First application of a microscopic K^-NN absorption model in calculations of kaonic atoms

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Introduction

- K^- multi-nucleon absorption in the surface region of atomic nuclei represents about 20%

  NC 53 (1968) 313 (Berkeley), *NPB 35 (1971) 332 (BNL)*, *NC 39A (1977) 538 (CERN)*

- K^- multi-nucleon absorption in atoms described by phenomenological optical potential

  E. Friedman, A. Gal, NPA 959 (2017) 66

- Model for K^-NN absorption in nuclear matter using free-space chiral amplitudes

  T. Sekihara et al., PRC 86 (2012) 065205

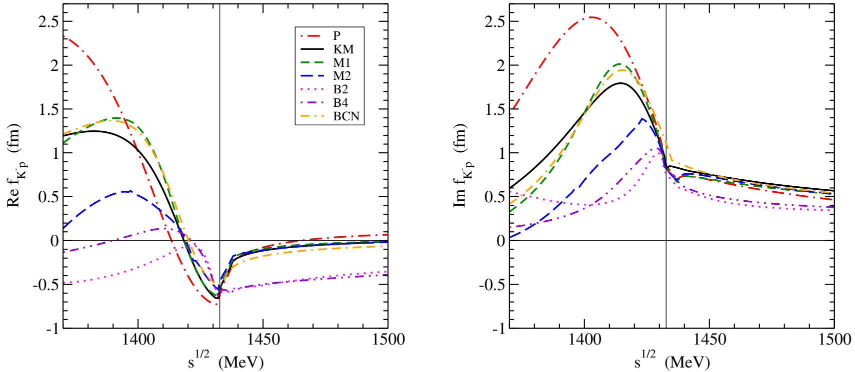
- New experimental data on K^-NN absorption (AMADEUS@DAΦNE)

  K. Piscicchia et al., PLB 782 (2018) 339

  R. Del Grande et al., EPJ C79 (2019) 190

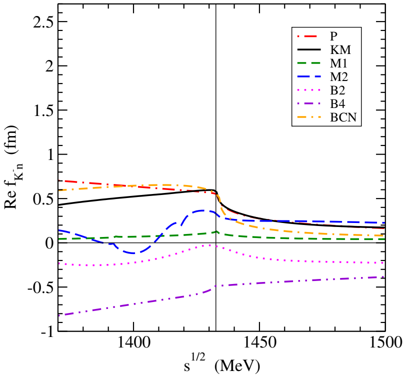
- Solid microscopic model for K^-NN absorption needed!

Free-space K^-p amplitudes in various chiral models



Prague (P)	*A. Cieply, J. Smejkal, Nucl. Phys. A 881 (2012) 115*
Kyoto-Munich (KM)	*Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A 881 (2012) 98*
Murcia (M1 and M2)	*Z. H. Guo, J. A. Oller, Phys. Rev. C 87 (2013) 035202*
Bonn (B2 and B4)	*M. Mai, U.-G. Meißner, Nucl. Phys. A 900 (2013) 51*
Barcelona (BCN)	*A. Feijoo, V. Magas, A. Ramos, Phys. Rev. C 99 (2019) 035211*

Free-space $K^- n$ amplitudes



Kaonic atoms

- Info about $K^- N$ interaction below threshold provided by kaonic atoms

  65 data points (energy shifts, widths, yields=upper level widths) from CERN, Argonne, RAL, BNL

- Chirally motivated models fail to describe kaonic atom data

  E. Friedman, A. Gal, NPA 959 (2017) 66

model	B2	B4	M1	M2	P	KM
$\chi^2(65)$	1174	2358	2544	3548	2300	1806

Multinucleon processes

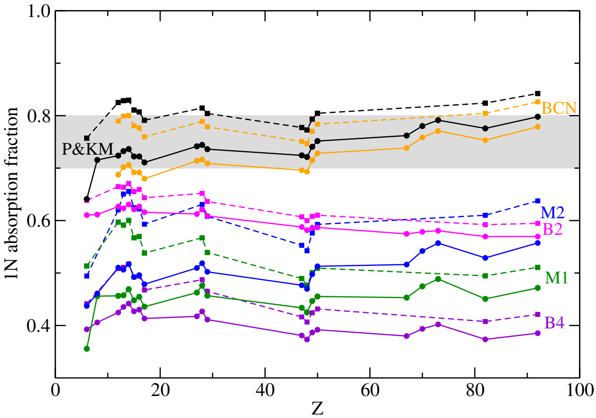
- Chiral models include only $K^- N \to \pi Y$ ($Y = \Lambda, \Sigma$) decay channel
- K^- interactions with two and more nucleons should be included, (e.g., $K^- + N + N \to Y + N$) $\leftarrow$ analysis of kaonic atom data
  E. Friedman, A. Gal, NPA 959 (2017) 66

$$V^{\mathrm{phen}}_{K^-\mathrm{multiN}} = -4\pi B(\frac{\rho}{\rho_0})^{\alpha}\rho \ ,$$

where B is a complex amplitude, ρ is nuclear density distribution, ρ_0 is saturation density and α is positive

- $\chi^2(65)$ goes down to 105 - 125

Single- vs. multi-nucleon processes



- Fraction of *single-nucleon* absorption 0.75 ± 0.05 (average value) used as an additional constraint.

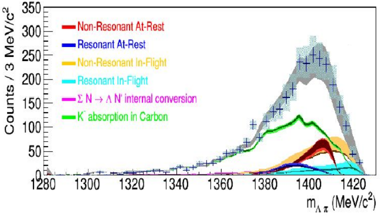
→ Only P, KM and BCN models found acceptable in kaonic atom analysis

E. Friedman, A. Gal, NPA 959 (2017) 66

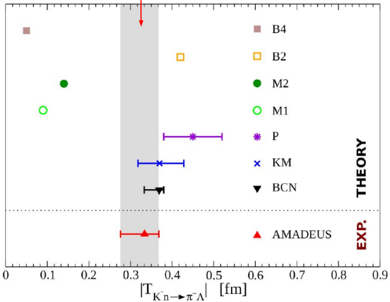
K. Piscicchia, talk at THEIA-STRONG2020 Web-Seminar,20 December 2020

Outcome of the measurement

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



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



[K. Piscicchia, S. Wycech, L. Fabbietti et al. Phys.Lett. B782 (2018) 339-345]
[K. Piscicchia, S. Wycech, C. Curceanu, Nucl. Phys. A 954 (2016) 75-93]

Microscopic model for $K^- NN$ absorption in nuclear matter

Microscopic model for K^- two-nucleon absorption in symmetric nuclear matter *J. Hrtánková, À. Ramos, PRC 101 (2020) 035204*

- based on a meson-exchange approach
  H. Nagahiro et al., PLB 709 (2012) 87
- P and BCN chiral $K^- N$ amplitudes employed
- Pauli correlations in the medium for $K^- N$ amplitudes considered
- real part of the $K^- NN$ optical potential evaluated as well
- $K^- N$ optical potential derived within the same approach

K^-N absorption in nuclear matter

$$K^-N \to \pi Y \quad (Y = \Lambda, \Sigma)$$

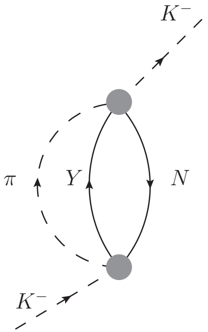


Fig.1: Feynman diagram for K^- absorption on a single nucleon in nuclear matter. The shaded circles denote the K^-N t-matrices derived from a chiral model.

$K^- NN$ absorption in nuclear matter

$$K^- + N + N \to Y + N \quad (Y = \Lambda, \Sigma)$$

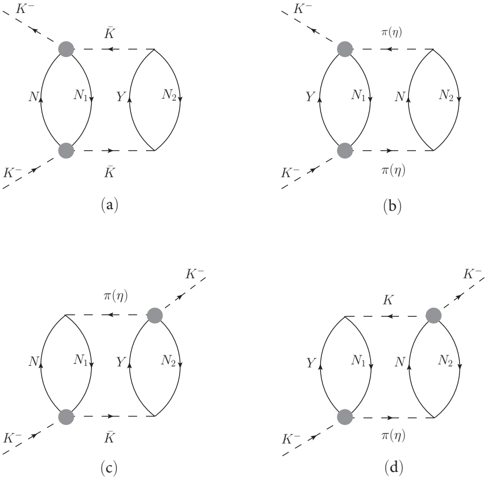


Fig.2: Two-fermion-loop (2FL) Feynman diagrams for non-mesonic K^- absorption on two nucleons N_1, N_2 in nuclear matter. The shaded circles denote the $K^- N$ t-matrices derived from a chiral model.

$K^- NN$ absorption in nuclear matter

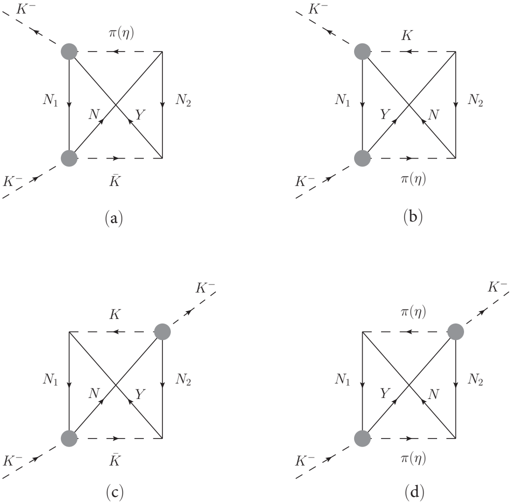


Fig.3: One-fermion-loop (1FL) Feynman diagrams for non-mesonic K^- absorption on two nucleons N_1, N_2 in nuclear matter. The shaded circles denote the $K^- N$ t-matrices derived from a chiral model.

$K^- NN$ absorption in nuclear matter

- $V_{K^-N} = \sum_{channels} V_{K^-N \to \pi Y}$ (Fig.1)
- $V_{K^-NN} = \sum_{\text{channels}} V^{\text{2FL}}_{K^-NN} + V^{\text{1FL}}_{K^-NN}$ (Fig.2 and 3)

  $\rightarrow$ contributions from 37 2FL and 28+33 1FL diagrams

Table 1: All considered channels for mesonic and non-mesonic K^- absorption in matter.

$K^- N$	$\rightarrow \pi Y$	$K^- N_1 N_2$	$\rightarrow YN$
$K^- p$	$\rightarrow \pi^0 \Lambda$	$K^- pp$	$\rightarrow \Lambda p$
	$\rightarrow \pi^0 \Sigma^0$		$\rightarrow \Sigma^0 p$
	$\rightarrow \pi^+ \Sigma^-$		$\rightarrow \Sigma^+ n$
	$\rightarrow \pi^- \Sigma^+$	$K^- pn(np)$	$\rightarrow \Lambda n$
$K^- n$	$\rightarrow \pi^- \Lambda$		$\rightarrow \Sigma^0 n$
	$\rightarrow \pi^- \Sigma^0$		$\rightarrow \Sigma^- p$
	$\rightarrow \pi^0 \Sigma^-$	$K^- nn$	$\rightarrow \Sigma^- n$

AMADEUS: Ratio for 2N absorption

Recently measured ratio *R. Del Grande et al., EPJ C79 (2019) 190*

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

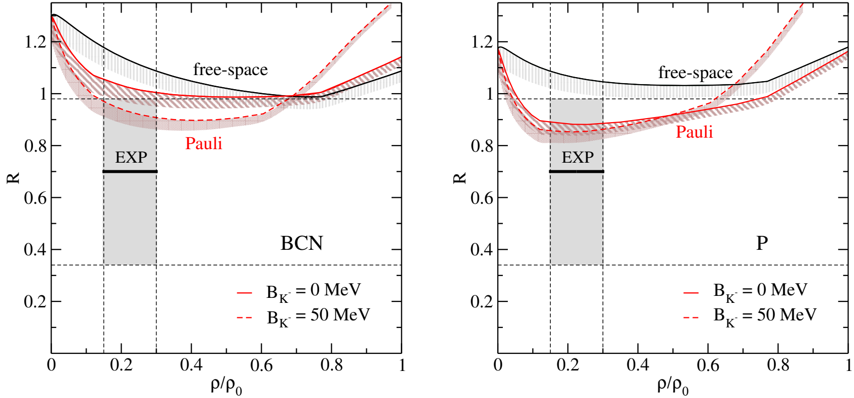


Fig.4: The ratio R as a function of relative density, calculated using the free-space and Pauli blocked amplitudes for $B_{K^-} = 0$ MeV and $B_{K^-} = 50$ MeV. Color bands denote the uncertainty due to different cut-off values $\Lambda_c = 800 - 1200$ MeV.

Branching ratios for mesonic absorption

Table 2: Primary-interaction ratios (in %) for mesonic absorption of K^- in nuclear matter, calculated with free-space and Pauli blocked BCN amplitudes for $B_{K^-} = 0$ MeV and $p_{K^-} = 0$ MeV/c. The errors denote the uncertainty due to the cut-off dependence. The experimental data corrected for primary interaction are shown for comparison.

BCN	$0.3\rho_0$		Exp. [1]	
mesonic ratio	f.s.	Pauli	^{4}He	^{12}C
$\Sigma^+\pi^-/K^-$	19.6 ± 0.6	28.8 ± 0.7	31.2 ± 5.0	29.4 ± 1.0
$\Sigma^-\pi^0/K^-$	6.2 ± 0.2	5.7 ± 0.1	4.9 ± 1.3	2.6 ± 0.6
$\Sigma^-\pi^+/K^-$	21.9 ± 0.6	14.8 ± 0.4	9.1 ± 1.6	13.1 ± 0.4
$\Sigma^0\pi^-/K^-$	6.2 ± 0.2	5.7 ± 0.1	4.9 ± 1.3	2.6 ± 0.6
$\Sigma^0\pi^0/K^-$	18.1 ± 0.5	19.2 ± 0.5	17.7 ± 2.9	20.0 ± 0.7
$\Lambda\pi^0/K^-$	3.8 ± 0.1	3.5 ± 0.1	5.2 ± 1.6	3.4 ± 0.2
$\Lambda\pi^-/K^-$	7.6 ± 0.2	7.0 ± 0.2	10.5 ± 3.0	6.8 ± 0.3
total 1N ratio	83.3 ± 2.4	84.6 ± 2.2	83.5 ± 7.1	77.9 ± 1.6

[1] *C. Vander Velde-Wilquet et al., NC 39 A (1977) 538*

Branching ratios for non-mesonic absorption

Table 3: Primary-interaction total ratios (in %) for non-mesonic and total (1N+2N) K^- absorption in matter and corresponding ratios corrected for Σ-Λ conversion with different conversion rates, a) - 60% for Σ^+-Λ, 22.5% for Σ^--Λ, 72% for Σ^0-Λ, b) - 50% for all Σ's, calculated with Pauli blocked BCN amplitudes for $B_{K^-} = 0$ MeV and $p_{K^-} = 0$ MeV/c. The errors denote the uncertainty due to the cut-off dependence.

BCN	$0.3\rho_0$	$0.3\rho_0$ + Σ-Λ conv.		Exp. [1]
non-mesonic ratio		a)	b)	^{4}He
$(\Lambda N + \Sigma^0 N)/K^-$	7.2 ± 1.1	10.5 ± 1.5	11.3 ± 1.6	11.7 ± 2.4
$(\Sigma^- N)/K^-$	4.3 ± 0.6	3.4 ± 0.4	2.2 ± 0.3	3.6 ± 0.9
$\Sigma^+ n/K^-$	3.8 ± 0.5	1.5 ± 0.2	1.9 ± 0.3	1.0 ± 0.4
$(\Sigma^0 N)/K^-$	3.7 ± 0.5	1.0 ± 0.1	1.9 ± 0.2	2.3 ± 1.0
total 2N ratio	15.4 ± 2.2	15.4 ± 2.2		16.4 ± 2.6
total ratio				
Σ^+/K^-	32.6 ± 0.2	13.0 ± 0.1	16.3 ± 0.1	17.0 ± 2.7
Σ^-/K^-	24.8 ± 0.1	19.21 ± 0.04	12.39 ± 0.03	13.8 ± 1.8
Σ^0/K^-	28.7 ± 0.1	8.03 ± 0.04	14.3 ± 0.1	10.8 ± 5.0
Λ/K^-	14.0 ± 0.3	59.7 ± 0.1	57.0 ± 0.2	58.4 ± 5.7
Σ^+/Σ^-	1.31 ± 0.01	0.68 ± 0.01	1.31 ± 0.01	1.2 ± 0.2

[1] *P. A. Katz et al., PRD 1 (1970) 1267*

Application to kaonic atoms

- K^-NN model applied in calculations of energy shifts and widths in kaonic atoms
- BCN amplitudes used $\rightarrow$ in-medium modifications included (Pauli or WRW *T. Wass, M. Rho, W. Weise, NPA 617 (1997) 449*)
- microscopic $K^-N + K^-NN$ potentials calculated for 23 targets and confronted with kaonic atom data
- $K^-N + K^-NN$ potentials then supplemented by a phenomenological term describing 3 and 4 nucleon processes $\sim -4\pi B(\frac{\rho}{\rho_0})^\alpha \rho$
- values of α and complex amplitude B fitted to data

Kaonic atoms calculations

Table 4: Values of χ^2 for shifts, widths and yields in selected K^- atoms, calculated with K^-N, $K^-N + K^-NN$ and K^-N+phen. multiN potentials based on BCN Pauli or WRW modified amplitudes. Experimental data are shown for comparison.

BCN		WRW		Pauli		phen.	EXP
		K^-N	$+K^-NN$	K^-N	$+K^-NN$	K^-N + phen. multiN	
C^{12}	$\Delta(\epsilon)$	101.52	34.35	25.13	11.48	1.76	-0.59 (0.08)
	Γ	44.80	27.45	17.00	9.44	0.70	1.73 (0.15)
	Γ^*	1.71	1.47	0.15	0.67	2.74	0.99 (0.20)
P^{31}	$\Delta(\epsilon)$	41.04	15.13	10.46	6.35	0.03	-0.33 (0.08)
	Γ	13.72	10.34	11.43	6.42	0.24	1.44 (0.12)
	Γ^*	5.17	4.70	5.98	1.87	0.30	1.89 (0.30)
S^{32}	$\Delta(\epsilon)$	475.71	209.40	90.77	80.82	1.24	-0.494 (0.038)
	Γ	0.76	2.83	67.35	43.29	9.24	2.19 (0.10)
	Γ^*	13.32	10.85	9.45	2.78	0.47	3.03 (0.44)
Cl^{35}	$\Delta(\epsilon)$	38.27	17.69	4.23	4.62	2.10	-0.99 (0.17)
	Γ	5.94	2.56	10.94	5.39	0.00	2.91 (0.24)
	Γ^*	7.92	4.53	2.27	0.74	0.15	5.8 (1.70)
Cu^{63}	$\Delta(\epsilon)$	33.50	8.93	1.54	2.71	3.19	-0.370 (0.047)
	Γ	0.31	0.02	4.90	3.57	2.25	1.37 (0.17)
	Γ^*	0.98	0.13	0.24	0.73	1.52	5.2 (1.1)
Sn^{118}	$\Delta(\epsilon)$	9.00	8.81	6.57	8.50	2.15	-0.41 (0.18)
	Γ	0.42	0.03	0.35	0.71	0.29	3.18 (0.64)
	Γ^*	24.53	15.08	5.04	4.80	4.09	15.1 (4.4)
Pb^{208}	$\Delta(\epsilon)$	7.52	3.67	3.24	4.84	0.34	-0.02 (0.012)
	Γ	0.12	0.10	0.31	0.38	0.39	0.37 (0.15)
	Γ^*	0.06	0.18	0.35	0.41	0.52	4.1 (2)
χ^2	total	820.37	378.24	277.69	200.54	33.71	
	S^{32}out	330.58	155.16	110.13	73.65	22.76	

Kaonic atom data - ^{32}S

E. Friedman et al, NPA 579 (1994) 518

- $\chi^2(^{32}S)$=127 for 'KN+KNN Pauli'
- comparison with data from Ref. [18]:
  - configuration with 2p+2n in 2s1/2 $\rightarrow \chi^2(^{32}S)$= 54!
  - configuration with 2p+2n in 1d3/2 $\rightarrow \chi^2(^{32}S)$=42!

Table 1
Compilation of K^- atomic data

Nucleus	Transition	ϵ (keV)	Γ (keV)	Y	Γ_u (eV)	Ref.
S	$4\rightarrow3$	-0.550 ± 0.06	2.330 ± 0.200	0.22 ± 0.02	3.10 ± 0.36	[18]
		-0.43 ± 0.12	2.310 ± 0.170	–	–	[21]
		-0.462 ± 0.054	1.96 ± 0.17	0.23 ± 0.03	2.9 ± 0.5	[19]
Cl	$4\rightarrow3$	-0.770 ± 0.40	3.80 ± 1.0	0.16 ± 0.04	5.8 ± 1.7	[18]
		-0.94 ± 0.40	3.92 ± 0.99	–	–	[22]
		-1.08 ± 0.22	2.79 ± 0.25	–	–	[21]
Co	$5\rightarrow4$	-0.099 ± 0.106	0.64 ± 0.25	–	–	[19]
Ni	$5\rightarrow4$	-0.180 ± 0.070	0.59 ± 0.21	0.30 ± 0.08	5.9 ± 2.3	[20]
		-0.246 ± 0.052	1.23 ± 0.14	–	–	[19]
Cu	$5\rightarrow4$	-0.240 ± 0.220	1.650 ± 0.72	0.29 ± 0.11	7.0 ± 3.8	[20]
		-0.377 ± 0.048	1.35 ± 0.17	0.36 ± 0.05	5.1 ± 1.1	[19]

[18] *G. Backenstoss et al. PLB 38 (1972) 181; NPB 73 (1974) 189*

Confrontation with kaonic atom data

Table 5: Values of $\chi^2(65)$ resulting from comparisons of predictions with kaonic atom data using K^-N, $K^-N + K^-NN$, and $K^-N + K^-NN$+phen. multiN potentials. Values of complex amplitude B and parameter α for potentials based on Pauli blocked and WRW modified BCN amplitudes.

	K^-N	$K^-N + K^-NN$	+ phen.	ReB (fm)	ImB (fm)	α
Pauli	825	565	105	-1.97(13)	-0.93(11)	1.4
WRW	2378	1123	116	-0.90(9)	0.72(10)	0.6

- best fit K^-N + phen. multiN potential based on BCN amplitudes ReB = -1.3 fm, ImB = 1.9 fm, $\alpha = 1$, $\chi^2 = 112.3$

Calculated branching ratios in ^{12}C+K^- atom

Table 6: Primary-interaction branching ratios (in %) for mesonic ($K^- N \to Y\pi$, $Y = \Lambda, \Sigma$) and non-mesonic absorption ($K^- NN \to YN$) of K^- in ^{12}C+K^- atom (l=2), calculated with $K^- N + K^- NN$ potentials based on WRW and Pauli blocked BCN and P amplitudes.The experimental data corrected for primary interaction are shown for comparison.

^{12}C + K^- (l=2)	BCN		P		Exp. [1]
mesonic ratio	WRW	Pauli	WRW	Pauli	^{12}C
$\Sigma^+\pi^-$	26.9	22.4	28.1	22.1	29.4 ± 1.0
$\Sigma^-\pi^0$	8.3	7.7	7.2	5.9	2.6 ± 0.6
$\Sigma^-\pi^+$	15.5	17.5	17.1	17.6	13.1 ± 0.4
$\Sigma^0\pi^-$	8.4	7.9	7.3	5.9	2.6 ± 0.6
$\Sigma^0\pi^0$	17.2	16.4	19.3	17.3	20.0 ± 0.7
$\Lambda\pi^0$	5.2	5.0	4.2	3.7	3.4 ± 0.2
$\Lambda\pi^-$	10.4	9.9	8.3	7.2	6.8 ± 0.3
total 1N ratio	91.9	87.0	90.7	82.0	77.9 ± 1.6
non-mesonic ratio	WRW	Pauli	WRW	Pauli	76% CF_3Br + 24% C_3H_8 [2]
$\Lambda p + \Lambda n + \Sigma^0 p + \Sigma^0 n$	4.2	6.7	4.6	9.0	14.1 ± 2.5 [a]
$\Sigma^- p + \Sigma^- n$	1.7	3.1	2.1	4.2	7.3 ± 1.3 [a]
$\Sigma^+ n$	2.2	3.5	2.6	4.8	4.3 ± 1.2 [a]
$\Sigma^0 p + \Sigma^0 n$	1.9	3.1	2.2	4.2	-
total 2N ratio	8.1	13.0	9.3	18.0	$(16 \pm 3(\text{stat.})^{+4}_{-5}(\text{syst.}))$ [3]

[a] multinucleon capture rate

[1] *C. Vander Velde-Wilquet et al., NC 39 A (1977) 538*

[2] *H. Davis et al., NC 53 A (1968) 313*

[3] *R. Del Grande et al., EPJ C79 (2019) 190*

AMADEUS data on Λp and $\Sigma^0 p$ production

Λp analysis: K⁻ multi-nucleon absorption BRs

[R. Del Grande, K. Piscicchia, O. Vazquez Doce et al., Eur.Phys.J. C79 (2019) no.3, 190]

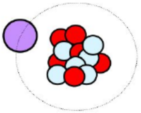
Process	Branching Ratio (%)
2NA-QF Λp	0.25 ± 0.02 (stat.) $^{+0.01}_{-0.02}$(syst.)
2NA-FSI Λp	6.2 ± 1.4(stat.) $^{+0.5}_{-0.6}$(syst.)
2NA-QF Σ^0p	0.35 ± 0.09(stat.) $^{+0.13}_{-0.06}$(syst.)
2NA-FSI Σ^0p	7.2 ± 2.2(stat.) $^{+4.2}_{-5.4}$(syst.)
2NA-CONV Σ/Λ	2.1 ± 1.2(stat.) $^{+0.9}_{-0.5}$(syst.)
3NA Λpn	1.4 ± 0.2(stat.) $^{+0.1}_{-0.2}$(syst.)
3NA Σ^0pn	3.7 ± 0.4(stat.) $^{+0.2}_{-0.4}$(syst.)
4NA Λpnn	0.13 ± 0.09(stat.) $^{+0.08}_{-0.07}$(syst.)
Global $\Lambda(\Sigma^0)$p	21 ± 3(stat.) $^{+5}_{-6}$(syst.)

AMADEUS data on Λp and $\Sigma^0 p$ production

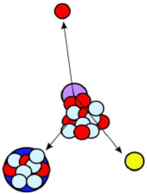
Λp analysis: Quasi total K⁻ 2NA BR

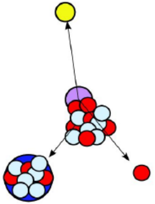
QUASI Total 2NA BR = 2NA-QF Λp + 2NA-QF Σ^0p + 2NA-FSI Λp + 2NA-FSI Σ^0p + 2NA-Conv.

	primary interaction	secondary interaction
2NA-FSI Λp	$K^- pn \to \Lambda n$	$\Lambda p \to \Lambda p$
	$K^- pn \to \Lambda n$	$n p \to n p$
	$K^- pp \to \Lambda p$	$\Lambda N \to \Lambda N$
	$K^- pp \to \Lambda p$	$p N \to p N$
2NA-FSI Σ^0p	$K^- pn \to \Sigma^0 n$	$\Sigma^0 p \to \Sigma^0 p$
	$K^- pn \to \Sigma^0 n$	$n p \to n p$
	$K^- pp \to \Sigma^0 p$	$\Sigma^0 N \to \Sigma^0 N$
	$K^- pp \to \Sigma^0 p$	$p N \to p N$
2NA-Conv.	$K^- pn \to \Sigma^0 n$	$\Sigma^0 p \to \Lambda p$
	$K^- pp \to \Sigma^0 p$	$\Sigma^0 p \to \Lambda p$
	$K^- pp \to \Sigma^0 p$	$\Sigma^0 n \to \Lambda n$
	$K^- pn \to \Sigma^- p$	$\Sigma^- p \to \Lambda n$
	$K^- pp \to \Sigma^+ n$	$\Sigma^+ n \to \Lambda p$



QF case: the hyperon or the proton cross the daughter nucleus without FSI





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Comparison with AMADEUS data

Table 7: Branching ratio (in %) for ΛN and $\Sigma^0 N$ production in $K^- NN$ absorption at rest ($p_{K^-} = 0$ MeV/c) in the ^{12}C+K^- atom for the lower (l=1) and upper (l=2) state, calculated with $K^- N + K^- NN$ potentials based on the WRW modified and Pauli amplitudes derived from the P and BCN models. Theoretical values are compared with the AMADEUS data on QF+FSI BR's.

BR	BCN				P				Exp. [3]
	WRW		Pauli		WRW		Pauli		
	l=1	l=2	l=1	l=2	l=1	l=2	l=1	l=2	
ΛN	5.45	2.32	4.23	3.02	5.27	2.17	4.30	3.19	$6.45 \pm 1.41(\text{stat.})^{+0.5}_{-0.6}(\text{syst.})$
$\Sigma^0 N$	4.44	2.09	3.99	2.93	5.11	2.37	4.53	3.47	$7.55 \pm 2.2(\text{stat.})^{+4.2}_{-5.4}(\text{syst.})$

Summary

- Interactions of K^- with two and more nucleons important for realistic description of the K^--nucleus interaction
  - only P, KM, and BCN models compatible with available data
- We have developed a microscopic model for K^-NN absorption in nuclear matter using amplitudes derived from the P and BCN chiral meson-baryon interaction models

  J. Hrtánková, À. Ramos, PRC 101 (2020) 035204
  - Pauli blocked amplitudes included $\rightarrow$ medium effects non-negligible
  - Calculated ratios in good agreement with experimental data

Summary

- Microscopic $K^- N + K^- NN$ potentials confronted with kaonic atom data *J. Óbertová, E. Friedman, J. Mareš, preprint submitted to PRC (2022), arXiv:2208.14946[nucl-th]*
    - the description of kaonic atoms improves considerably when microscopic $K^- NN$ potentials are included (χ^2 drops down twice)
    - microscopic $K^- N + K^- NN$ potentials still have to be supplemented by a phenomenological term to account for K^--3N (4N) processes and to get χ^2/d.p.≤ 2
- Further improvements of the $K^- NN$ model $\rightarrow$ inclusion of hadron self-energies in progress!
- EXPERIMENT:
    - It would be desirable to revise some kaonic atom data
    - More data on 3N and 4N absorption fractions are needed