K^- nucleon/multi-nucleon interaction studies by AMADEUS towards clarifying the existence of kaonic nuclear states

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1. Intoduction

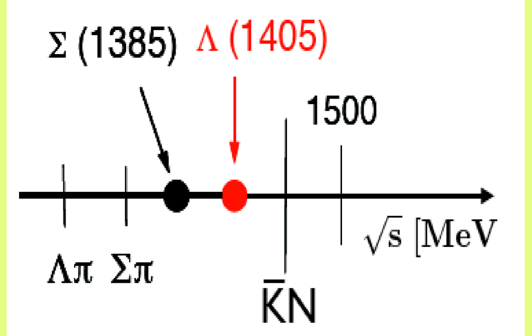
The existence of **Kaonic Nuclear States** of K^-, also called kaonic nuclear clusters, was already predicted in 1986 [1]. Since then they have been intensively debated by the scientific community, both by experimentalists and by the theoreticians. According to some theories the existence of very deeply bound states is possible while other theories are predicting much less bound states [2-4]. Therefore, in order to clarify this issue, experimental data are needed. **AMADEUS** goal is to do the first complete investigation of the Λp, $\Sigma^0 p$, Λd, $\Sigma^0 d$ and Λt channels, searching for signals coming from the possible bound states and, in the same time, exploring intensively the rich physics of these channels [5-8]. The absorption of low momentum K^-mesons ($p_K \sim 127$ MeV/c), produced by the DAΦNE [1] collider, on He and C nuclear targets is investigated, with the aim to get information on the resonant and non-resonant transition amplitudes few MeV below the $\bar{K}N$ threshold, which represent good tests for the theoretical predictions of the low energy QCD models in the strangeness sector. The measurement of K^- multiN BRs and low-momentum cross sections, are an essential tool for the investigation of the possible existence of K K^- multiN bound states and for the investigation of the Kbar properties in nuclear medium.

2. Motivation

- **nuclear and particle physics:** studies of in-medium modification of $\bar{K}N$ interaction for low energies in non-perturbative QCD

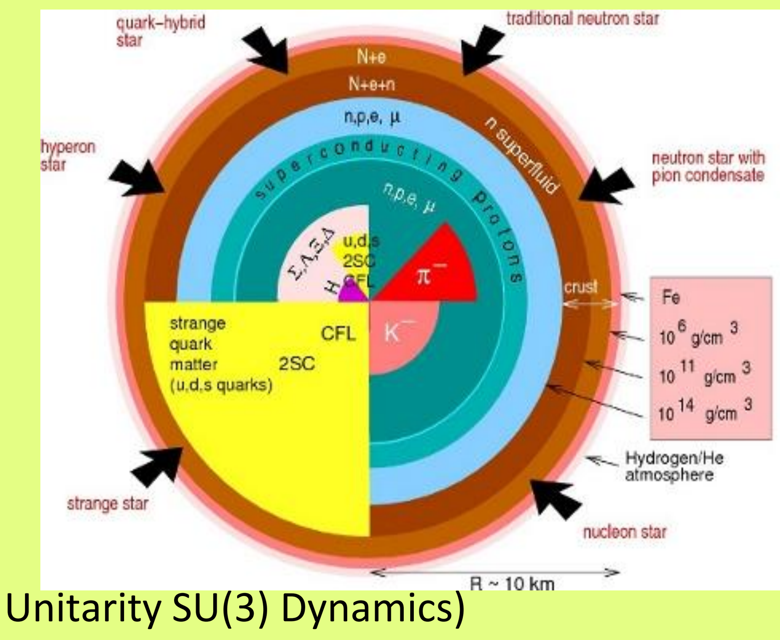
solving following problems:
(i) hadron masses (related to the chiral symmetry breaking), **(ii) hadron interactions in nuclear medium** and **(iii) structure of the dense nuclear matter** [2-4]

ChPT not applicable to the $\bar{K}N$ channel due to the $\Lambda(1405)$ and the $\Sigma(1385)$ resonances just below the KN mass threshold

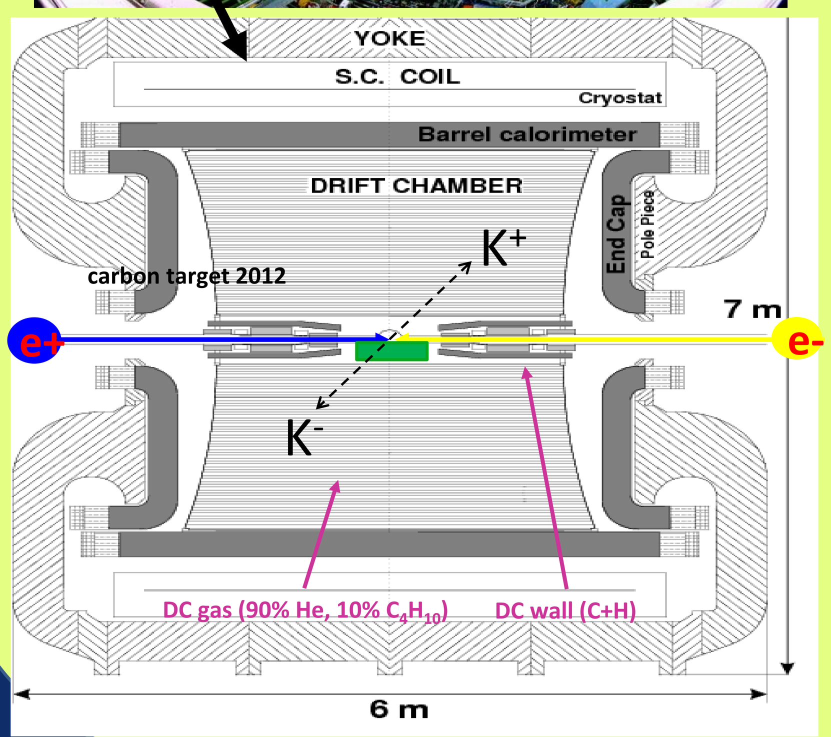


Possible solutions:
- Non-perturbative Coupled Channels Approach (Chiral Unitarity SU(3) Dynamics)
- Phenomenological KN and NN potentials

- **astrophysics:** the binding of the kaon in nuclear medium may impact on models describing the structure of **neutron stars** (Equation of State of neutron stars) [9-11] including binaries which are expected to be sources of the gravitational waves.



3. AMADEUS experiment



DAΦNE

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

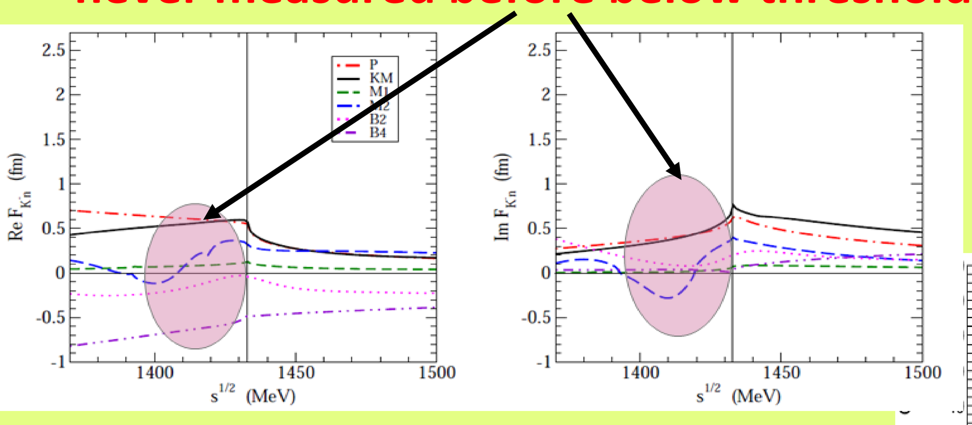
KLOE

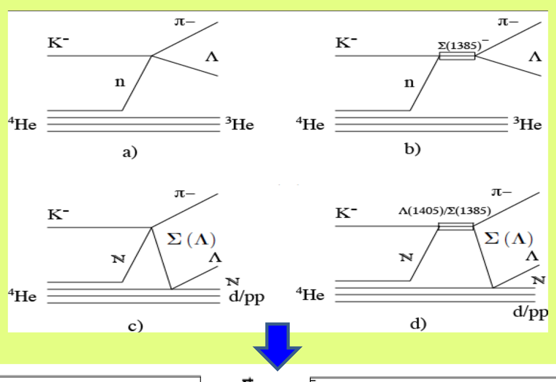
- Cilindrical DC with **4π geometry** & electromagnetic calorimeter
- **96% acceptance**
- **high efficiency and resolution** for charged and neutral particles
- exclusive measurement of the considered processes

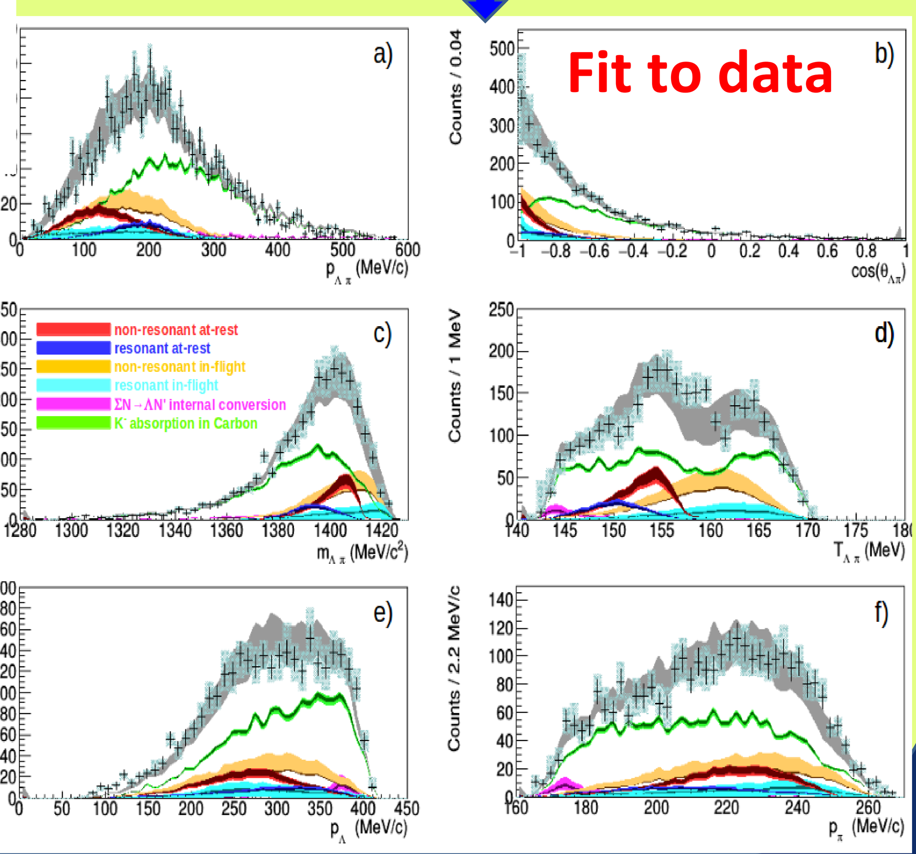
K^- absorption on light nuclei AT REST & IN FLIGHT

4. K^-"n" → $\Lambda\pi^-$ resonant vs. non-resonant

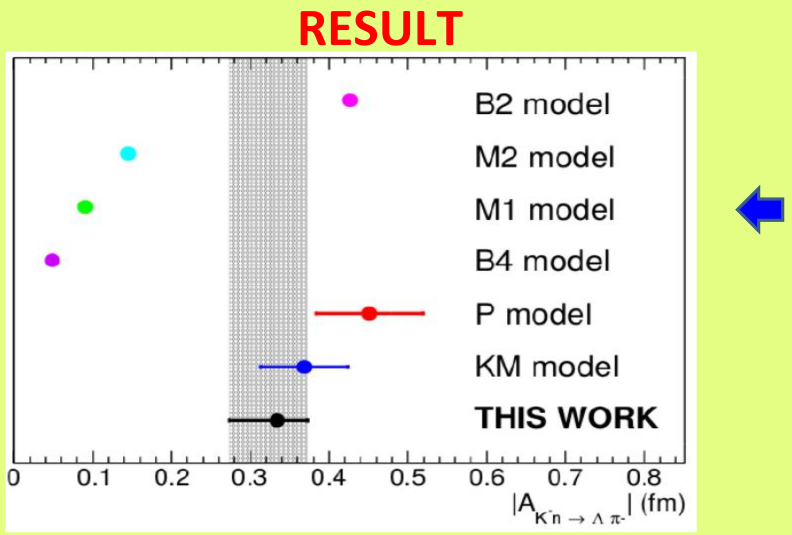
Non-resonant transition amplitude **never measured before below threshold**







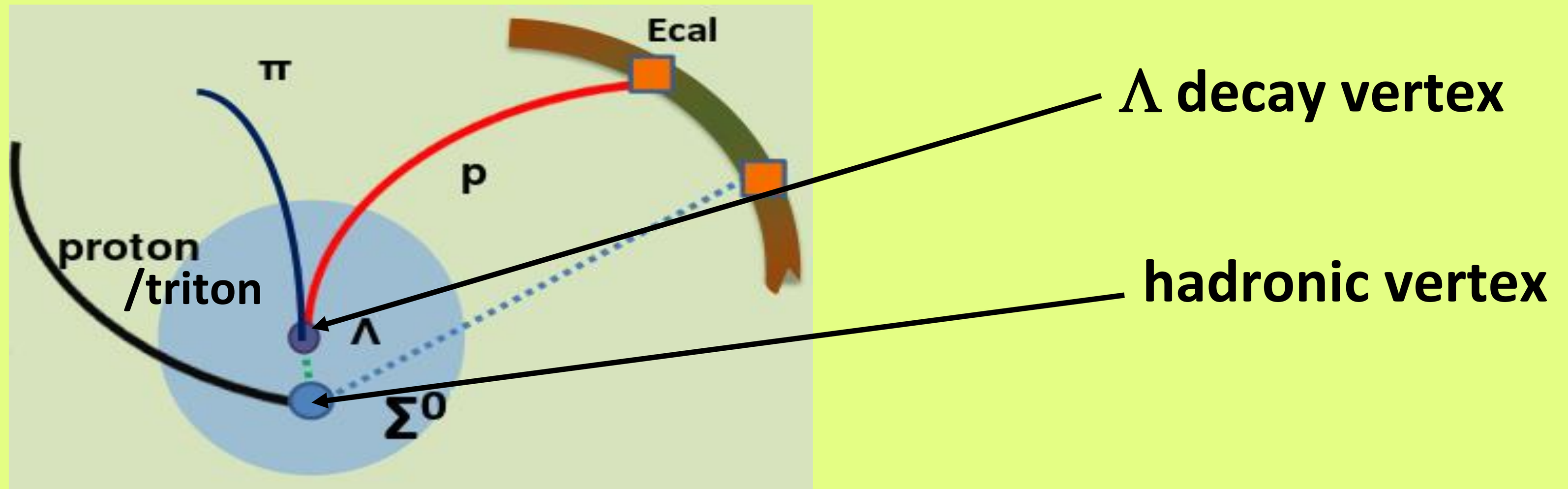
RESULT

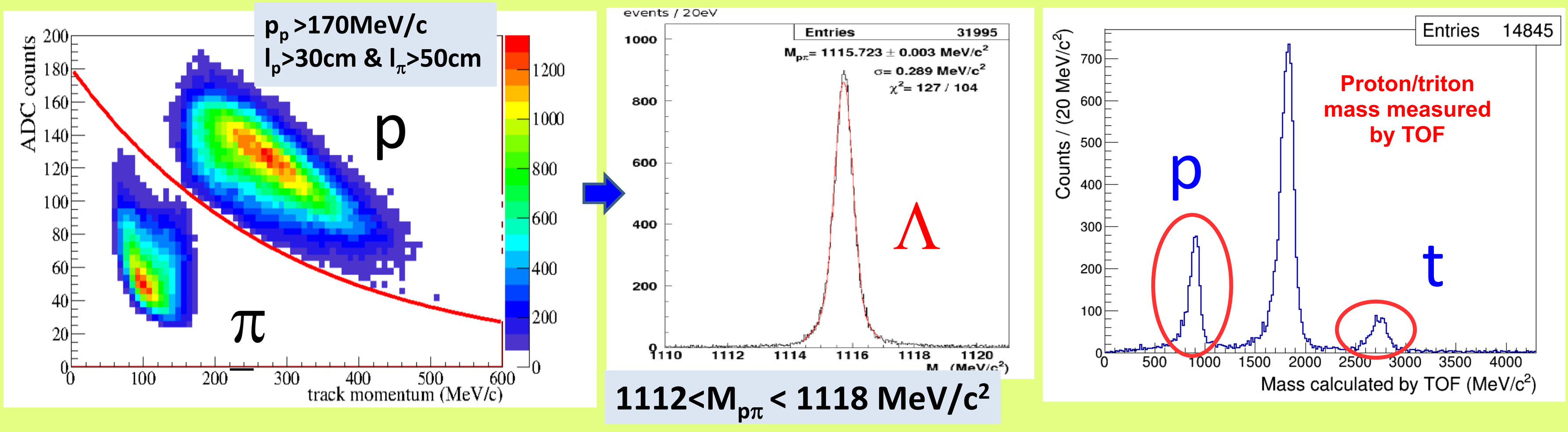


$|f^s_{ar}| = (0.334 \pm 0.018 \text{ stat } ^{+0.034}_{-0.058} \text{ syst})$ fm [7]

5. K^- - multiN absorption and search for DBKNS

$K^- \, {}^{12}C \to \Lambda/\Sigma^0 \, p$ (2NA) $\qquad$ $K^- \, {}^4He \to \Lambda/\Sigma^0 \, t$ (4NA)





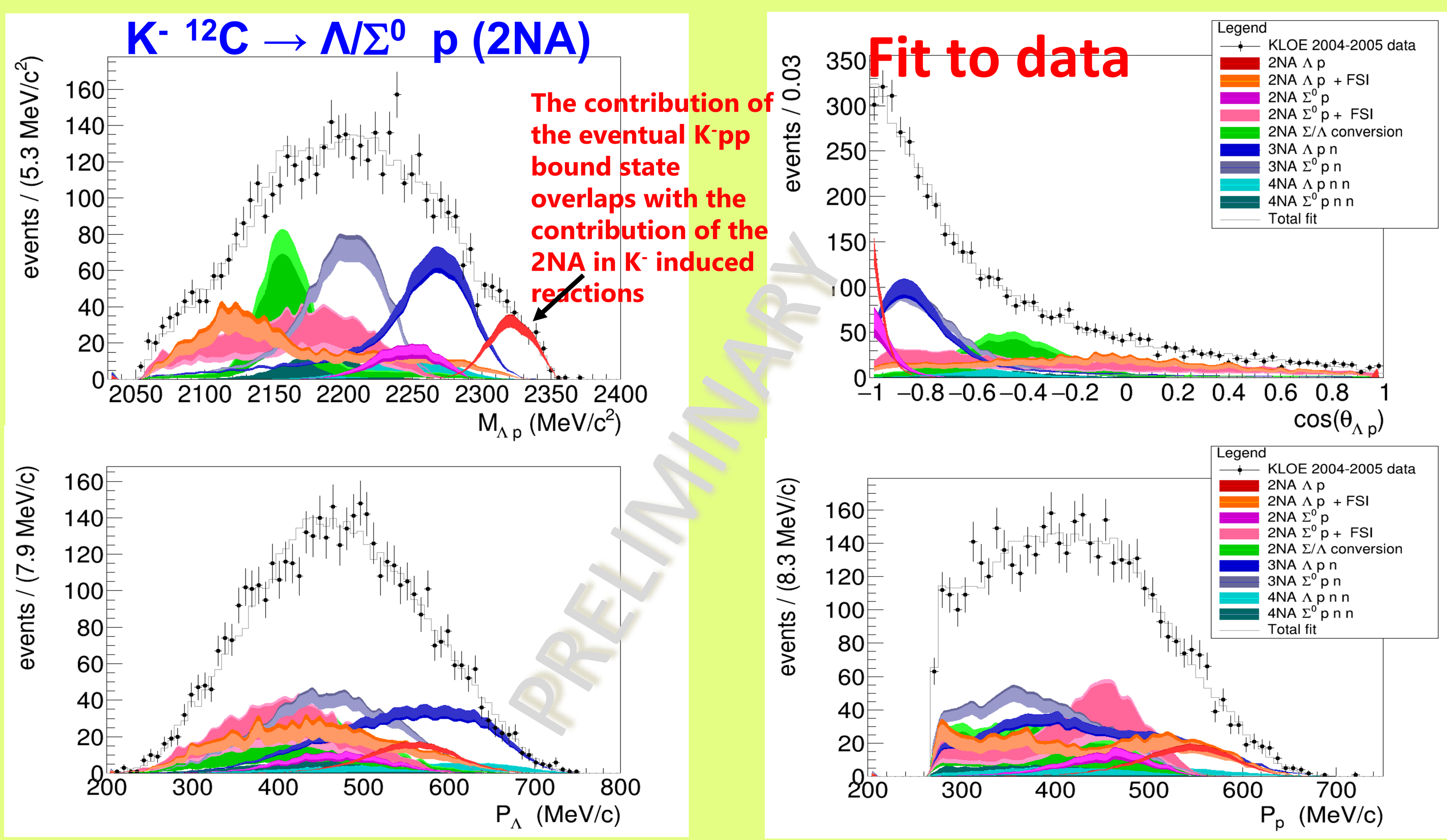
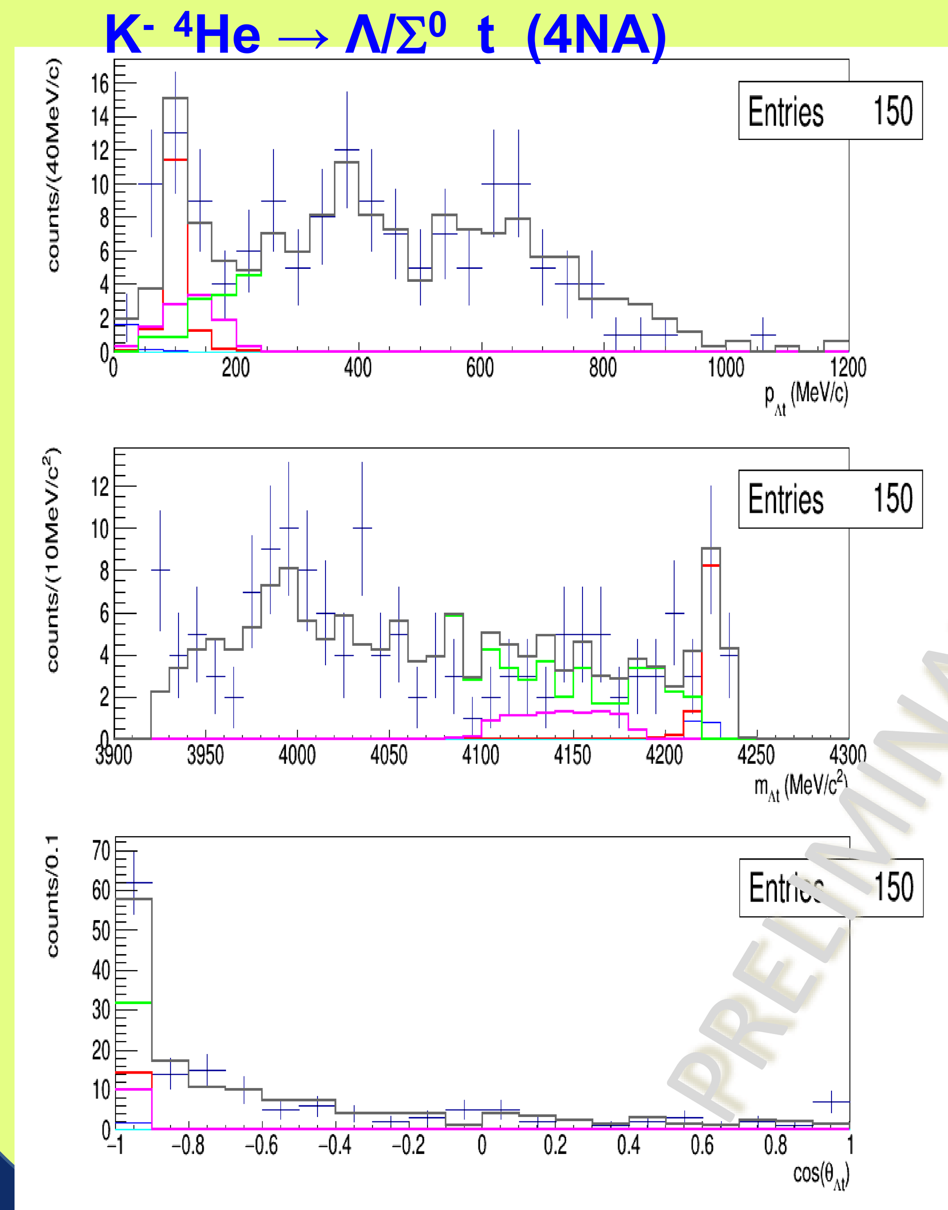


Table 1 Branching ratios and cross sections of the K^- multi-nucleon absorption processes. The statistical and systematic errors are also shown.

Process	Banching 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 $\Sigma^0 p$	0.35 ± 0.09(stat.) $^{+0.13}_{-0.06}$(syst.)	3.9 ± 1.0 (stat.) $^{+1.4}_{-0.7}$ (syst.)	@	128 ± 29
2NA-FSI $\Sigma^0 p$	7.2 ± 2.2(stat.) $^{+4.2}_{-5.4}$(syst.)	80 ± 25 (stat.) $^{+46}_{-60}$ (syst.)	@	128 ± 29
3NA Λpn	1.4 ± 0.2(stat.) $^{+0.1}_{-0.2}$(syst.)	15 ± 2 (stat.) ± 2 (syst.)	@	117 ± 23
3NA $\Sigma^0 pn$	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.)			
2NA-Σ/Λconv.	2.1 ± 1.2(stat.) $^{+0.9}_{-0.5}$(syst.)			

$$BR(K^{-12}C \to \Lambda(\Sigma^0)pR) = 0.177 \pm 0.024(stat.)^{+0.027}_{-0.032}(syst.)$$

$K^- \, {}^4He \to \Lambda/\Sigma^0 \, t$ (4NA)



data

--- carbon data from DC wall

--- 4NA $K^- \, {}^4He \to \Lambda t$ in flight MC

--- 4NA $K^- \, {}^4He \to \Lambda t$ at rest MC

--- 4NA $K^- \, {}^4He \to \Sigma^0 t$, $\Sigma^0 \to \Lambda\gamma$ MC

--- 4NA $K^- \, {}^4He \to \Sigma^0 t$, $\Sigma^0 \to \Lambda\gamma$ MC

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

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

6. References

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