Studies of low-energy K^- hadronic nucleus/nuclei interactions with light nuclei by AMADEUS

Magdalena Skurzok*

On the behalf of the AMADEUS collaboration

Jagiellonian University in Krakow

Istituto Nazionale di Fisica Nucleare

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4 - 12.09.2020

Plan

1. Motivation and scientific case

2. AMADEUS @ DAΦNE

3. Analysis results

4. Summary

Motivation and 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.

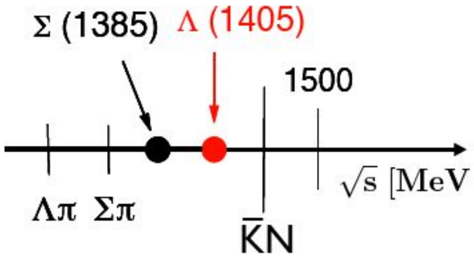
Chiral perturbation theory (ChPT): effective field theory where mesons and baryons represent the effective degrees of freedom instead of the fundamental quark and gluon fields.

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

- 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 <u>quark s</u> 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 $J^P = \frac{1}{2}^-$

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**

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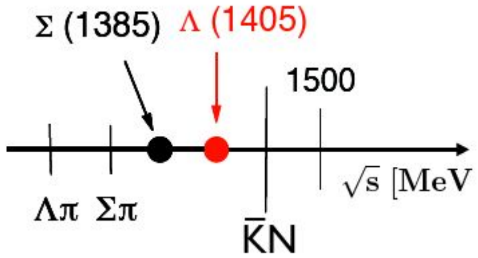

Λ(1405) I=0 $J^P = ½^-$

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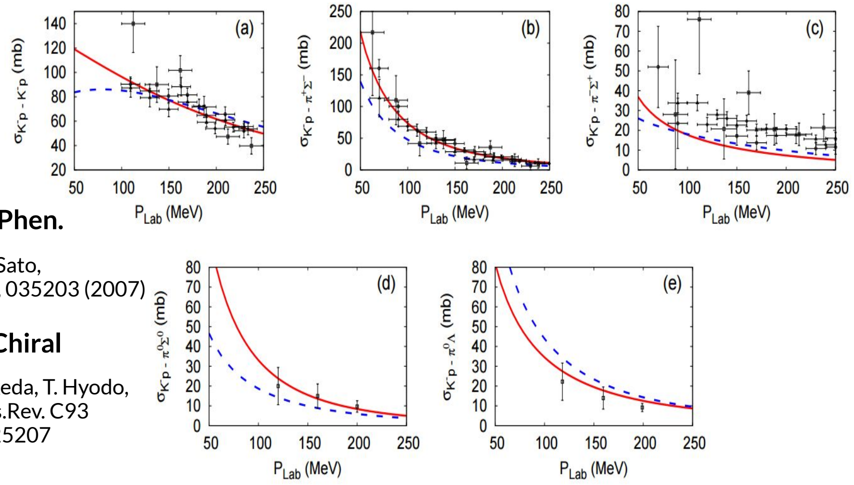
Possible solutions:

- ➢ **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.

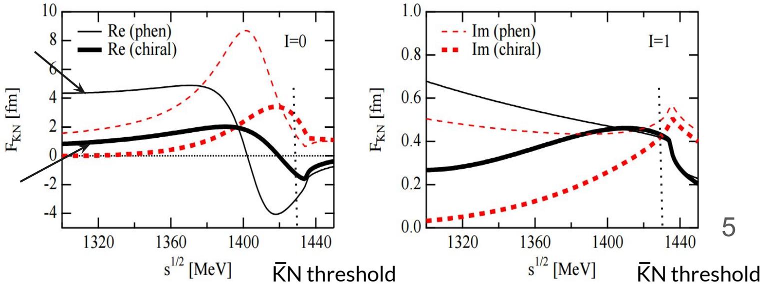
Re Im

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

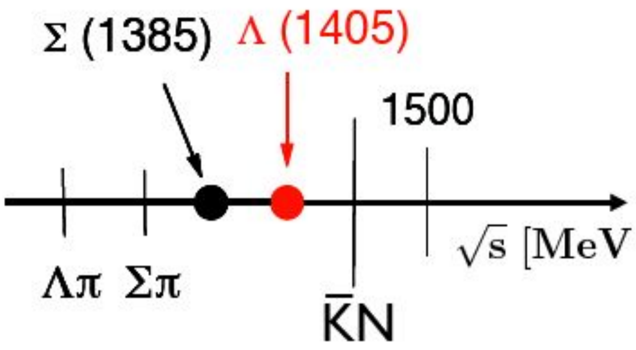
Chiral [Y. Ikeda, T. Hyodo, W. Weise, Phys. Lett. B706, 63 (2011)]

Phenomenologic potential model

Chiral SU(3) dynamics



The controversial nature of the **Λ(1405)**

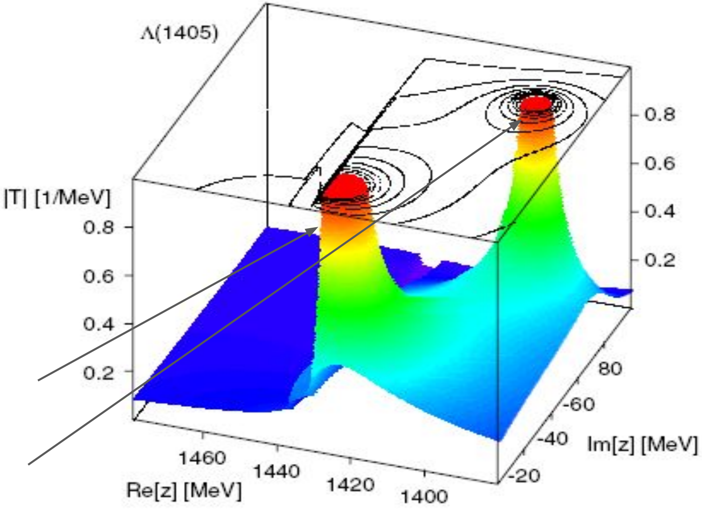


The Λ(1405) state does not fit with the simple three quarks model (*uds*) and it is commonly accepted that **it is, at least partially, a K̄N bound state**.

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

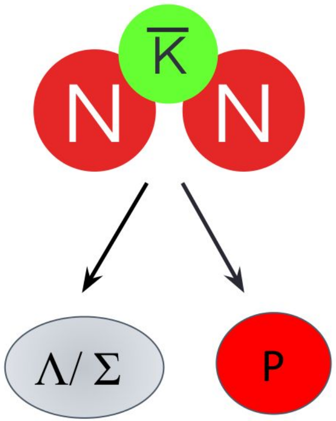
  M = 1425 MeV → **mainly coupled to the K̄N channel**

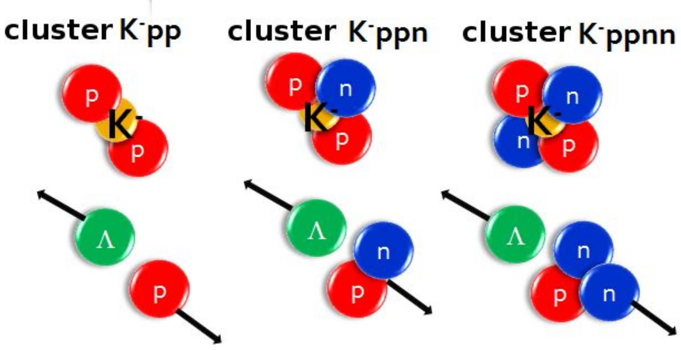
  M = 1380 MeV → **mainly coupled to the Σπ channel**



- **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.

Possible existence of **kaonic bound states**





Λ + p
Σ^0 + p

Λ + d
Σ^0 + d

Λ + t
Σ^0 + t

Wycech (1986) - Akaishi & Yamazaki (2002)

Predicted in the **$\overline{K}$N 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

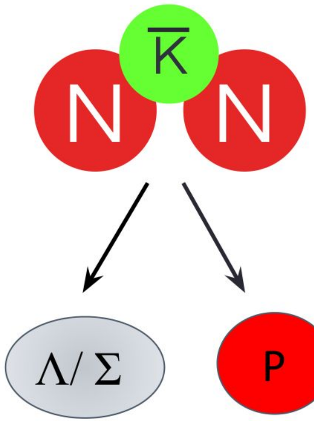
Theory

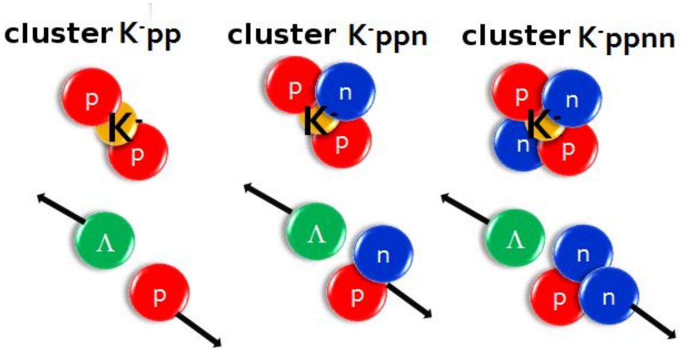
Chiral models	BE [MeV]	Γ [MeV]	Reference
Dote, Hyodo, Weise	17 - 23	40 - 70	Phys. Rev. C 79 (2009) 014003
Barnea, Gal, Liverts	16	41	Phys. Lett. B 712 (2012) 132
Ikeda, Kamano, Sato	9 - 16	34 - 46	Prog. Theor. Phys. (2010) 124 (3)
Bicudo	14.2 - 53	13.8 - 28.3	Phys. Rev. D 76 (2007) 031502
Bayar, Oset	15 - 30	75 - 80	Nucl. Phys. A 914 (2013) 349
Dote, Inoue, Myo	21.2 - 32.2	9 - 31.7	Prog. Theor. Exp. Phys. 2015 (2015) 043D02
Sekihara, Oset, Ramos	16	72	Prog. Theor. Exp. Phys. 2016 (2016) 123D03
Phen. approach	**BE [MeV]**	**Γ [MeV]**	**Reference**
Akaishi, Yamazaki	48	61	Phys. Rev. C 65 (2002) 044005
Ikeda, Sato	60 - 95	45 - 90	Phys. Rev. C 76 (2007) 035203
Shevchenko, Gal, Mares	55 - 70	90 - 110	Phys. Rev. Lett. 98 (2007) 082301
Revai, Shevchenko	32	49	Phys. Rev. C 90 no. 3 (2014) 034004
Maeda, Akaishi, Yamazaki	51.5	61	Proc. Jpn. Acad. B 89 (2013) 418
Wycech, Green	40 - 80	40 - 85	Phys. Rev. C 79 (2009) 014001

Experiments

Experiment	BE [MeV]	Γ [MeV]	Reference
FINUDA	115^{+6}_{-5}(stat.)$^{+3}_{-4}$(syst.)	67^{+14}_{-11}(stat.)$^{+2}_{-3}$(syst.)	PRL 94 (2005), 212303
OBELIX	160.9±4.9	<24.4±8.0	NPA 789 (2007), 222
E549	-	-	MPLA 23 (2008), 2520
DISTO	103±3(stat.)±5(syst.)	118±8(stat.)±10(syst.)	PRL 104 (2010), 132502
LEPS/SPring-8	Upper limit		PLB 728 (2014), 616
HADES	Upper limit		PLB 742 (2015), 242
E27	95^{+18}_{-17}(stat.)$^{+30}_{-21}$(syst.)	162^{+87}_{-45}(stat.)$^{+66}_{-78}$(syst.)	PTEP (2015), 021D01
AMADEUS	Upper limit		PLB 758 (2016), 134
E15 1st run	15^{+6}_{-8}(stat.)±12(syst.)	110^{+19}_{-17}(stat.)±27(syst.)	PTEP (2016), 051D01
E15 2nd run	47±3(stat.)$^{+3}_{-6}$(syst.)	115±7(stat.)$^{+10}_{-20}$(syst.)	PLB 789 (2019), 612

Possible existence of **kaonic bound states**





$\Lambda + p$	$\Lambda + d$	$\Lambda + t$
$\Sigma^0 + p$	$\Sigma^0 + d$	$\Sigma^0 + t$

Wycech (1986) - Akaishi & Yamazaki (2002)

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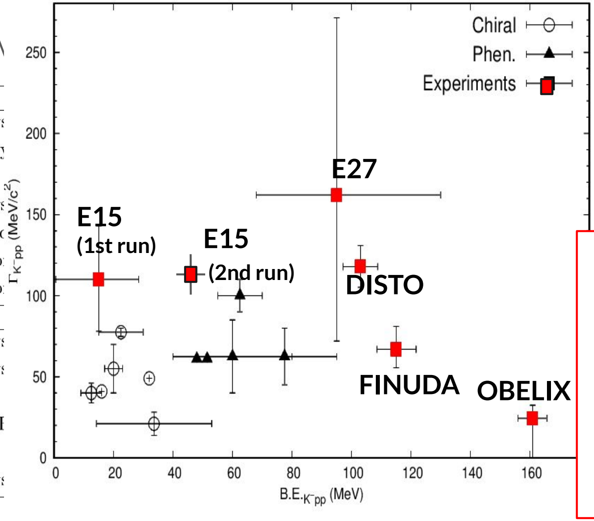
Wycech, Green	40 - 80	40 - 85	Phys



Experiments

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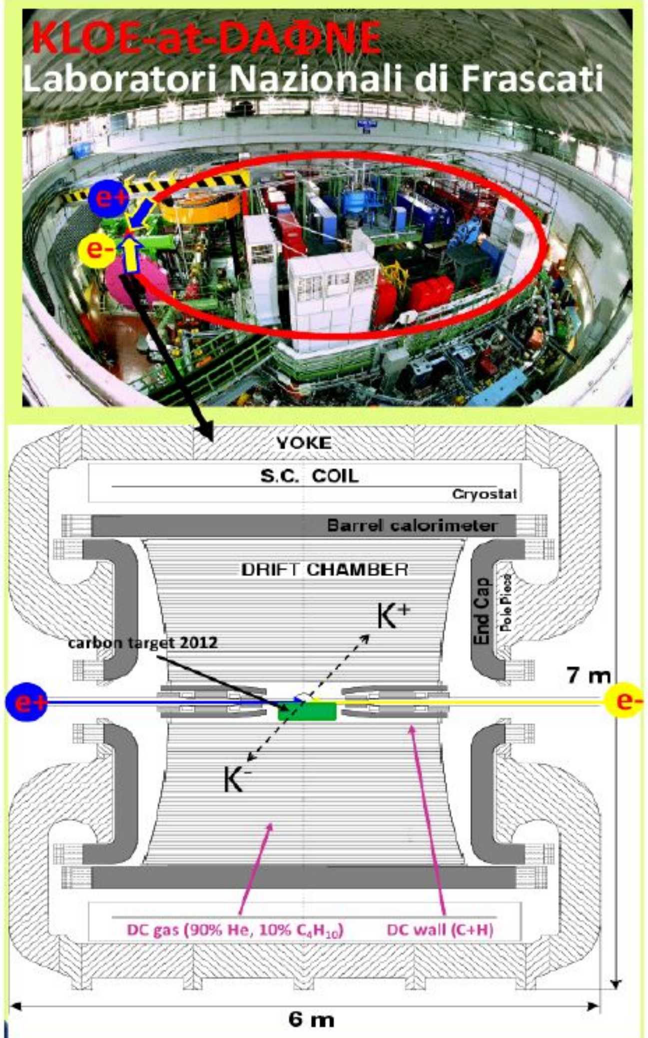
160.9±4.9	<24.4±8.0	NPA 789 (2007), 222
-	-	MPLA 23 (2008), 2520

FINUDA, E549, E15, AMADEUS: K⁻ induced reactions
DISTO, HADES: p-p collisions
OBELIX: anti-p annihilations
E27: π induced reactions
LEPS/SPring-8: photoproduction

E15 → first clear evidence in K⁻ induced reactions
(theoretical interpretation by Sekihara, Oset, Ramos)

AMADEUS @ DAΦNE



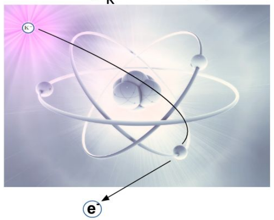
DAΦNE

- $\phi \rightarrow K^- K^+$ (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

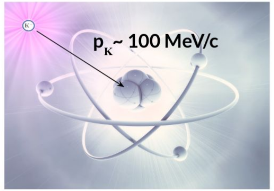
KLOE

- 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)



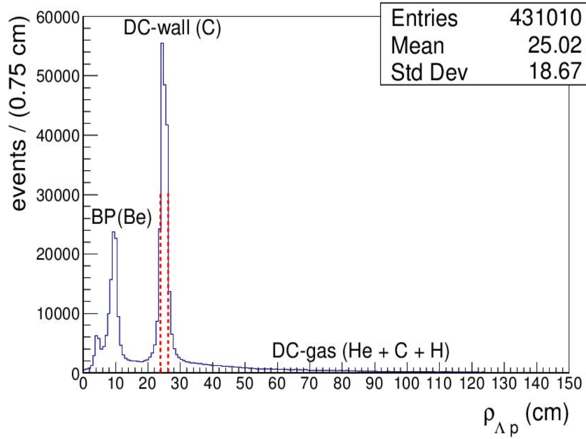
IN-FLIGHT
(p_K ~ 100 MeV/c)



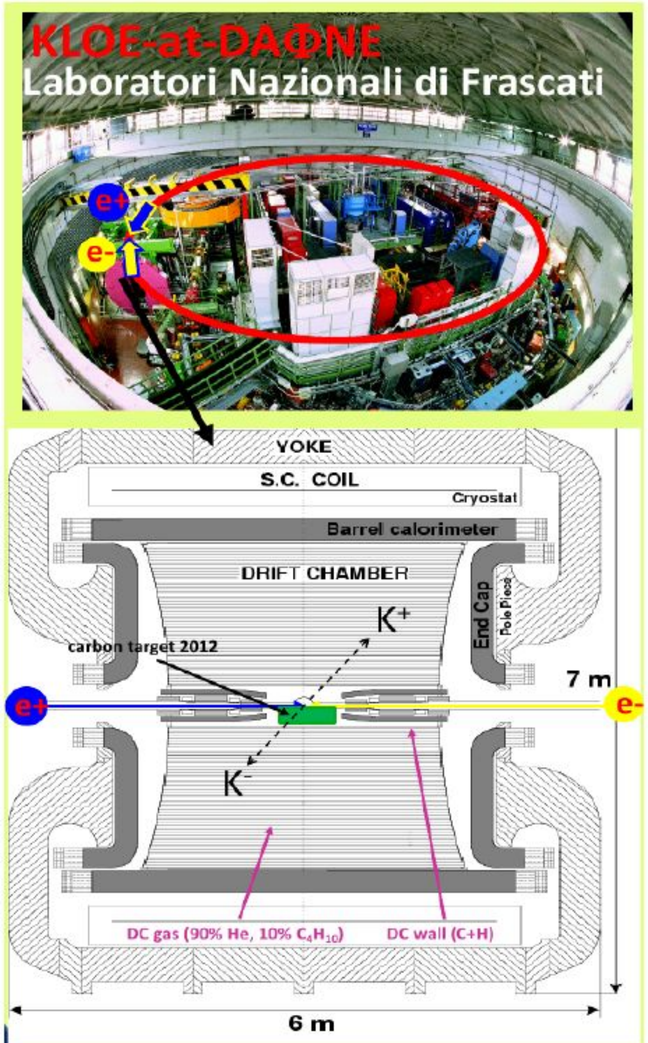
AMADEUS: KLOE 2004-2005 dataset analysis ($\mathcal{L}$ = 1.74 pb-1)

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}).



AMADEUS @ DAΦNE



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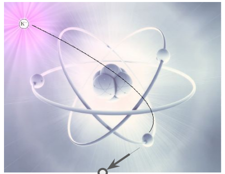
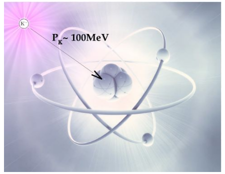
⬇

- exclusive measurement of the considered

K^- absorption on light nuclei AT REST & IN FLIGHT



K- absorbed from atomic orbit



AMADEUS: KLOE 2004-2005 dataset analysis (ℒ = 1.74 pb-1)

AMADEUS scientific case

- nature of Λ(1405) and K^-N amplitude below threshold

- low-energy charged K cross section (for p=100MeV)

⇩

Yπ correlation studies (Λπ, Σπ final states)

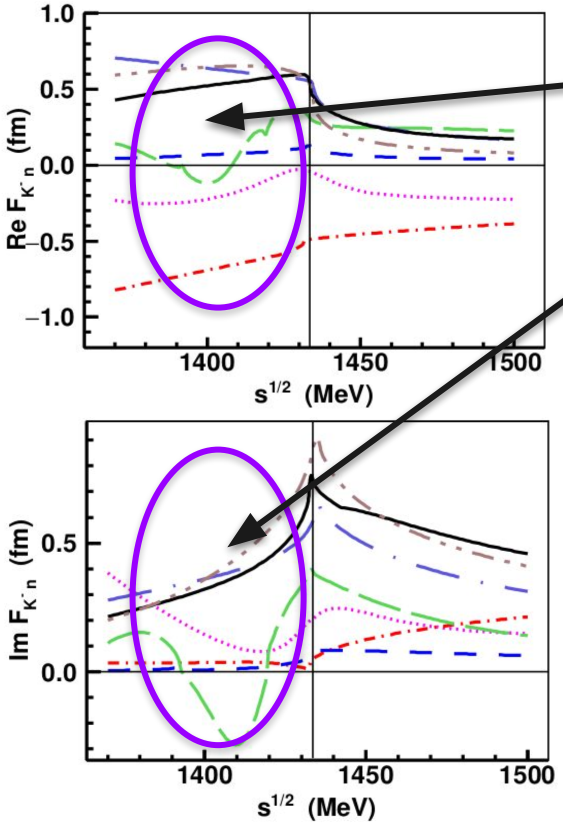
- K^- multiN absorption

- kaonic nuclear clusters

⇩

YN correlation studies (Λp, Σ^0p, Λt final states)

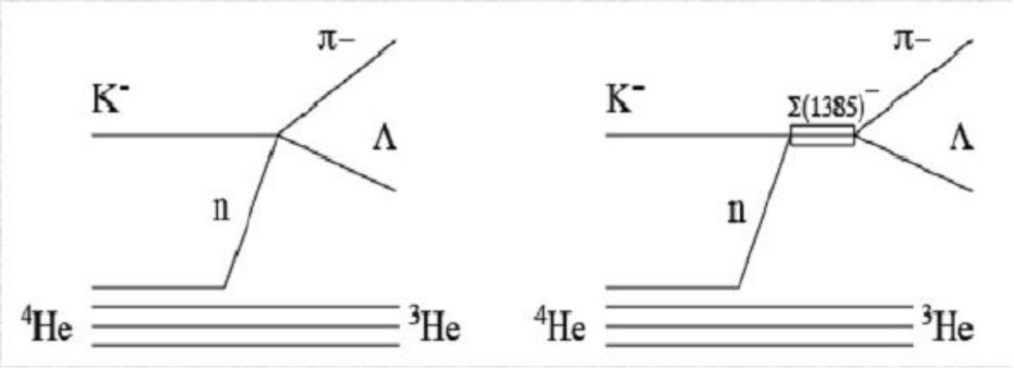
$\Lambda\pi^-$ analysis: K^-n non-resonant transition amplitude



First determination of the non-resonant transition amplitude below threshold

Investigated using:

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



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

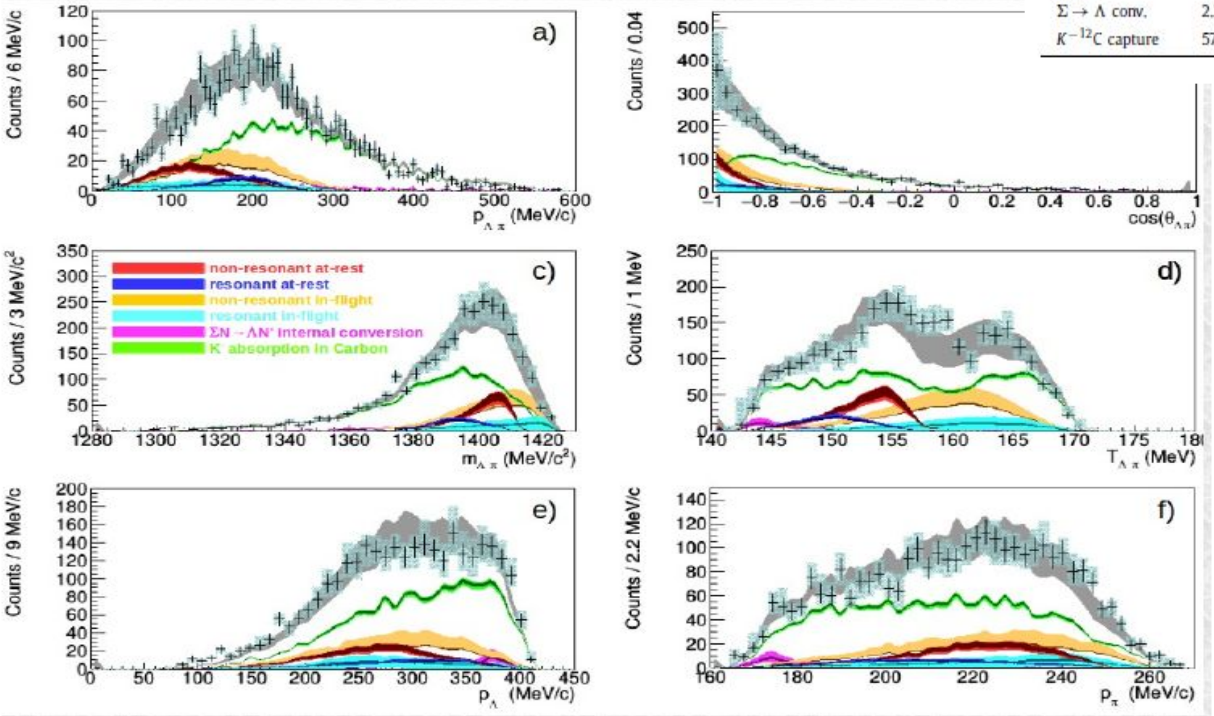
K^-n scattering amplitude with Chiral models

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

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

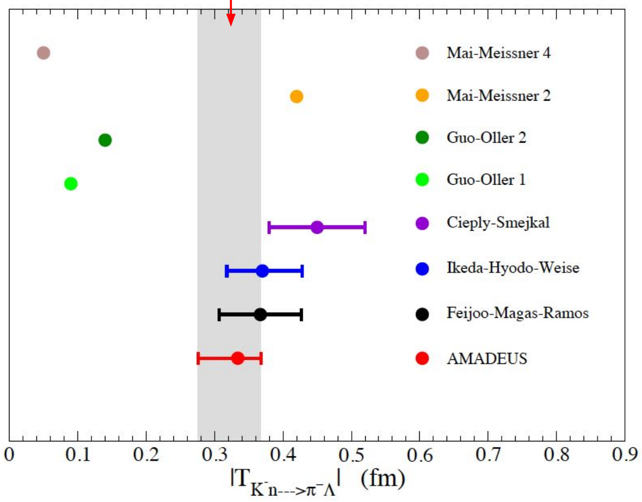
non-resonant transition amplitude below threshold

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



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%	$^{+5.9}_{-3.3}$%
Σ → Λ conv.	2.2%	± 0.3%	$^{+1.6}_{-0.8}$%
K^{-12}C capture	57.0%	± 1.2%	$^{+2.2}_{-3.2}$%

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



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

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

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

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

Motivation:

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

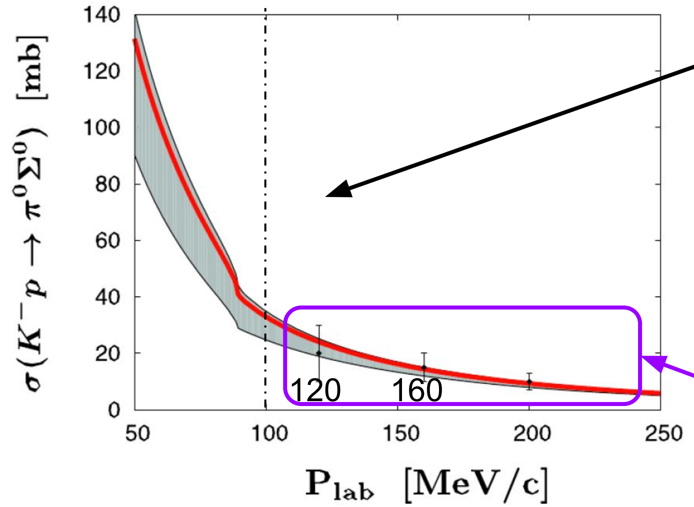
- three points in the p_K=120-200 MeV/c range (bubble chamber experiments),
- uncertainties larger than 30%,
- the $K^- p \to \Sigma^0 \pi^0$ cross sections are obtained **not directly but** on the basis of the isospin symmetry argument, from the measurement of $K^- p \to \Lambda\pi^0$ events

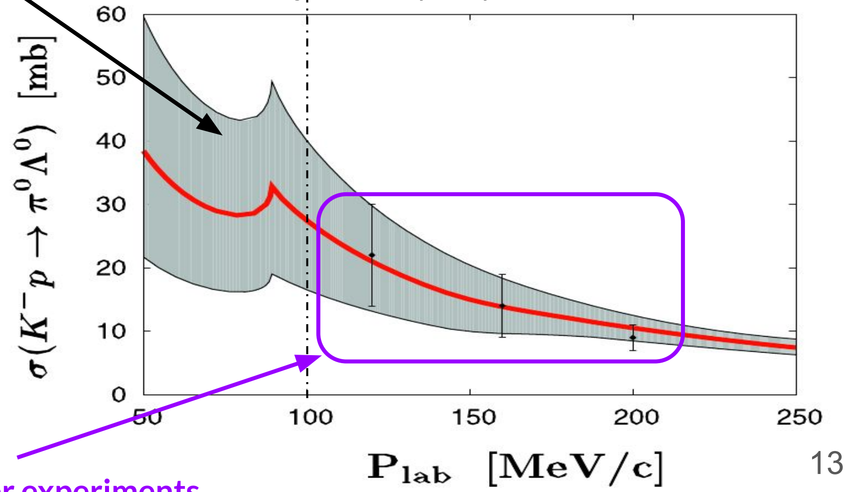
Low momentum K^- scattering cross sections in this Isospin I = 0 channel represent a fundamental input for the non-perturbative low energy QCD models

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

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

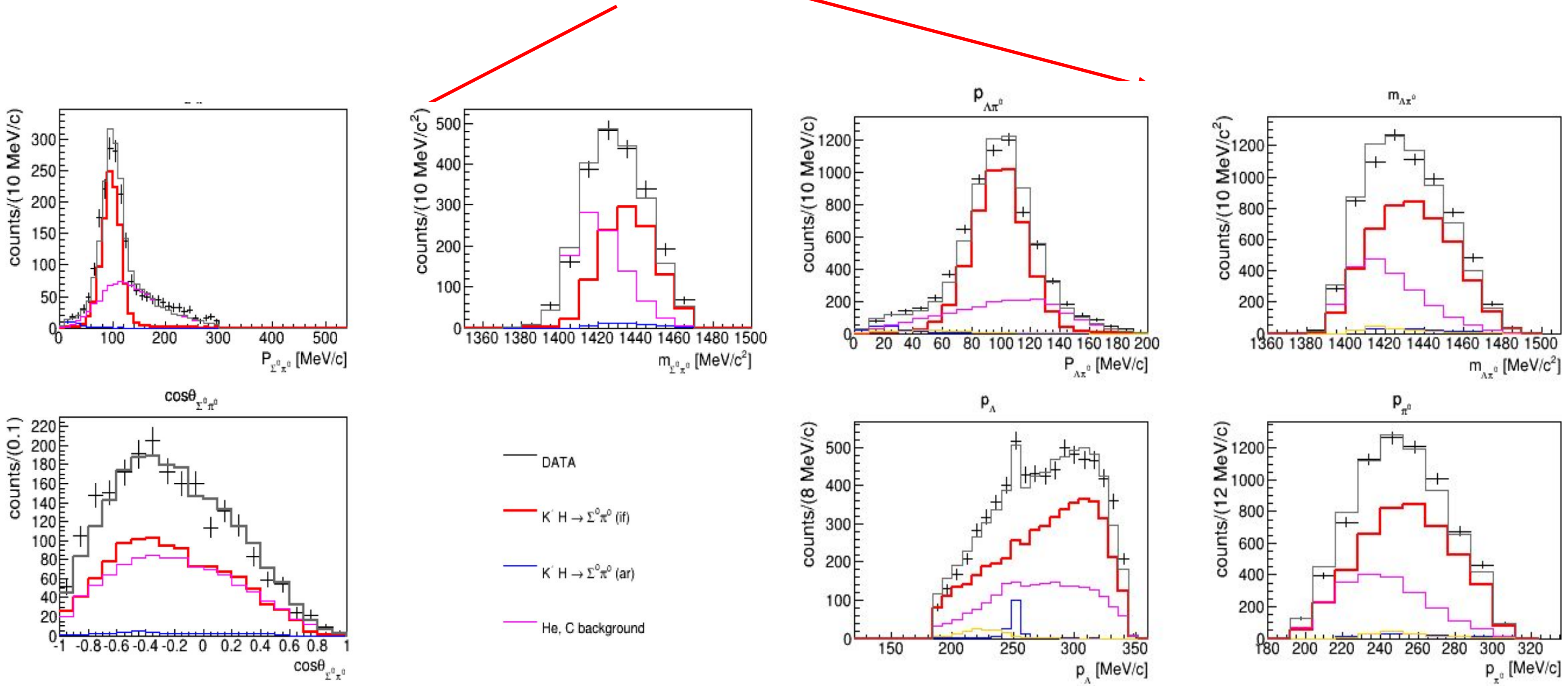
no experimental data





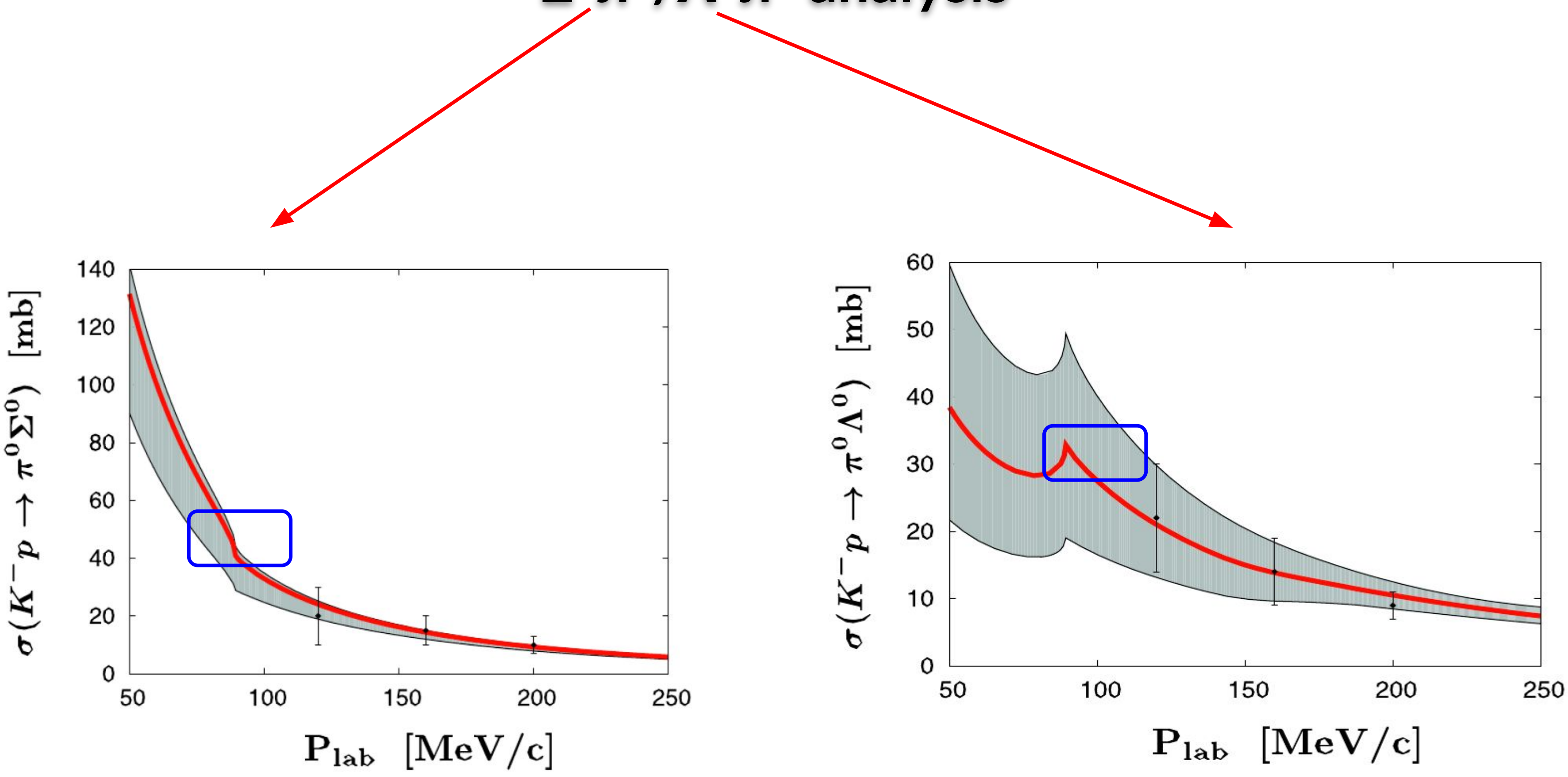
bubble chamber experiments

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



PRELIMINARY

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



Cross sections for p_K = 98±10 MeV/c

K^- multi-nucleon absorptions

In K^--nuclei optical potential a K^- multi-nucleon absorption term is necessary to fit the kaonic atoms data:

$$V_{K^-}(\rho) = V_{K^-}^{(1)}(\rho) + V_{K^-}^{(2)}(\rho)$$

multi-nucleon term

[E. Friedman, A. Gal, Nucl. Phys. A 959, 66 (2017)]
[Hrtánková, J. & Mareš, J. Phys. Rev. C96, 015205 (2017)]

single nucleon term from chiral models

- **Single nucleon absorption (1NA):** K^- "N" → Y π → pionic processes
- **Two nucleon absorption (2NA):** K^- "NN" → Y N
- **Three nucleon absorption (3NA):** K^- "NNN" → Y (NN)
- **Four nucleon absorption (4NA):** K^- "NNNN" → Y (NNN)

→ non-pionic processes

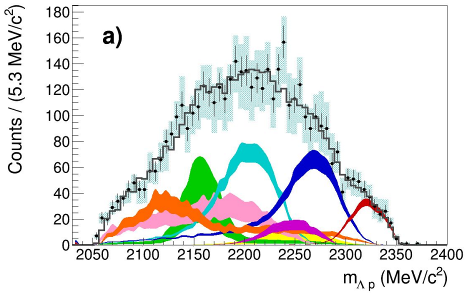
bound nucleons = "N", "NN", "NNN", "NNNN"
bound or unbound nucleons = (NN), (NNN)
Y = Λ, Σ

Λp analysis: K⁻ multi-nucleon absorption BRs and σ

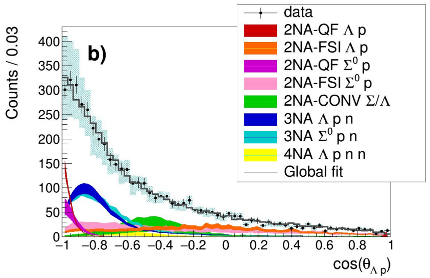
Simultaneous fit of:

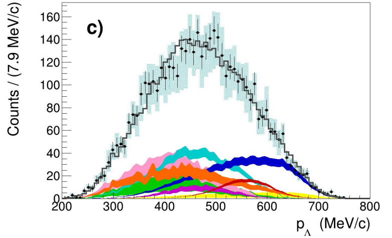
- Λp invariant mass;
- angular correlation;
- proton momentum;
- Λ momentum.

Total reduced χ^2: χ^2/dof = 0.94

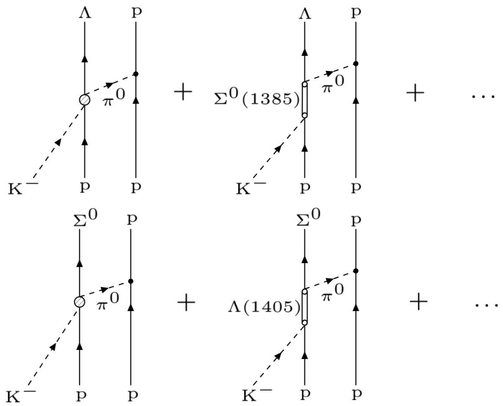


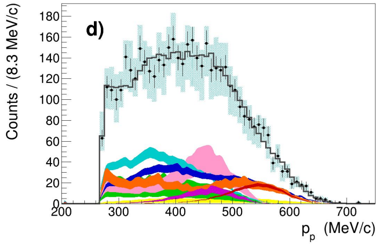
R. Del Grande et al., Eur. Phys. J. C79 (2019) no.3, 190





Process	Branching Ratio (%)	σ (mb)	@	p_K (MeV/c)
2NA-QF Λp	0.25 ± 0.02 (stat.) $^{+0.01}_{-0.02}$(syst.)	2.8 ± 0.3 (stat.) $^{+0.1}_{-0.2}$ (syst.)	@	128 ± 29
2NA-FSI Λp	6.2 ± 1.4(stat.) $^{+0.5}_{-0.6}$(syst.)	69 ± 15 (stat.) ± 6 (syst.)	@	128 ± 29
2NA-QF Σ^0p	0.35 ± 0.09(stat.) $^{+0.13}_{-0.06}$(syst.)	3.9 ± 1.0 (stat.) $^{+1.4}_{-0.7}$ (syst.)	@	128 ± 29
2NA-FSI Σ^0p	7.2 ± 2.2(stat.) $^{+4.2}_{-5.4}$(syst.)	80 ± 25 (stat.) $^{+46}_{-60}$ (syst.)	@	128 ± 29
2NA-CONV Σ/Λ	2.1 ± 1.2(stat.) $^{+0.9}_{-0.5}$(syst.)	-		
3NA Λpn	1.4 ± 0.2(stat.) $^{+0.1}_{-0.2}$(syst.)	15 ± 2 (stat.) ± 2 (syst.)	@	117 ± 23
3NA Σ^0pn	3.7 ± 0.4(stat.) $^{+0.2}_{-0.4}$(syst.)	41 ± 4 (stat.) $^{+2}_{-5}$ (syst.)	@	117 ± 23
4NA Λpnn	0.13 ± 0.09(stat.) $^{+0.08}_{-0.07}$(syst.)	-		
Global $\Lambda(\Sigma^0)$p	21 ± 3(stat.) $^{+5}_{-6}$(syst.)	-		





The ratio between the branching ratios of the 2NA-QF in the Λp channel and in the Σ^0p is measured to be:

$$\mathcal{R} = \frac{BR(K^-pp \to \Lambda p)}{BR(K^-pp \to \Sigma^0 p)} = 0.7 \pm 0.2(stat.)^{+0.2}_{-0.3}(syst.)$$

and the ratio between the corresponding phase spaces is $\mathcal{R}' \simeq 1.22$.

According to the pion exchange model:

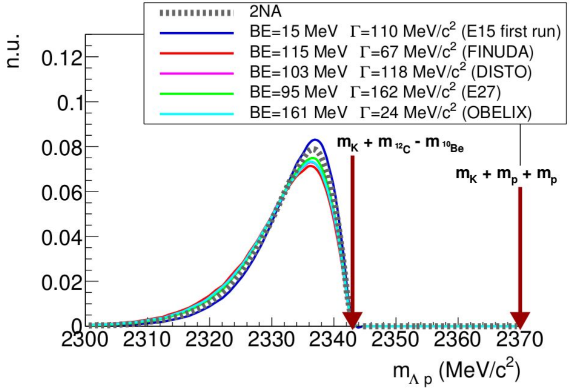
$$\frac{BR(K^-pp \to \Lambda p)}{BR(K^-pp \to \Sigma^0 p)} = \frac{BR(K^-p \to \Lambda\pi^0)}{BR(K^-p \to \Sigma^0\pi^0)}$$

[E. Oset and H. Toki, Phys. Rev. C 74 (2006) 015207]

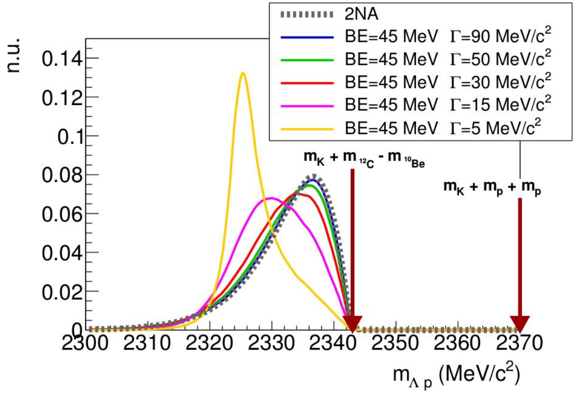
information on the in-medium properties of the Λ(1405).

Λp analysis: K^-pp bound state search

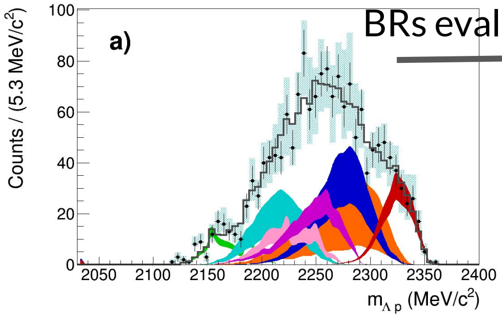
Using BE and Γ from experiments:



Fixing BE and moving Γ:

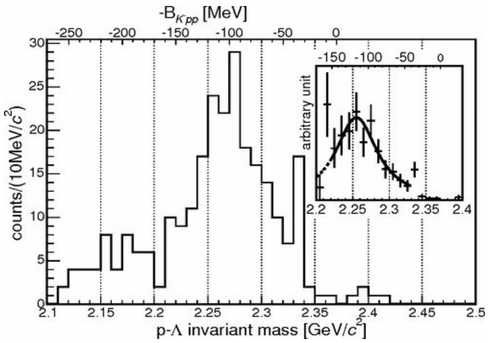


AMADEUS at DAΦNE



BRs evaluation

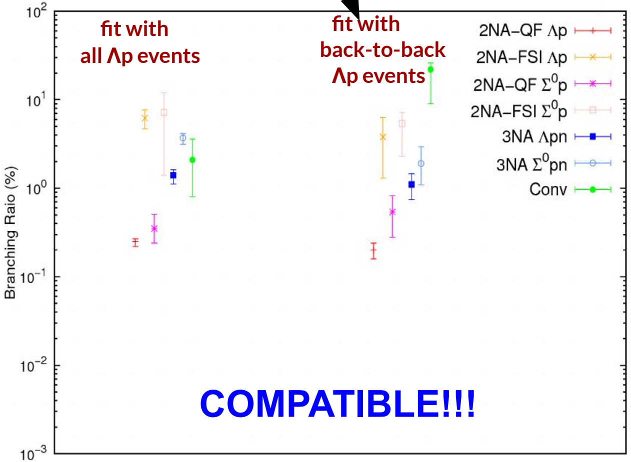
FINUDA at DAΦNE



[M. Agnello et al., Phys. Rev. Lett. 94, 212303 (2005)]

R. Del Grande et al., Eur. Phys. J. C79 (2019) no.3, 190

Process	Branching Ratio (%)
2NA-QF Λp	$0.20 \pm 0.04(\mathrm{stat.}) \pm 0.02(\mathrm{syst.})$
2NA-FSI Λp	$3.8 \pm 2.3(\mathrm{stat.}) \pm 1.1(\mathrm{syst.})$
2NA-QF $\Sigma^0 p$	$0.54 \pm 0.20(\mathrm{stat.})\ ^{+0.20}_{-0.16}(\mathrm{syst.})$
2NA-FSI $\Sigma^0 p$	$5.4 \pm 1.5(\mathrm{stat.})\ ^{+1.0}_{-2.7}(\mathrm{syst.})$
2NA-CONV Σ/Λ	$22 \pm 4(\mathrm{stat.})\ ^{+1}_{-12}(\mathrm{syst.})$
3NA Λpn	$1.1 \pm 0.3(\mathrm{stat.}) \pm 0.2(\mathrm{syst.})$
3NA $\Sigma^0 pn$	$1.9 \pm 0.7(\mathrm{stat.})\ ^{+0.8}_{-0.4}(\mathrm{syst.})$



K^-pp bound state contribution **completely overlaps** with the K^-2NA

Λt analysis: Cross section and BR for 4NA in $K^- \, {}^4He \rightarrow \Lambda t$ process

Previous data:

- in ^{4}**He:** bubble chamber experiment

/M. Roosen, J. H. Wickens, Il Nuovo Cimento 66, 101 (1981)/

only **3 events** compatibile with Λt kinematics found

BR$(K^- \, {}^4He \rightarrow \Lambda t)$ **=** $(3 \pm 2) \times 10^{-4} / K_{stop}$ → **global, no 4NA**

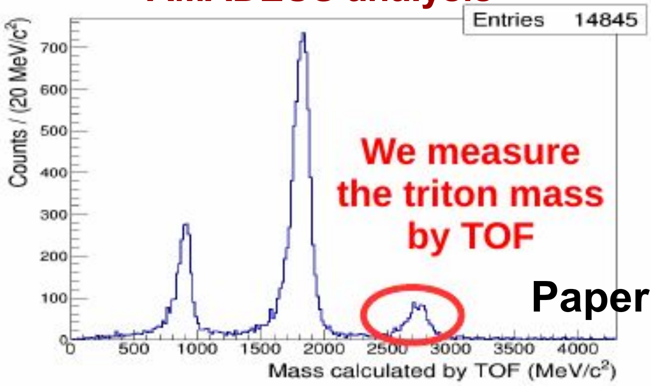
- in **solid targets:** ^{6,7}**Li,** ^{9}**Be** (FINUDA)

/Phys. Lett. B, 229 (2008)/

40 events, only **back-to-back data**

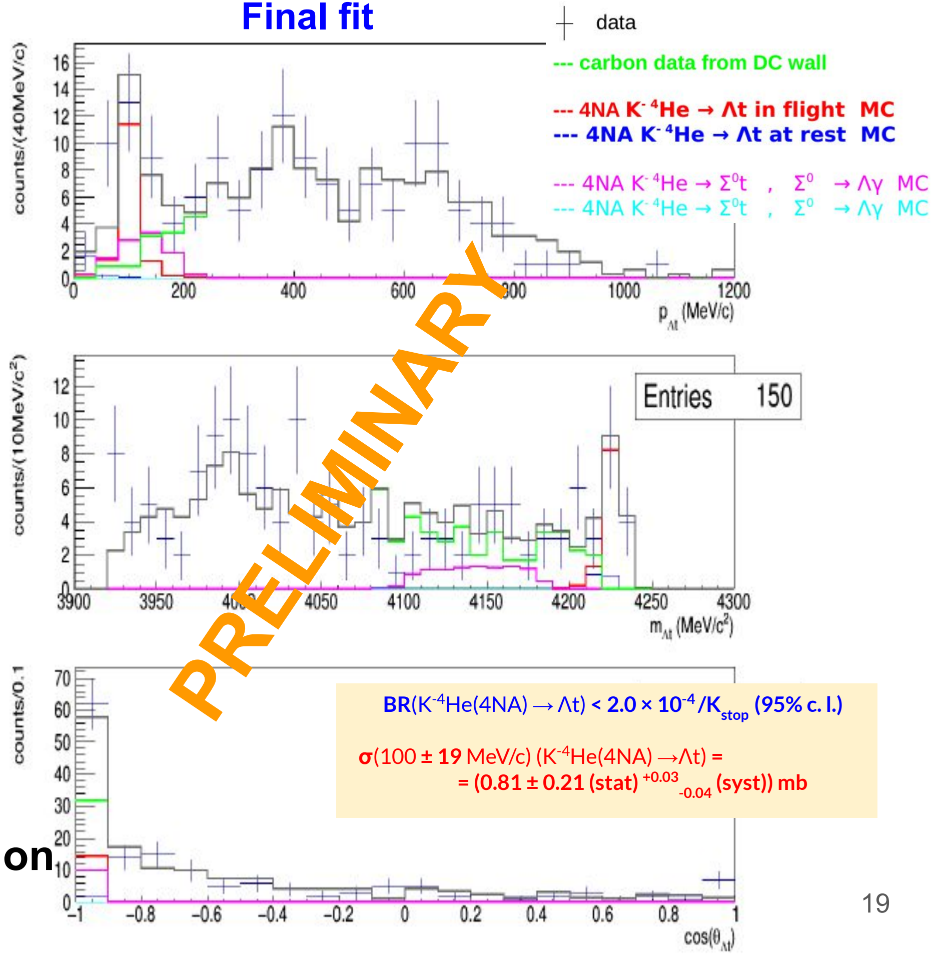
Λt emission yield → $10^{-3} - 10^{-4} / K^-_{stop}$ → **global, no 4NA**

AMADEUS analysis



Paper in preparation

Final fit



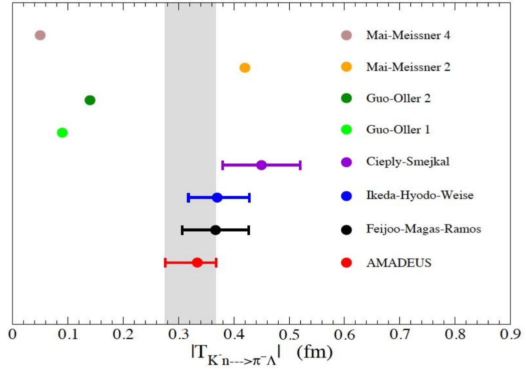
BR$(K^- \, {}^4He(4NA) \rightarrow \Lambda t)$ **<** $2.0 \times 10^{-4} / K_{stop}$ **(95% c. l.)**

$\sigma(100 \pm 19$ MeV/c$)$ $(K^- \, {}^4He(4NA) \rightarrow \Lambda t)$ =
= $(0.81 \pm 0.21\,(stat)\,^{+0.03}_{-0.04}\,(syst))$ mb

Summary

K$^-$n amplitude below threshold

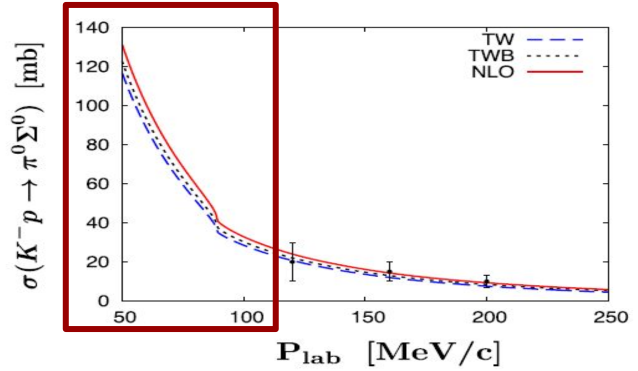
$$|f^s_{ar}| = (0.334 \pm 0.018\,\text{stat}^{+0.034}_{-0.058}\text{syst})\ \text{fm}\,.$$



Λ p channel: 2NA, 3NA and 4NA BRs and σ

Process	Branching Ratio (%)	σ (mb)	@	p_K (MeV/c)
2NA-QF Λp	0.25 ± 0.02 (stat.) $^{+0.01}_{-0.02}$(syst.)	2.8 ± 0.3 (stat.) $^{+0.1}_{-0.2}$ (syst.)	@	128 ± 29
2NA-FSI Λp	6.2 ± 1.4(stat.) $^{+0.5}_{-0.6}$(syst.)	69 ± 15 (stat.) $\pm$ 6 (syst.)	@	128 ± 29
2NA-QF Σ^0p	0.35 ± 0.09(stat.) $^{+0.13}_{-0.06}$(syst.)	3.9 ± 1.0 (stat.) $^{+1.4}_{-0.7}$ (syst.)	@	128 ± 29
2NA-FSI Σ^0p	7.2 ± 2.2(stat.) $^{+4.2}_{-5.4}$(syst.)	80 ± 25 (stat.) $^{+46}_{-60}$ (syst.)	@	128 ± 29
2NA-CONV Σ/Λ	2.1 ± 1.2(stat.) $^{+0.9}_{-0.5}$(syst.)	-		
3NA Λpn	1.4 ± 0.2(stat.) $^{+0.1}_{-0.2}$(syst.)	15 ± 2 (stat.) $\pm$ 2 (syst.)	@	117 ± 23
3NA Σ^0pn	3.7 ± 0.4(stat.) $^{+0.2}_{-0.4}$(syst.)	41 ± 4 (stat.) $^{+2}_{-5}$ (syst.)	@	117 ± 23
4NA Λpnn	0.13 ± 0.09(stat.) $^{+0.08}_{-0.07}$(syst.)	-		
Global $\Lambda(\Sigma^0)$p	21 ± 3(stat.) $^{+5}_{-6}$(syst.)	-		

K$^-$p → $\Sigma^0\pi^0$ cross section

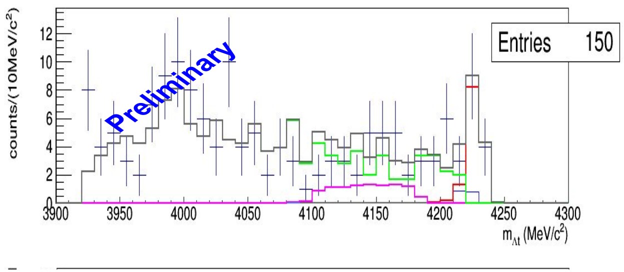


Λ t channel: 4NA BRs and σ

BR(K$^-$ ^{4}He(4NA) → Λt) < 2.0 × 10^{-4} /K$_{stop}$ (95% c. l.)

σ(100 ± 19 MeV/c) (K$^-$ ^{4}He(4NA) →Λt) =

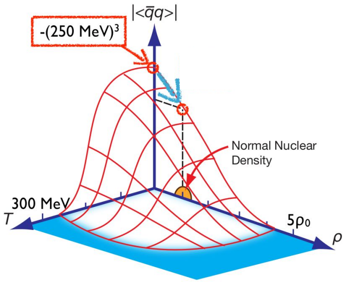
= (0.81 ± 0.21 (stat) $^{+0.03}_{-0.04}$ (syst)) mb



Thank you for your attention!

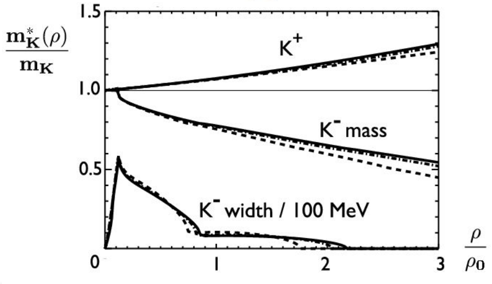
Impact on in-medium K̄N interaction

- Partial restoration of chiral symmetry in medium

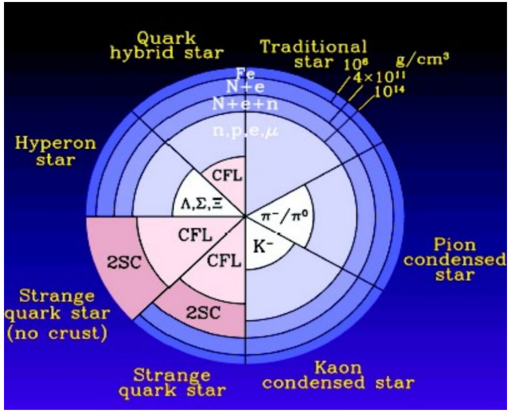


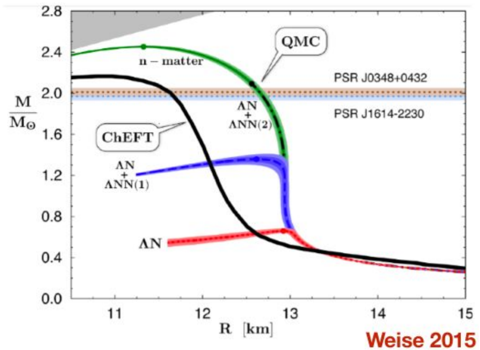
kaon mass modification:

$$m_K^{*2} = m_K^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho + \mathcal{O}\left(k_F^4\right)$$

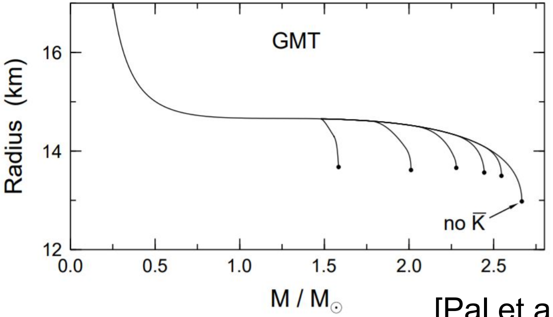


- Impact on Equation of State (EoS) of Neutron Stars:





Weise 2015



[Pal et al. (2000)]

K⁻ condensate can change EoS-stiffness

but: hyperons become more relevant at higher densities
[Gal et al. (2016)]

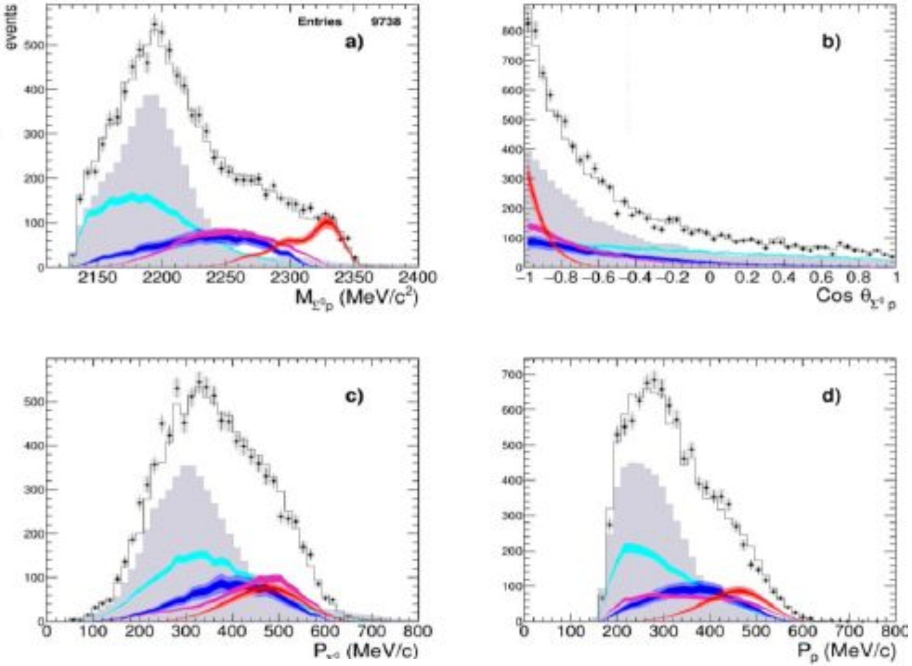
Σ^0p analysis: K^- multi-nucleon absorptions in ^{12}C

Final fit

- data
- π^0 background
- 4NA+Uncorr.
- 3NA
- 2NA FSI
- 2NA QF
- Total fit

$$\chi^2 = 0.85$$

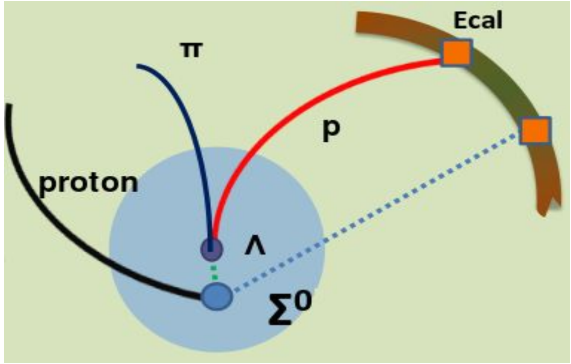
2NA-QF clearly separated From other processes



	yield / $K^-_{stop} \cdot 10^{-2}$	$\sigma_{stat} \cdot 10^{-2}$	$\sigma_{syst} \cdot 10^{-2}$
2NA-QF	0.127	$\pm$ 0.019	$^{+0.004}_{-0.008}$
2NA-FSI	0.272	$\pm$ 0.028	$^{+0.022}_{-0.023}$
Tot 2NA	0.376	$\pm$ 0.033	$^{+0.023}_{-0.032}$
3NA	0.274	$\pm$ 0.069	$^{+0.044}_{-0.021}$
Tot 3body	0.546	$\pm$ 0.074	$^{+0.048}_{-0.033}$
4NA + bkg.	0.773	$\pm$ 0.053	$^{+0.025}_{-0.076}$

$K^- \, ^{12}C \rightarrow \Sigma^0 \, p \, R \rightarrow (p \, \pi^-) \, \gamma \, p \, R$

detected particles



No statistically significant bound state emerges at 2σ level

O. Vazquez Doce, et. al., Phys. Lett. B758, 134 (2016)

$\Lambda\pi^-$ analysis: K^-n non-resonant transition amplitude

Λ(1405) case

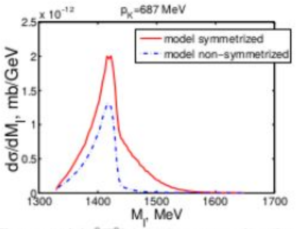


FIG. 4: Theoretical ($\pi^0\Sigma^0$) invariant mass distribution for an initial kaon lab momenta of 687 MeV. The non-symmetrized distribution also contains the factor 1/2 in the cross section.

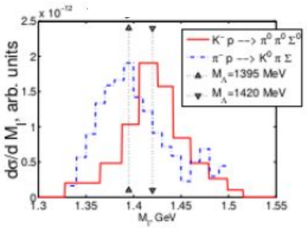
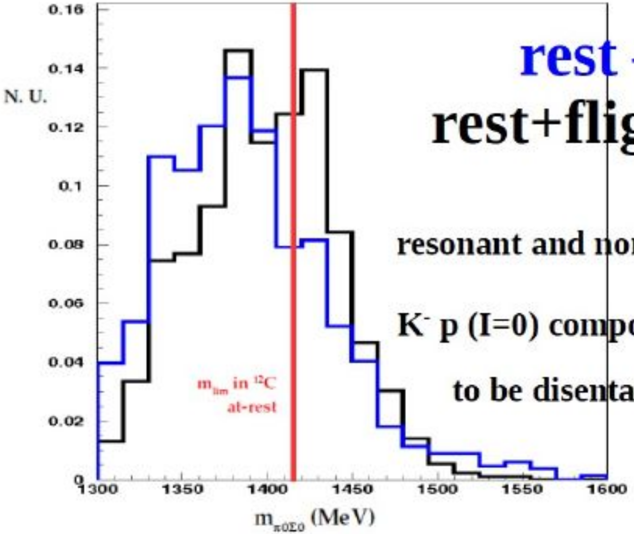


FIG. 5: Two experimental shapes of Λ(1405) resonance. See text for more details.

IN FLIGHT K^- ^{12}C opens window between 1416 MeV and KN threshold



resonant and non-resonant

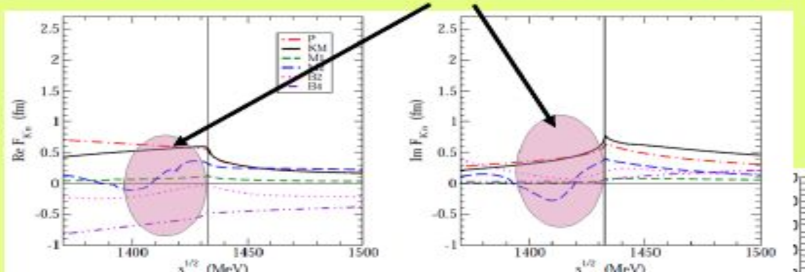
K^-p (I=0) components are

to be disentangled

Goal: how much comes from resonance in $K^-N \rightarrow Y\pi$

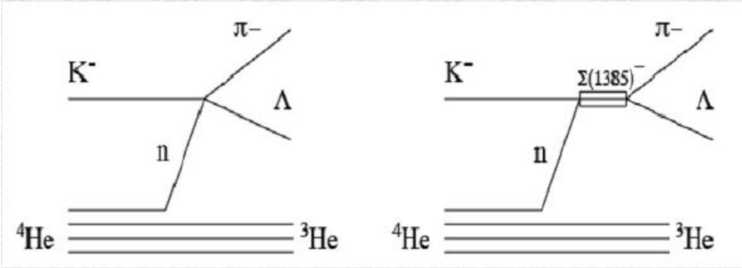
Non-resonant transition amplitude

never measured before below threshold



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

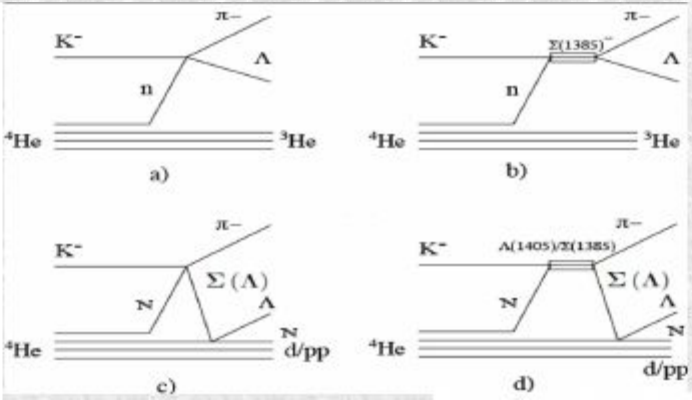
K^-"n" → $\Lambda\pi^-$ direct formation in ^{4}He



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

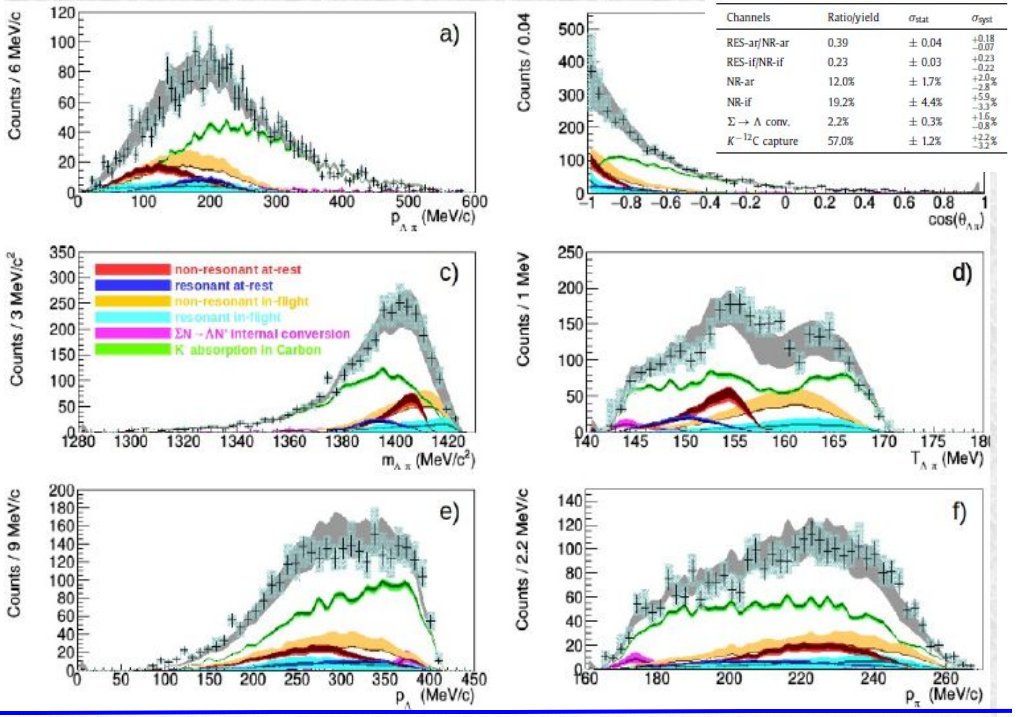
$K^- \, {}^4He \rightarrow \Lambda p^- \, {}^3He$ resonant and non-resonant processes

K. P., S. Wycech and C. Curceanu, Nucl. Phys. A954 (2016) 75-93
R. Del Grande, K. P., S. Wycech, Acta Phys. Pol. B 48 (2017) 1881

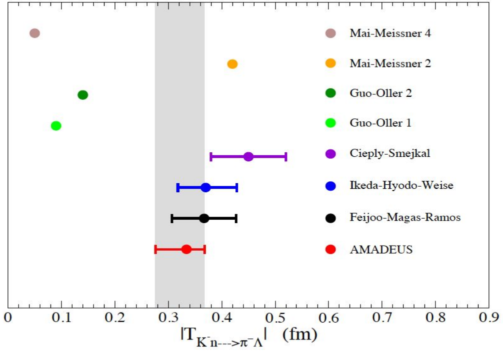


Simulations for resonant and non-resonant processes performed based on calculations for both S-state and P-state K- capture AT REST and IN FLIGHT

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



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%	$^{+5.9}_{-3.3}$%
$\Sigma \rightarrow \Lambda$ conv.	2.2%	± 0.3%	$^{+1.6}_{-0.8}$%
$K^{-\,12}C$ capture	57.0%	± 1.2%	$^{+2.2}_{-3.2}$%



From the well known Σ* transition probability:

$$\frac{\mathrm{NR-ar}}{\mathrm{RES-ar}} = \frac{\int_0^{pmax} P_{ar}^{nr}(p_{\Lambda\pi})\, dp_{\Lambda\pi}}{\int_0^{pmax} P_{ar}^{res}(p_{\Lambda\pi})\, dp_{\Lambda\pi}} =$$

$$= |f_{ar}^{s}|^2 \cdot 8,94 \cdot 10^5 \mathrm{MeV}^2$$

$$|f_{ar}^{nr}| = |A_{K^-n\rightarrow\Lambda\pi^-}| = (0.334 \pm 0.018\,\mathrm{stat}^{+0.034}_{-0.058}\mathrm{syst})\ \mathrm{fm}$$

1) extract the amplitude for each model .. $A_{K\text{-}n} = (\mathrm{Re}F^2_{K\text{-}n} + \mathrm{Im}F^2_{K\text{-}n})^{1/2}$
2) scale the amplitudes for the K^-n couplings to the $\Sigma^-\pi^0$ and $\Sigma^0\pi^-$ channels:

$$\frac{Prob_{K^-n\rightarrow\Lambda\pi^-}}{Prob_{K^-n\rightarrow\Sigma^-\pi^0}} = \frac{Ph_{K^-n\rightarrow\Lambda\pi^-}}{c_1 Ph_{K^-n\rightarrow\Sigma^-\pi^0}}$$

Isospin (I, I_z) = = (1 , -1) component

Phase spaces ratios

$$\frac{Prob_{K^-n\rightarrow\Lambda\pi^-}}{Prob_{K^-n\rightarrow\Sigma^0\pi^-}} = \frac{Ph_{K^-n\rightarrow\Lambda\pi^-}}{c_2 Ph_{K^-n\rightarrow\Sigma^0\pi^-}}$$

K. Piscicchia, et. al., Phys. Lett. B782, 339 (2018)