Chiral dynamics of K^- nucleus interaction: A critical analysis of deeply bound kaonic states in nuclei.

E. Oset and H. Toki Phys. Rev. C74 (2006) 015207

V. Magas, A. Ramos, E. Oset and H. Toki Phys. Rev. C, in print

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Unitarized Chiral Perturbation Theory

Skillful combination of the information of the Chiral Lagrangians and unitarity in coupled channels.

- Pioneering work of *Kaiser, Siegel, Waas, Weise 95-97* using Lipmann-Schwinger eq. and input from Chiral Lagrangians as potential.

- Subsequent work

– Inverse Amplitude Method (IAM)→ { Truong; *Dobado, Peláez '97*; *Oller, E.O., Peláez '98* }

– (N/D) method→ { *Oller, E.O. '99*; *Oller, Meissner '01* }

– Bethe-Salpeter eq.→ { *Oller, E.O. '97*; *Nieves, Ruiz-Arriola '00* }

Hosaka, Hyodo ; Lutz, Kolomeitsev ; Borasoy, Nißler, Weise

–Applications→ { *Ramos, Vicente, Marco, Parreño, Toki, Hirenzaki*
Hosaka, Oka, Nacher, Palomar, Jido, Inoue, Roca
Cabrera, Okumura, Takahashi, Mizobe, Chiang
Kamalov, Bennhold, Hernández, García Recio }

Meson-Baryon interaction

$$\mathcal{L}_1^{(B)} = \langle \overline{B} i\gamma^\mu \nabla_\mu B \rangle - M_B \langle \overline{B} B \rangle + + \frac{D}{2} \langle \overline{B} \gamma^\mu \gamma_5 \{u_\mu, B\} \rangle + \frac{F}{2} \langle \overline{B} \gamma^\mu \gamma_5 [u_\mu, B] \rangle$$

$$u_\mu = i u^\dagger \partial_\mu U u^\dagger \quad ; u^2 = U = e^{i \frac{\sqrt{2}}{f} \Phi}$$

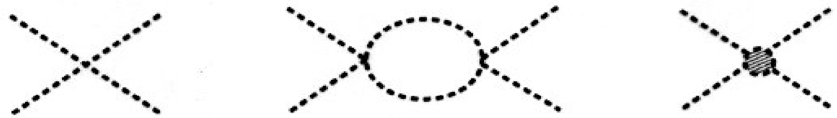
$$\nabla_\mu B = \partial_\mu B + [\Gamma_\mu, B] \; ; \; \Gamma_\mu = \frac{1}{2} (u^+ \partial_\mu u + u \partial_\mu u^+)$$

$$B(x) \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda^0 & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda^0 & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda^0 \end{pmatrix}$$

χ **PT:** (mesons)

$$\Phi \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}$$

L_2 L_2 L_2 L_4



Successful at low energies

Problems→ { Limited energy range of applicability; Cannot deal with resonances }

General scheme *Oller, Meissner PL '01* (meson baryon as exemple)

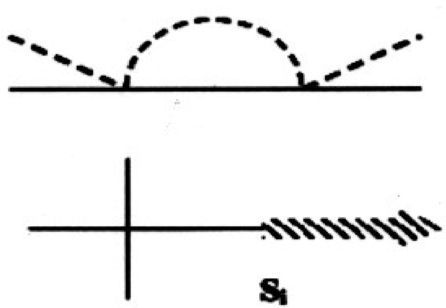
- **Unitarity** in coupled channels $\bar{K}N$, $\pi\Sigma$, $\pi\Lambda$, $\eta\Sigma$, $\eta\Lambda$, $K\Xi$, in $S=-1$

$$\begin{aligned} \mathrm{Im}T_{ij} &= T_{il}\sigma_{ll}T^*_{lj} \\ \sigma_l &\equiv \sigma_{ll} \equiv \frac{2Mq_l}{8\pi\sqrt{s}} \\ \sigma &= -\mathrm{Im}T^{-1} \end{aligned}$$

- Dispersion relation

$$\begin{aligned} T^{-1}_{ij} &= -\delta_{ij}\left\{\hat{a}_i(s_0) + \frac{s-s_0}{\pi}\int_{s_i}^{\infty} ds' \frac{\sigma(s')_i}{(s-s')(s'-s_0)}\right\} + \\ &+ V^{-1}_{ij} \equiv -g(s)_i\delta_{ij} + V^{-1}_{ij} \end{aligned}$$

g(s) accounts for the right hand cut



V accounts for local terms, pole terms and crossed dynamics. V is determined by matching the general result to the χPT expressions (usually at one loop level)

$$g(s) = \frac{2M_i}{16\pi^2}\left\{a_i(\mu) + \log\frac{m_i^2}{\mu^2} + \frac{M_i^2 - m_i^2 + s}{2s}\log\frac{M_i^2}{m_i^2} + \right. \\ \left. + \frac{q_i}{\sqrt{s}}\log\frac{m_i^2 + M_i^2 - s - 2q_i\sqrt{s}}{m_i^2 + M_i^2 - s + 2q_i\sqrt{s}}\right\}$$

μ regularization mass

a_i subtraction constant

Inverting T^{-1}:

$$T = [1 - Vg]^{-1}V$$

Example 1: Take $V \equiv$ lowest order chiral amplitude

In meson-baryon S-wave

$$[1 - V\,g]\,T = V \rightarrow T = V + V\,g\,T$$

Bethe Salpeter eqn. with kernel V

This is the method of *E. O., Ramos '98* using cut off to regularize the loops

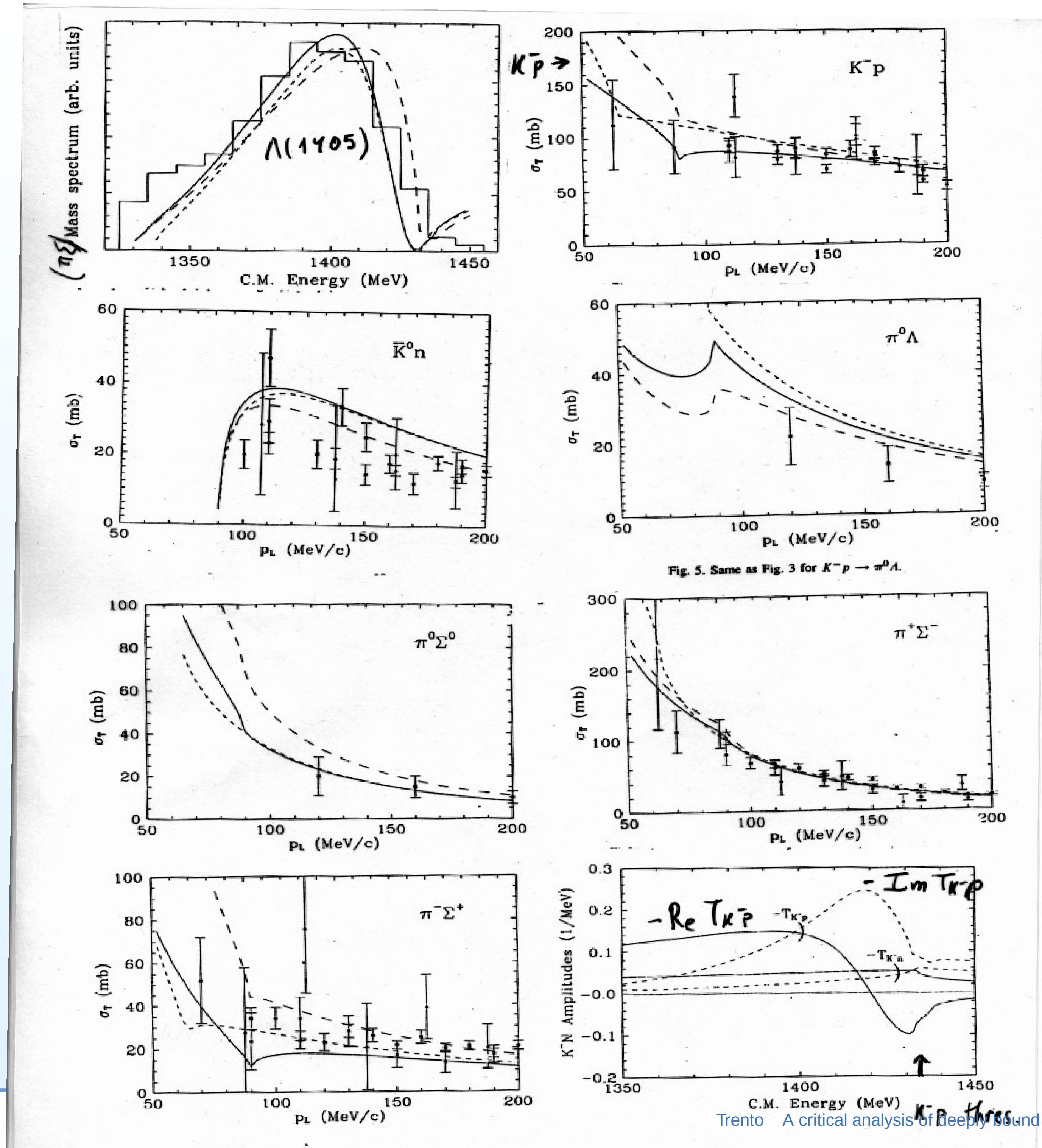
Oller, Meissner show equivalence of methods with

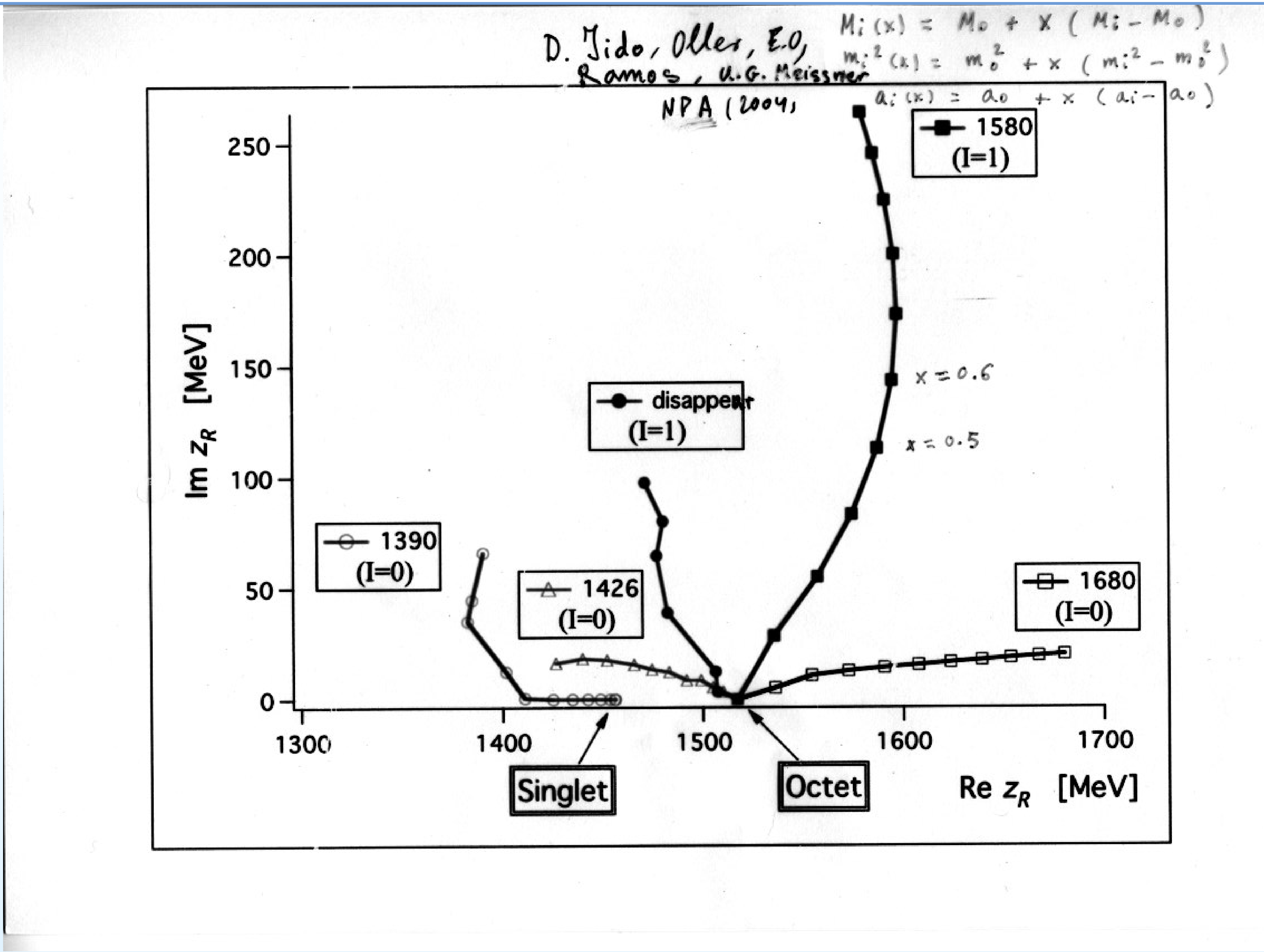
$$a_i(\mu) \simeq -2\ln\left[1 - \sqrt{1 + \frac{m_i^2}{\mu^2}}\right] \; ;$$

μ cut off

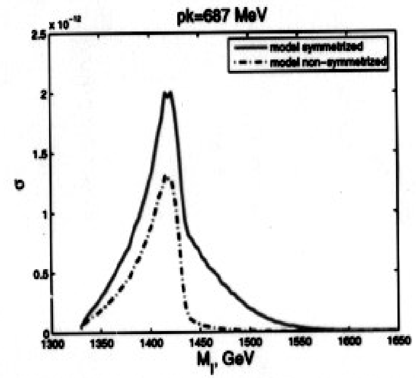
$$a_i \simeq -2 \rightarrow \mu \simeq 630\,\text{MeV in } \bar{K}N$$

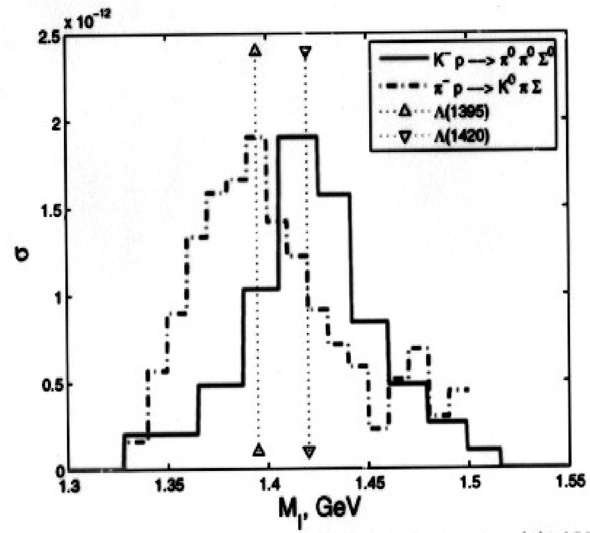
If higher order Lagrangians not well determined then fit a_i to the data


Λ(1405)
(πΣ) Mass spectrum (arb. units)
C.M. Energy (MeV)
K⁻p →
K⁻p
$\bar{K}^0 n$
$\pi^0\Lambda$
$\pi^0\Sigma^0$
$\pi^+\Sigma^-$
$\pi^-\Sigma^+$
σ_T (mb)
p_L (MeV/c)
Fig. 5. Same as Fig. 3 for $K^- p \to \pi^0 \Lambda$.
$-\mathrm{Re}\, T_{K^-p}$
$-\mathrm{Im}\, T_{K^-p}$
$-T_{K^-p}$
$-T_{K^-n}$
K^-N Amplitudes (1/MeV)
K^-p thres.


D. Jido, Oller, E.O,
Ramos, U.G. Meissner
NPA (2004)
$M_i(x) = M_0 + x(M_i - M_0)$
$m_i^2(x) = m_0^2 + x(m_i^2 - m_0^2)$
$a_i(x) = a_0 + x(a_i - a_0)$
1580 (I=1)
disappear (I=1)
1390 (I=0)
1426 (I=0)
1680 (I=0)
x = 0.6
x = 0.5
Im z_R [MeV]
Re z_R [MeV]
Singlet
Octet
0
50
100
150
200
250
1300
1400
1500
1600
1700

Evidence for the two pole structure of the $\Lambda(1405)$





$\Gamma \simeq 30$ MeV
$M \simeq 1420$ Me

$\Gamma \simeq 65$ MeV
$M \simeq 1396$ Me

Puri, March 2005

Evidence for the two pole structure of the $\Lambda(1405)$ resonance and the nature of the $\Lambda(1520)$ – p.6/1

$\pi^- p \to K^0 \pi \Sigma$ from Thomas NPB (73); $K^- p \to \pi^0 \pi^0 \Sigma^0$ from Prakhov PRC (04)

theory: Hyodo et al. PRC (03); Magas et al. PRL (05)

Recent calculations

The lowest order calculations have been improved recently in

Borasoy, Niessler and Weise, PRL (2005);Oller, Prades, Verbeni, PRL(2005); Oller (2006); Borasoy, Meissner and Niessler (2206)

Common features: two poles for the $\Lambda(1405)$, one around 1420 MeV with narrow width ($\sim 30 MeV$). The second one at lower energies, wider but changes much from model to model . Observation of the $\Lambda(1405)$ with different shapes in different reactions should further constraint the models.

Some differences: predictions for the scattering lenghts. More experimental work on $K^- p$ atoms is needed.

Repercussion in K^- nucleus potential of differences of models:

1. Differences much smaller in K^- nucleus potential when the selfconsistency requirement is imposed.
2. With respect to the message of this talk, these differences are small compared to the factor 20 difference with respect to Akaishi K^- nucleus potential.

K^- in a nuclear medium

One does many body corrections in the $\bar{K}N$ amplitude

$$t(s) \rightarrow \tilde{t}(q, p)$$

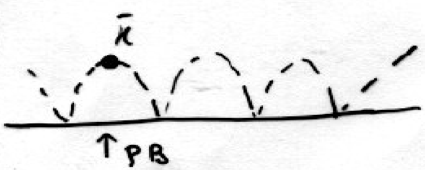
(q: K, p: N)

$$\Rightarrow \Pi_{\bar{K}}(q^0, q, \rho) = 2\int \frac{d^3p}{(2\pi)^3}\, n(\vec{p}) \left[\tilde{t}_{\bar{K}p}(q, p) + \tilde{t}_{\bar{K}n}(q, p)\right]$$

$$N \rightarrow \frac{1-n(\vec{p})}{p^0 - \varepsilon(p) + i\epsilon} + \frac{n(\vec{p})}{p^0 - \varepsilon(p) - i\epsilon}$$

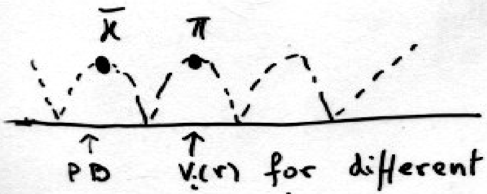
Pauli blocking — Koch 94; Waas, Weise 97

Shifts the $\Lambda(1405)$ at higher energies



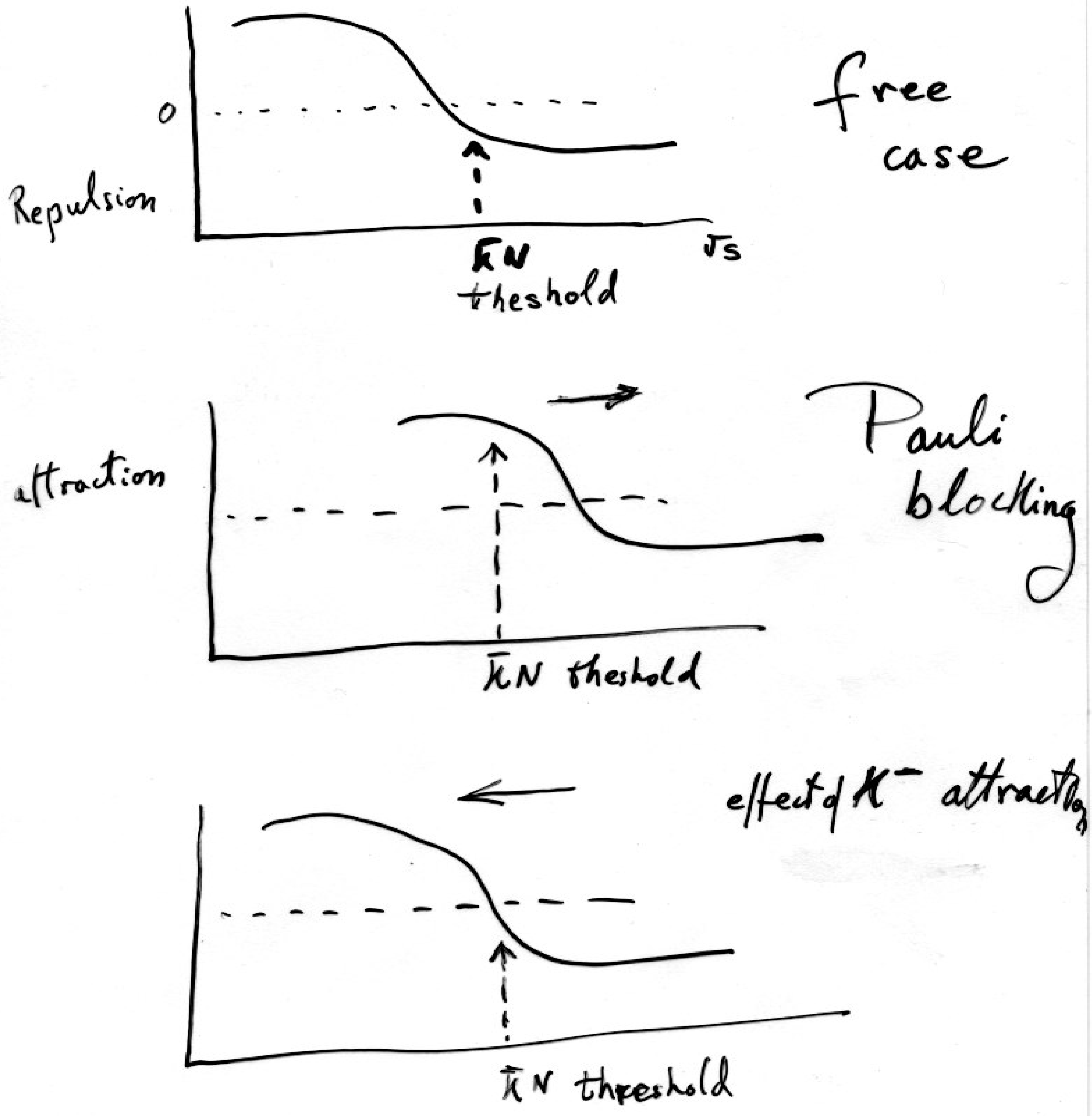
Selfconsistent use of $\bar{K}$ selfenergy in the loops — Lutz 98

Brings back the $\Lambda(1405)$ to the free position



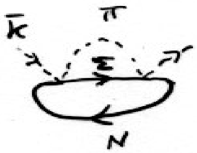
Sefcons. $\bar{K}$ + π selfenergy + mean field baryon potential — Ramos, E.-O. NPA (2000)

Opens new decay channels and widens spectral function


0
Repulsion
K̄N
theshold
√s
free
case
attraction
Pauli
blocking
K̄N theshold
effect of K⁻ attraction
K̄N threshold

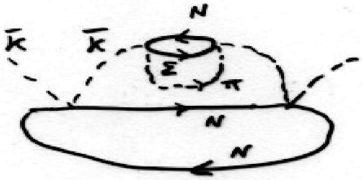
Medium decay channels

Koch, Waas, Weise



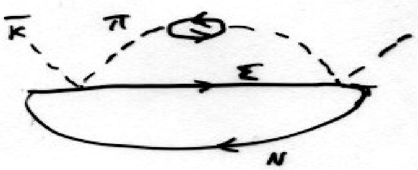
$\bar{K} \Rightarrow (\Sigma h)\pi \;,\; (\Lambda h)\pi$

Lutz

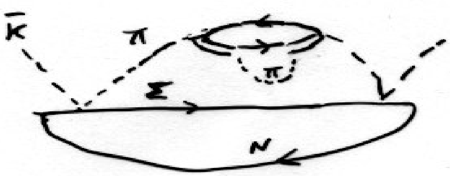


$+ \; \bar{K} \to (\Sigma h)(p h)\pi, (\Lambda h)(p h)\pi$

Ramos

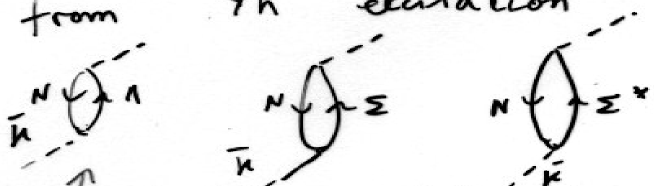


$+ \; \bar{K} \to (\Sigma h)(p h) \,,\, (\Lambda h)(p h)$



+ extra $(\Sigma h)(p h)\pi, (\Lambda h)(p h)\pi$

In addition we have p-wave $\bar{K}$ selfenergy from Yh excitation



↑ Couplings related to SU(3) coeff. D, F of original chiral Lagrangian

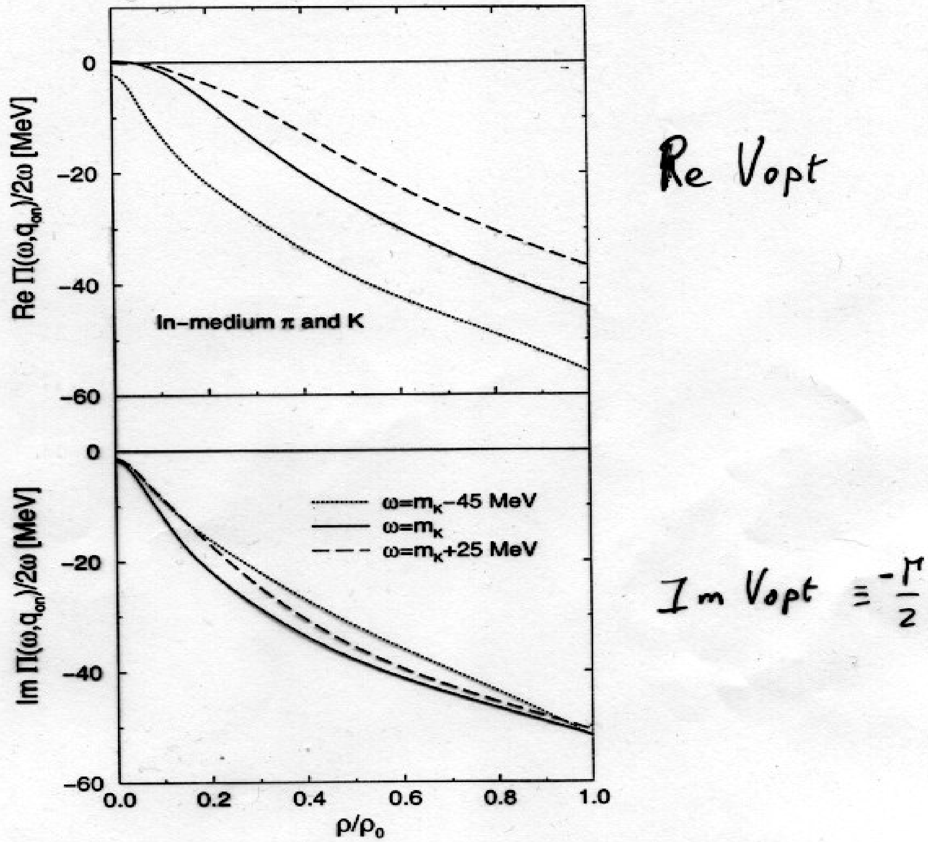


FIG. 7. Real (top) and imaginary (bottom) parts of the K^- optical potential as a function of density obtained from the *In-medium pions and kaons* approximation. Results are shown for three different K^- energies: $\omega = m_K - 45$ MeV (dotted lines), $\omega = m_K$ (solid lines) and $\omega = m_K + 20$ MeV (dashed lines).

Similar results in

Schaffner-Bielich, Koch, Effenberg NPA 2000

Cieply, Friedman, Gal, Mares NPA 2001

25

Hirenzaki, Okumura, E.O., Ramos, Toki
PRC 2000

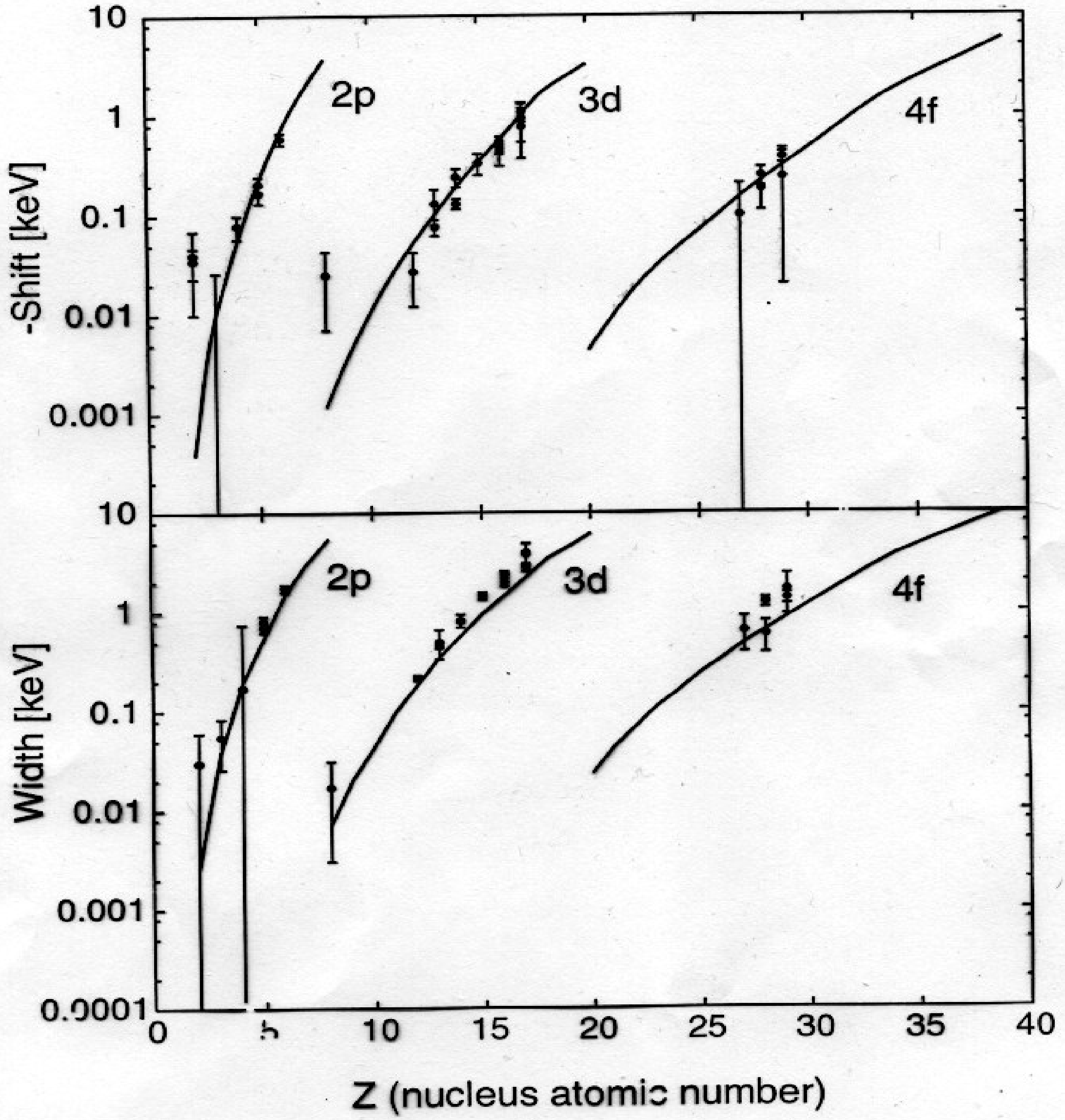
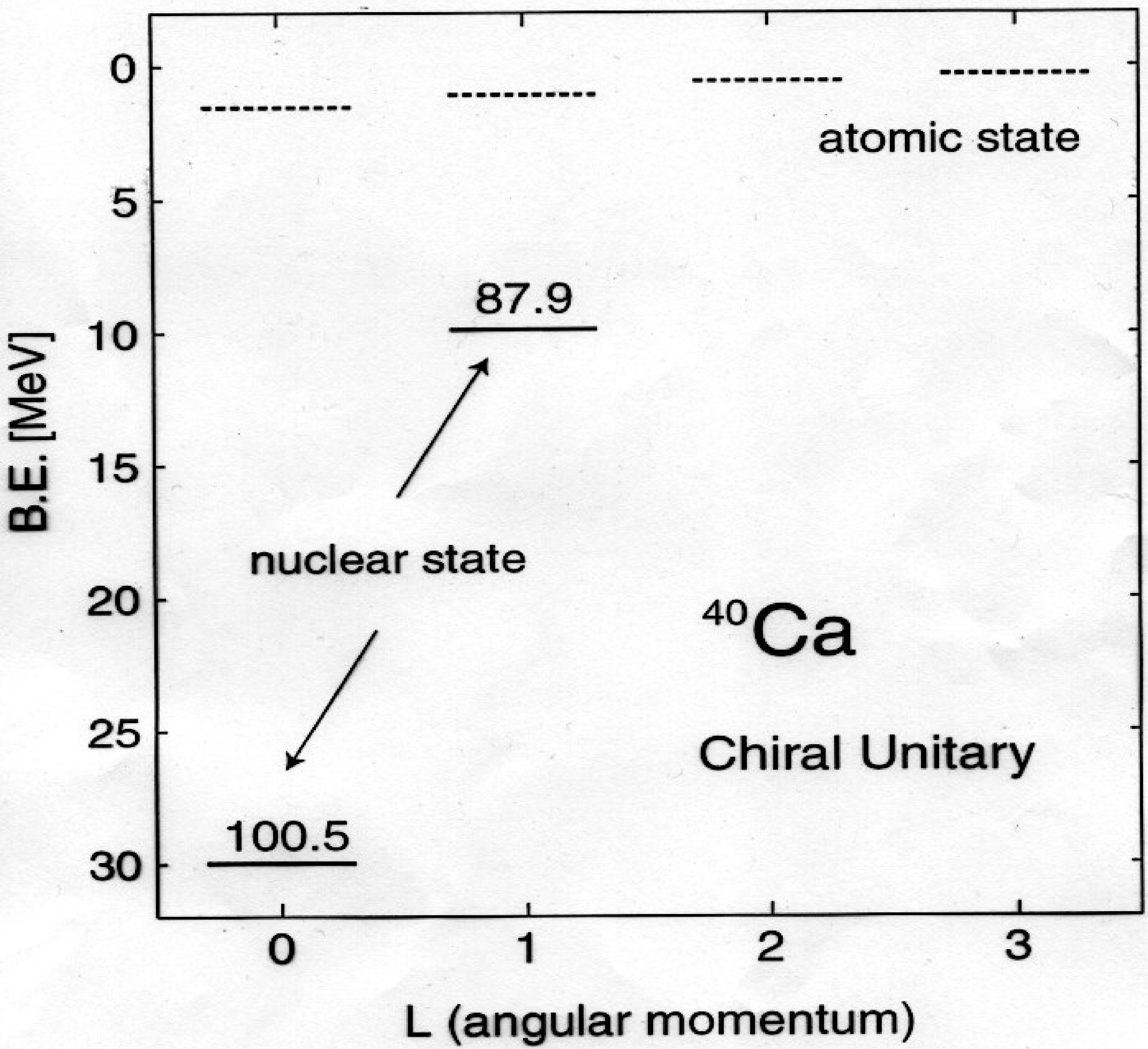


Fig.3

Improvements on the micooscopic potential

Baca, Garcia Recio and Nieves show in NPA (2000) that the microscopic potential gives also good results for the rest of the available kaonic atom data.

They also add extra phenomenological terms and perform a best fit to the data, concluding that the extra terms amount to about 20 percent of the microscopic potential.


0
5
10
15
20
25
30
B.E. [MeV]
atomic state
87.9
nuclear state
100.5
40Ca
Chiral Unitary
0
1
2
3
L (angular momentum)

Claims for deeply bound Kaon atoms

Theoretical claim of deep potential, Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 044005.

Quoting the authors textually,

"we construct phenomenologically a quantitative $\bar{K}N$ interaction model that is as simple as possible using free $\bar{K}N$ scattering data, the KpX data of kaonic hydrogen and the binding energy and width of $\Lambda(1405)$, which can be regarded as an isospin I=0 bound state of $\bar{K}+N$".

They use as input $v_{\bar{K}N,\bar{K}N}$, $v_{\bar{K}N,\pi\Sigma}$, $v_{\bar{K}N,\pi\Lambda}$, which are fitted to data, and set $v_{\pi\Sigma,\pi\Sigma}$, $v_{\pi\Lambda,\pi\Lambda}$ equal zero "to simply reduce the number of parameters".

The last condition implies that they miss the second pole of the $\Lambda(1405)$

The chiral Lagrangian gives

$$v_{\pi\Sigma,\pi\Sigma} = \frac{4}{3}\, v_{\bar{K}N,\bar{K}N}$$

Theoretical claims

The claim of the $\Lambda(1405)$ as a bound state of $\bar{K}N$ is not supported by the chiral theory.
This assumption leads to a I=0 $\bar{K}N$ amplitude below threshold twice as big as a standard chiral amplitude.

AY take into account Pauli Blocking of intermediate states to get $\bar{K}$ nucleus potential.

For the A=3 and 4 systems leads to binding energies of the kaon of the order of 70 MeV with widths around 75 MeV, (from $K^- N \to \pi\Sigma$).

Next, the nucleus is allowed to shrink to densities $\rho = 10\rho_0$

Then, K^- bound in ^3He by 108 MeV and in ^4He by 86 MeV

$\Gamma = 20 - 24$ MeV from $K^- p \to \pi\Lambda$

Extra deffi ciencies in the K^- potential

No selfconsistency in the calculation: Overestimate

No many body decay channels, $K^- NN \to \Lambda N, \Sigma N$

Rough estimate made of these channels, $\Gamma = 12 MeV$

More realistic is 22 MeV at $\rho = \rho_0$

But if $\rho = 10\rho_0$, Γ should be even bigger, hence more than 44 MeV altogether
This agrees with Mares, Friedman and Gal NPA(2006)

Experimentalist "find" a possible deeply bound K^- state. Suzuki et al. PLB597 (2004)

$K^- \, {}^4He \to Sp$, S(3115) Strange tribaryon.
But I=1, and if K^- state, B=195 MeV

Contradiction with AY with I=0 and 108 MeV!!

The saga continues

AY strike back:

Introduce relativistic corrections (use Klein Gordon equation) (The chiral theories always did)

some spin orbit corrections

Increase ad hoc the $\bar{K}N$ interaction

B=195 comes out then

At this point the K^- potential in the center of the nucleus has become 618 MeV!!!

Experimental reconversion: ..... Sato in BadHonnef, PANIC05... claim the state seen is indeed a K^- bound state.

Sato in Kyoto meeting February 2006: back to strange tribaryon claim.

Discussion of the KEK experiment, Suzuki et al.

- Kaons at rest absorbed: $K^- \, {}^4He \to S \; p$, They see a peak in the p spectrum around 500 MeV/c.
- Auger emission of the p. Binding energy taken by K^-.
- Alternative explanation
  ..
  .. Many possible conventional mechanisms studied and discarded
- The one passing all tests
- $K^- NN \to \Lambda N \qquad p_N = 562 MeV/c$
- $K^- NN \to \Sigma N \qquad p_N = 488 MeV/c$
  The other nucleons left as spectators
- exp. peak seen at $p_p = 475 MeV/c$ (some energy loss in thick target)
  But what about a peak at $p_p = 562 MeV/c$ from $K^- pp \to \Lambda p$?

KEK Suzuki et al

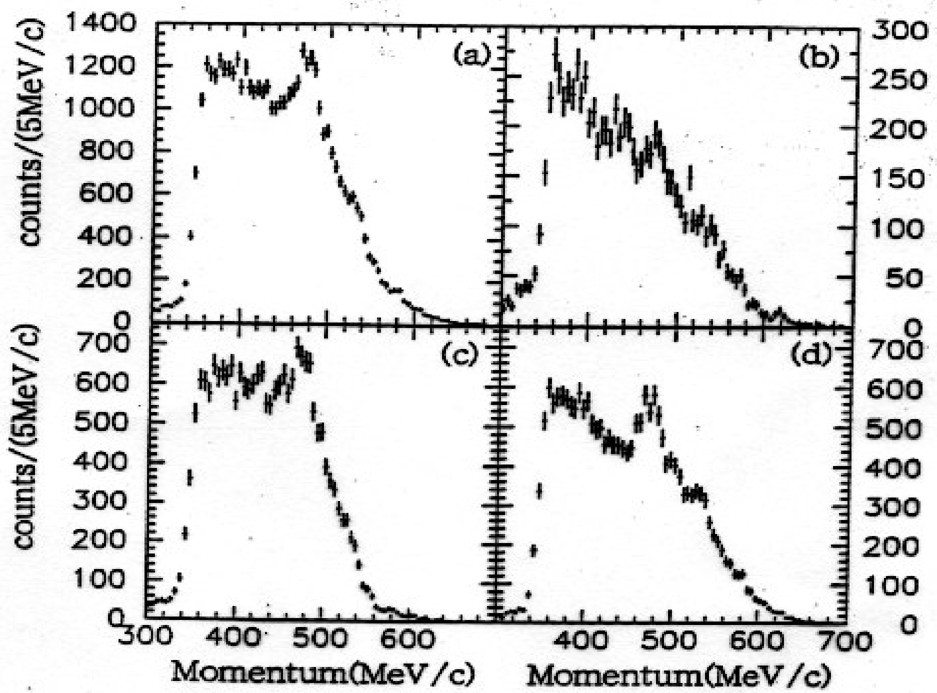


Fig. 5. Proton momentum spectra without energy-loss correction, with cut conditions defined in Fig. 4: (a) with the "π"-cut, (b) with the "p"-cut, (c) with "fast-π"-cut, and (d) with "π"-cut excluding the fast pions.

Further tests of K^- absorption mechanism

- Peak at 545 MeV/c seen in experiment !!
- Further tests
- $K^- pp \longrightarrow \Lambda p$
$$\Lambda \longrightarrow \pi N \quad p_\pi = [61 - 146] MeV/c$$
- $K^- pp \longrightarrow \Sigma p$
$$\Sigma \longrightarrow \pi N \quad p_\pi = [162 - 217] MeV/c$$
- A cut in the pion momenta could help
Test partially done: cut done that accepts 90 % of 255 MeV/c ("fast pions") and complementary
- Peak from $K^- pp \rightarrow \Sigma p$ seen in boths cuts
- Peak from $K^- pp \rightarrow \Lambda p$ seen in basically only the non "fast pions"

Further considerations

- Why more strength in Σp peak than in Λp peak?
- Katz et al. PRD 1 (70) $K^- \, {}^4He \to$

$$\begin{array}{ll} \Sigma^- p \, d & 1.6 \;\; percent \\ \Sigma^- ppn & 2.0 \;\; percent \\ \Lambda(\Sigma^0) pnn & 11.7 \;\; percent \end{array}$$

- 2.3 % for Σ^0 and 9.4 % for Λ, using isospin symmetry
- Another estimate

$$\frac{Y\,(\Sigma^0 NN)}{Y\,(\Lambda NN)} = \frac{\sigma(K^- p \to \pi^0 \Sigma^0)}{\sigma(K^- p \to \pi^0 \Lambda)} \tag{1}$$

  This ratio is about 1 experimentally
- Using these estimates: ratio of Σp to Λp about [1.2-2.5]
- Rates of K^- absorption around 1%, in agreement with strength of peak estimated by Suzuki.

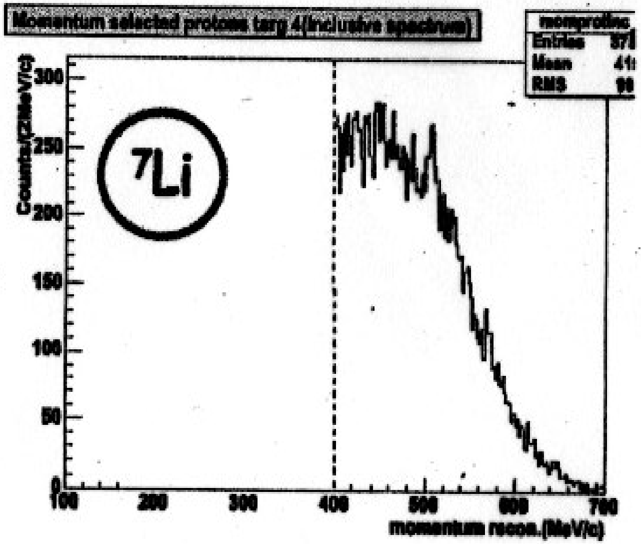
Further tests

- These peaks should be seen in other nuclei!!, what can we predict?
- In K^- absorption two protons are removed. Binding energy smaller than 28 MeV of ^4He breakup. Hence, bigger energy of emitted p in heavier nuclei.
- Estimates
  502 MeV/c for Σp
  574 MeV/c for Λp
- FINUDA sees peaks in ^7Li (and other nuclei) at
  505 MeV/c and 570 MeV/c
- Peaks should get narrower in heavier nuclei, because of smaller recoil energy of the nucleus
- Signals should gradually disappear for heavier nuclei because of p distortion
  These are indeed features of the FINUDA experiment

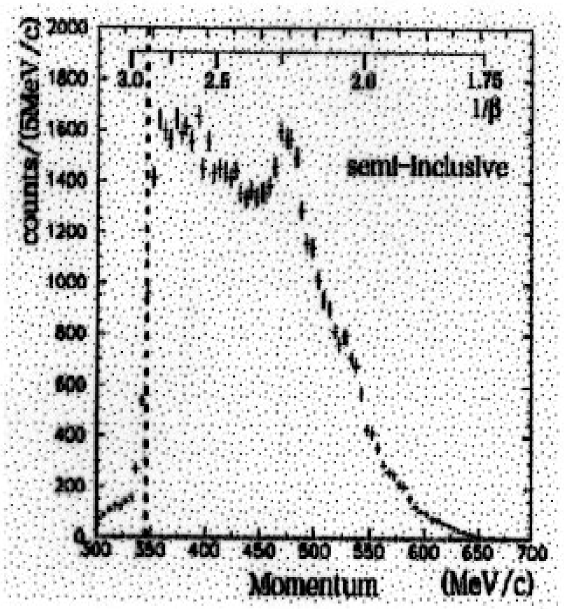
Pre

Monoenergetic protons at 510 MeV/c

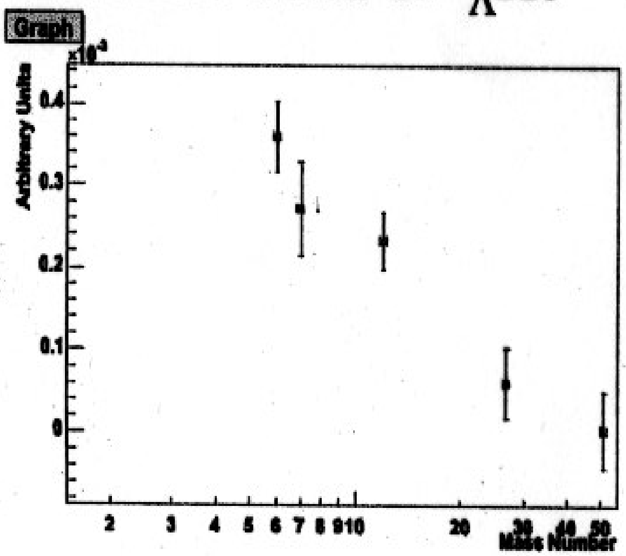
FINUDA from 7Li,…



KEK E471 from ^{4}He



FINUDA Yield of $^4{}_\Lambda$He



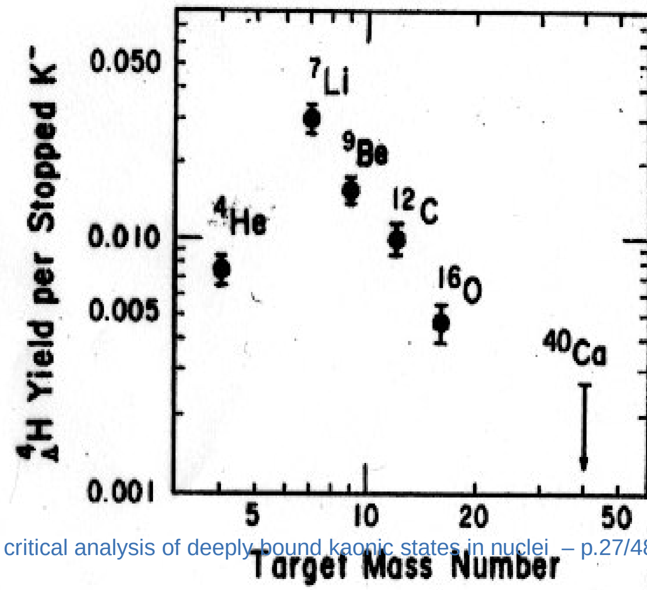
Tamura et al.

Yield of $^4{}_\Lambda$H

^{4}He/^{7}Li ~ 1/4

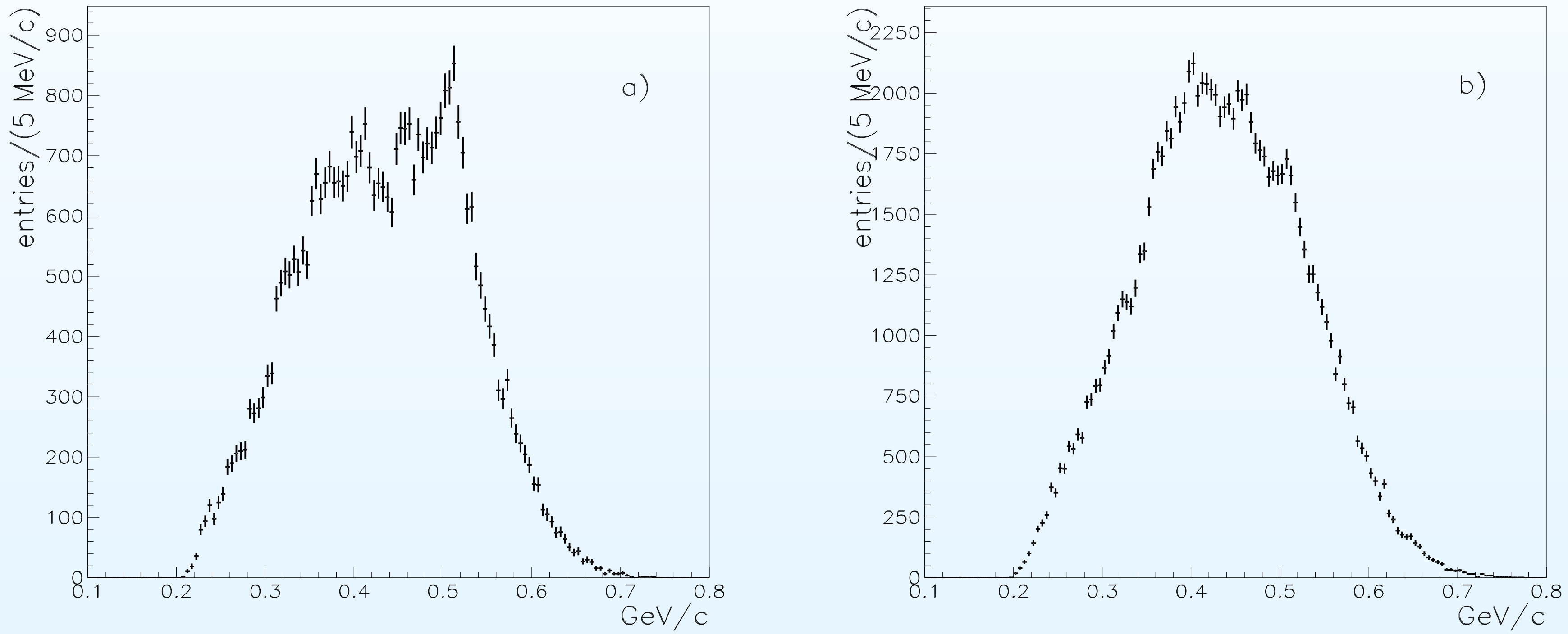
Yield of $^4{}_\Lambda$He

^{4}He/^{7}Li ~ 1/3



New FINUDA data on p spectra June (2006)

Recent paper by the FINUDA Collaboration Agnello et al. nucl-ex/0606021



Proton spectra in ^{6}Li and ^{12}C

In addition they measure pions in coincidence to prove that the peak around 500 MeV/c comes from Σ production and further decay into πN.

Conclusions of the new FINUDA paper June (2006)

The inclusive proton momentum spectrum in K^- reactions induced in ^6Li exhibits a sharp structure around 500 MeV/c which can be rather easily explained as due to the interaction of the K^- on a "quasi"-deuteron cluster in the ^6Li nucleus, leading to the two-body final state $\Sigma^- p$. Both the observed proton and the π^- from the Σ^- decay have the right kinematic features to confirm that they belong to this reaction.

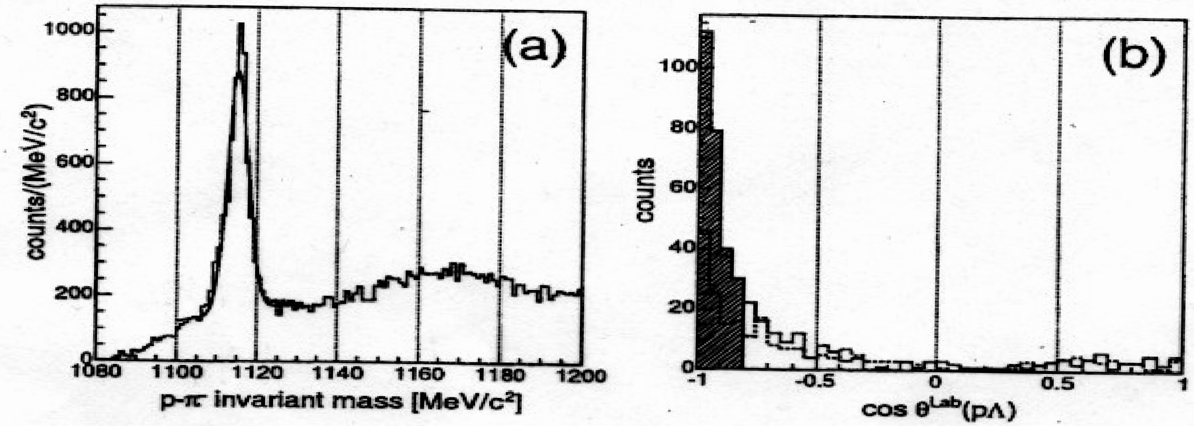
Since the signal is quite similar to the observations of E471 in K^- induced reactions on a ^{4}He target, the peaks observed by the two experiments could have the same nature, and maybe they are simply due to a two-body reaction where a K^- interacts on a “quasi" deuteron, both in ^{6}Li and in ^{4}He. This possibility makes the claim for a deeply bound state unnecessary.

A feeble signal can also be distinguished at about 580 MeV/c. Probably it is due to the absorption reaction $K^-(NN) \rightarrow \Lambda N$

FINUDA experiment, M. Agnello et al. PRL 94 (2005)

- K^- absorption at rest from $^6Li,^7Li,^{12}C....$
  They look for events back to back. Find two peaks in Λp invariant mass: a narrow one at higher energies and a broad one at lower energies. The latter is identified with a bound K^- state.
- Cuts: $p_\Lambda > 300 MeV/c$ to eliminate $K^-p \rightarrow \Lambda\pi$
  $|cos(\theta)| > 0.8$
- Narrow peak identified as $K^-pp \rightarrow \Lambda p$ removing binding energy
  Broad one at lower energies: "bound K^- state in pp " with B=115 MeV.
- Questions:
  where does the binding energy of the kaon go?
  Where is the strength if $K^-pp \rightarrow \Lambda p$ exciting the nucleus (largest part)?

FINUDA Agnello et al



) Invariant-mass distribution of a proton and a π^- for all the events in which these two particles are observed, ssian together with a linear background in the invariant-mass range of 1100–1130 MeV/c^2. (b) Opening angle Λ and a proton: solid line, ^{6}Li, ^{7}Li, and ^{12}C; dashed line, ^{27}Al and ^{51}V. The shaded area ($\cos\theta^{\rm Lab} < -0.8$) is sel k event.

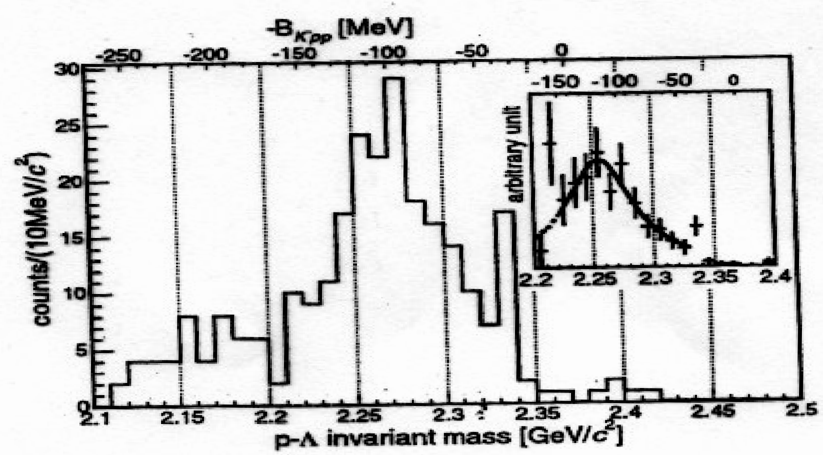


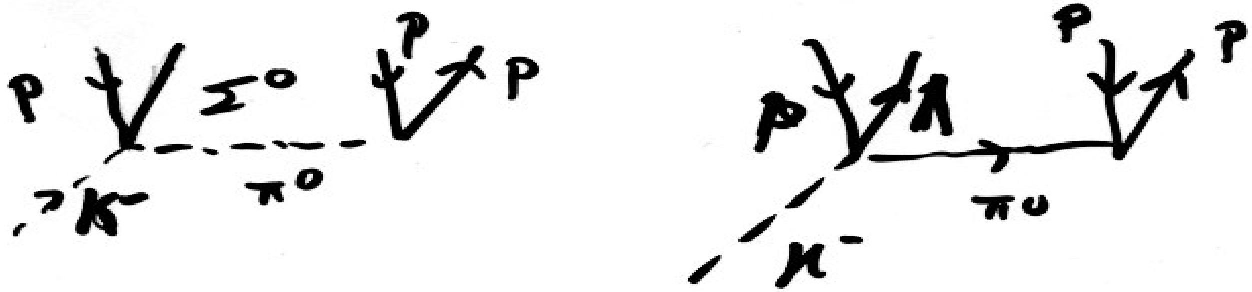
FIG. 3. Invariant mass of a Λ and a proton in back-to-back correlation ($\cos\theta^{\rm Lab} < -0.8$) from light targets before the acceptance correction. The inset shows the result after the acceptance correction for the events which have two protons with well-defined good tracks. Only the bins between 2.22 and

Our description of the peaks

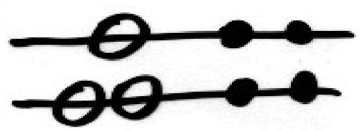
- We run a computer simulation code for K^- absorption in nuclei by pp and pn pairs:
- $|\Psi(r)|^2$ distribution for K^- peaked around surface of nucleus
- K^- absorbed by pp or pn, with momenta randomly chosen from local Fermi sea.
- energy and momentum conservation including nuclear potential
- Λp, Λn emitted according to phase space
- p, n have further collisions
  pN -> p' N   np -> pn   (fast n to fast p)
  done according to $\sigma\rho$ probability per unit length and experimental angular distributions ($\sigma_\Lambda = \frac{2}{3}\sigma_N$)
- Λp invariant mass reconstructed from final events.

Analysis of fi rst peak: g.s. formation of residual nucleus

- Analogy to α decay:
  p and Λ survival probability without collisisions times formation probability.
- Survival probability
  P= $exp(-\int \sigma\rho dl)$
  Calculated by MC simulation, P ~ 0.4
- Formation probability:
  $| < \Phi(r, A-2, final)|\Phi(r, A-2, initial) > |^2, \ | \sim 0.3-0.7|^2$
- Rate of g.s. formation $\sim 0.4 * 0.25 \sim 0.1$
- THE LARGEST PART OF THE K^- ABSORPTION EVENTS GO INTO NUCLEAR EXCITATION, MOSTLY TO THE CONTINUUM
  where is this strength in the experiment?



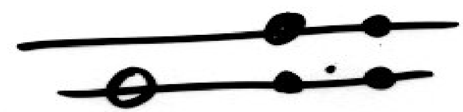
Schematic



p n

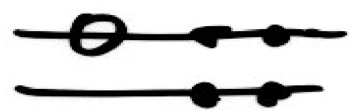
^{7}Li:

K⁻ ^{7}Li → p p ^{5}H g.s



^{5}H

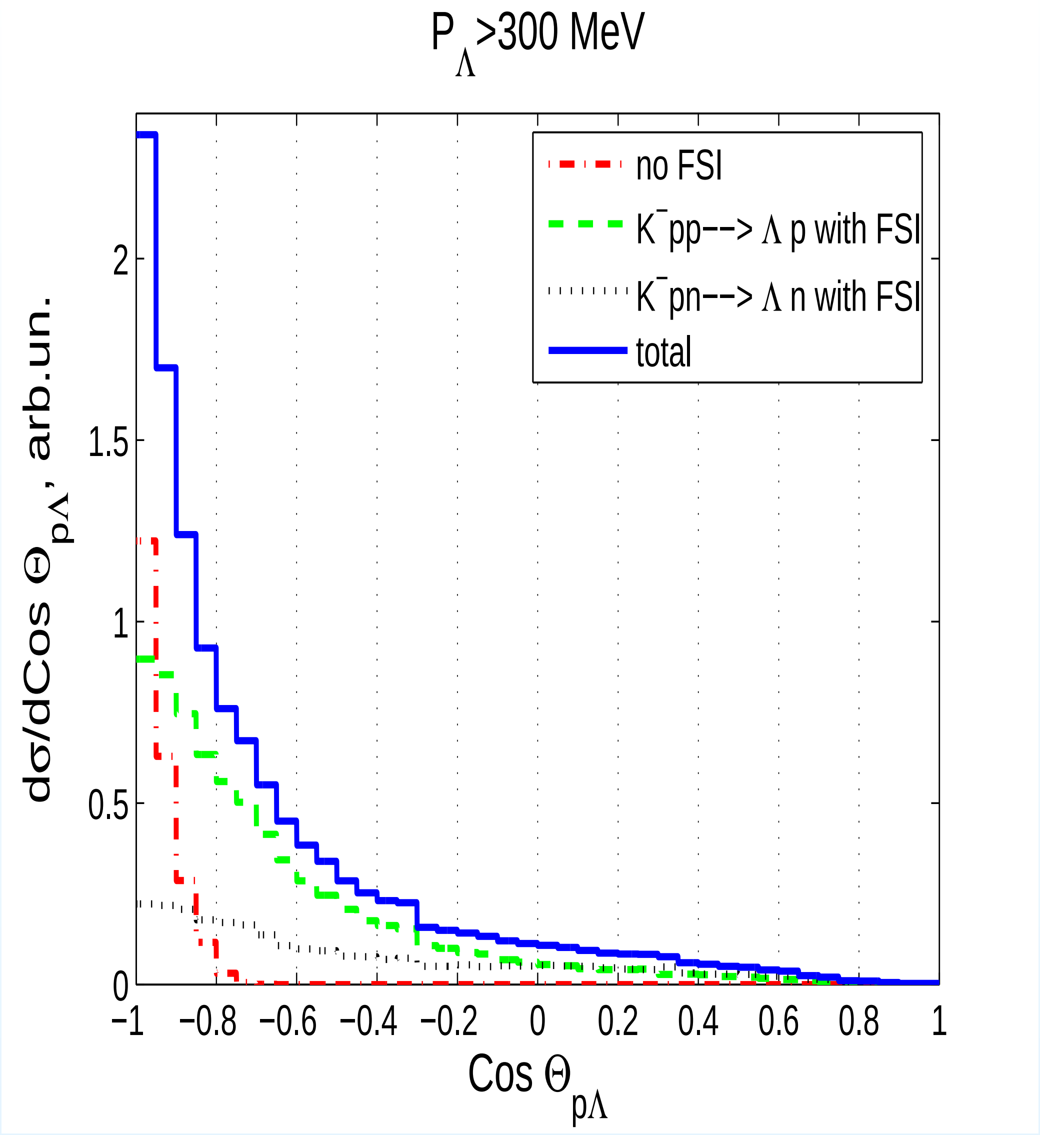
excitation



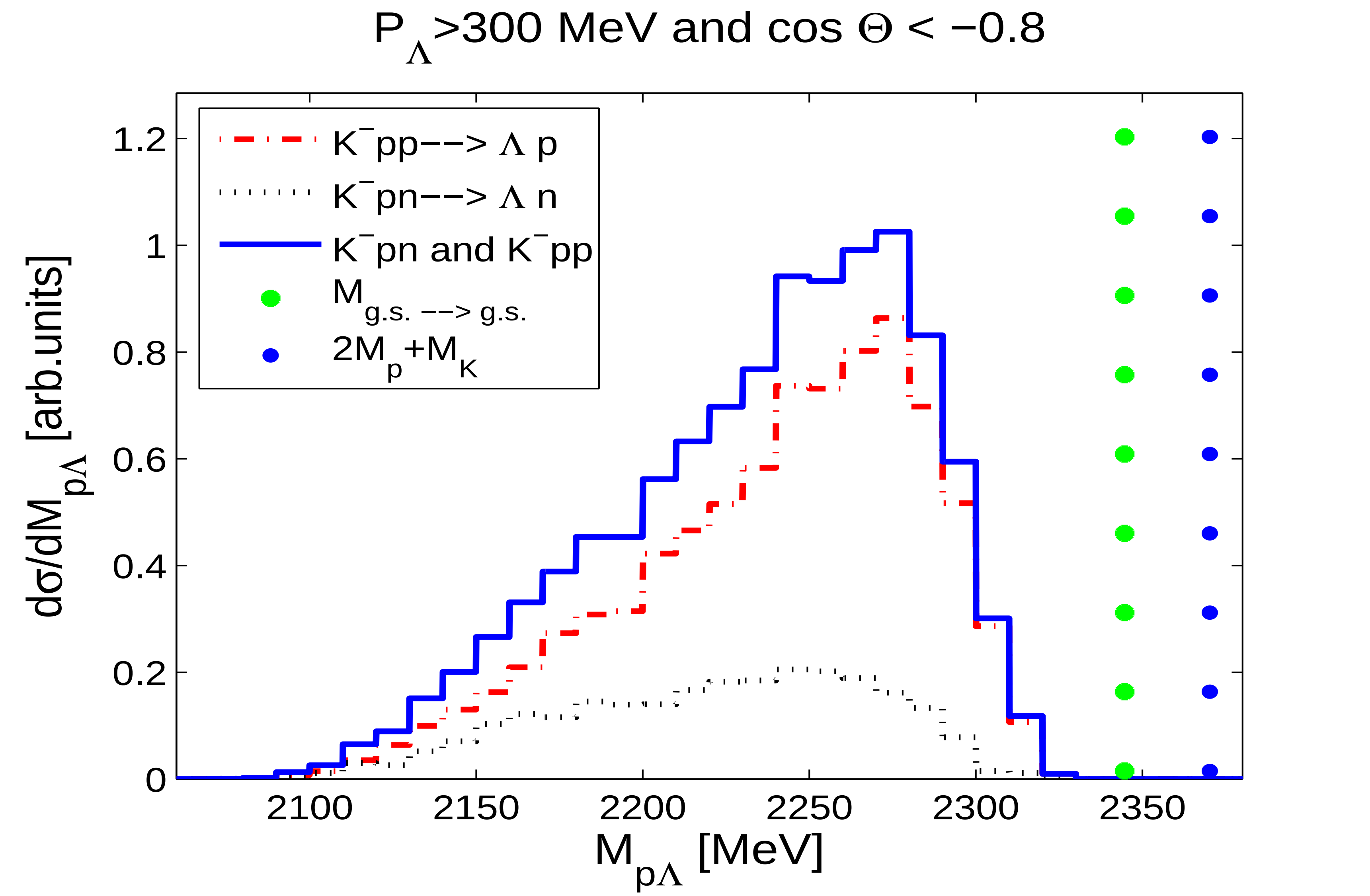
little overlap with ^{5}H breakup channels

MC simulation of K^- absorption: inclusive

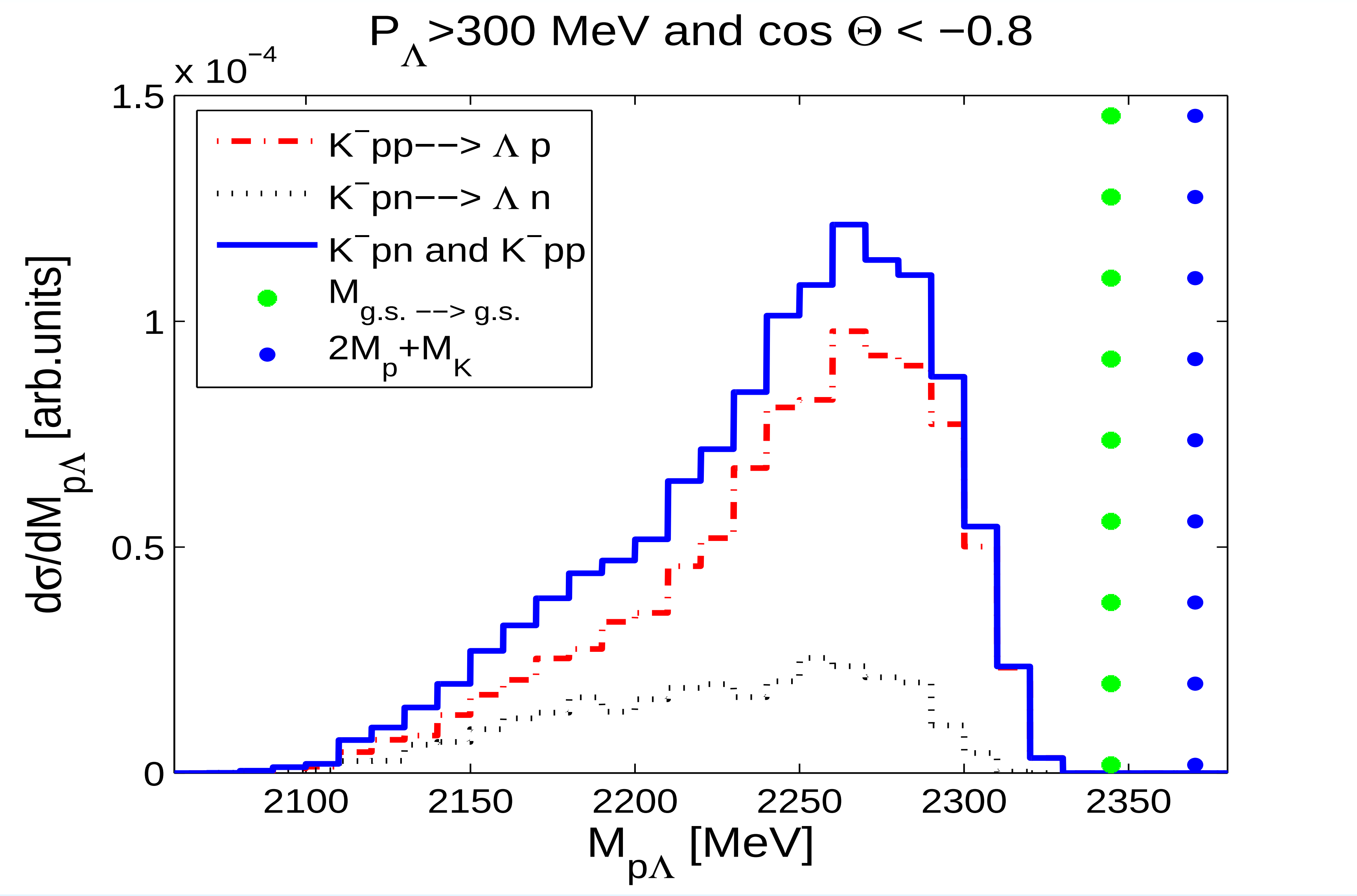
- The MC simulation is done as described before
  This has been applied with success to other physical problems:
  (e,e') inclusive reactions
  (π, π') inclusive reactions
  (p,p') inclusive reactions
- In all tese processes a distinct peak appears which collects most of the strength: the quasielastic peak
  The QSE peak comes mostly from one collision of the particles exciting the nucleus to the continuum
- In the present case this QSE peak comes from the collision of the p (or Λ) after $K^- NN \to \Lambda N$
- THE QSE PEAK ACCOUNTS FOR THE SECOND PEAK OF THE FINUDA EXPERIMENT



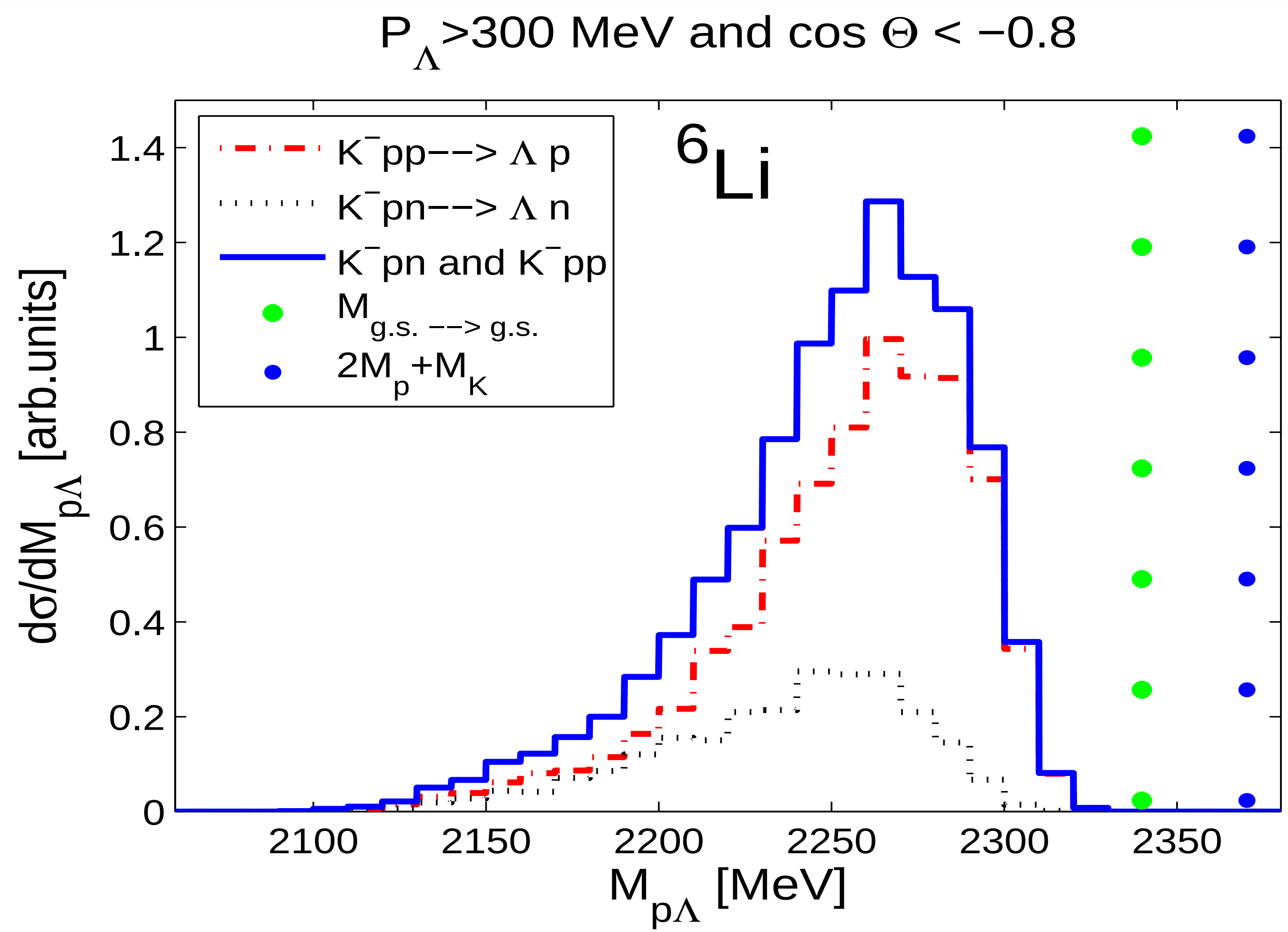
P_Λ>300 MeV
no FSI
$K^- pp \to \Lambda p$ with FSI
$K^- pn \to \Lambda n$ with FSI
total
$d\sigma/d\mathrm{Cos}\,\Theta_{p\Lambda}$, arb.un.
Cos $\Theta_{p\Lambda}$
0
0.5
1
1.5
2
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1



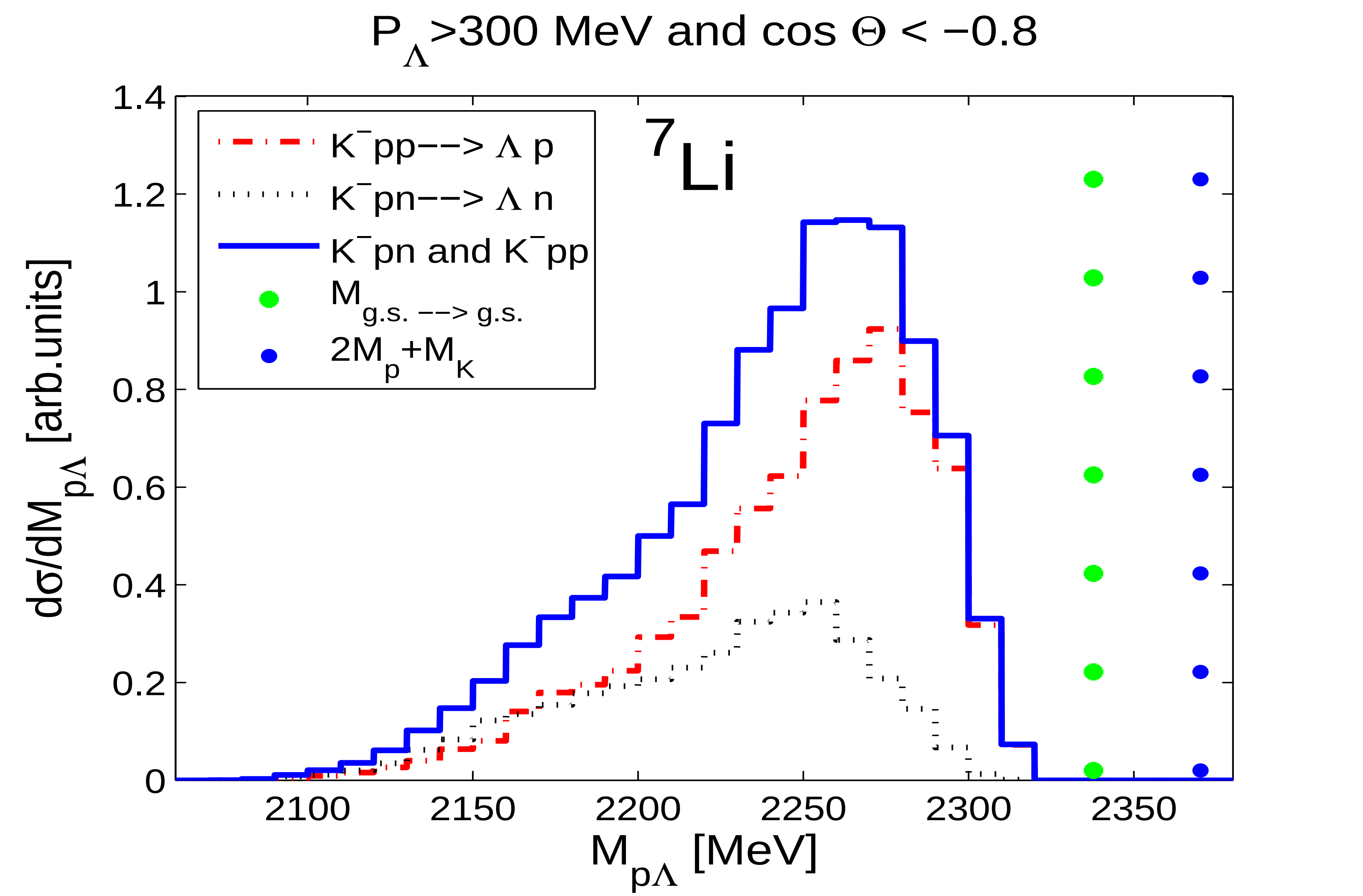
^{12}C Results imposing the experimental angle cut for back to back events, $\cos\Theta_{\vec{p}_\Lambda \vec{p}_p} < -0.8$, and up to three collisions.



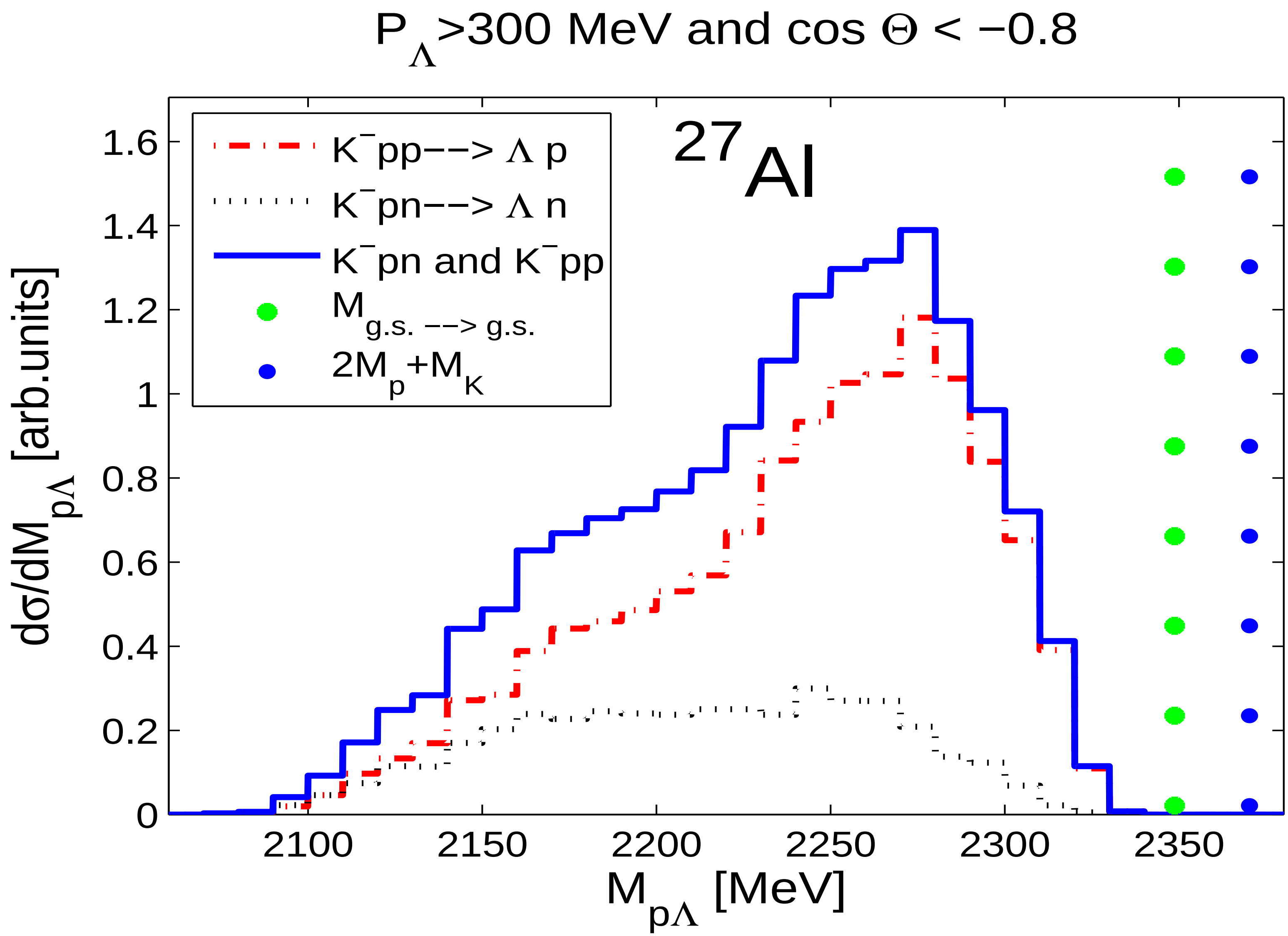
^{12}C Results imposing the experimental angle cut for back to back events, $\cos\Theta_{\vec{p}_\Lambda \vec{p}_p} < -0.8$, and up to three collisions. 3d orbit.



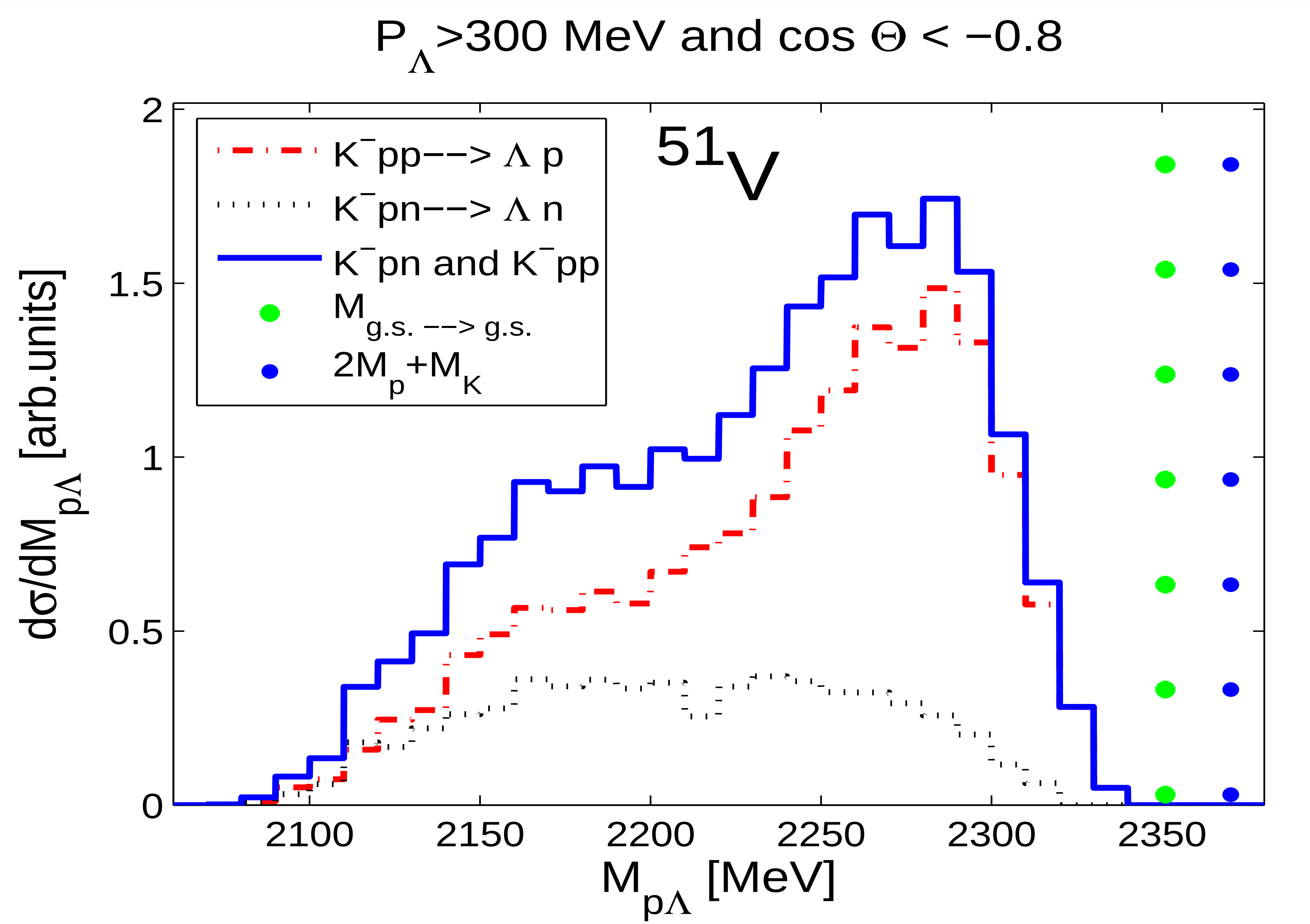
^6Li. K^- absorption from 2p orbit.



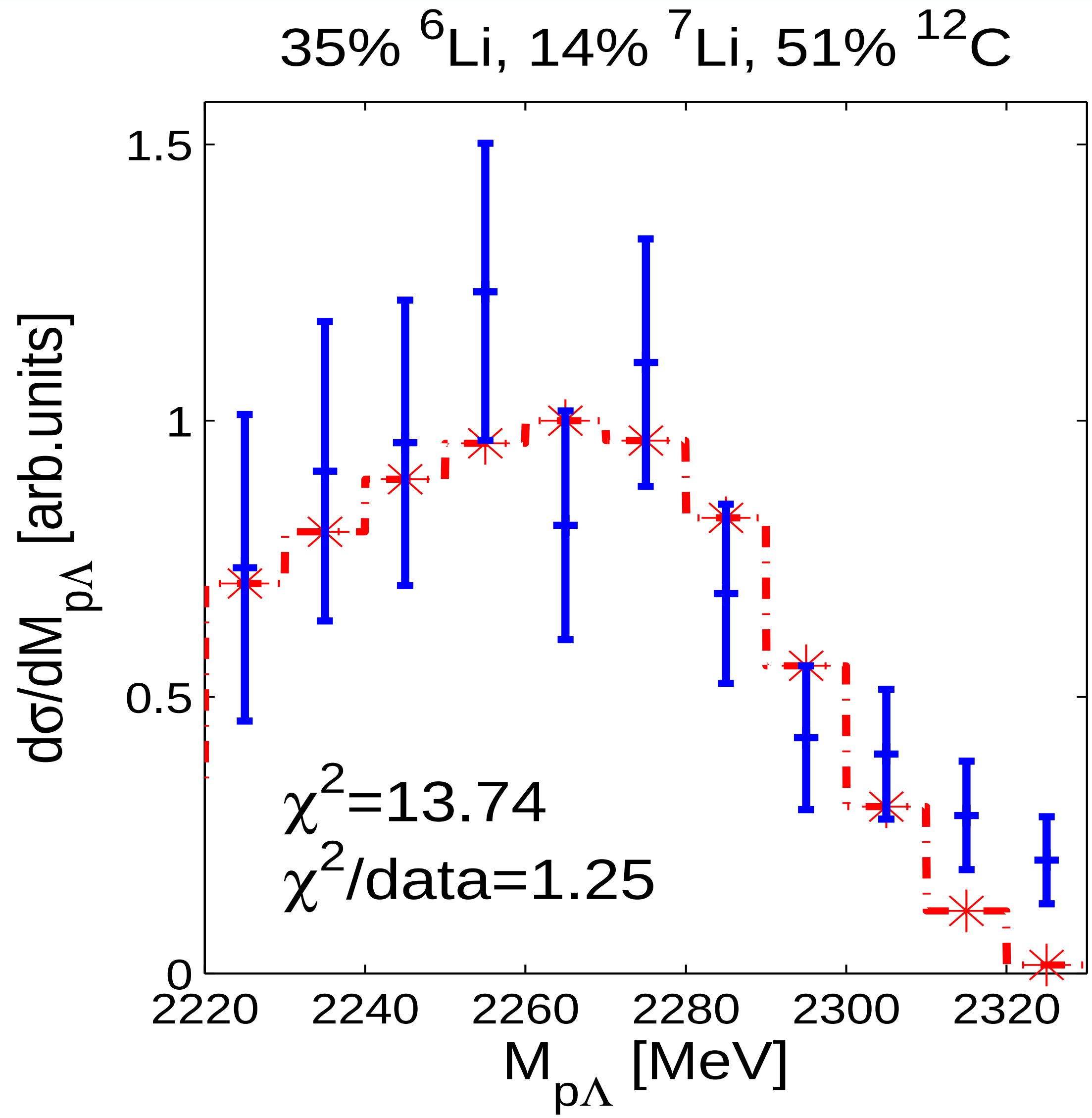
^7Li. K^- absorption from 2p orbit.



^{27}Al. K^- absorption from 3p orbit.



^{51}V. K^- absorption from 4f orbit.



Results using the same mixture of nuclei as in the FINUDA experiment.

Other channels studied

- $K^- pp \to \Sigma^+ n$, $\to \Sigma^0 p$
  followed by, $\Sigma^+ n \to \Lambda p$, $\Sigma^0 p \to \Lambda p$
  this peaks around the third experimental peak and has smaller strength than $K^- pp \to \Lambda p$
- $K^- pp \to \Sigma^0 p$
  $$\Sigma^0 \to \Lambda \gamma \; , \quad \sqrt{s} = 2240 - 2300 MeV$$
  hence, (Λp) invariant mass in QES peak and all events back to back
  strength smaller, $\sim 10 - 30 \;\; percent$ of $K^- pp \to \Lambda p$ events.
- If one releases the back to back condition then the one body absorption mechanism is very large. One can have
  $K^- N \to \Lambda \pi$ followed by π absorption, or
  $K^- N \to \Sigma \pi$ followed by $\Sigma N \to \Lambda N$

  All these events produce large strength at lower Λp invariant masses and highly uncorrelated in angles.

Conclusions

- The K^- optical potential on which predictions of narrow deeply bound K^- states was done is overly exagerated and incomplete in the decay channels.
- The KEK and FINUDA experiment do not have any support for the interpretation of the data as bound kaons except the " theoretical predictions" of the mentioned work.
- We have shown that all the peaks can be interpreted in terms of K^- absorption on pairs of nucleons,
  in KEK with remnant nucleus as spectator
  in FINUDA, first peak with remnant nucleus as spectator
  second peak with nuclear excitation to the continuum
- These mechanisms passed all tests for which there were available data.

Borasoy

Niessler

Weise

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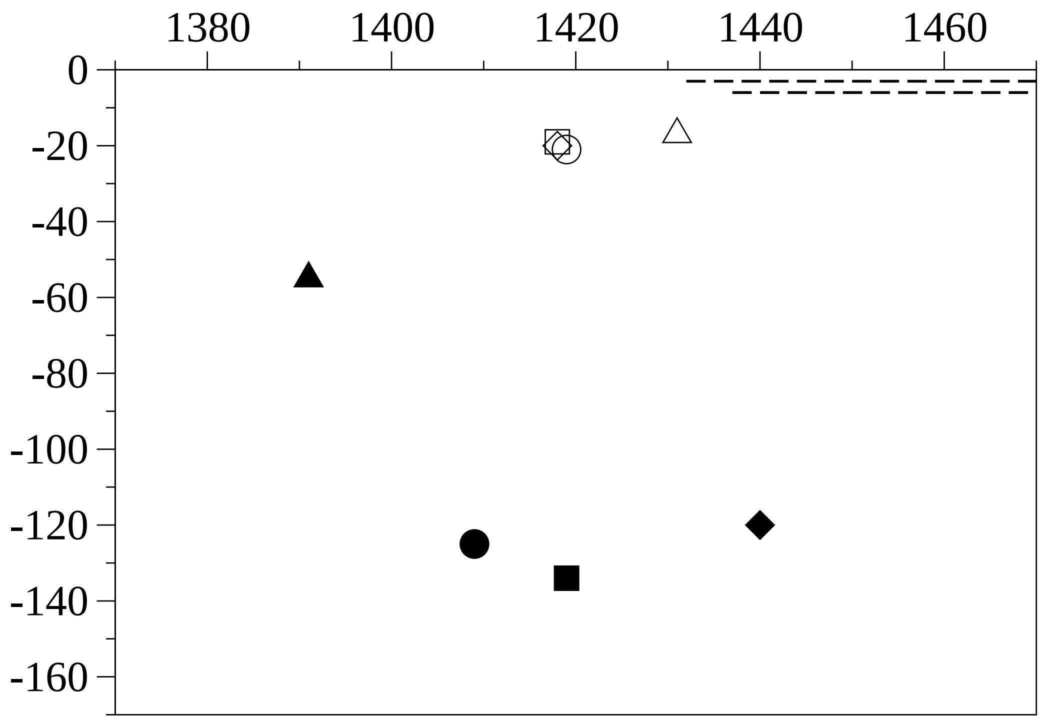

Pole positions of the T matrix in the complex W plane. The triangles, diamonds, squares and circles correspond to the "WT", "c", "s" and "u" approach, respectively. The dashed lines represent the $K^- p$ and $\bar{K}^0 n$ cuts, respectively. Right: Pole positions of the T matrix in the complex W plane. The circles, triangles and squares correspond to the fi ts "1", "2" and "3", respectively.

Summary of DHD06 Workshop, Kyoto Feb 2006

- Akaishi strikes back, confusion of cut off in field theory and range of interaction. No selfconsistency yet, still $10\rho_0$ density.
- Yamazaki strikes back, makes wrong assumption on final state in $K^{-}\ {}^4He$ absorption going to $p\Sigma\ nn$ instead of $p\Sigma\ d$ (small recoil energy of d, 10 MeV for 200 MeV/c of Fermi motion). Misses the experimental fact of the narrow signal in FINUDA for K^- absorption without extra final state interaction. Disguised offer of compromise, peaks partly from K^- absorption and partly from production of tribaryon. Compromise rejected: too much coincidence that the peaks appear in all nuclei at the K^- absorption kinematics.
- No help from any body else of the japanese community.
- No claims in the experimental talks about deeply bound kaon atoms. Back to tribaryon claim.
- Iwasaki pledge "please understand all this is still preliminary, we are working to understand what happens"
- The paper of 2003 with claims for deeply bound K from the $K^-(at\ rest)$ absorption in ${}^4He$, (K^-, n) has been withdrawn.

Summary of DHD06 Workshop, Kyoto Feb 2006

- Y. Yamagata presents calculations of (K^-, p) in flight and concludes that even if there are deeply bound kaon states the signal would be too weak to be seen in present experiments.
- S. Okada (Hayano exp.) presents results for $3d \longrightarrow 2p$ X-rays of Kaonic Helium. 2p shift: Old experiments 40 eV, chiral unitary model 0.2 eV, Akaishi potential 11 eV. New experiment compatible with zero with 3-4 eV precision.