Studies of a K^- single nucleon absorption processes by AMADEUS

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Motivation & Scientific Case

The investigation of the **in-medium modification of the $\bar{K}N$ interaction** is of **fundamental** for the low-energy QCD in the non perturbative regime.

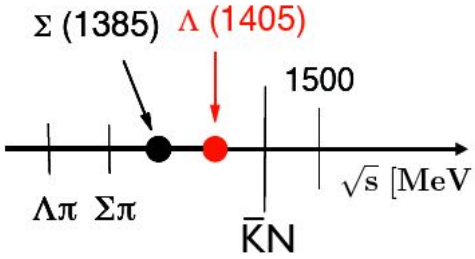
Chiral perturbation theory (ChPT): effective field theory where mesons and baryons represent the effective degrees of freedom instead of the fundamental quark and gluon fields.

$$\mathcal{L}_{eff} = \mathcal{L}_{mesons}(\Phi) + \mathcal{L}_{B}(\Phi, \Psi_B)$$

- The chiral symmetry is **spontaneously broken** → the existence of massless and spinless Nambu-Goldstone bosons which are identified with the pions. Explicitly broken by **q** masses.
- **Very successful** in describing the πN, ππ and NN interactions in the low-energy regime and is considered as the theory of the low-energy strong interaction **in the SU(2) flavour sector**.

The extension of the theory to the sector with the quark s turns out to be more problematic since it is not directly applicable to the $\bar{K}N$ channel.

The χPT is not applicable to the $\bar{K}N$ channel due to the emerging of the Λ(1405) and the Σ(1385) resonances just below the $\bar{K}N$ mass threshold



Λ(1405) I=0 $J^P = ½^-$

M = $(1405.1^{+1.3}_{-1.0})$ MeV Γ = (50.5 ± 2.0) MeV

decay modes: Σπ (I=0) 100%

Σ(1385) I=1 $J^P = 3/2^+$

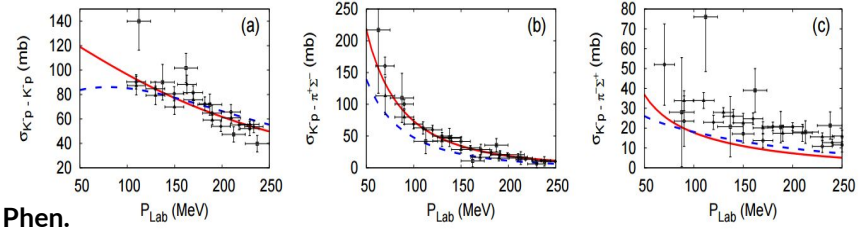
decay modes: Λ π (I=1) (87.0 ± 1.5) %

Σ π (I=1) (11.7 ± 1.5) %

Possible solutions:

- **Non-perturbative Coupled Channels approach: Chiral Unitary SU(3) Dynamics**
- **Phenomenological $\bar{K}N$ and NN potentials**

The parameters of the models are constrained by the existing scattering data

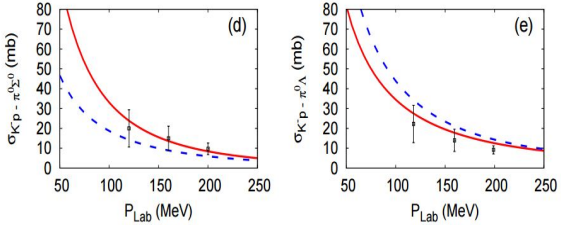


Phen.

Y. Ikeda and T. Sato, Phys. Rev. C76, 035203 (2007)

Chiral

S. Ohnishi, Y. Ikeda, T. Hyodo, W. Weise, Phys.Rev. C93 (2016) no.2, 025207



...but... large differences in the subthreshold extrapolations!

Significantly weaker attraction in chiral SU(3) models than in phenomenological potential models.

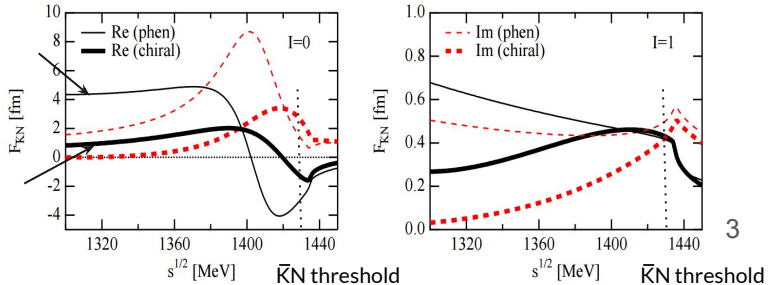
Re Im

Phen. [Y. Akaishi, T. Yamazaki, Phys. Rev. C65, 044005 (2002)]

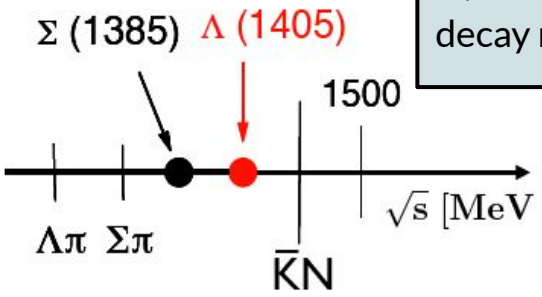
Chiral [Ikeda, T. Hyodo, W. Weise, Phys. Lett. B706, 63 (2011)]

Phenomenologic potential model

Chiral SU(3) dynamics



The controversial nature of the **Λ(1405)** and kaonic bound states



Λ(1405) I=0 $J^P = ½^-$
decay modes: Σπ (I=0)

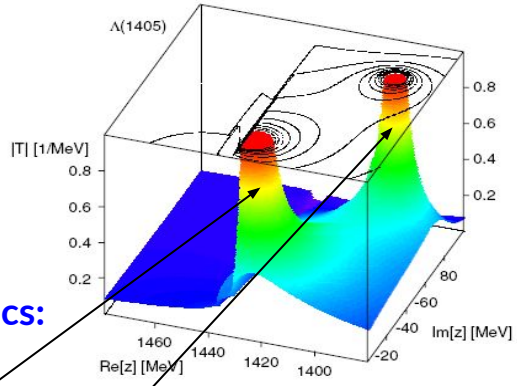
The Λ(1405) state does not fit with the simple three quarks model (*uds*) and it is commonly accepted that **it is, at least partially, a K̄N bound state**.

Wycech (1986) - Akaishi & Yamazaki (2002)

Predicted in the **KN interaction in the I=0** channel due to the strong interaction

Essential impact on the EoS of Neutron Stars

gravitational waves signal emitted by binary system of Neutron Stars

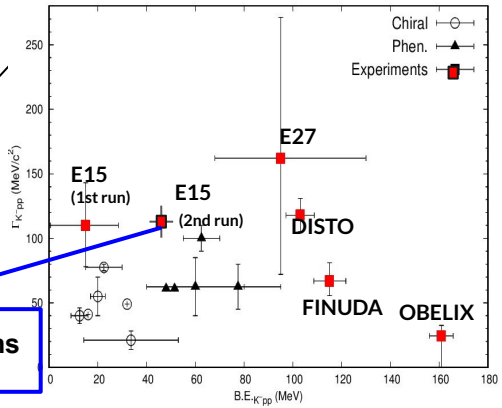


- **Chiral SU(3) coupled channel dynamics:**
  the state is given by the superpositions of **two poles of the K̄N scattering amplitude**.

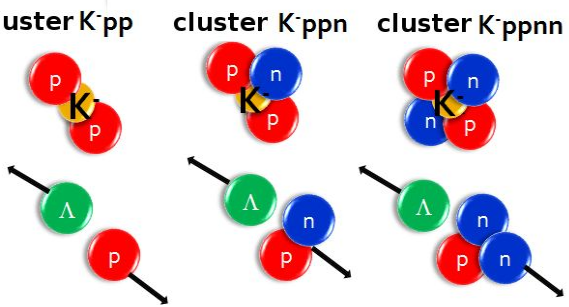
  M = 1425 MeV → mainly coupled to the K̄N channel

  M = 1380 MeV → mainly coupled to the Σπ channel

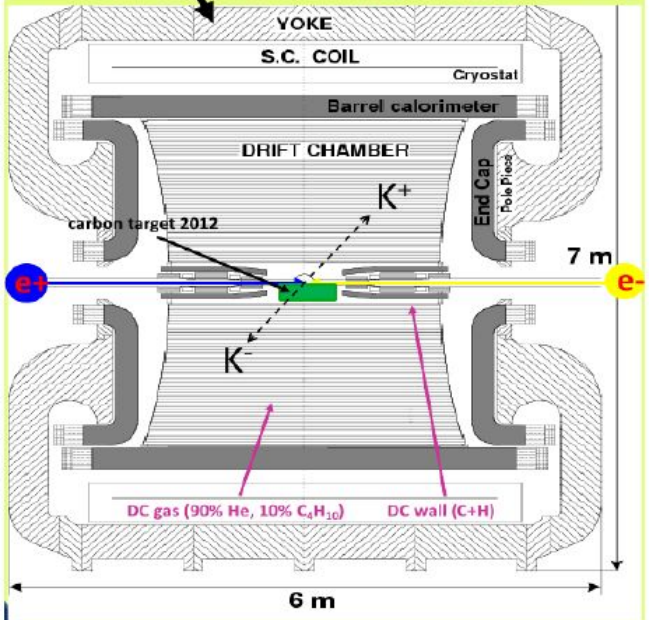
- **Phenomenological potentials models:**
  the **Λ(1405) is a pure K̄N bound state** with mass M=1405 MeV, binding energy BE = 27 MeV and width Γ=50 MeV.



E15 → first clear evidence in K^- induced reactions
Phys.Lett.B 789 (2019) 620-625



AMADEUS @ DAΦNE



DAΦNE

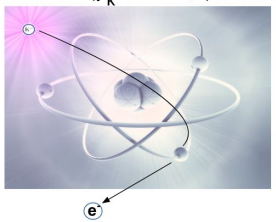
- $\phi \rightarrow K^- K^+$ (49.2%), ≈1000 ϕ/s
- monochromatic **low momentum** Kaons ≈127 Mev/c
- **back to back** $K^- K^+$ topology
- **small hadronic background** due to the beam

KLOE

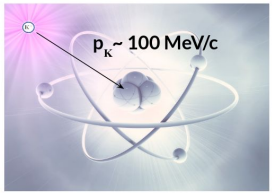
- Cilindrical DC with **4π geometry** & electromagnetic calormeter
- **96% acceptance**
- **high efficiency and resolution** for charged and neutral particles

- exclusive measurement of the considered

AT-REST
K^- absorbed from atomic orbitals
(p_K ~ 0 MeV/c)



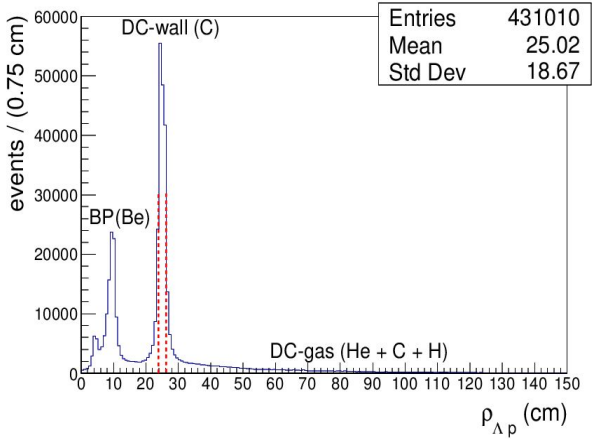
IN-FLIGHT
(p_K ~ 100 MeV/c)



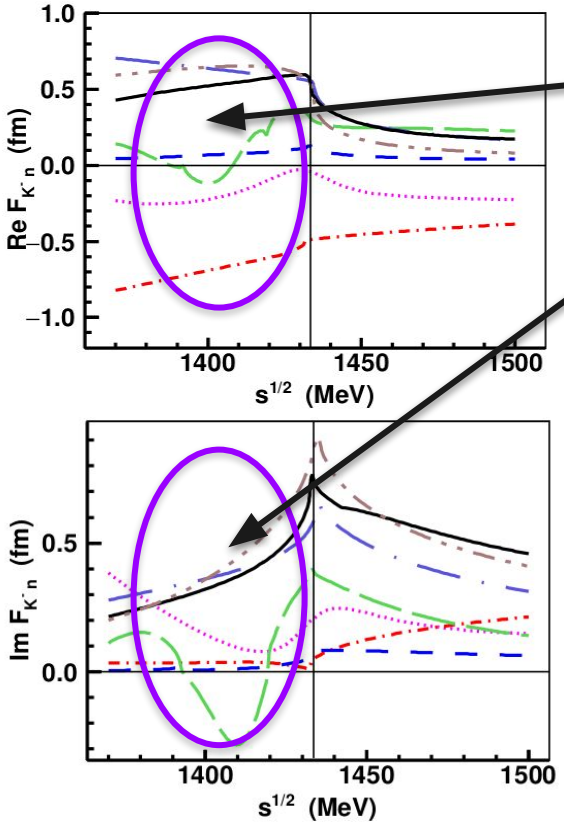
AMADEUS: KLOE 2004-2005 dataset analysis ($\mathcal{L}$ = 1.74 pb-1)

Possibility to use KLOE materials as an active target

- DC wall (750 μm C foil , 150 μm Al foil);
- DC gas (90% He, 10% C_4H_{10}).



Λπ⁻ analysis: K⁻n non-resonant transition amplitude



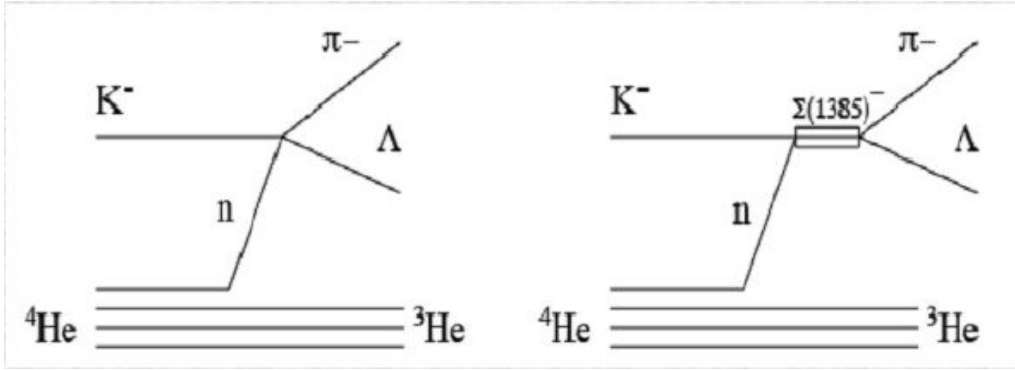
K⁻n scattering amplitude with Chiral models

J. Hrtankova, J. Mares, Phys. Rev. C96, 015205 (2017)
A. Cieply et al, Nycl. Phys. A 954, 17 (2016)

First determination of the non-resonant transition amplitude below threshold

Investigated using:

$K^- "n" \rightarrow \Lambda\pi^-$ direct formation in ^{4}He (DC volume)



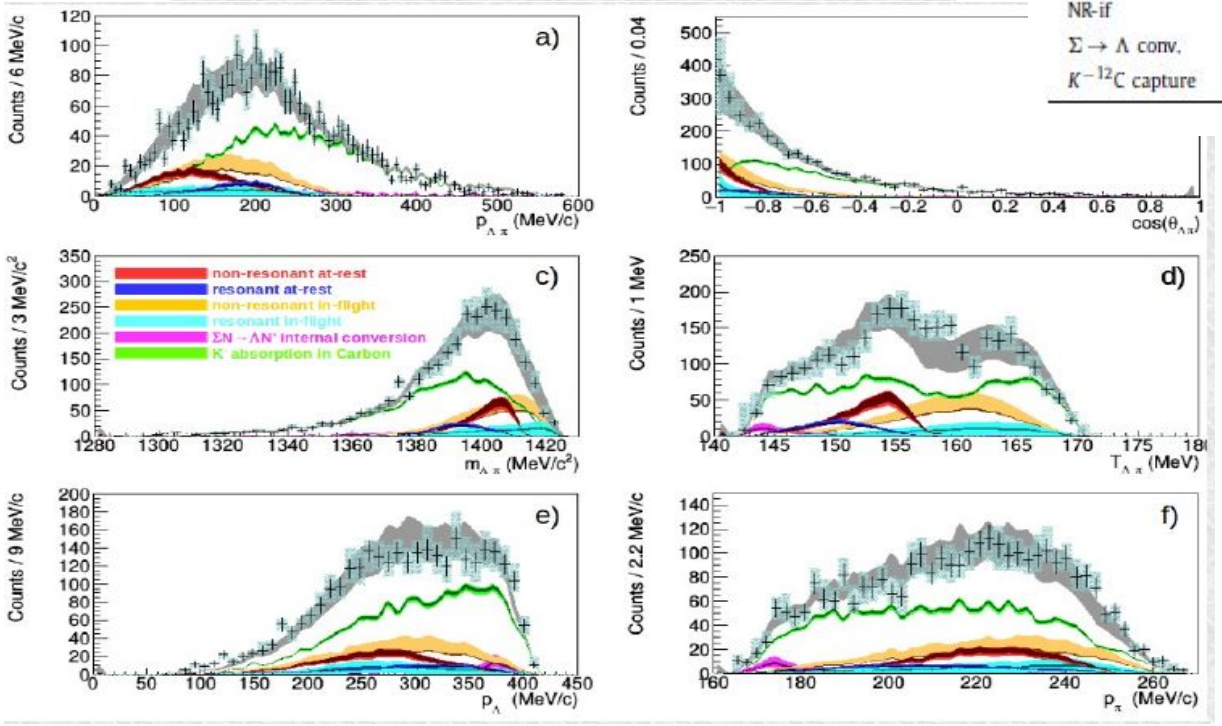
$$|f^{N\text{-}R}_{\Lambda\pi}(I=1)| \Rightarrow |f^{N\text{-}R}_{\Sigma\pi}(I=0)|$$

The detailed characterisation of the yield and spectral shape of the non-resonant $K\bar{N}$ absorption is fundamental reference to extract the Λ(1405) properties in $\bar{K}N$ absorption experiments

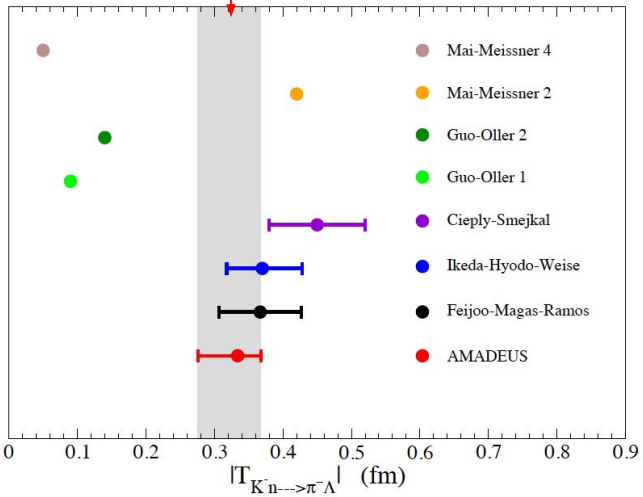
non-resonant transition amplitude below threshold

Channels	Ratio/yield	σ_{stat}	σ_{syst}
RES-ar/NR-ar	0.39	± 0.04	$^{+0.18}_{-0.07}$
RES-if/NR-if	0.23	± 0.03	$^{+0.23}_{-0.22}$
NR-ar	12.0%	± 1.7%	$^{+2.0}_{-2.8}$%
NR-if	19.2%	± 4.4%	$^{+5.9}_{-3.3}$%
$\Sigma \to \Lambda$ conv.	2.2%	± 0.3%	$^{+1.6}_{-0.8}$%
$K^{-}{}^{12}C$ capture	57.0%	± 1.2%	$^{+2.2}_{-3.2}$%

Simultaneous fit : ($p_{\Lambda\pi^-}$ - $m_{\Lambda\pi^-}$ - $\cos(\theta_{\Lambda\pi^-})$



$$|f^s_{ar}| = (0.334 \pm 0.018\,\mathrm{stat}^{+0.034}_{-0.058}\mathrm{syst})\ \mathrm{fm}\,.$$



Investigated using: **K⁻ "n" ^{3}He → Λπ⁻ ^{3}He**

(33±6) MeV below KN threshold $E_{\mathrm{Kn}} \sim -B_n - < \frac{p^2_{\Lambda\pi}}{2\mu_{\pi,\Lambda,^3\mathrm{He}}} >$

K. Piscicchia, et. al., Phys. Lett. B782, 339 (2018)
K. Piscicchia, S. Wycech, C. Curceanu, Nucl. Phys. A 954, 75 (2016)

$\Sigma^0\pi^0/\Lambda^0\pi^0$ analysis

Motivation:

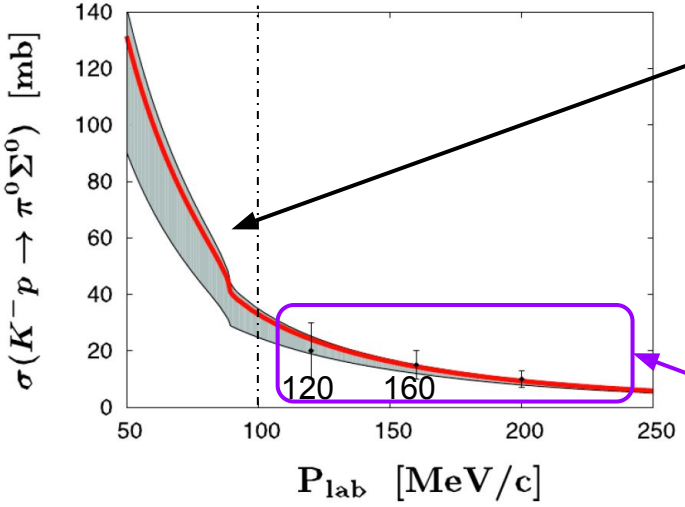
1) The available data for the inelastic $K^- p \rightarrow \Sigma^0 \pi^0$ cross section close to threshold:

- three points in the p_K=120-200 MeV/c range (bubble chamber experiments),
- uncertainties larger than 30%,
- the $K^- p \rightarrow \Sigma^0 \pi^0$ cross sections are obtained **not directly but** on the basis of the isospin symmetry argument, from the measurement of $K^- p \rightarrow \Lambda\pi^0$ events

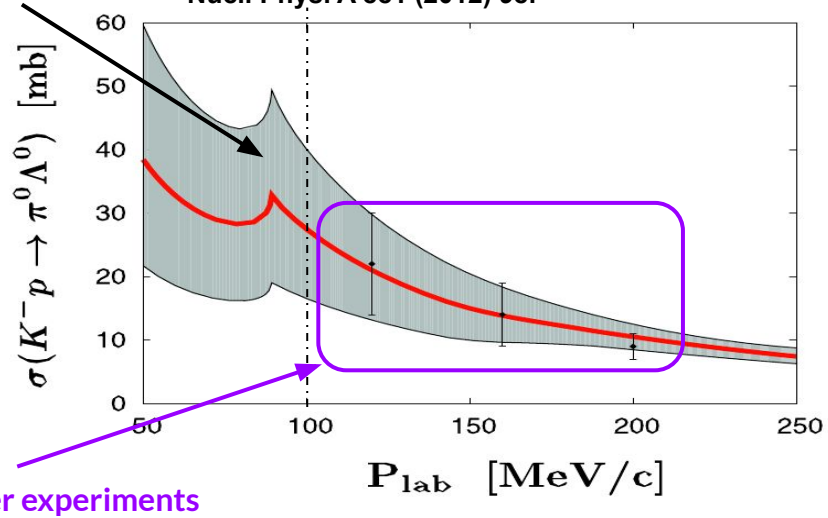
Low momentum K^- scattering cross sections in this Isospin I = 0 channel represent a fundamental input for the non-perturbative low energy QCD models

[1] W. E. Humphrey and R. R. Ross, Phys. Rev. 127 (1962) 1305.
[2] J. K. Kim, Columbia University Report No. NEVIS-149 (1966).

no experimental data

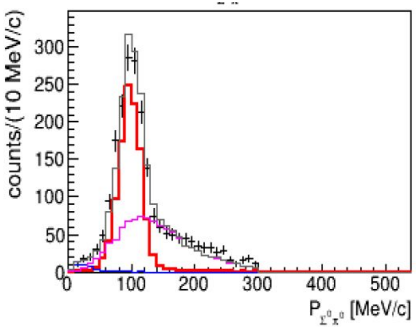


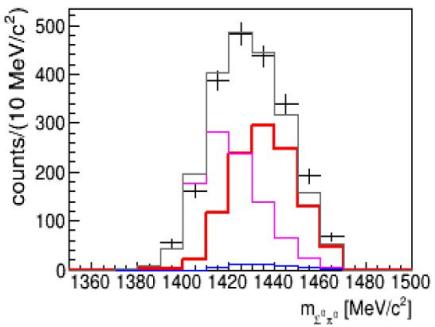
Theoretical calculation:
Y. Ikeda, T. Hyodo, W. Weise,
Nucl. Phys. A 881 (2012) 98.

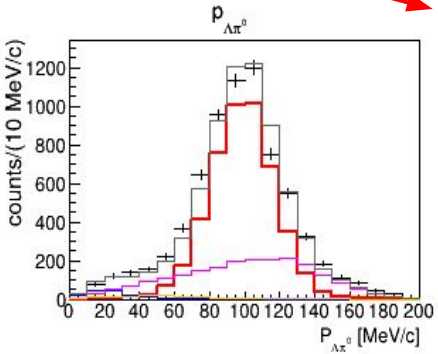


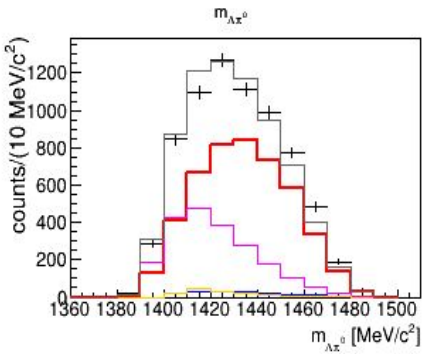
bubble chamber experiments

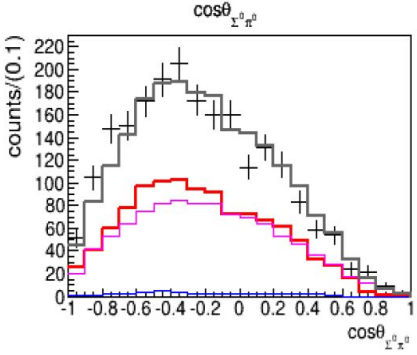
$\Sigma^0\pi^0/\Lambda^0\pi^0$ analysis

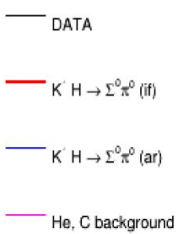


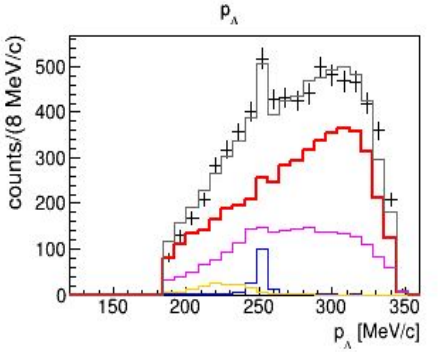


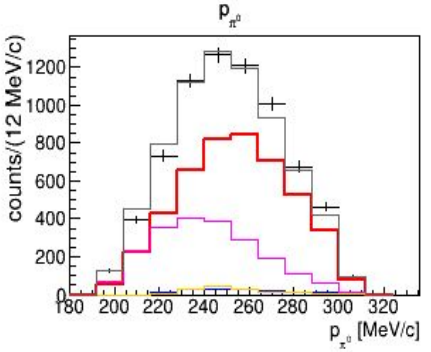






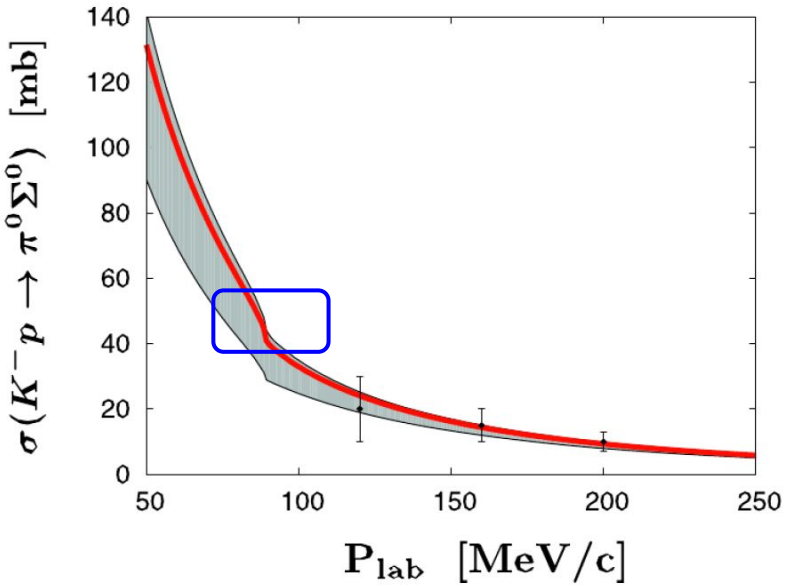


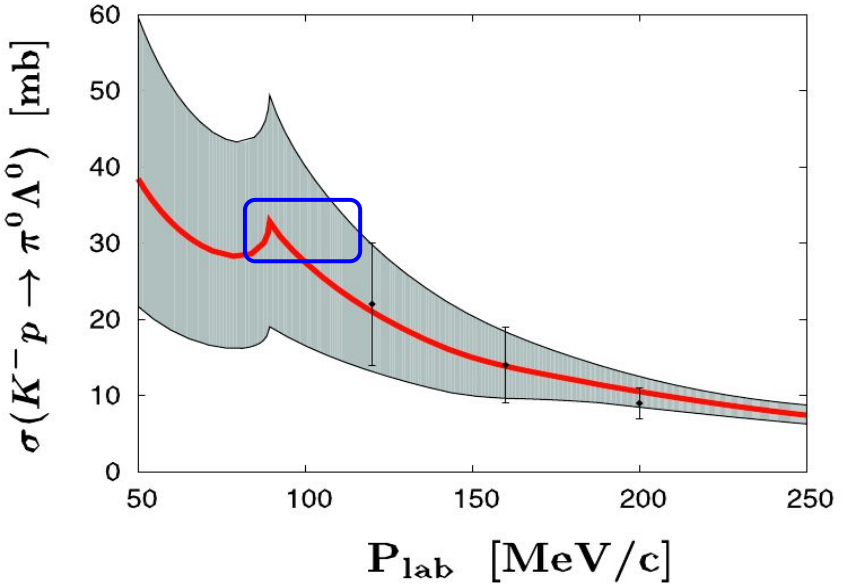




PRELIMINARY

$\Sigma^0\pi^0/\Lambda^0\pi^0$ analysis





Cross sections for p_K = 98±10 MeV/c