A critical view on the deeply bound K^-pp system

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The FINUDA experiment

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

$$K^- \quad {}^{A}Z_{g.s.} \quad \rightarrow \quad (\Lambda p) \quad {}^{A-2}(Z-2)$$

Nuclei: ${}^{6}\mathrm{Li},\ {}^{7}\mathrm{Li},\ {}^{12}\mathrm{C},\ {}^{27}\mathrm{Al},\ {}^{51}\mathrm{V}$

- The invariant mass of the Λp pair is measured, $M_{\Lambda p}$.
- The same elementary reaction as in KEK: $K^- p\, p \rightarrow \Lambda\, p$
  ($p_\Lambda > 300$ MeV/c to eliminate $K^- N \rightarrow \Lambda\, \pi$)
- A peak for the transition to the g.s. of the daugther nucleus should be observed at: $M_{\Lambda p} = m_K + M(A,Z) - M(A-2, Z-2)$

$$\begin{array}{lll} {}^{6}\mathrm{Li} & \rightarrow & 2340\ \mathrm{MeV} \\ {}^{7}\mathrm{Li} & \rightarrow & 2338\ \mathrm{MeV} \\ {}^{12}\mathrm{C} & \rightarrow & 2345\ \mathrm{MeV} \end{array} \qquad \begin{array}{lll} {}^{27}\mathrm{Al} & \rightarrow & 2349\ \mathrm{MeV} \\ {}^{51}\mathrm{V} & \rightarrow & 2351\ \mathrm{MeV} \end{array}$$

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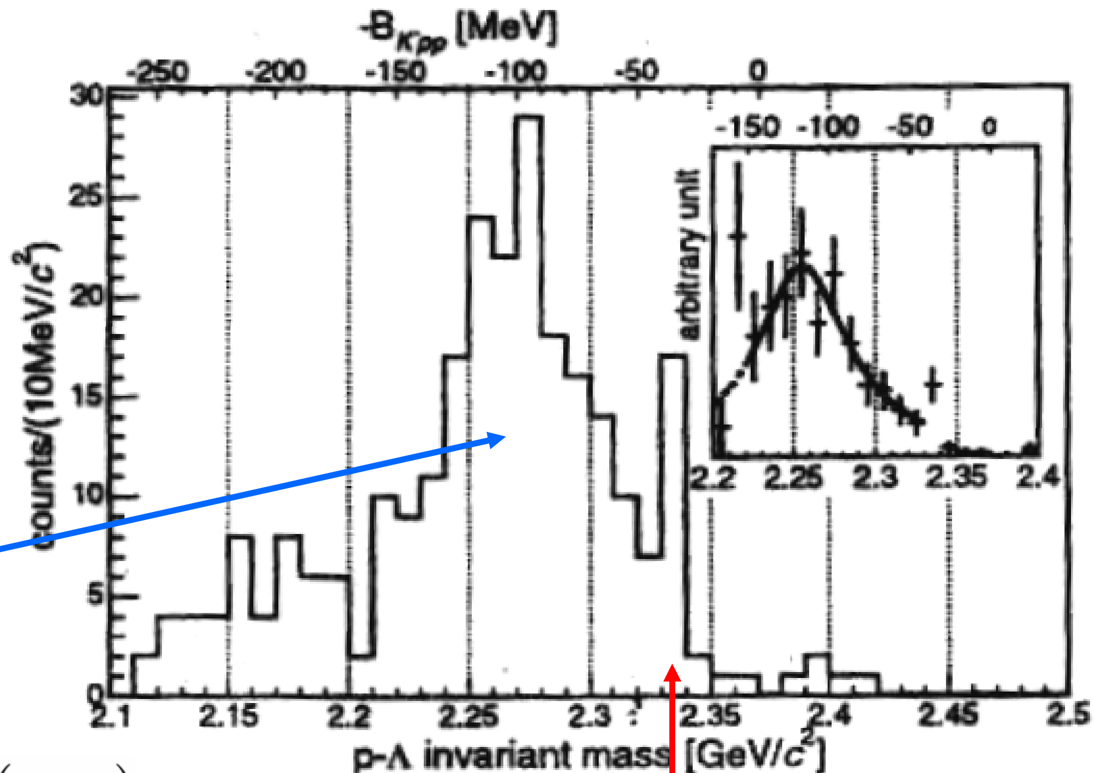

Interpreted by the FINUDA experiment as a (K⁻pp) bound state

$$B_{K^-pp} = 115^{+6}_{-5}(\mathrm{stat})^{+3}_{-4}(\mathrm{syst})$$

Transition to the g.s. of daughter nucleus

We will give an alternative explanation in terms of more conventional physics → FSI interaction of the primary Λ and p (produced after K- absorption) as they cross the daughter nucleus!

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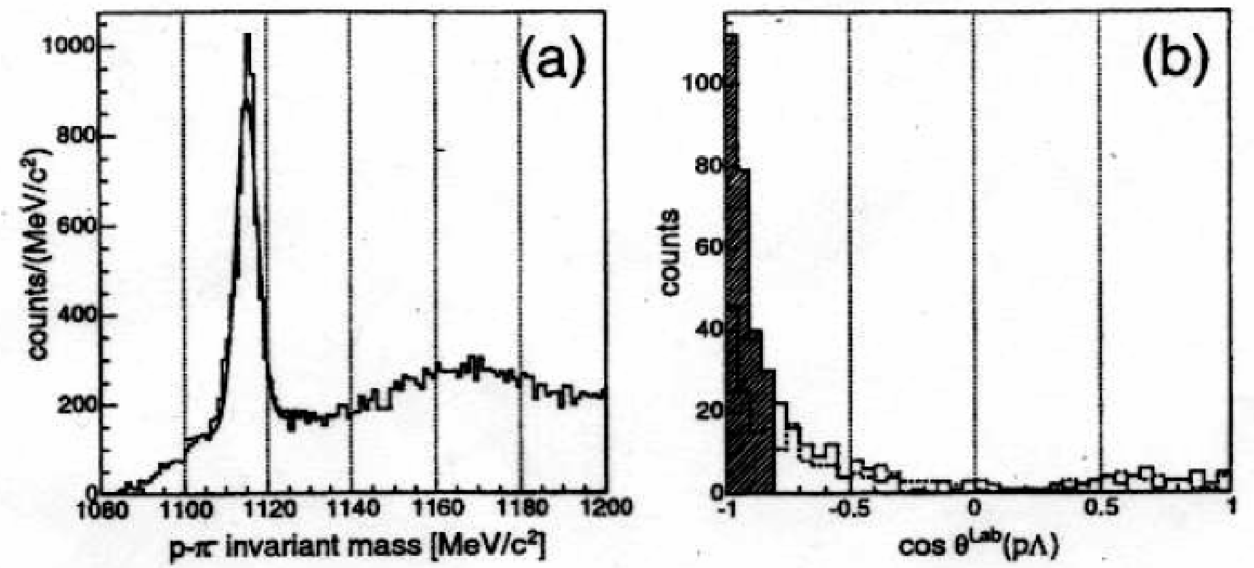


) Invariant-mass distribution of a proton and a π^- for all the events in which these two particles are observ
ssian together with a linear background in the invariant-mass range of 1100–1130 MeV/c^2. (b) Opening ang
Λ and a proton: solid line, ^{6}Li, ^{7}Li, and ^{12}C; dashed line, ^{27}Al and ^{51}V.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

Our calculation

Monte Carlo simulation of K^- absorption by pp and pn pairs in nuclei

$$K^- pp \to \Lambda p \qquad K^- pn \to \Lambda n$$

- The K^- is absorbed mainly from the lowest atomic orbit for which the energy shift has been measured
- The K^- is absorbed by two nucleons with momenta randomly chosen within the local Fermi sea: $|\vec{p}_1|, |\vec{p}_2| < k_F(r)$
- Primary Λ and N emitted according to phase space: $\vec{p}_\Lambda, \vec{p}_N$
- Further collisions of Λ and N as they cross the nucleus according to a probability per unit length $\sigma\rho$ with $\sigma_\Lambda \sim 2\sigma_N/3$
- Finally, the invariant Λp mass is reconstructed from the final events

S. Hirenzaki, Y. Okumura, H. Toki, E. Oset and A. Ramos, Phys. Rev. C61, 055205 (2000)

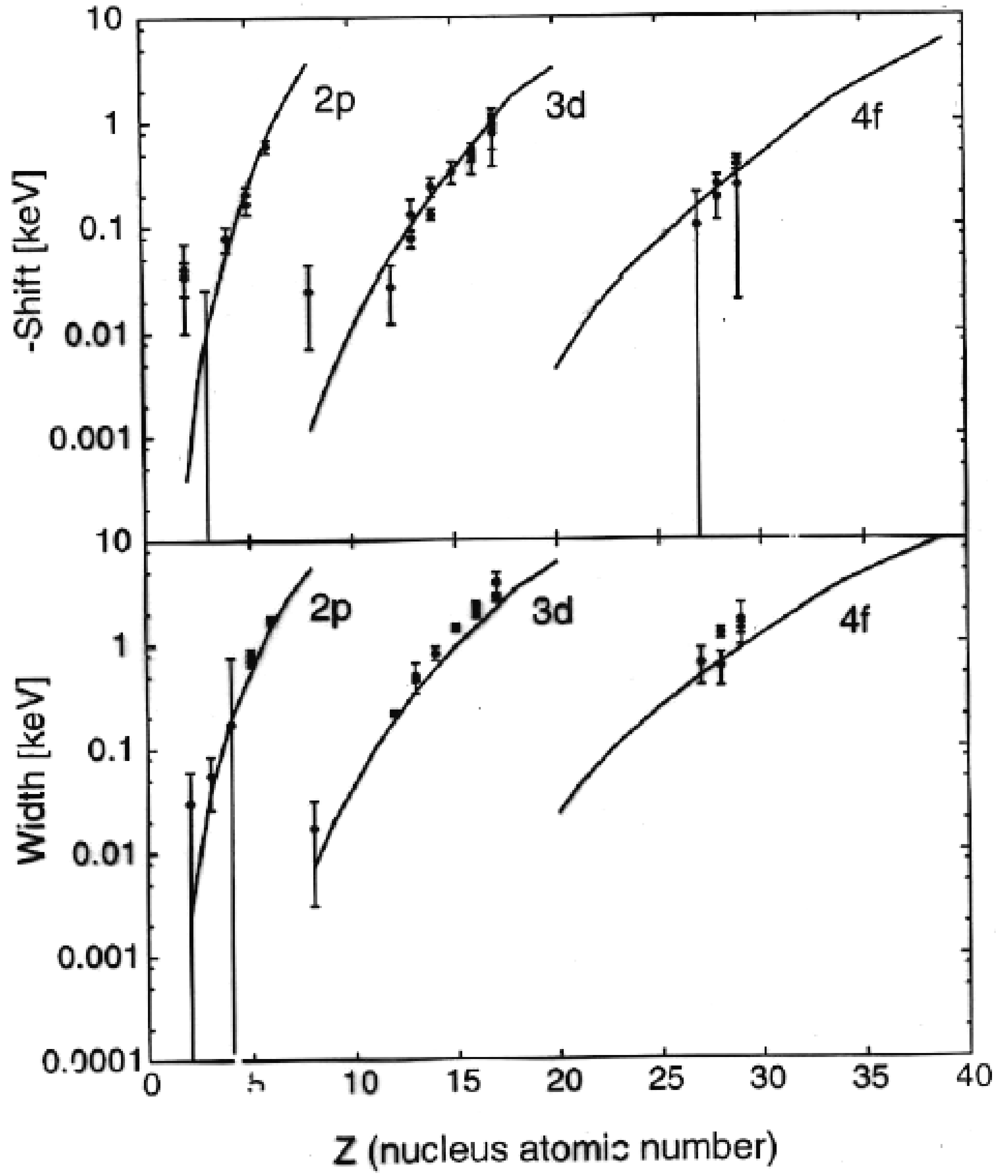
$^{6}_{3}\mathrm{Li} \rightarrow 2p$

$^{7}_{3}\mathrm{Li} \rightarrow 2p$

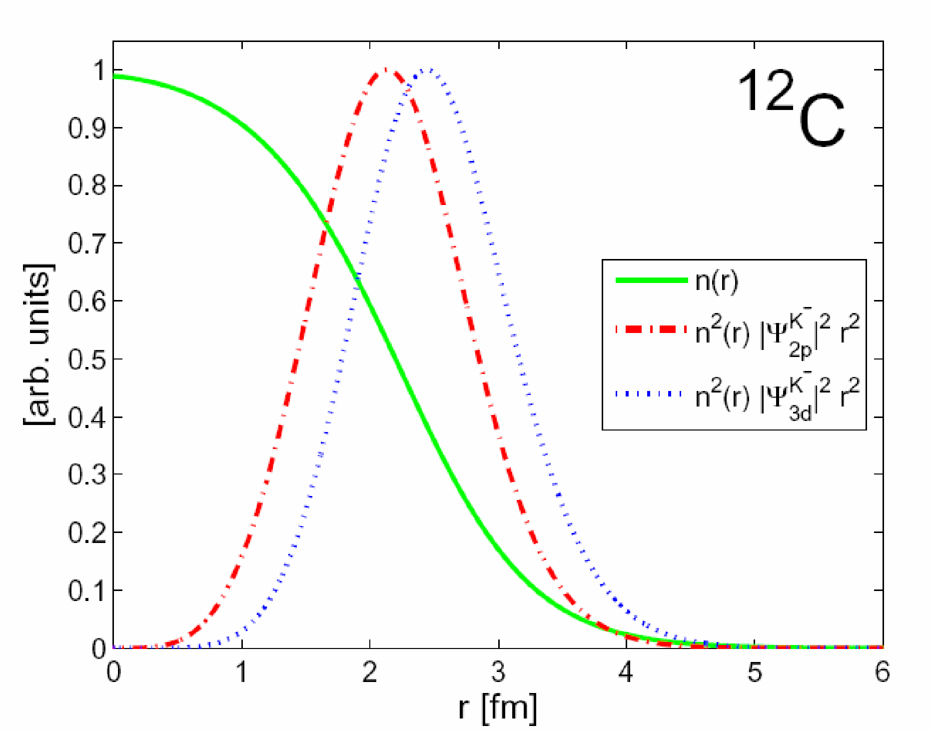
$^{12}_{6}\mathrm{C} \rightarrow 2p$

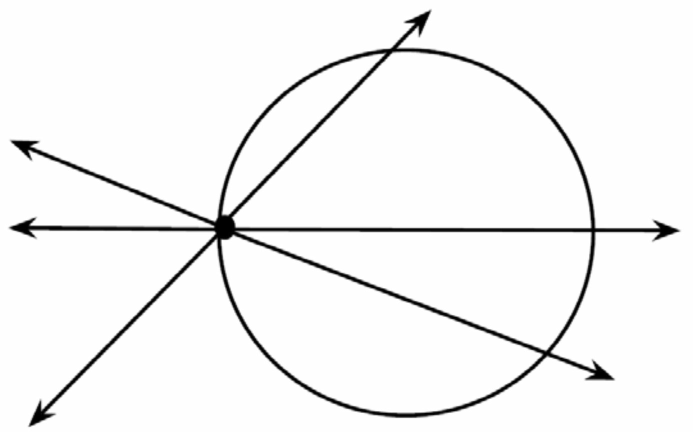
$^{27}_{13}\mathrm{Al} \rightarrow 3d$

$^{51}_{23}\mathrm{V} \rightarrow 4f$



Nuclear density profile and overlap $r^2|\Psi^{nl}_{K^-}(r)|^2\rho^2(r)$





First (narrow) peak: formation of the g.s. of the daughter nucleus

$$K^- \quad {}^{A}Z_{g.s.} \quad \rightarrow \quad (\Lambda p) \quad {}^{A-2}(Z-2)_{g.s.}$$

$$M_{\Lambda p} \sim 2340 - 2345 \text{ MeV}$$ for the light nuclei

How much strength?

Formation probability (FP) x Survival probability (P_S)

$$|\langle {}^{A-2}(Z-2)_{g.s.} \,|\, (pp)^{-1} \; {}^{A}Z_{g.s.} \rangle|^2 \qquad P = e^{-\int \sigma \rho \, dl}$$

In light nuclei: FP ~ | 0.3 - 0.7 |^2 = 0.1 – 0.5, P_S ~ 0.6 → 10 - 30%
(ex: ^{7}Li $(pp)^{-1}$ → ^{5}H)

In heavier nuclei: FP increases but P_S decreases → also below 30%

→The largest part of the K- absorption events go into nuclear excitations, mostly to the continuum.

Where is this strength located? Obviously at smaller invariant Λp masses

Second (wider) peak: Quasi-elastic peak (QEP) after K^- absorption

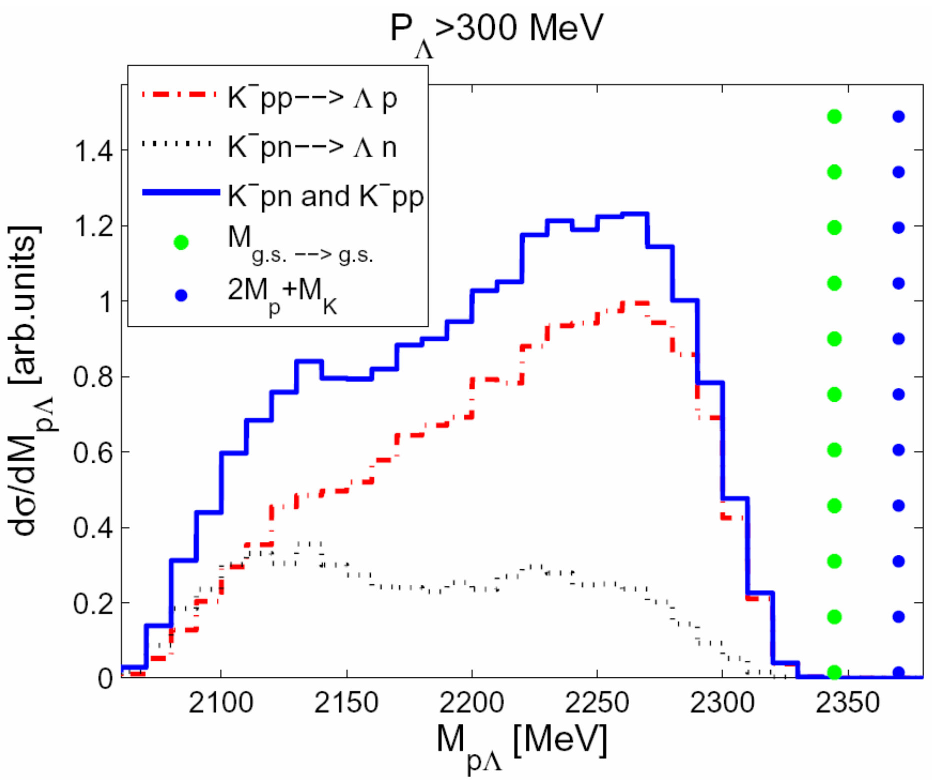
A peak is generated in our Monte Carlo simulations when the primary Λ and p (produced after K^- absorption) undergo quasi-elastic collisions with the nucleus, exciting it to the continuum.

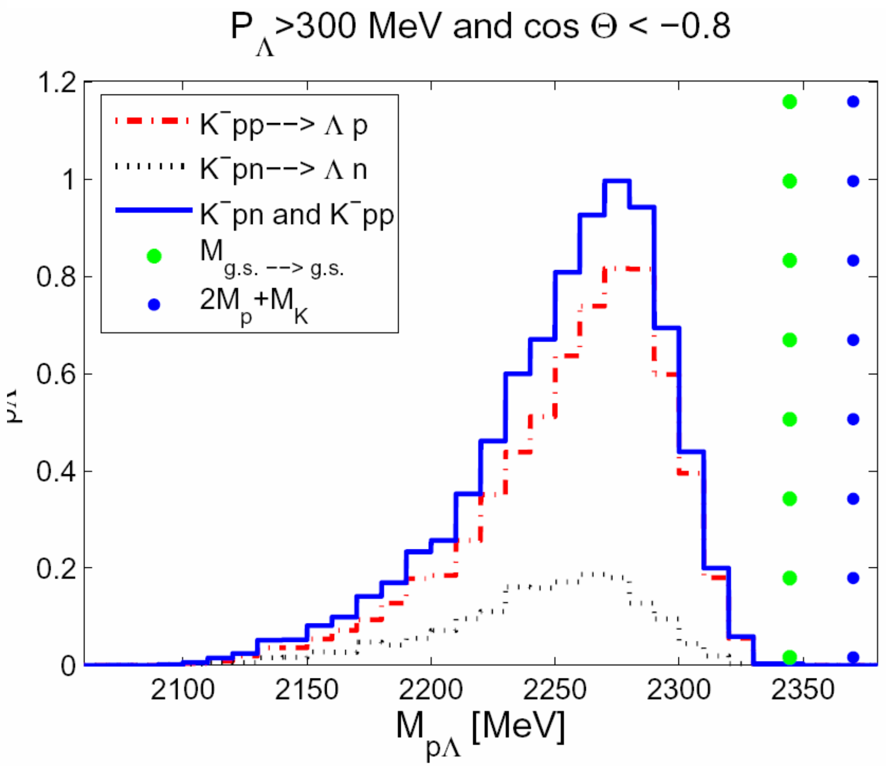
This is the analogue of the quasi-elastic peak (QEP) observed in nuclear inclusive reactions using a variety of different probes: (e,e'), (p,p'), (π,π'),… (The QEP comes mostly from one collision of the particles exciting the nucleus to the continuum).

→ The QEP accounts for the second peak of the FINUDA experiment!

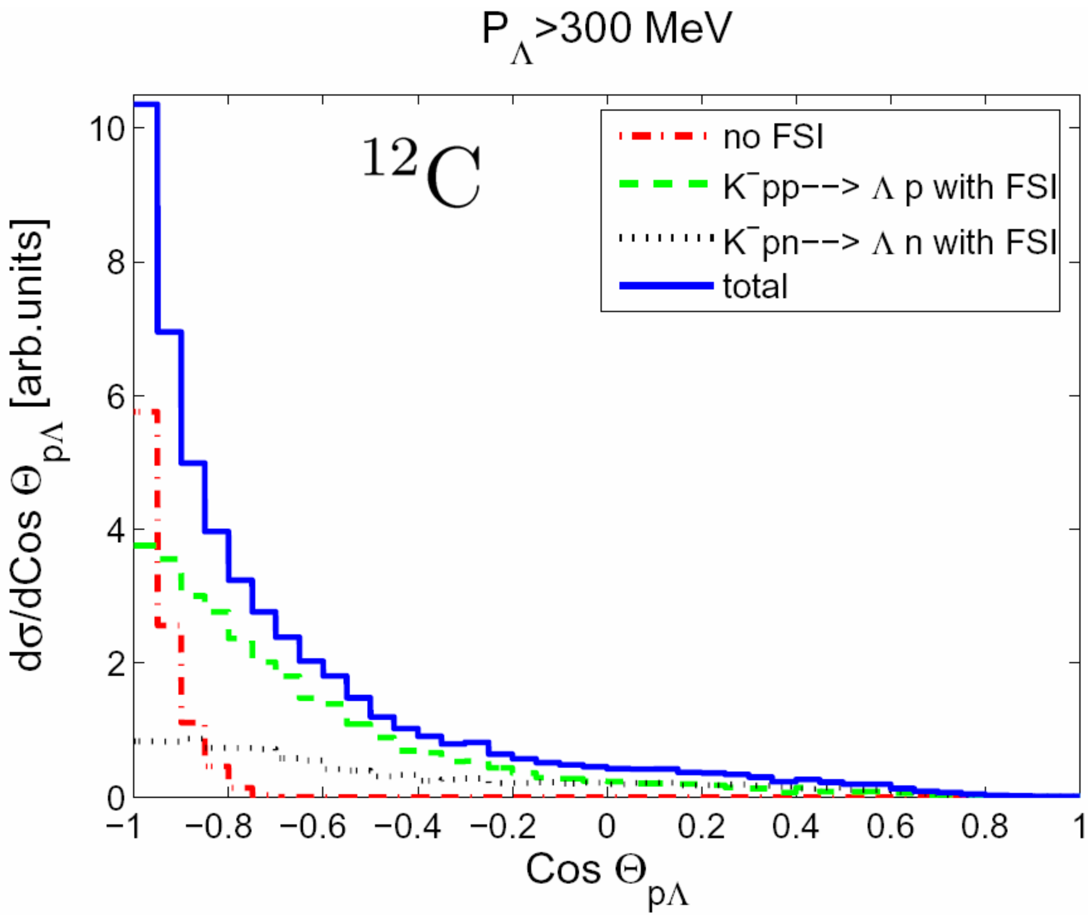
Invariant mass distribution (one-collision)

$^{12}\mathrm{C}$

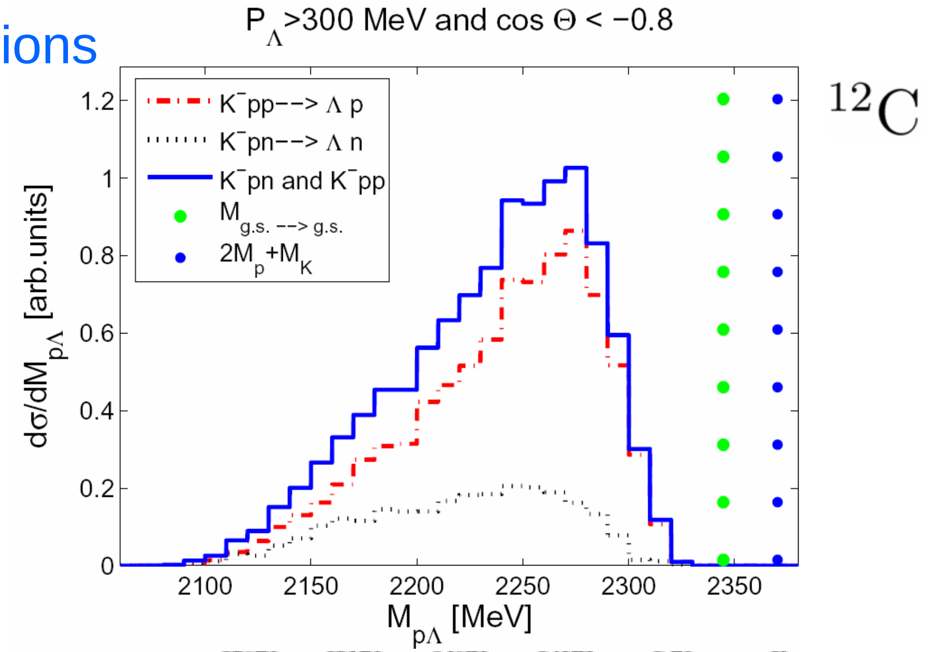


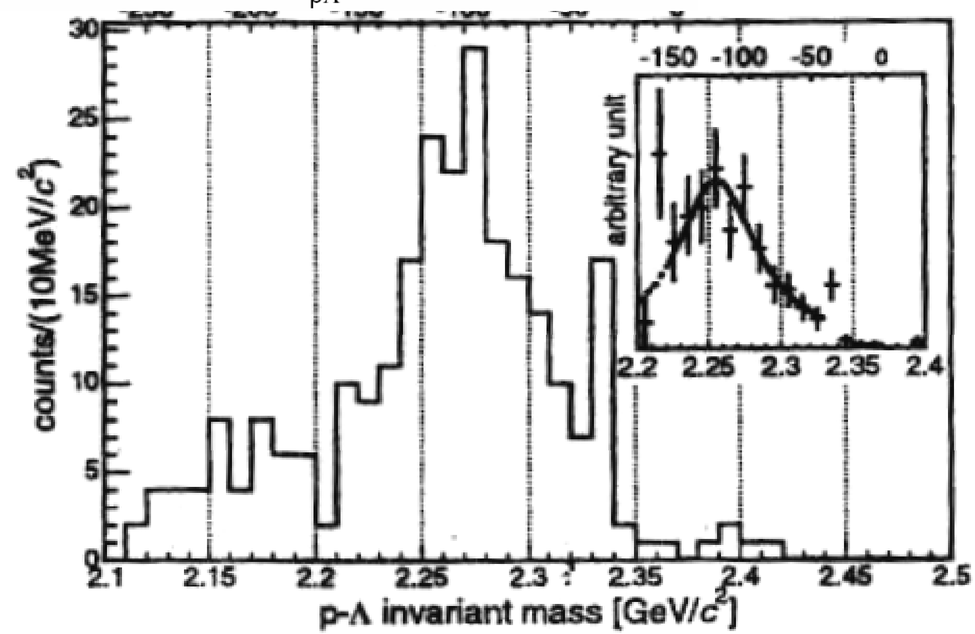


Angular correlations

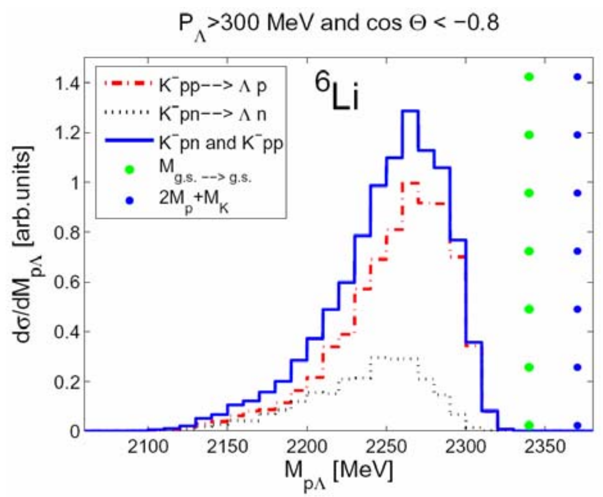


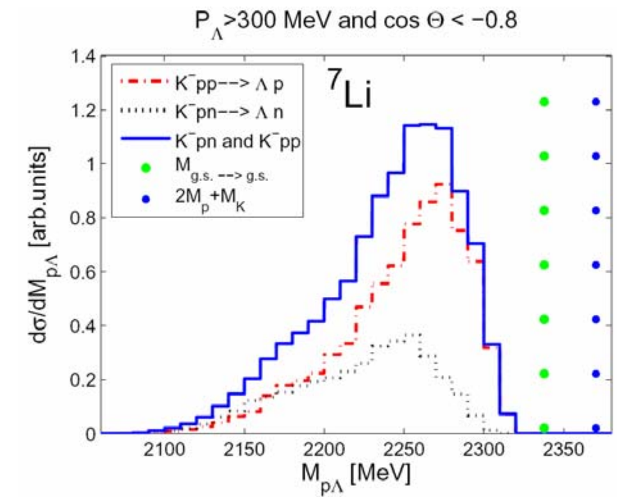
Allowing up to three collisions

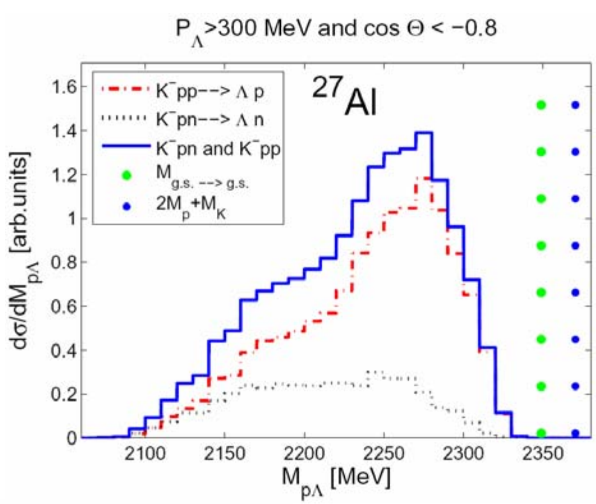


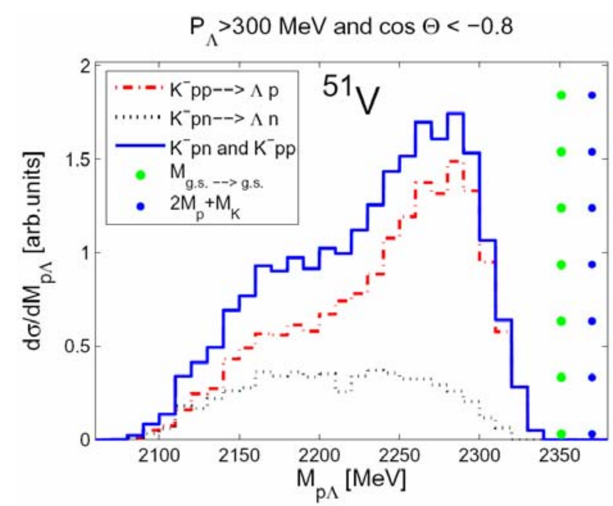


Other nuclei









Other channels

A) $K^- pp \to \Sigma^+ n,\ \Sigma^0 p$

followed by $\Sigma^+ (n)_{\rm sea} \to \Lambda p,\ \Sigma^0 (p)_{\rm sea} \to \Lambda p$

This peaks around 2170 MeV (where there is indeed a small third peak in the experiment) and has a smaller strength than $K^- pp \to \Lambda p$

B) $K^- pp \to \Sigma^0 p$

followed by $\Sigma^0 \to \Lambda \gamma,\qquad \sqrt{s} = 2240 - 2300 \ {\rm MeV}$

→ located in the region of the QEP and all events back-to-back, but strength is small, ~ 10-30% of $K^- pp \to \Lambda p$ events

Conclusion

We have shown that the Λp invariant mass distribution of the FINUDA experiment is naturally explained in terms of the $K^- pN \longrightarrow \Lambda N$ reaction followed by further interaction of the Λ or the N in the daughter nucleus, without the need of invoking exotic mechanisms like the formation of a K^-pp bound state.

V. K. Magas, E. Oset, A. Ramos and H. Toki, nucl-th/0601013