

Kaon-nucleon/nuclei interaction studies at DAΦNE present and future perspectives -- 1

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On the behalf of the AMADEUS collaboration

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AMADEUS at LNF



Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI



The AMADEUS collaboration

Anti-kaonic **M**atter **A**t **D**_{AΦNE}: an **E**xperiment with **U**nravelling **S**pectroscopy



Motivation

AMADEUS (Antikaonic Matter At DAΦNE: an Experiment with Unravelling Spectroscopy)
investigates **low-energy K^- absorption in nuclei** with the aim to extract information on:

- K^-N interaction above and below threshold
 - $\Lambda(1405)$ nature
 - kaonic bound states
 - K^-N scattering amplitudes and cross sections
- K^-NN , K^-NNN , K^-NNNN (multi-nucleon) interactions
 - essential for the determination of K^- -nuclei optical potential
- In medium modification of the KbarN interaction
 - partial restoration of chiral symmetry → hadrons mass origin
 - Equation of State of Neutron Stars
 - modification of $\Lambda(1405)$ and $\Sigma(1385)$ properties in nuclear medium

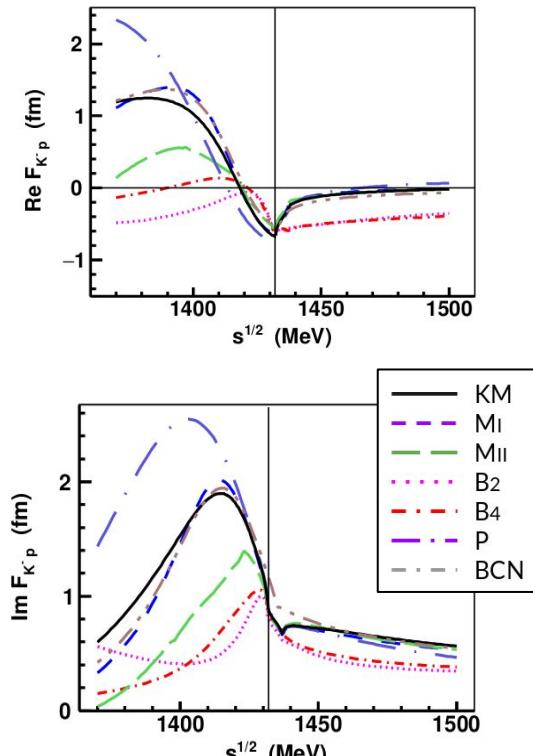
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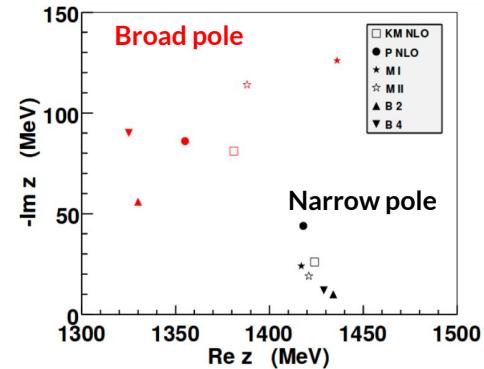
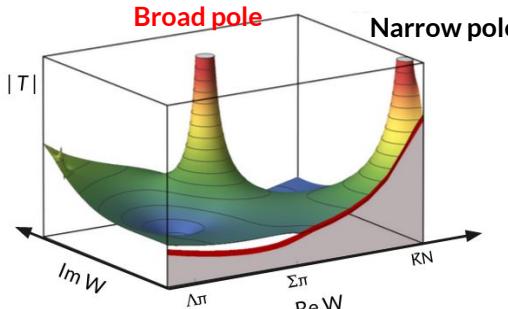
Motivation

$K^- p$ scattering amplitude



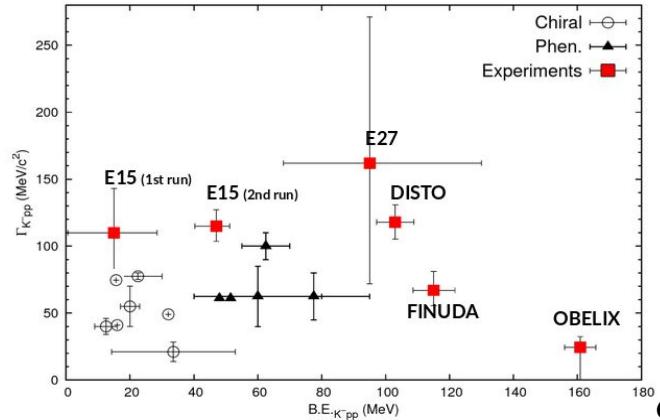
[from A. Cieply et al. Nucl.Phys. A954 (2016) 17-40]

$\Lambda(1405)$ state: dynamical origin. Two poles of the scattering amplitude \rightarrow pole positions is model dependent (relative contributions not measured experimentally)



$K^- pp$ bound state puzzle:

- KN input model is critical for the data interpretation
- different bound state production mechanisms give different predictions



K^- multi-nucleon absorptions

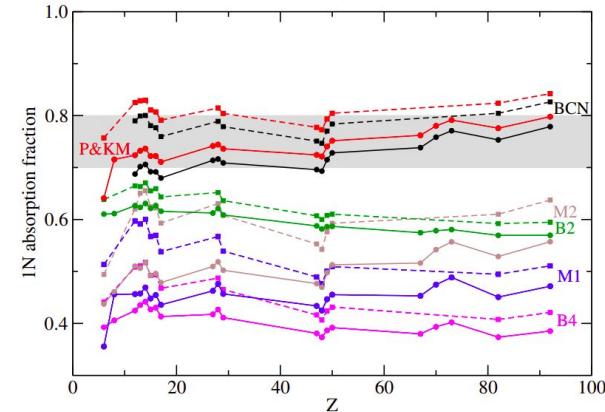
In order to fit the kaonic atoms data a K^- multi-nucleon absorption term is necessary in the K^- -nuclei optical potential:

$$V_{K^-}(\rho) = V_{K^-}^{(1)}(\rho) + V_{K^-}^{(2)}(\rho) \rightarrow \text{phen. multi-nucleon term}$$

[E. Friedman, A. Gal, Nucl. Phys. A 959, 66 (2017)]

[Hrtáková, J. & Mareš, J. Phys. Rev. C96, 015205 (2017)]

single nucleon term from chiral models



- Single nucleon absorption (**1NA**): $K^- "N" \rightarrow Y \pi$
- Two nucleon absorption (**2NA**): $K^- "NN" \rightarrow Y N$
- Three nucleon absorption (**3NA**): $K^- "NNN" \rightarrow Y (NN)$
- Four nucleon absorption (**4NA**): $K^- "NNNN" \rightarrow Y (NNN)$

→ multi-N processes

bound nucleons = “N”, “NN”, “NNN”, “NNNN”

bound or unbound nucleons = (NN), (NNN)

$Y = \Lambda, \Sigma$

Goals of AMADEUS

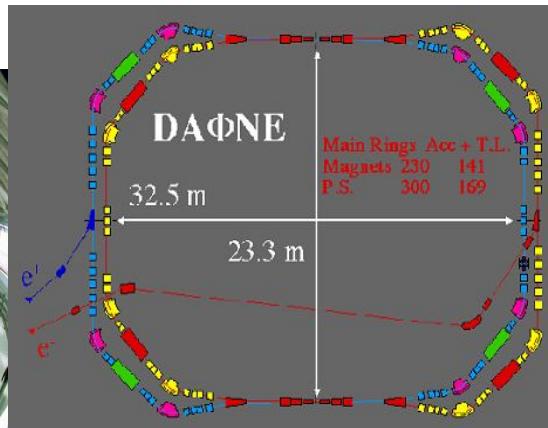
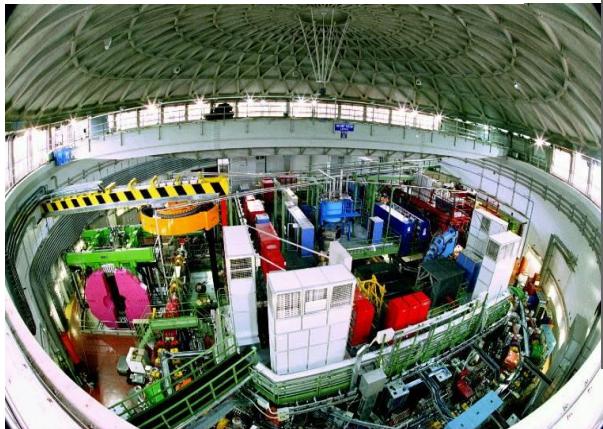
Unprecedented studies of the **low-energy charged kaons interactions in nuclear matter**: solid and gaseous targets (H , ${}^4\text{He}$, ${}^9\text{Be}$, ${}^{12}\text{C}$...) in order to obtain unique quality information about:

1. Controversial nature of the $\Lambda(1405)$ and **KbarN amplitude below threshold**
 - **Y π CORRELATION STUDIES**
(i.e. $\Lambda\pi$ and $\Sigma\pi$ and final states)
2. Low-energy charged kaon **cross sections** for momenta of 100 MeV/c
3. a) Interaction of K^- with more nucleons
(multi-nucleon K^- absorptions)
 - **YN CORRELATION STUDIES**
(i.e. Λp , $\Sigma^0 p$, and Λt final states)
b) possible existence of **kaonic bound states**
4. **future: YN scattering** → extremely poor experimental information from scattering data
(important for the EoS of Neutron Stars)

DAΦNE the Φ factory



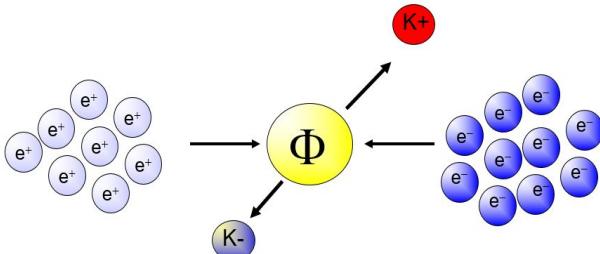
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- $e^+ e^-$ at 510 MeV
- Φ resonance decays at 49.2 % in K^+
- K^- back to back pair
- Very low momentum (≈ 127 MeV) K^- beam
- Flux of produced kaons: about 1000/second

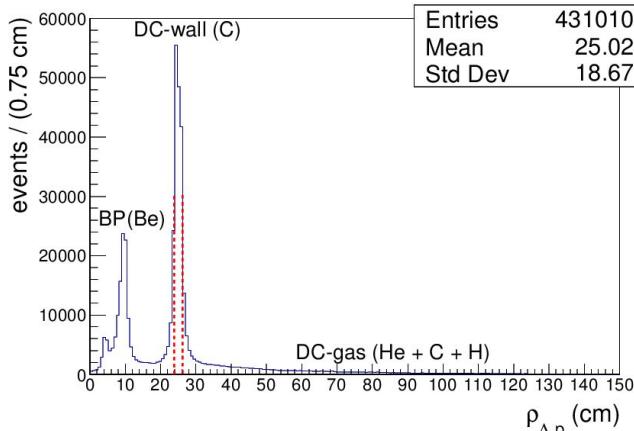
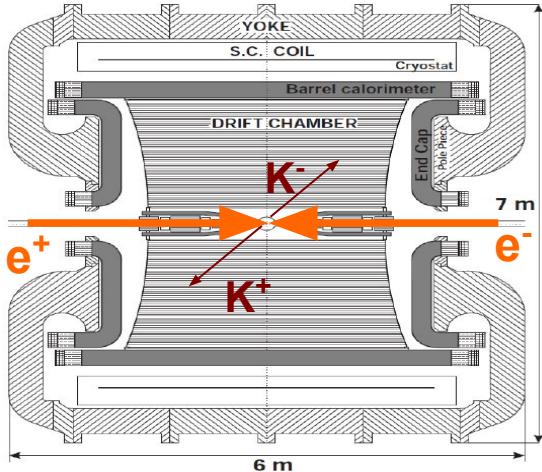


Best low momentum K^- factory in the world



Suitable for low-energy kaon physics:
→ **Kaonic atoms (SIDDHARTA-2)**
→ **Kaon-nucleons/nuclei interaction studies (AMADEUS)**

AMADEUS step 0



The KLOE detector

- Cylindrical drift chamber with a **4π geometry** and electromagnetic calorimeter
- **96% acceptance**
- optimized in the energy range of all **charged particles** involved
- **good performance** in detecting **photons and neutrons** checked by kloNe group

[M. Anelli et al., Nucl Inst. Meth. A 581, 368 (2007)]

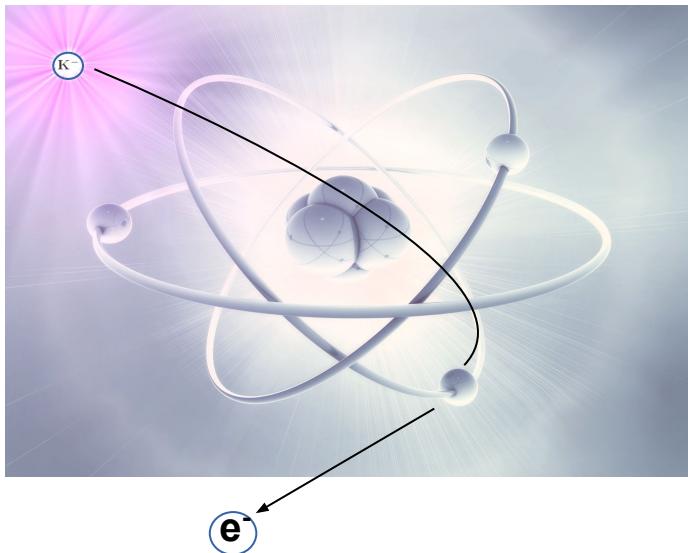
Presently we use **KLOE** as an **active target**

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

K^- absorptions at-rest and in-flight

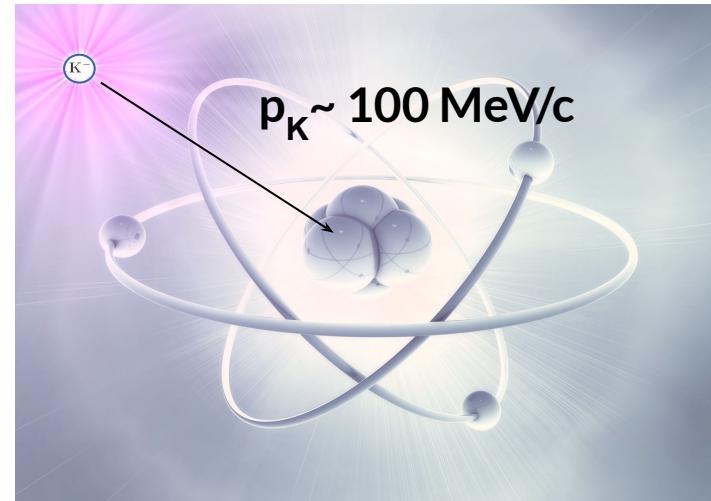
AT-REST

K^- absorbed from atomic orbitals
($p_K \sim 0 \text{ MeV}/c$)



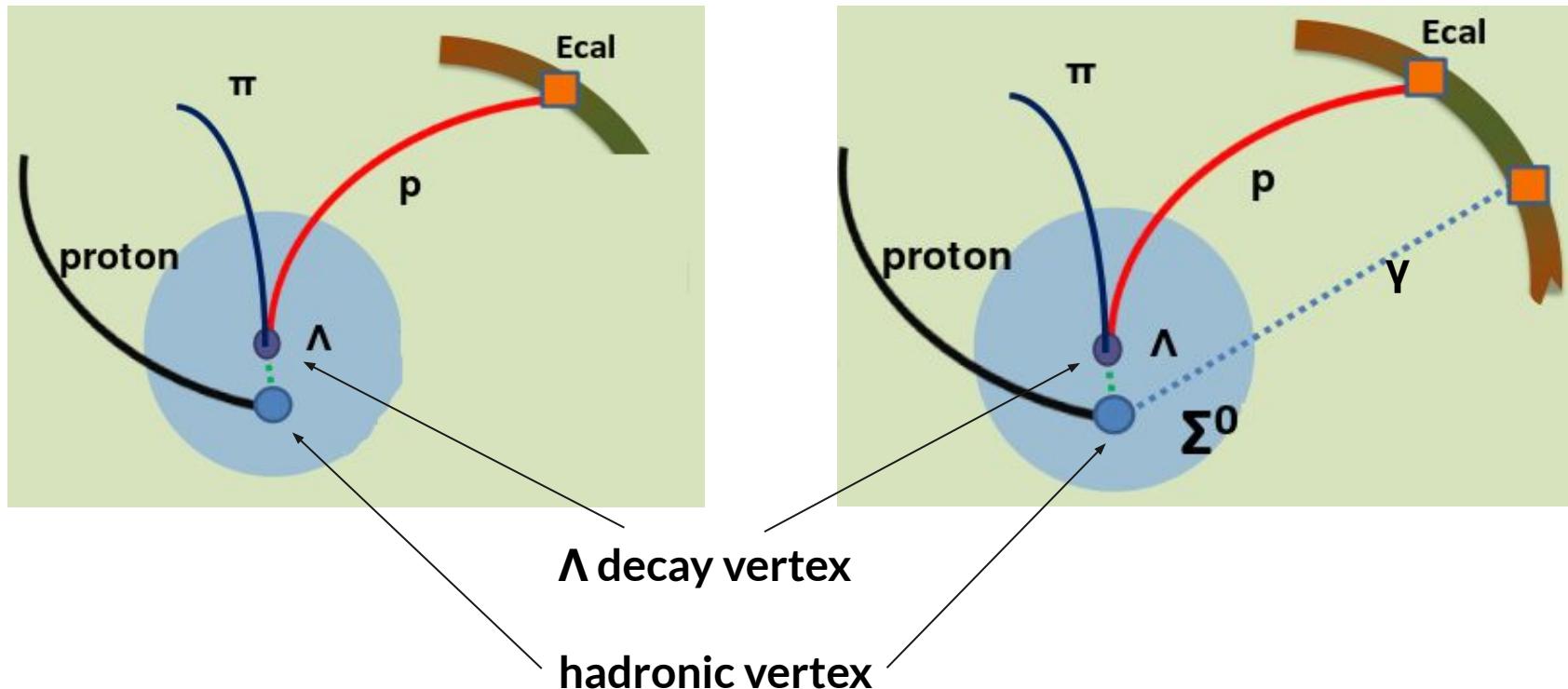
IN-FLIGHT

($p_K \sim 100 \text{ MeV}/c$)



YN correlation studies

K⁻ multi-nucleon absorptions are investigated by reconstructing the **hyperon-nucleon/nuclei** emitted in the final state of the process (i.e. Λp , $\Sigma^0 p$, and Λt final states)

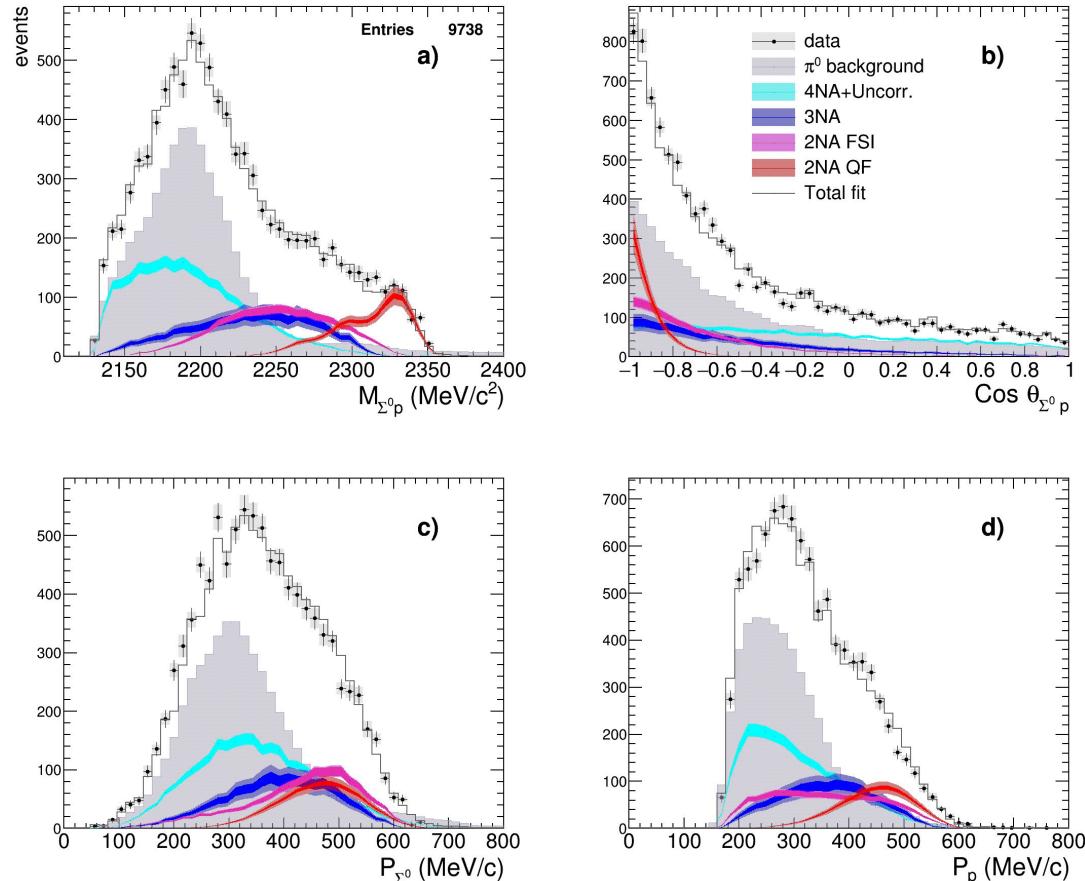


$\Sigma^0 p$ analysis: $K^- + ^{12}C \rightarrow \Sigma^0 + p + R$

Simultaneous fit of:

- $\Sigma^0 p$ invariant mass;
- angular correlation;
- proton momentum;
- Σ^0 momentum.

Total reduced χ^2 : $\chi^2/dof = 0.85$



[O. Vazquez Doce, L. Fabbietti et al.,
Phys.Lett. B 758, 134-139 (2016)]

$\Sigma^0 p$ analysis: $K^- + ^{12}C \rightarrow \Sigma^0 + p + R$

Simultaneous fit of:

- $\Sigma^0 p$ invariant mass;
- angular correlation;
- proton momentum;
- Σ^0 momentum.

Total reduced χ^2 : $\chi^2/dof = 0.807$

Best solution:

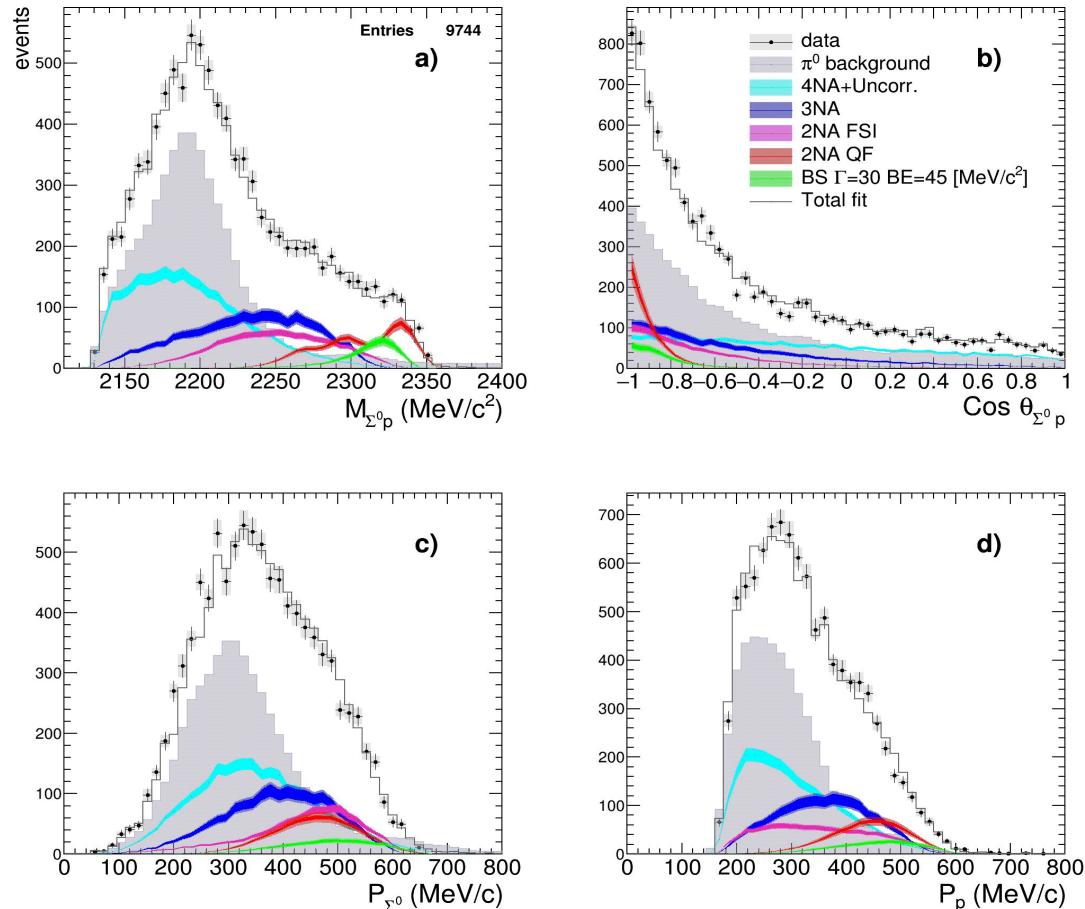
(best χ^2 and higher yield)

- $B = 45 \text{ MeV}/c^2$
- $\Gamma = 30 \text{ MeV}/c^2$

Statistical significance of 1σ

(evaluated by means of F-test method)

[O. Vazquez Doce, L. Fabbietti et al.,
Phys.Lett. B 758, 134-139 (2016)]

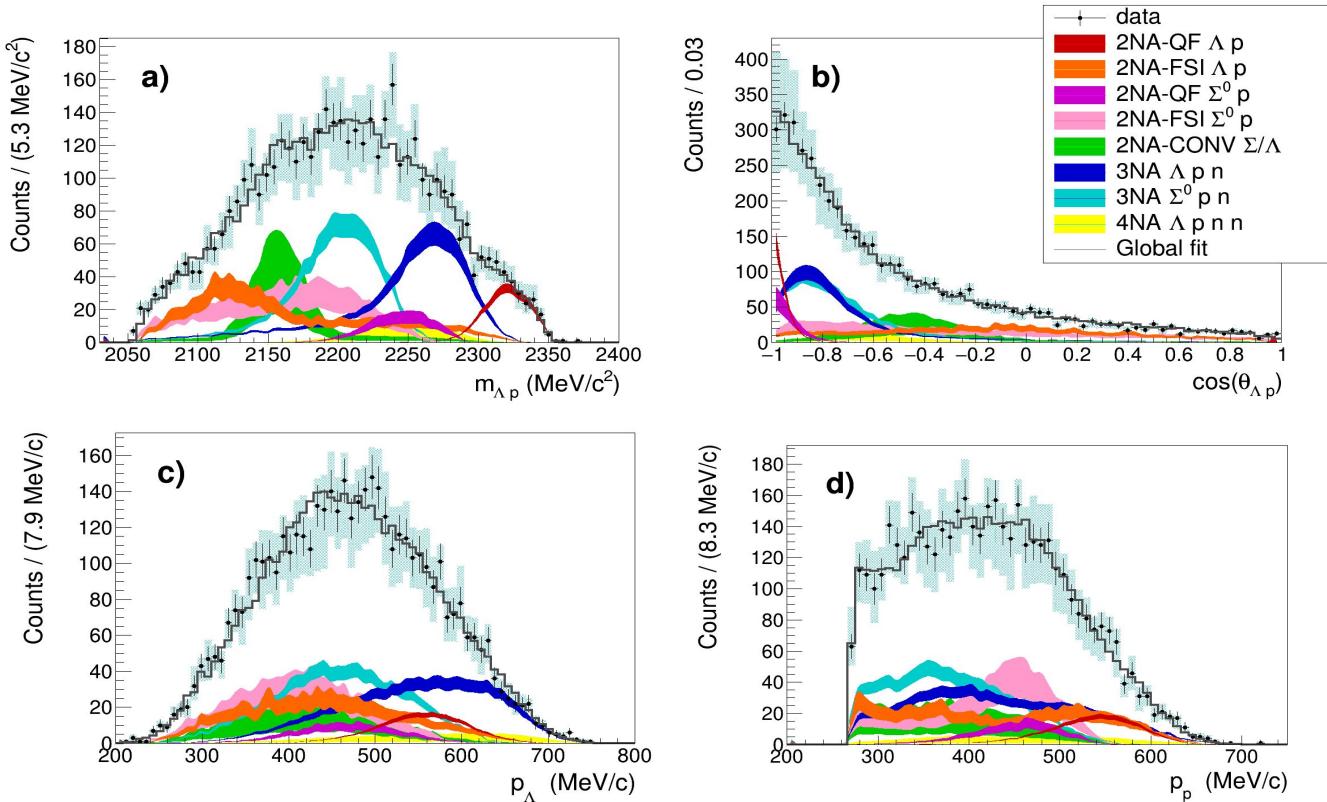


Λp analysis: $K^- + {}^{12}C \rightarrow \Lambda + p + R$

Simultaneous fit of:

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

Total reduced χ^2 : $\chi^2/dof = 0.94$



[R. Del Grande, K. Piscicchia, O. Vazquez Doce et al., Eur.Phys.J. C79 (2019) no.3, 190]
[R. Del Grande, K. Piscicchia, S. Wycech, Acta Phys. Pol. B 48 (2017) 1881]

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

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

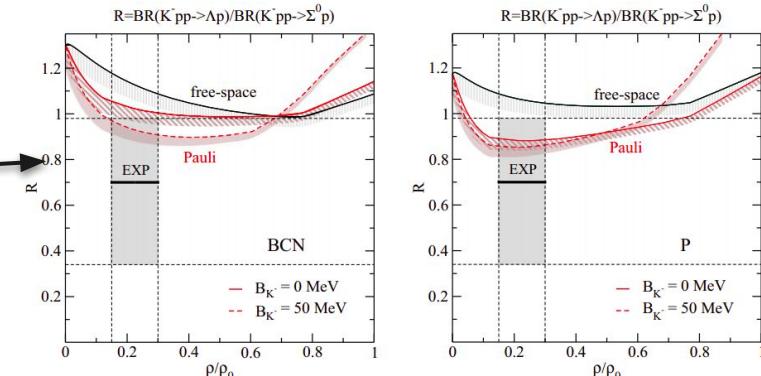
| Process | Branching Ratio (%) | σ (mb) | @ | p_K^- (MeV/c) |
|-----------------------------|--|--|---|-----------------|
| 2NA-QF Λp | 0.25 ± 0.02 (stat.) $^{+0.01}_{-0.02}$ (syst.) | 2.8 ± 0.3 (stat.) $^{+0.1}_{-0.2}$ (syst.) | @ | 128 ± 29 |
| 2NA-FSI Λp | 6.2 ± 1.4 (stat.) $^{+0.5}_{-0.6}$ (syst.) | 69 ± 15 (stat.) ± 6 (syst.) | @ | 128 ± 29 |
| 2NA-QF $\Sigma^0 p$ | 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 |
| 2NA-CONV Σ/Λ | 2.1 ± 1.2 (stat.) $^{+0.9}_{-0.5}$ (syst.) | - | | |
| 3NA $\Lambda p n$ | 1.4 ± 0.2 (stat.) $^{+0.1}_{-0.2}$ (syst.) | 15 ± 2 (stat.) ± 2 (syst.) | @ | 117 ± 23 |
| 3NA $\Sigma^0 p n$ | 3.7 ± 0.4 (stat.) $^{+0.2}_{-0.4}$ (syst.) | 41 ± 4 (stat.) $^{+2}_{-5}$ (syst.) | @ | 117 ± 23 |
| 4NA $\Lambda p n n$ | 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 $\Sigma^0 p$ is measured to be:

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

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

Information on the in-medium dynamics



[J. Hrtáková and A. Ramos. Phys. Rev. C, 101(3):035204, 2020]

Total BR of the K⁻ 2NA process in ¹²C

Hyperon-nucleon pairs produced in K⁻2NA process:

Λp Λn $\Sigma^0 p$ $\Sigma^0 n$ $\Sigma^+ n$ $\Sigma^- p$ $\Sigma^- n$

BCN calculation at $0.3 \rho_0$ (baryon density in ¹²C) → BR(K⁻2NA → YN) = (15.4 ± 2.2) %
[J. Hrtánková and A. Ramos. Phys. Rev. C, 101(3):035204, 2020]

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| Global $\Lambda(\Sigma^0)p$ | 21 ± 3 (stat.) $^{+5}_{-6}$ (syst.) |

We measure a total K⁻2NA BR in ¹²C

$\rightarrow (16.1 \pm 2.9 \text{ (stat.)} ^{+4.3}_{-5.5} \text{ (syst.)})\%$,

Λp and $\Sigma^0 p$ pairs in the final state....

....information on the remaining YN
pairs provided by FSI e Conversion
reactions

[R. Del Grande, K. Piscicchia et al., 2020 Phys. Scr. 95 084012]

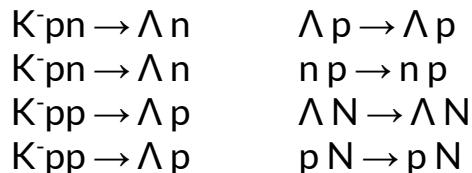
Total BR of the K^- 2NA process in ^{12}C

FSI and Conversion reactions contributing to the measured BRs

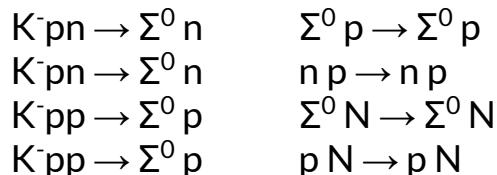
primary interaction

secondary interaction

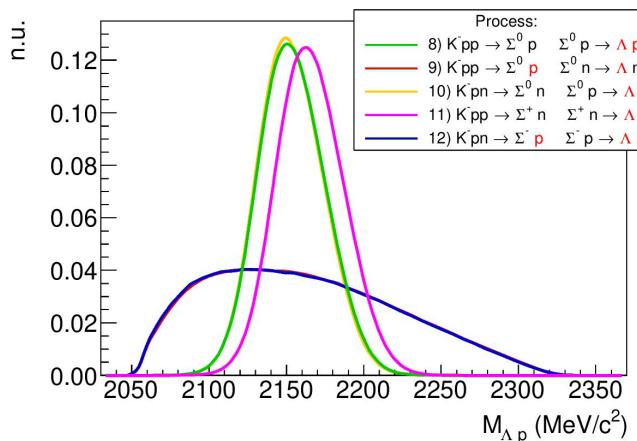
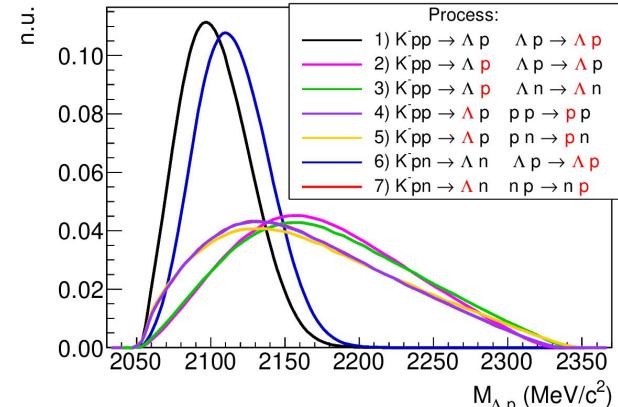
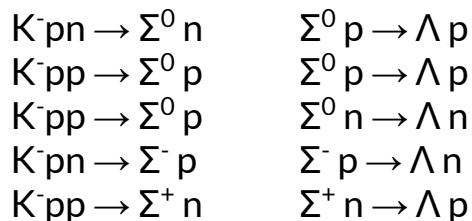
2NA-FSI Λp



2NA-FSI $\Sigma^0 p$



2NA-Conv.



red = detected
 Λp pair

Total BR of the K⁻ 2NA process in ¹²C

the only missing components are:

- $\text{BR}(\Sigma^-\text{n}) = (0.12 \pm 0.01\text{(syst.)})\%$
- $\text{BR}(\text{QF-}\Lambda\text{n} + \text{QF-}\Sigma^0\text{n}) = (0.76 \pm 0.09\text{(stat.)}^{+0.13}_{-0.06}\text{(syst.)})\%$
- $\text{BR}(\text{FSI-}\Lambda\text{n} + \text{FSI-}\Sigma^0\text{n}) = (1.62 \pm 0.04\text{(stat.)}^{+0.22}_{-0.21}\text{(syst.)})\%$
- $\text{BR}(\text{no conv } \Sigma^+ \text{ and } \Sigma^-) = (3.04 \pm 0.03\text{(stat.)} \pm 0.92\text{(syst.)})\%$

$$\rightarrow (5.5 \pm 0.1\text{(stat.)}^{+1.0}_{-0.9}\text{(syst.)})\%$$

[R. Del Grande, K. Piscicchia et al., Phys. Scr. 95 (2020) 084012]

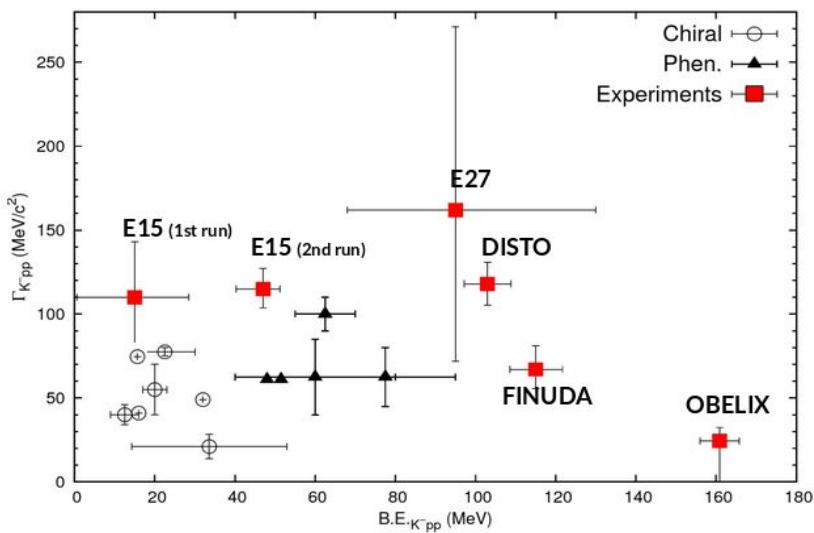
[R. Del Grande, K. Piscicchia et al., Few Body Syst. 62 (2021) 1, 7]

Including the missing components the total BR of the K⁻2NA is:

$$\text{BR}(K^-\text{2NA} \rightarrow YN) = (21.6 \pm 2.9\text{(stat.)}^{+4.4}_{-5.6}\text{(syst.)})\%$$

K^-pp bound state

- KN input model is critical for the theoretical interpretation
- different bound state production mechanisms give different predictions
- **E15 gives positive evidence in K^- induced reactions in flight (theoretical interpretation by Sekihara, Oset, Ramos)**



Experiments

Theory

| | BE (MeV) | Γ (MeV) | Reference |
|--------------------------|----------|----------------|---------------------------------------|
| Dote, Hyodo, Weise | 17-23 | 40-70 | Phys.Rev.C79 (2009) 014003 |
| Akaishi, Yamazaki | 48 | 61 | Phys.Rev.C65 (2002) 044005 |
| Barnea, Gal, Liverts | 16 | 41 | Phys.Lett.B712 (2012) 132-137 |
| Ikeda, Sato | 60-95 | 45-80 | Phys.Rev.C76 (2007) 035203 |
| Ikeda, Kamano, Sato | 9-16 | 34-46 | Prog.Theor.Phys. (2010) 124(3): 533 |
| Shevchenko, Gal, Mares | 55-70 | 90-110 | Phys.Rev.Lett.98 (2007) 082301 |
| Revai, Shevchenko | 32 | 49 | Phys.Rev.C90 (2014) no.3, 034004 |
| Maeda, Akaishi, Yamazaki | 51.5 | 61 | Proc.Jpn.Acad.B 89, (2013) 418 |
| Bicudo | 14.2-53 | 13.8-28.3 | Phys.Rev.D76 (2007) 031502 |
| Bayar, Oset | 15-30 | 75-80 | Nucl.Phys.A914 (2013) 349 |
| Wycech, Green | 40-80 | 40-85 | Phys.Rev.C79 (2009) 014001 |
| Sekihara, Oset, Ramos | 16 | 72 | Prog.Theor.Phys. (2016) no.12, 123D03 |
| Sekihara, Oset, Ramos | 20 | 80 | E. Oset talk at UJ Symposium 2019 |

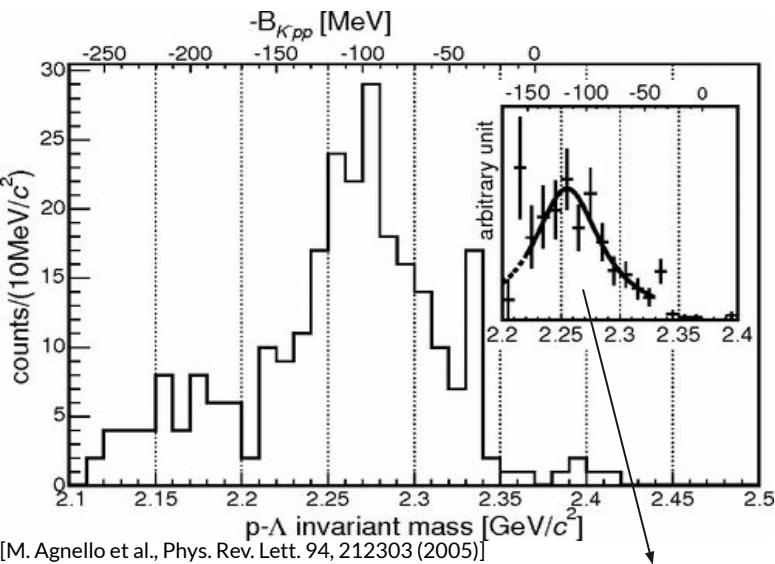
| Experiment | BE (MeV) | Γ (MeV) | Reference |
|---------------------------|---|--|------------------------|
| FINUDA | 115^{+6}_{-5} (stat.) $^{+3}_{-4}$ (syst.) | 67^{+14}_{-11} (stat.) $^{+2}_{-3}$ (syst.) | PRL 94 (2005), 212303 |
| OBELIX | 160.9 ± 4.9 | $< 24.4 \pm 8.0$ | NPA 789 (2007), 222 |
| 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 | 15^{+6}_{-8} (stat.) ± 12 (syst.) | 110^{+19}_{-17} (stat.) ± 27 (syst.) | PTEP (2016), 051D01 |
| E15 (2 nd run) | 47 ± 3 (stat.) $^{+3}_{-4}$ (syst.) | 115 ± 7 (stat.) $^{+10}_{-20}$ (syst.) | PLB 789 (2019), 620 |

Experimental search in K^- induced reactions

FINUDA at DAΦNE: $K^-_{\text{stop}} + X \rightarrow \Lambda + p + X'$

only back-to-back Λp pairs ($\cos\theta_{\Lambda p} < -0.8$)

detected particles



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

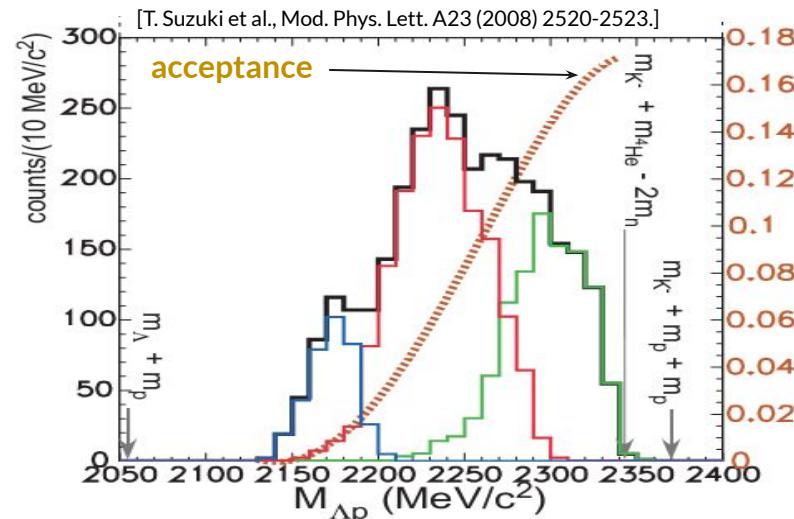
Interpreted as the signal of:
extracted parameters: $K^- pp \rightarrow \Lambda + p$

$$BE = (115^{+6}_{-5} \text{ (stat.)}^{+3}_{-4} \text{ (syst.)}) \text{ MeV}$$

$$\Gamma = (67^{+14}_{-11} \text{ (stat.)}^{+2}_{-3} \text{ (syst.)}) \text{ MeV}/c^2$$

E549 at KEK: $K^-_{\text{stop}} + {}^4\text{He} \rightarrow \Lambda + p + X'$

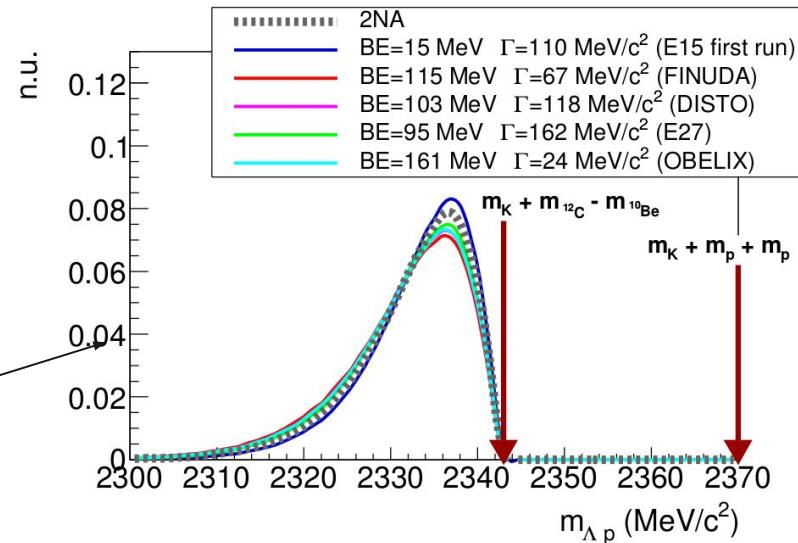
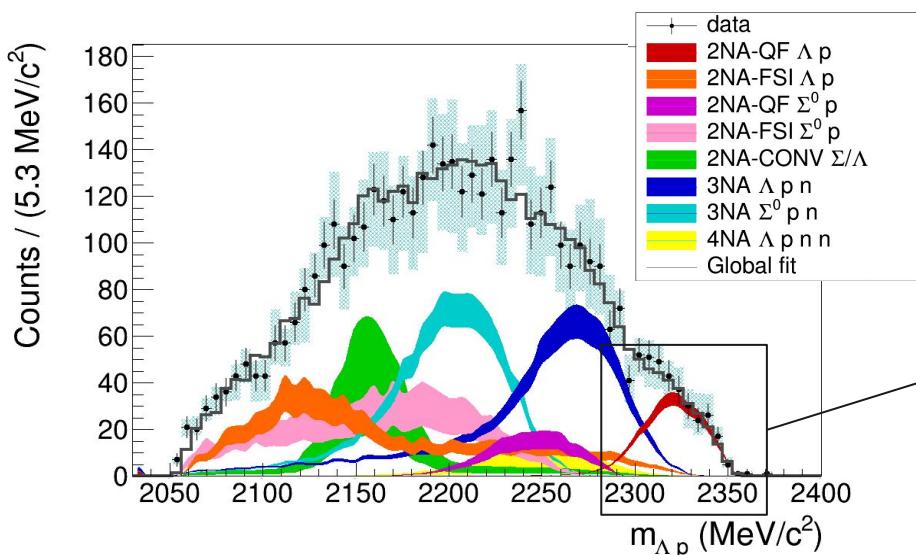
detected particles



Using the missing mass information, three components to the invariant mass spectrum are found:

- **1NA:** K^- single nucleon absorption
- **2NA:** K^- two nucleon absorption
- **2NA + conversion, multi-nucleon, or Bound State?**

Λp analysis: $K^- pp$ bound state

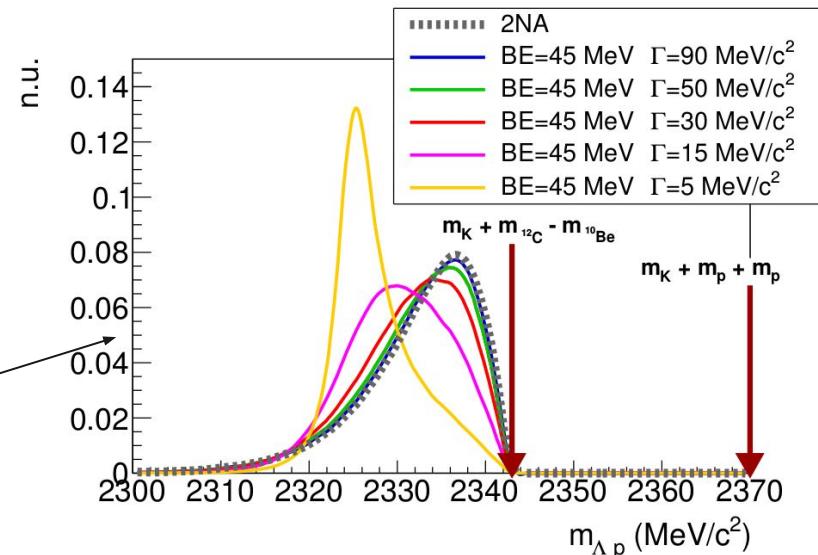
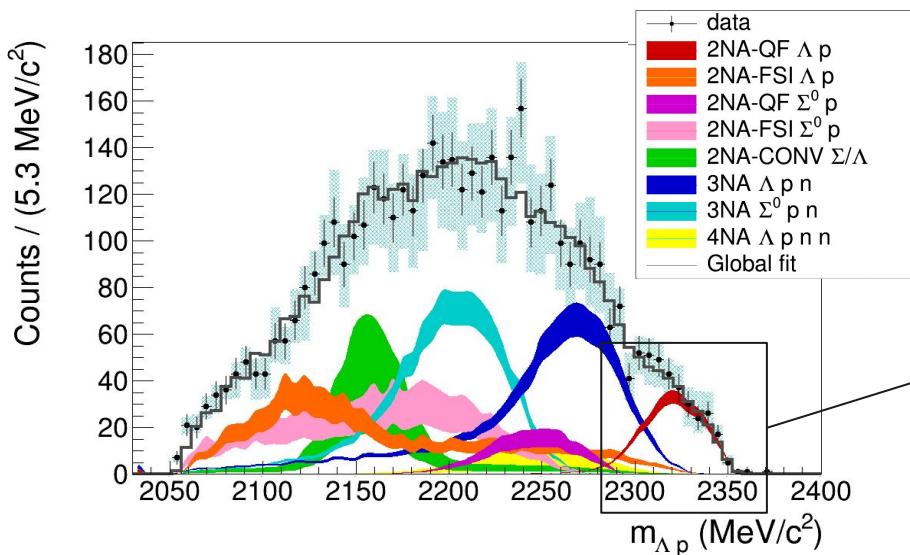


$K^- pp$ bound state contribution completely overlaps with the $K^- 2NA$

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

[R. Del Grande, K. Piscicchia, S. Wycech, Acta Phys. Pol. B 48 (2017) 1881]

Λp analysis: $K^- pp$ bound state

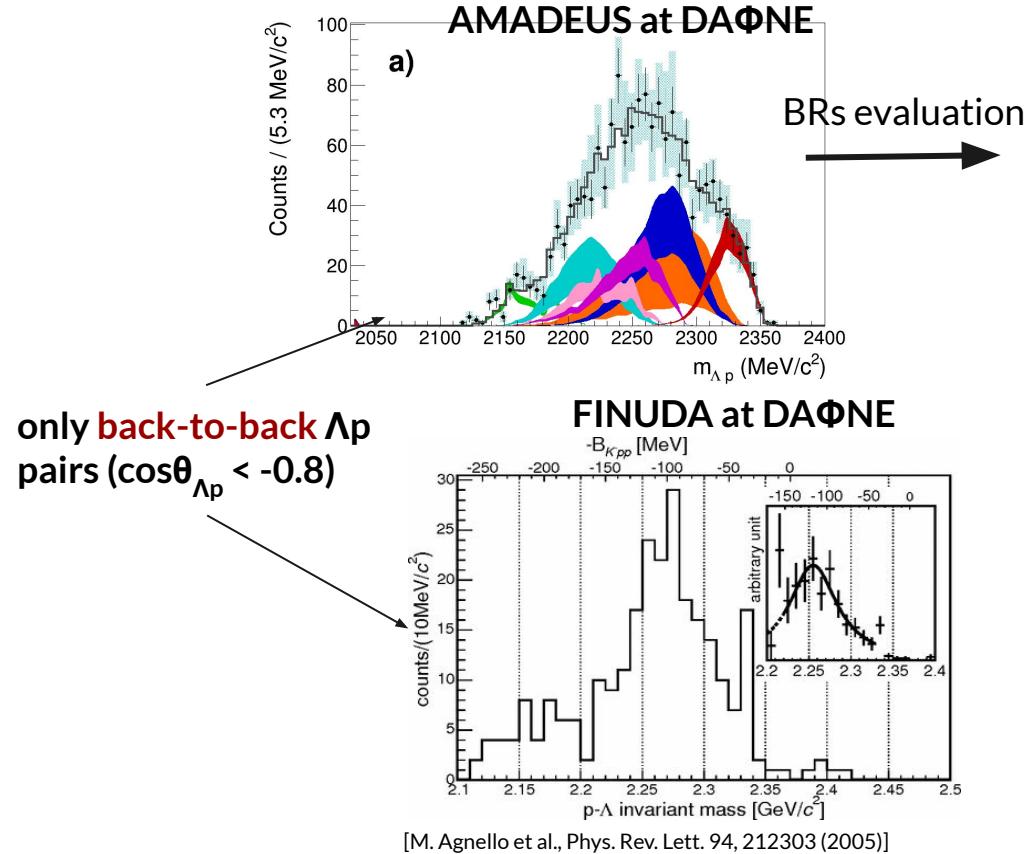


$K^- pp$ bound state contribution completely overlaps with the $K^- 2NA$

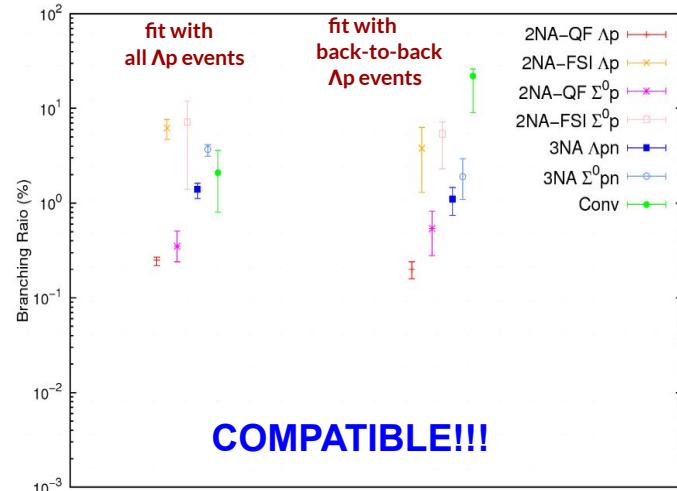
[R. Del Grande, K. Piscicchia, O. Vazquez Doce et al., Eur.Phys.J. C79 (2019) no.3, 190]

[R. Del Grande, K. Piscicchia, S. Wycech, Acta Phys. Pol. B 48 (2017) 1881]

Λp analysis: $K^- pp$ bound state search



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



Λ t analysis: Cross section and BR for 4NA

GOLDEN CHANNEL to extrapolate the K^- 4NA



Previous data:

- in ^4He : bubble chamber experiment

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

only 3 events compatible with Λ t kinematics found

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

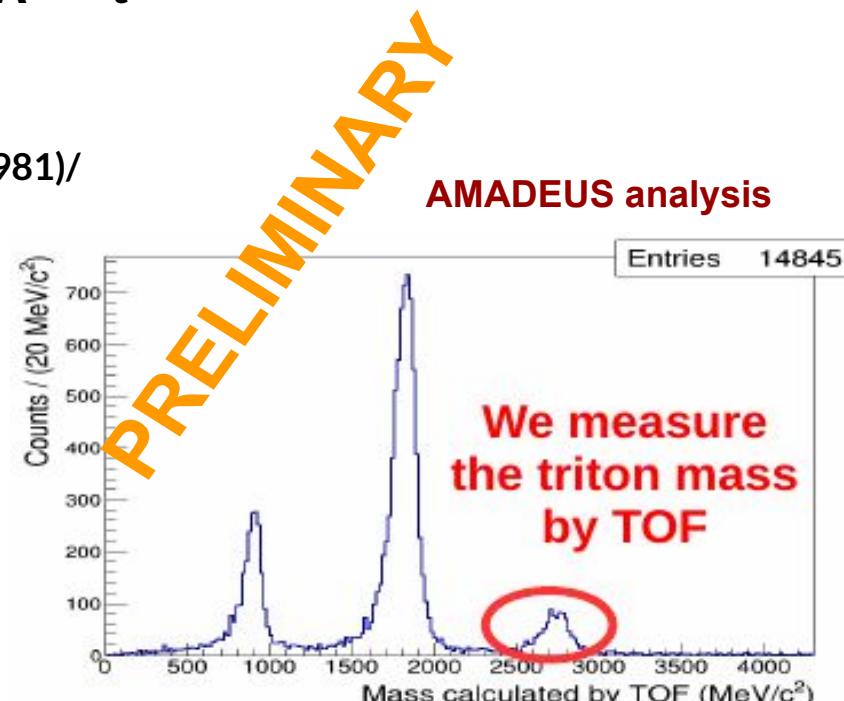
- in solid targets: $^{6,7}\text{Li}$, ^9Be (FINUDA)

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

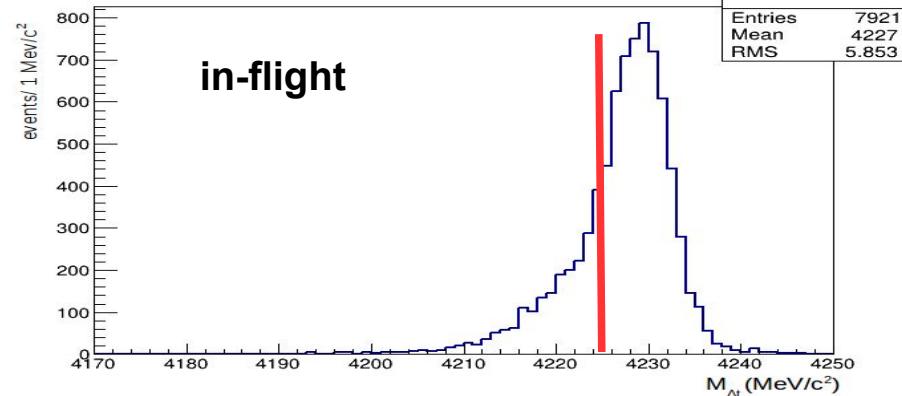
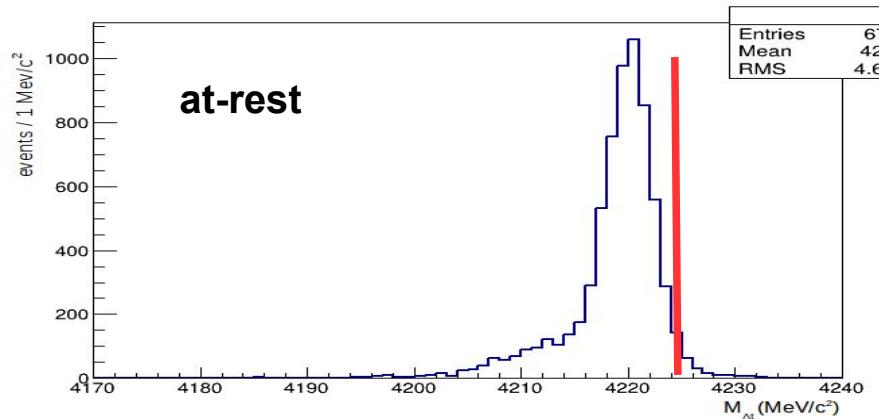
40 events, only back-to-back data

$$\Lambda t \text{ emission yield} \rightarrow 10^{-3} - 10^{-4} / K_{\text{stop}}$$

\rightarrow global, no 4NA



MC simulations: efficiency & resolution



mass threshold at-rest

$$M_{\Lambda t} \text{ invariant mass resolution} = 2.2 \text{ MeV/c}^2$$

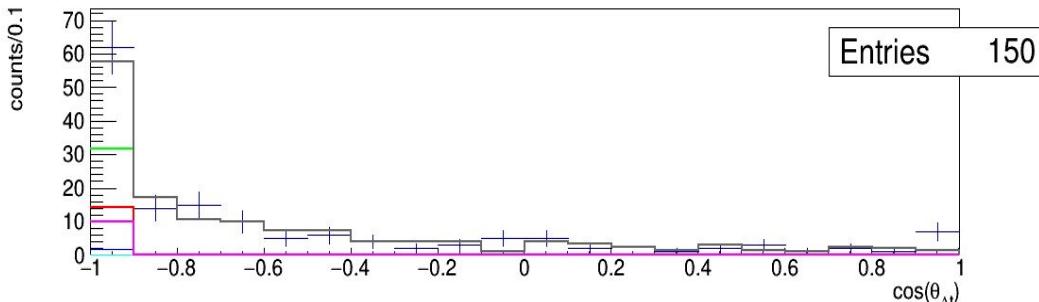
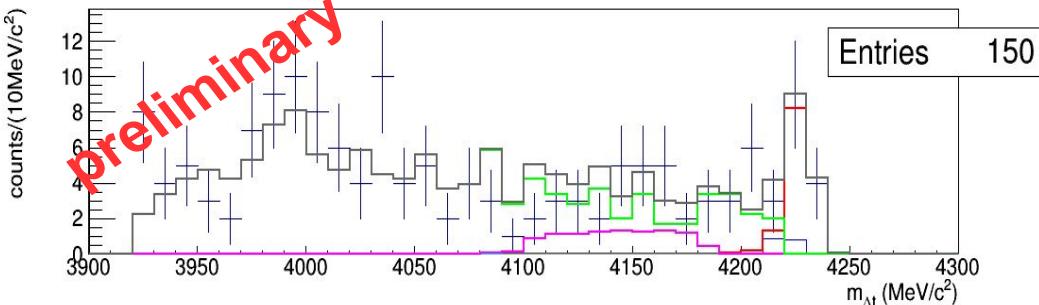
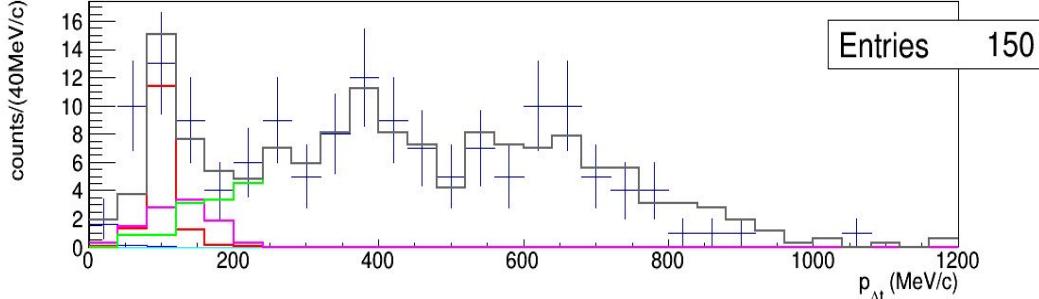
overall detection + reconstruction efficiency for 4NA direct Λt production :



at-rest

in-flight

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



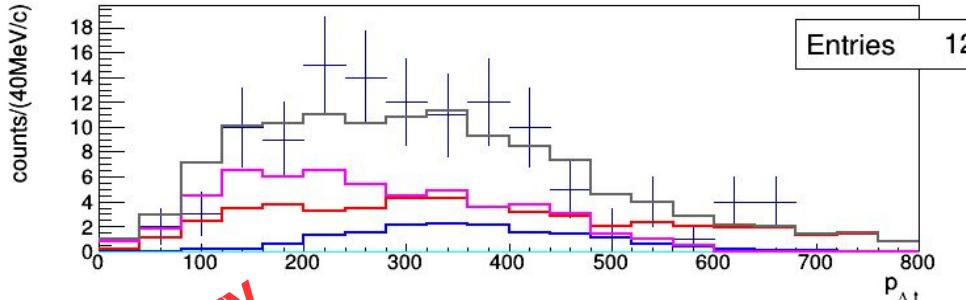
Preliminary

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

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

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

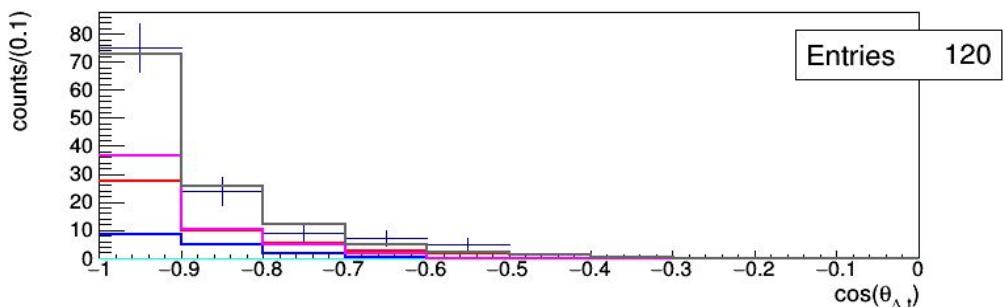
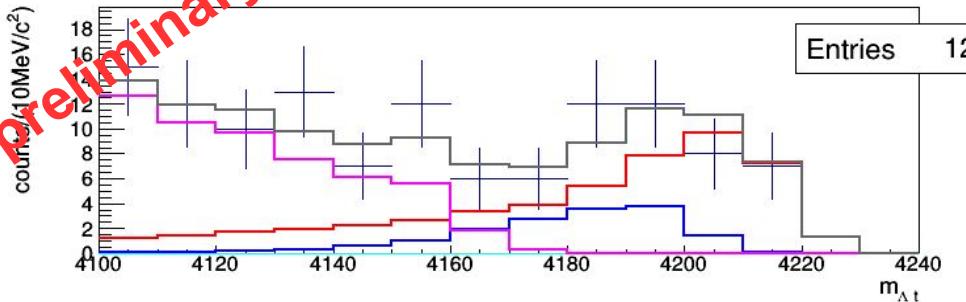
Preliminary



$$\text{BR}(K^{-12}\text{C}(4\text{NA}) \rightarrow \Lambda t {}^8\text{Be}) = 1.5 \pm 0.5 \times 10^{-4} \text{ (stat)} / K_{\text{stop}}$$

$$\sigma(K^{-12}\text{C} (4\text{NA}) \rightarrow \Lambda t {}^8\text{Be}) = 0.58 \pm 0.11 \text{ (stat)} \text{ mb}$$

$$\sigma(K^{-12}\text{C} (4\text{NA}) \rightarrow \Sigma^0 t {}^8\text{Be}) = 1.88 \pm 0.35 \text{ (stat)} \text{ mb}$$

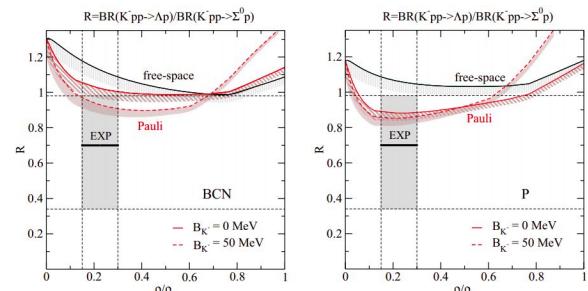


Summary on the Λ^- multi-NA and bound state search

$\Lambda^- p$ 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.) ± 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 |
| 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 $\Sigma^0 pn$ | 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.) | - | | |
| Global $\Lambda(\Sigma^0)p$ | 21 ± 3 (stat.) $^{+5}_{-6}$ (syst.) | - | | |

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



$\Lambda^- t$ channel: 4NA BRs and σ

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

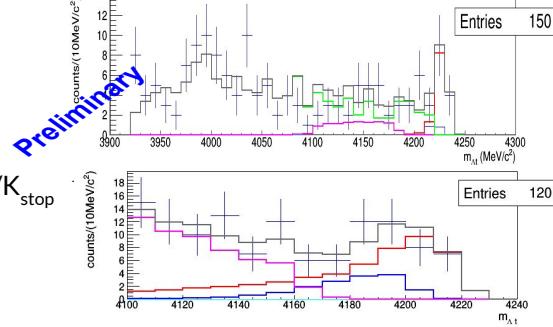
$$\sigma(100 \pm 19 \text{ MeV/c}) (K^-{}^4\text{He}(4\text{NA}) \rightarrow \Lambda t) =$$

$$= (0.81 \pm 0.21 \text{ (stat.)}^{+0.03}_{-0.04} \text{ (syst.)}) \text{ mb}$$

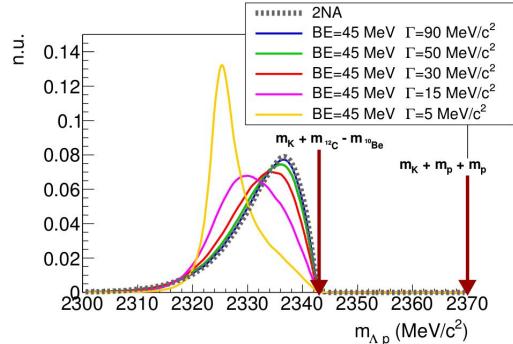
$$BR(K^-{}^{12}\text{C}(4\text{NA}) \rightarrow \Lambda t {}^8\text{Be}) = 1.5 \pm 0.5 \times 10^{-4} \text{ (stat.)} / K_{\text{stop}}$$

$$\sigma(K^-{}^{12}\text{C}(4\text{NA}) \rightarrow \Lambda t {}^8\text{Be}) = 0.58 \pm 0.11 \text{ (stat.)} \text{ mb}$$

$$\sigma(K^-{}^{12}\text{C}(4\text{NA}) \rightarrow \Sigma^0 t {}^8\text{Be}) = 1.88 \pm 0.35 \text{ (stat.)} \text{ mb}$$



$\Lambda^- pp$ bound state



Thank You