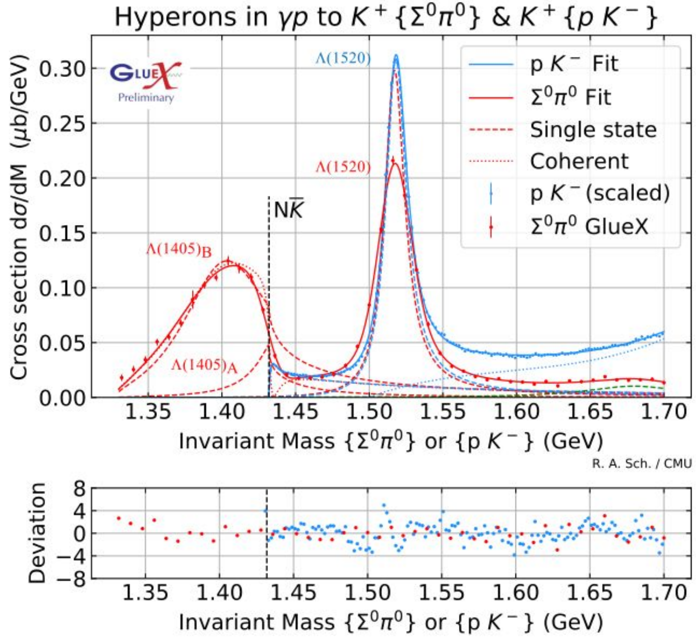
Enhancement in $M_{inv}(pK-)$ distribution near $N\bar{K}$ threshold => simultaneous fit of $M_{inv}(\Sigma^0\pi^0)$ and $M_{inv}(pK-)$ with K-matrix







V. Kladov
(HADES
Collaboration)



J. Ritman - ChDyn2024, 26-Aug-24

Summary

- Λ(1405) understanding needs an experimental input from different channels measurements
- Λ(1405) ‘golden channel’ reconstructed with prominent signal statistics and background reduction in new HADES data from p+p
- Signals corresponding to higher resonances in the final spectra
- Good statistics allowing the analysis of the lineshape and cross sections in *t* dependance
- Line shape analysis and extracting poles positions both from chiral unitary approach and K-matrix approach
- Angular distribution study and cross sections to be obtained

Thank you!