Strange tribaryons studied in the $^{4}He(K^{-}_{stopped}, \Lambda N)$ reaction

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2. Experiment
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4. ΛN +n semi-exclusive analysis
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Introduction -*Do deeply bound kaonic nuclear states with narrow widths exist ?*

-> No, they don't! They must be shallow and broad

-> Yes, they do.

Prediction 1 : T. Kishimoto (PRL **83** 4701 (1999))

BNL-AGS E930 (T. Kishimoto *et. al.,* 2001) with ^{16}O(in-flight K^-,n)

-> *narrow bound state(s)?* (NPA **754** 383c (2005))

KEK-PS E548 (T. Kishimoto *et. al.,* 2005) with ^{16}O/^{12}C (in-flight K^-,N)

-> *no narrow sates ! but deep potential* (PTP **118** 181 (2007), NPA **827** 321c (2009))

Prediction 2 : Y. Akaishi and T. Yamazaki (PRC **65** 044005 (2002), PLB **535** 70 (2002))

KEK-PS E471 (M. Iwasaki *et. al.*, 2002/2003) with ^{4}He(stopped K^-,N)

-> *observation of "strange tribaryons"* (nucl-ex/0310018,PLB **597** 263 (2004))

FINUDA (T. Bressani *et. al.*, 2003/2004/2006) with $^{6/7}$Li/ ^{12}C(stopped K^-,Λp/Λd)

-> *evidence for deeply bound ppK^- /ppnK^-state* (PRL **94** 210323 (2005), PLB **654** 80 (2007))

DISTO (Re-analysis by T. Ymazaki *et. al.*) with pp->pΛK^+ at 2.85 GeV

-> *indication of ppK^- bound state* (PRL **104** 132502 (2010))

KEK-PS E549/570 (M. Iwasaki *et. al.*/R. S. Hayano *et. al.*, 2005) with ^{4}He(stopped K^-,N)

-> *no narrow sates !* (PLB **659** 107 (2008) , PLB **688** 43 (2010))

Broad states with ^{4}He(stopped K^-,ΛN) ? -> *This talk*

Original aim of KEK-E549
- *Inclusive spectroscopy*

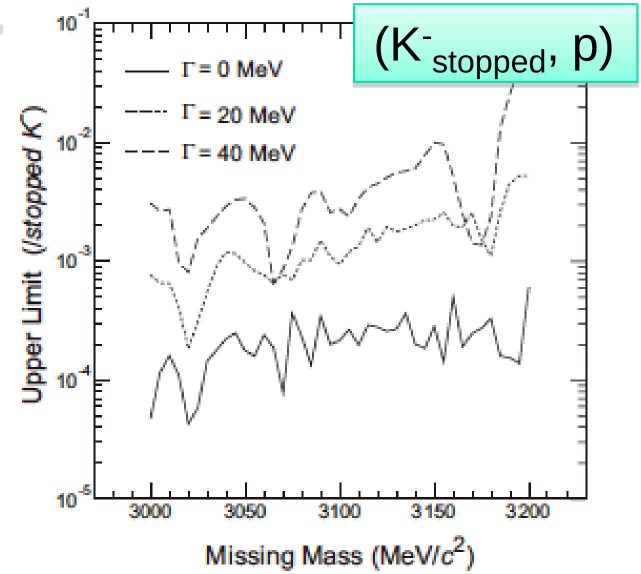
(semi-)Inclusive missing mass spectroscopy

of $(K_{bar}NNN)_{Z=0,T=1}$: S^0 / $(K_{bar}NNN)_{Z=1,T=0,1}$: S^+ via

$K^-_{stopped} + {}^4He$ -> $\boxed{p + S^0_{T=1}}$ ->M. Sato *et. al.*, PLB **659** 107

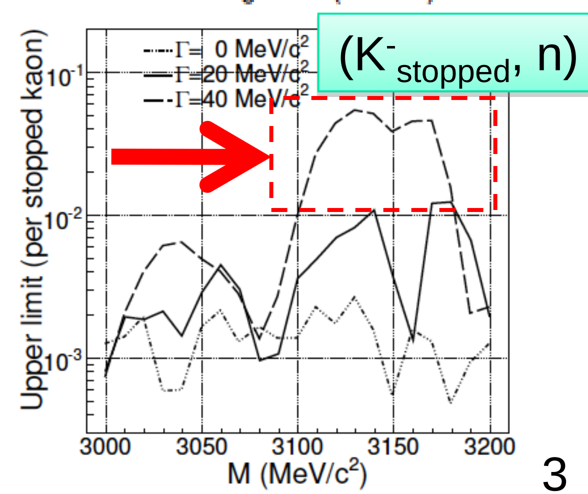
-> $n + S^+_{T=0,1}$
$S^+_{T=0,1}$ -> $Y(\pi)NN$
Y -> πN

->H. Yim *et. al.*, PLB **688** 43



✓ Very strict upper limits for narrow($\Gamma \leq 20$ MeV/c^2) states.

✓ ***Insensitive to broad ($\Gamma \geq 40$ MeV/c^2) states. Large upper limits at ~3140 MeV/c^2 for $\Gamma \geq 40$ MeV/c^2.***



Semi-exclusive studies - from ***non-mesonic final states***

Semi-exclusive missing mass spectroscopy via

$K^-_{stopped} + {}^4He \rightarrow N + {}^3S^{0/+}_{T=0,1}$ ***Y:Λ->arXiv:0711.4943***

${}^3S^{0/+}_{T=0,1} \rightarrow Y(\pi)NN$

Small statistics, but well resolved final states. Dibaryon?

$K^-_{stopped} + {}^4He \rightarrow {}^2S^{0/+}_{T=1/2,3/2} + N + N$

${}^2S^{0/+}_{T=1/2,3/2} \rightarrow YN$

Inclusive measurement for

Y:Λ->PRC **76** 068202 (2007)

$K^-_{stopped} + {}^4He \rightarrow {}^2S^0_{T=1/2} + d$

Semi-exclusive measurement for

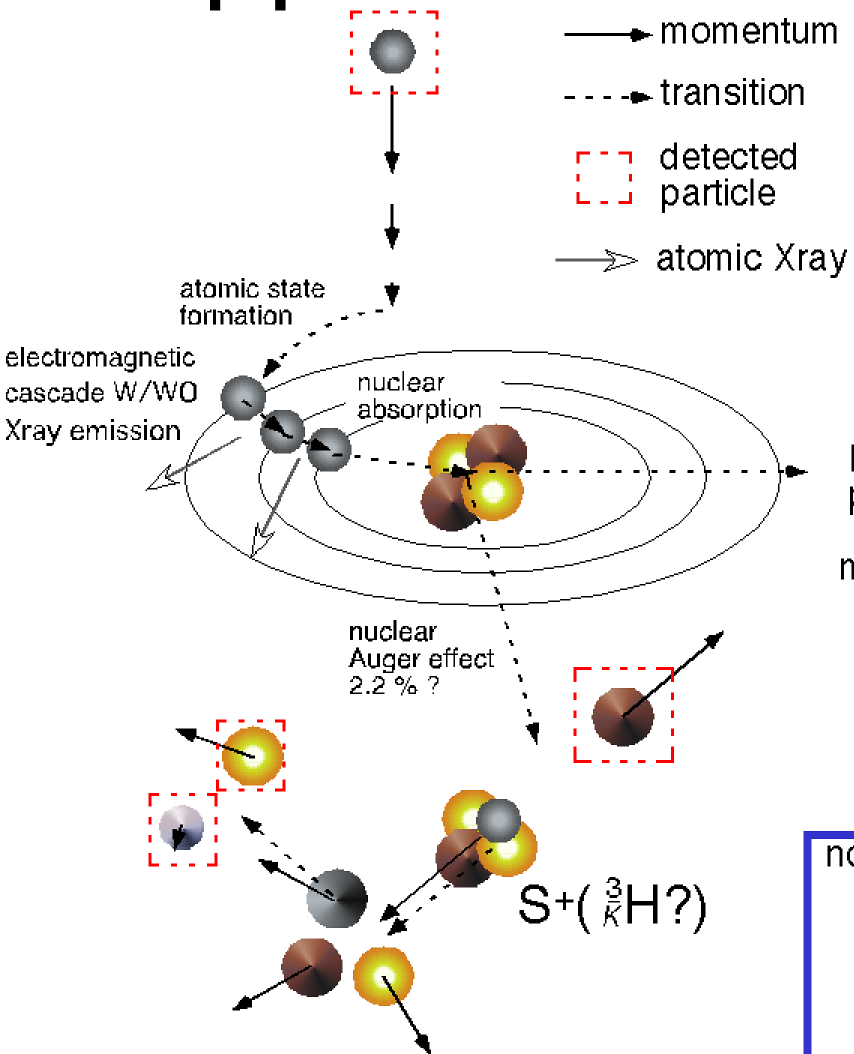
$K^-_{stopped} + {}^4He \rightarrow {}^2S^0_{T=1/2} + d$

${}^2S^0_{T=1/2} \rightarrow Yn$

$\rightarrow {}^3S^+_{T=0,1} + n$

${}^3S^+_{T=0,1} \rightarrow Yd$

Stopped K^- Reaction on ^{4}He



Background processes

mesonic processes ~ 80%

Quasi-free hyperon production ~ 70 %

$K^-N' \to Y\pi$

Λ/Σ hypernuclear formation ~ 3+5? %

$K^-\,{}^4He \to {}^4_{\Lambda/\Sigma}He\,\pi^-$

$\to {}^4_{\Lambda}H\,\pi^0$

non-mesonic processes ~ 17%

Multi(2/3/4)-Nucleon Absorption

$K^-NN' \to YN$ (2NA)

$K^-NNN' \to YNN$ (3NA)

$K^-NNNN' \to YNNN$ (4NA)

Dibaryon production+ its non-mesonic decay?

$K^-\,{}^4He \to XNN$

$X \to YN$

Only total capture rate is known. Dynamical nature is Speculative.

The Goals of this talk

Step 1. Does the Two-Nucleon Absorption Process,

K^- 'NN'(NN) -> YN (NN)

exist on **A>2** nuclei? How is the dynamical property if it exists??

This is closely related to the kaonic nuclear search, as

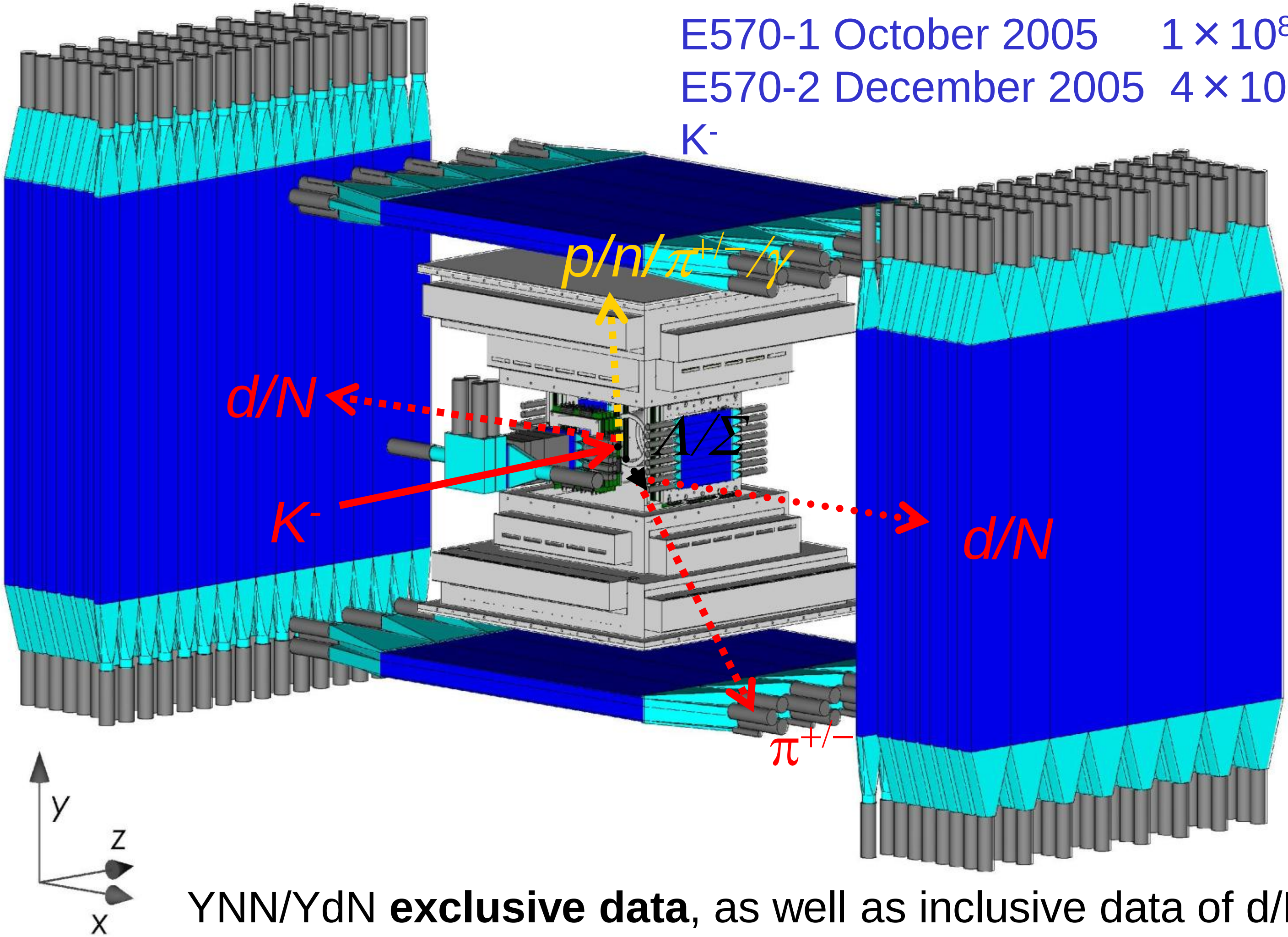
i) it behaves as so far unkown background, and

ii) non-mesonic decay mode of kaonic nucleus, to which experimental searches are mainly performed, is no more than two(or multi)-nucleon absorption at negative energy - ***therefore the decay branching ratio is bound by the spin-isospin property at 0-energy***.

Step 2. *Does the multibaryonic intensity, which is clearly separable from the contribution of multi-nucleon absorption process, exist?*

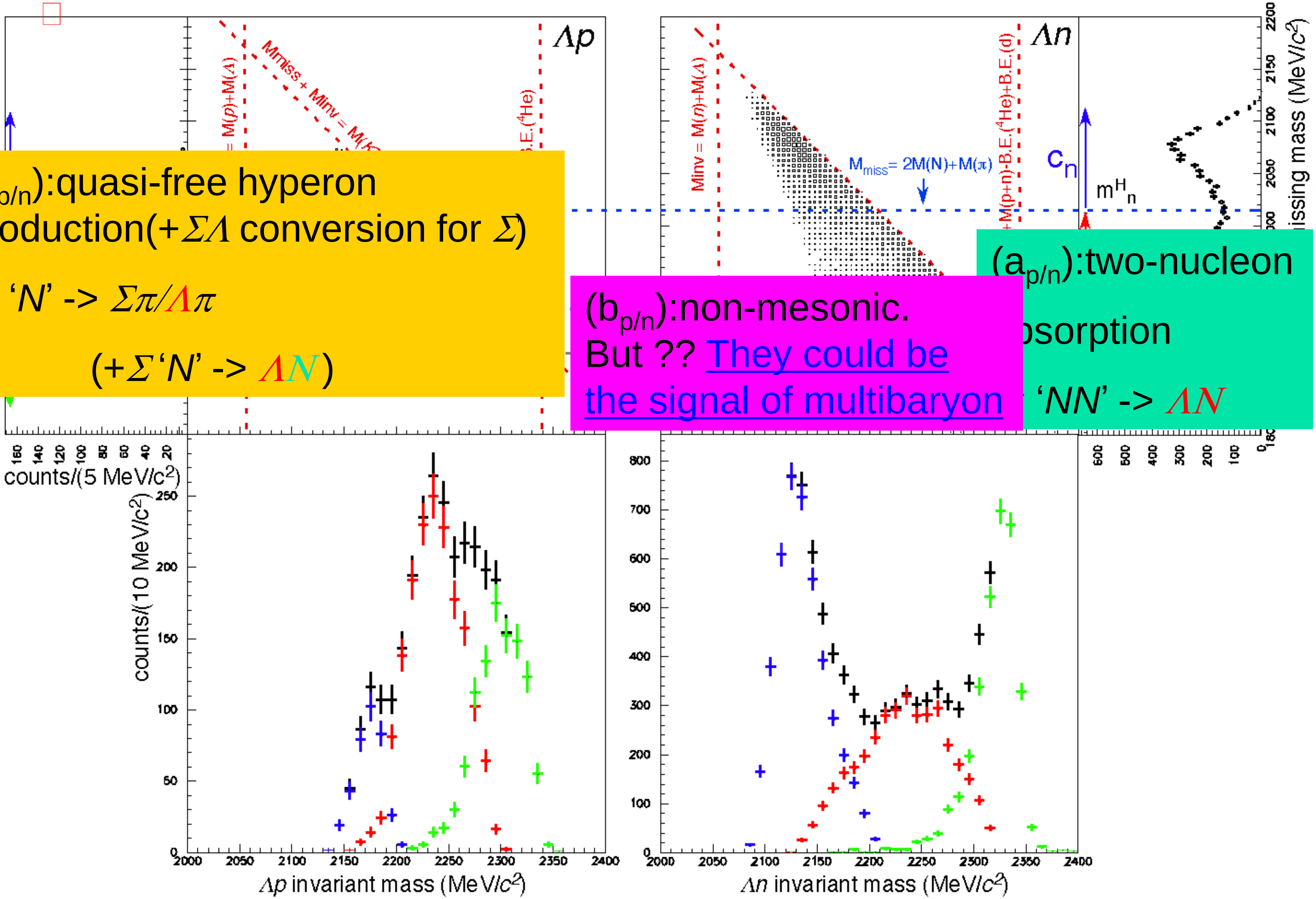
Measurement

E549 June 2005 1×10^8 stopped K^-
E570-1 October 2005 1×10^8 stopped K^-
E570-2 December 2005 4×10^7 stopped K^-



YNN/YdN **exclusive data**, as well as inclusive data of d/N.
Momentum decision by track detection+TOF method for π/p/n
-> ***remarkable momentum resolutions and PID for p/n/d***

ΛN correlations (1)



($c_{p/n}$):quasi-free hyperon production(+$\Sigma\Lambda$ conversion for Σ)

K^- 'N' -> $\Sigma\pi/\Lambda\pi$

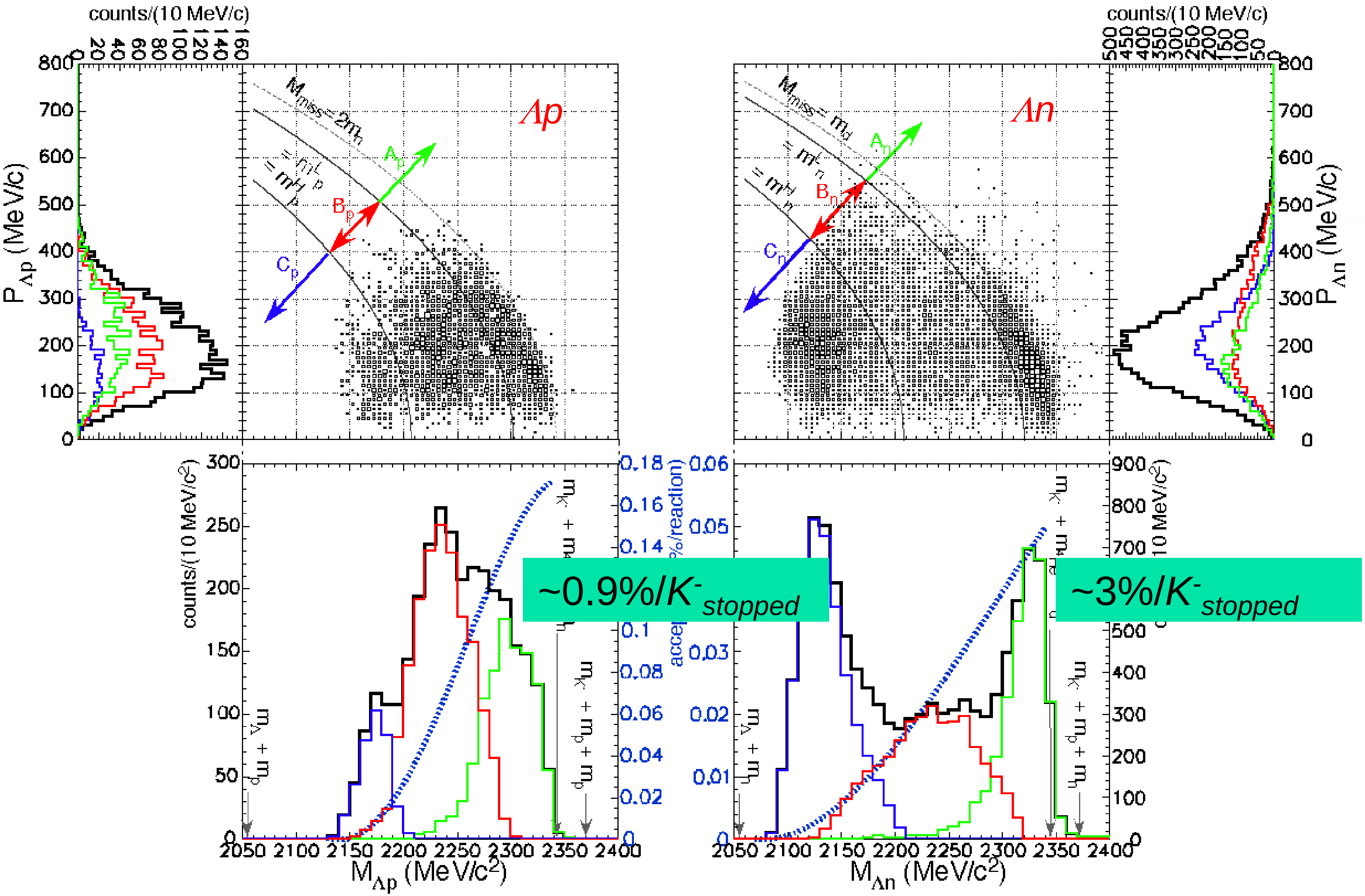
(+Σ'N' -> ΛN)

($b_{p/n}$):non-mesonic. But ?? They could be the signal of multibaryon

($a_{p/n}$):two-nucleon …sorption

… 'NN' -> ΛN

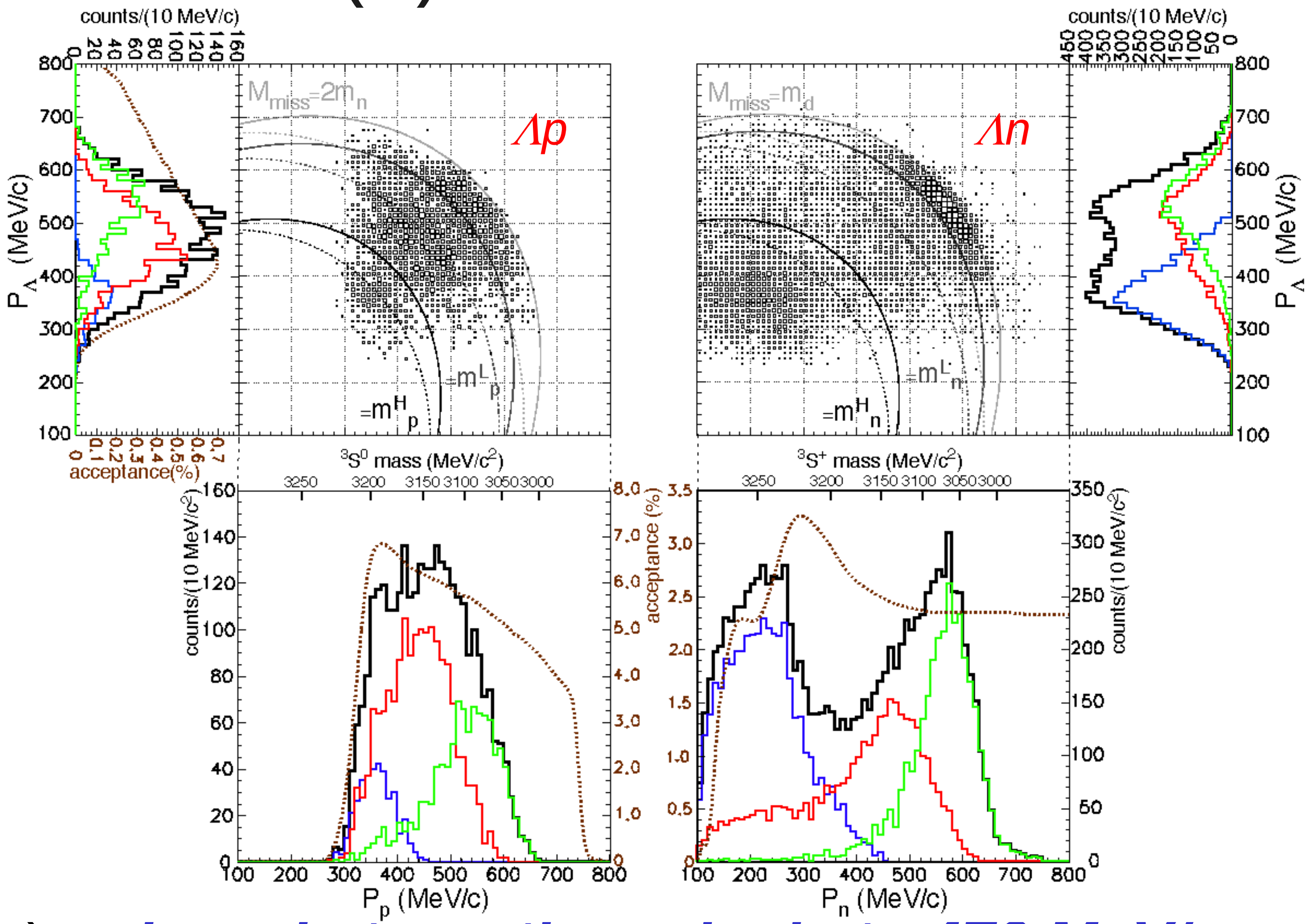
ΛN correlations (2)



1. **'NN'$_{I=0,S=1}$ dominance of** K^- $'NN'_{I,S}$ -> ΛN

2. **More intense contribution of B$_{p/n}$**

ΛN correlations (3)

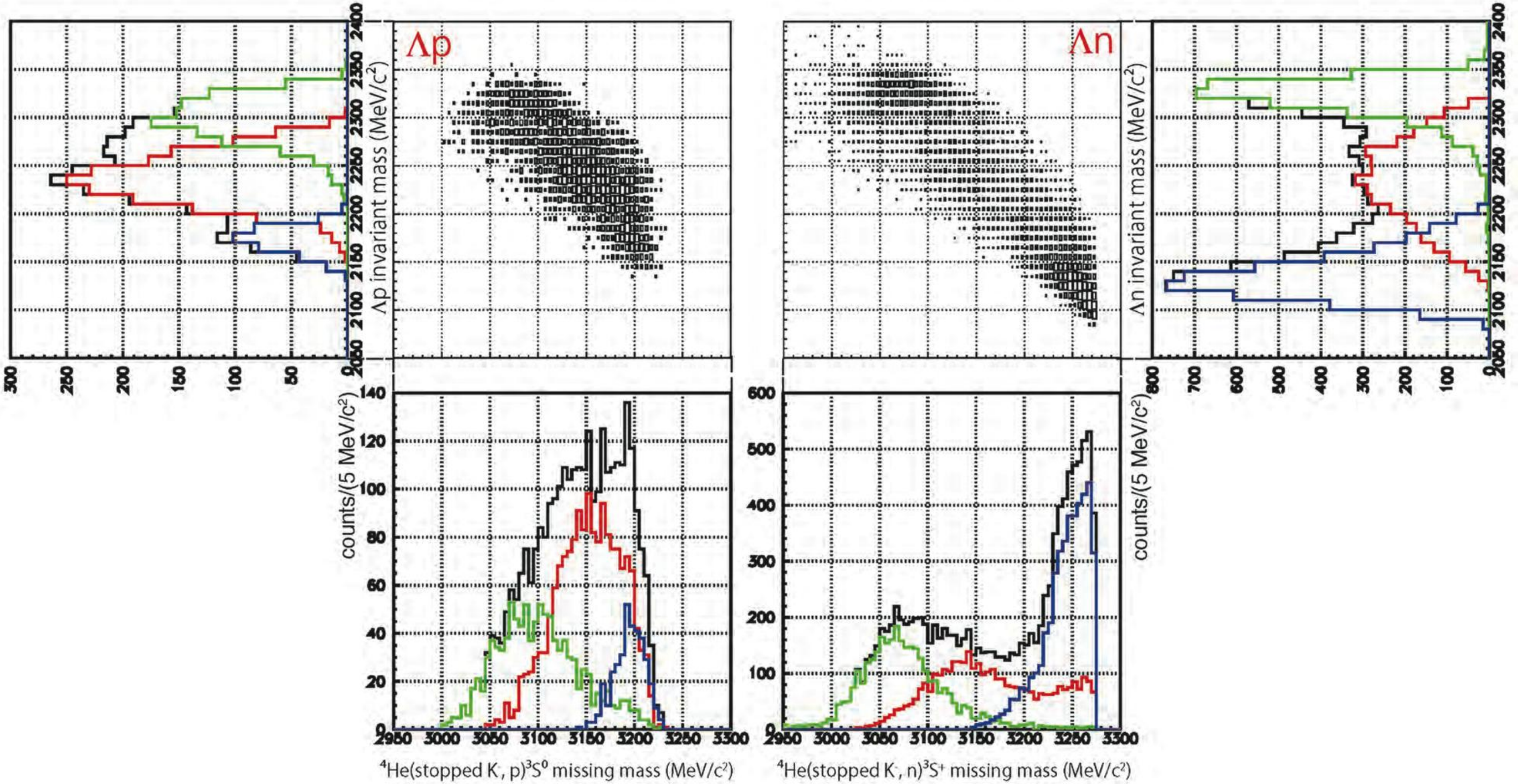


($b_{p/n}$) -> ***broad strength peaked at ~470 MeV/c***.

✓ $K^-NN(NN) \to \Lambda N(NN)$: two-nucleon absorption

followed by ***only one of*** N(N) -> NN or Λ (N) -> ΛN : elastic rescattering is ***unlikely***, to account for Λ and N momentum distributions ***both*** shifted. Λ and N momenta are seen to be ***lower at the same time***.

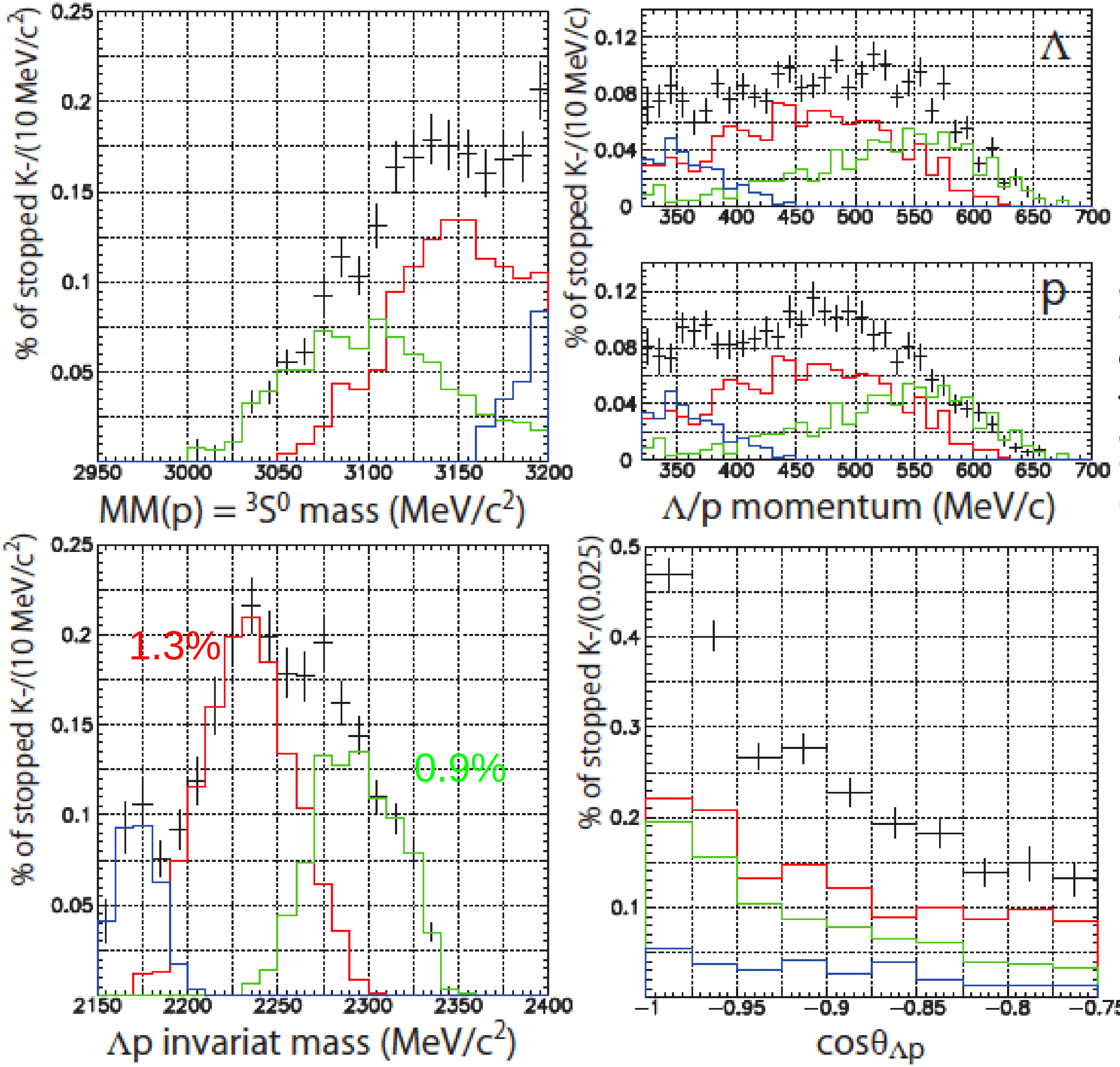
MM(N) VS IM(YN) plots



✔ ***$A_{p/n}$ (Two-Nucleon-Absorption) produces continuum BG as expected at tribaryon mass~3070 MeV/c^2***

B$_{p/n}$ peaks at tribaryon mass~3140 MeV/c^2 (B.E. 170 MeV), dibaryon mass ? -> Σ^0 contribution must be checked.

Normalized Λp spectra



Condition:
p_p> 320 MeV/c
p_Λ> 320 MeV/c
$\cos\theta_{\Lambda p}$<-0.75

Now, spectra are comparable to any theoretical calculation. Note that Σ^0 **contribution is not negligible** (later).

A_p:0.9%/$K^-_{stopped}$
B_p:1.3%/$K^-_{stopped}$

Peak positions do not shift by the acceptance correction.

Corrected Λn appears soon.

Summary of Observed Properties of a_p/a_n :***2-nucleon- absorption (2NA)***

K^- '*pp*' $_{I=1,S=0}$ -> Λp (a_p~0.9%/$K^-_{stopped}$)
K^- '*pn*' $_{I=1,S=0/I=0,S=1}$ -> Λn (a_n ~3%/$K^-_{stopped}$)
both exist on ^{4}He (the ***first observation on 'NN'*** $_{I=1,S=0}$) .

Consequences

1. Significantly small branch on Λp(***I=0,S=1 dominance***).
2. ***only ~30%*** of known $\Lambda(\Sigma^0)$(*pnn*)(11.7 +-2.4)% (PRD **1** 1267 (1970)) final states!
3. K^-d(=$[pn]_{I=0,S=1}$)-> Λn~***0.4***% at E_{Kbar}=0 (PRD **1** 1883 (1970))
and 0.9%/3% ~ 30% reaction rate of $K^-[NN]_{I=1,S=0}$-> ΛN leads
$K^-[pp]_{I=1,S=0}$-> Λp~***0.12***% at E_{Kbar}=0
-> $K^-[pp]_{I=1,S=0}$-> Λp ***is unlikely for any*** $\boldsymbol{E_{kbar}}$ **> YπN** decay threshold

Summary of Observed Properties of b_p/b_n : ***Multi-baryon candidates***

Intense(***~70% of ΛNNN final states***) so far unknown non-mesonic components exist on ***both*** $\Lambda p/\Lambda n$.

- ✓ b_p cannot be explained by the elastic re-scattering effect.
- ✓ b_n could be partly explained by that.

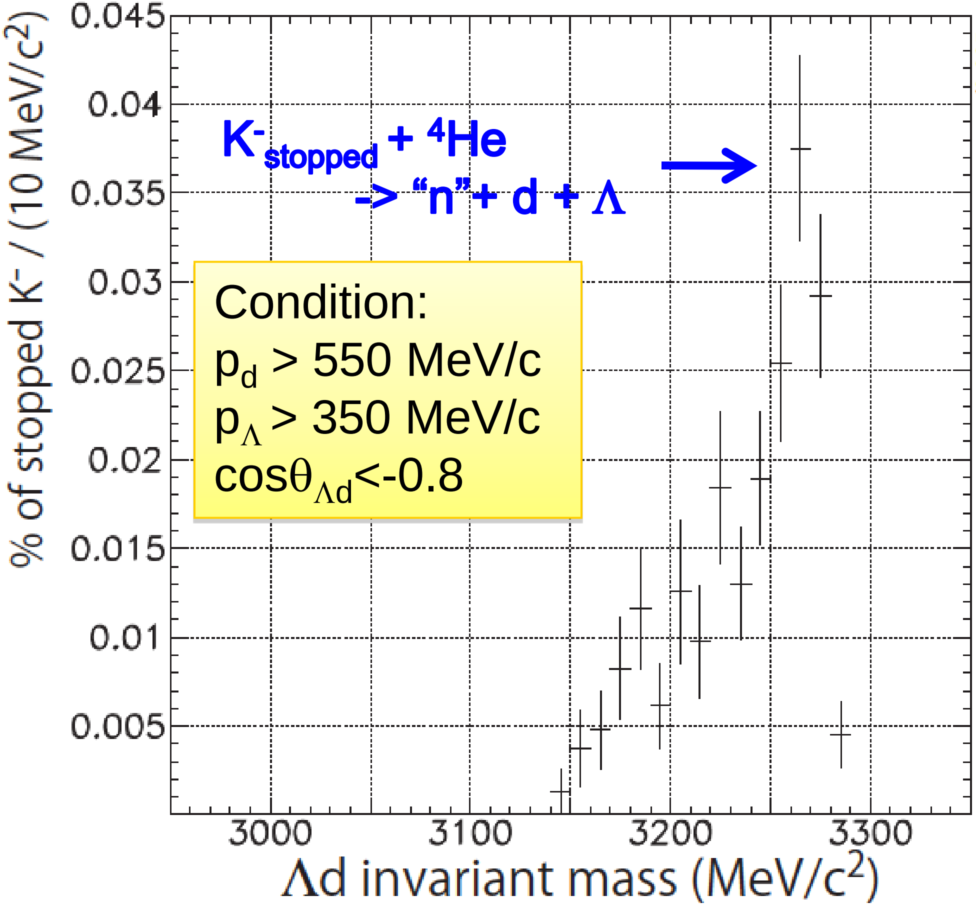
-> b_p is extremely peculiar.

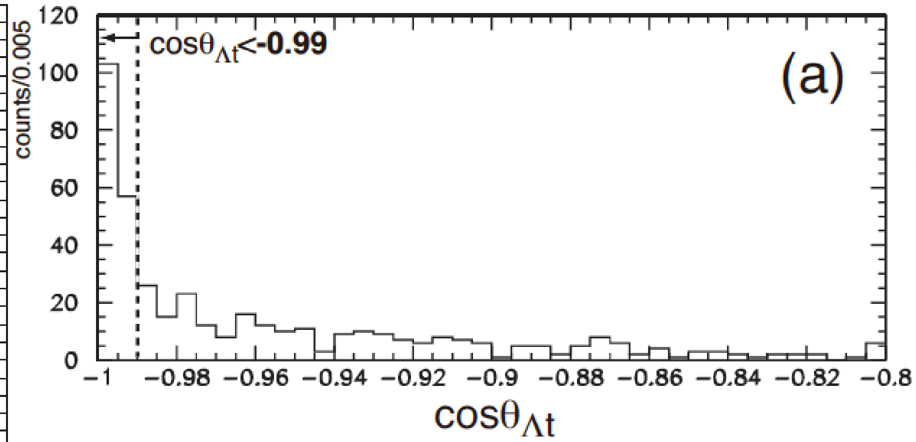
✔ ***The strength, which is likely to be the tribaryon signals, peaks at ~3140 MeV/c^2 (B.E. 170 MeV)***

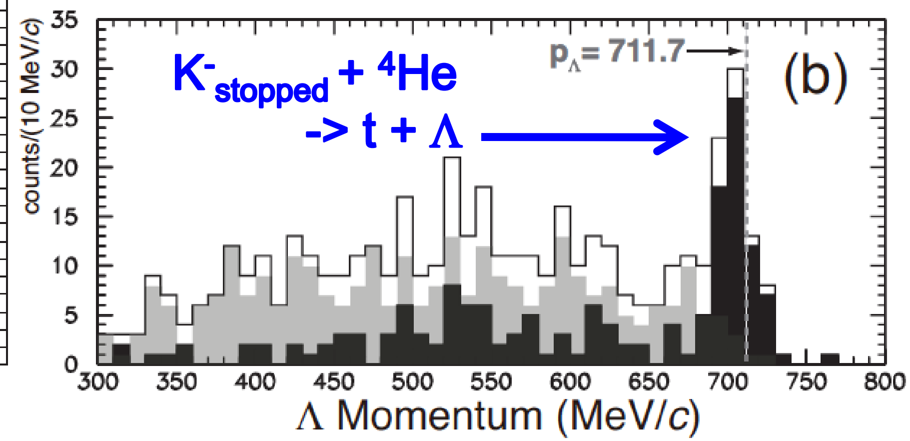
✔ ***Dibaryon (M~2230 MeV/c^2) interpretation is unlikely, except for unpredicted $K^-[pn]_{I=0,S=1}$***

Three- and Four-Nucleon Absorption

The existence of three- and four-nucleon absorption processes of K^- were also established in KEK E549…





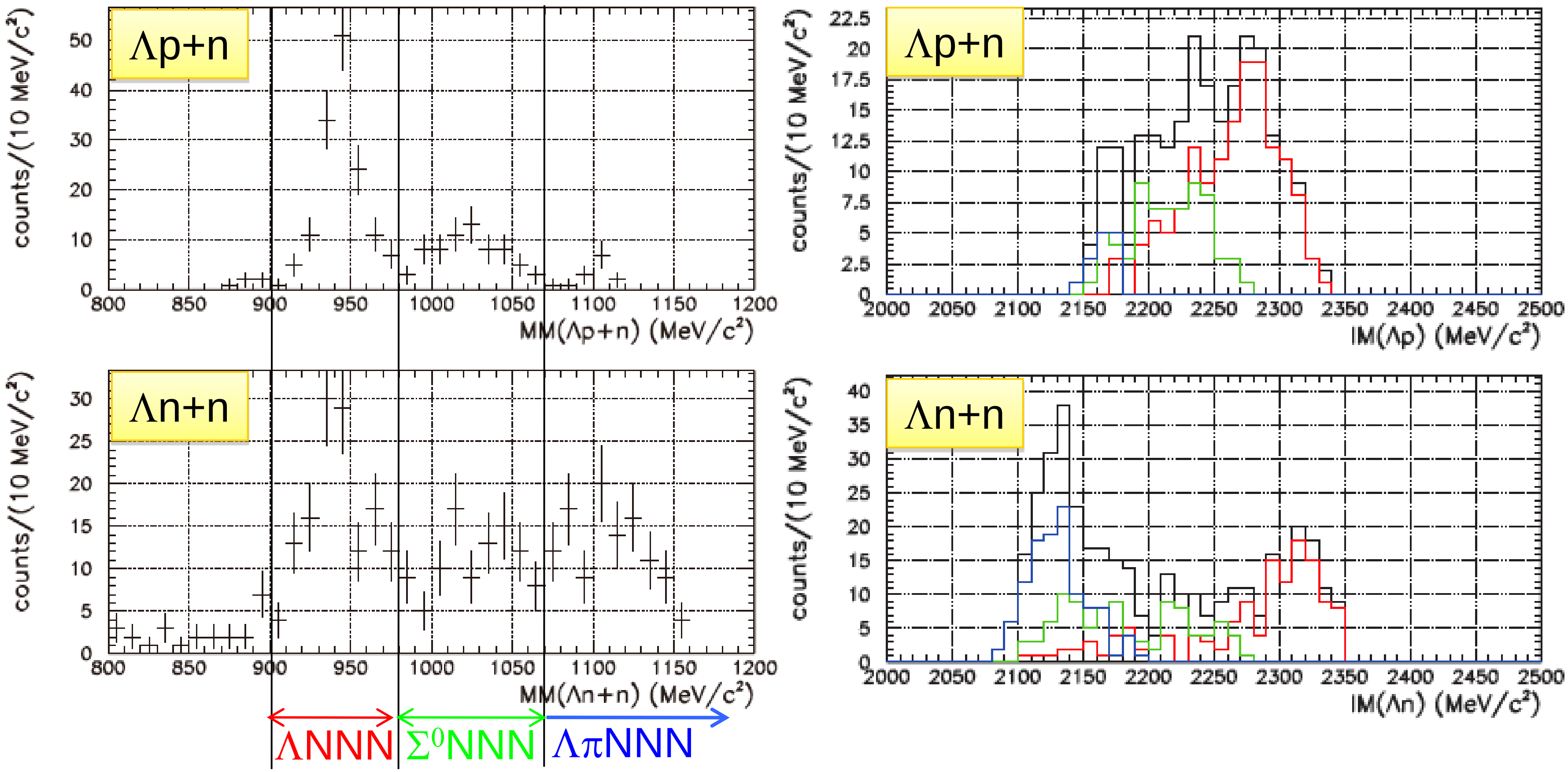


3NA(Λd Br.) : ~**0.1%/$K^-_{stopped}$**

4NA(Λt Br.) : **0.03%/$K^-_{stopped}$**

Three- and four-nucleon absorption processes do exist, but too rare to account for intense "B" components.

ΛN+n semi-exclusive analysis 1 – separation of Σ^0 and Λ final states

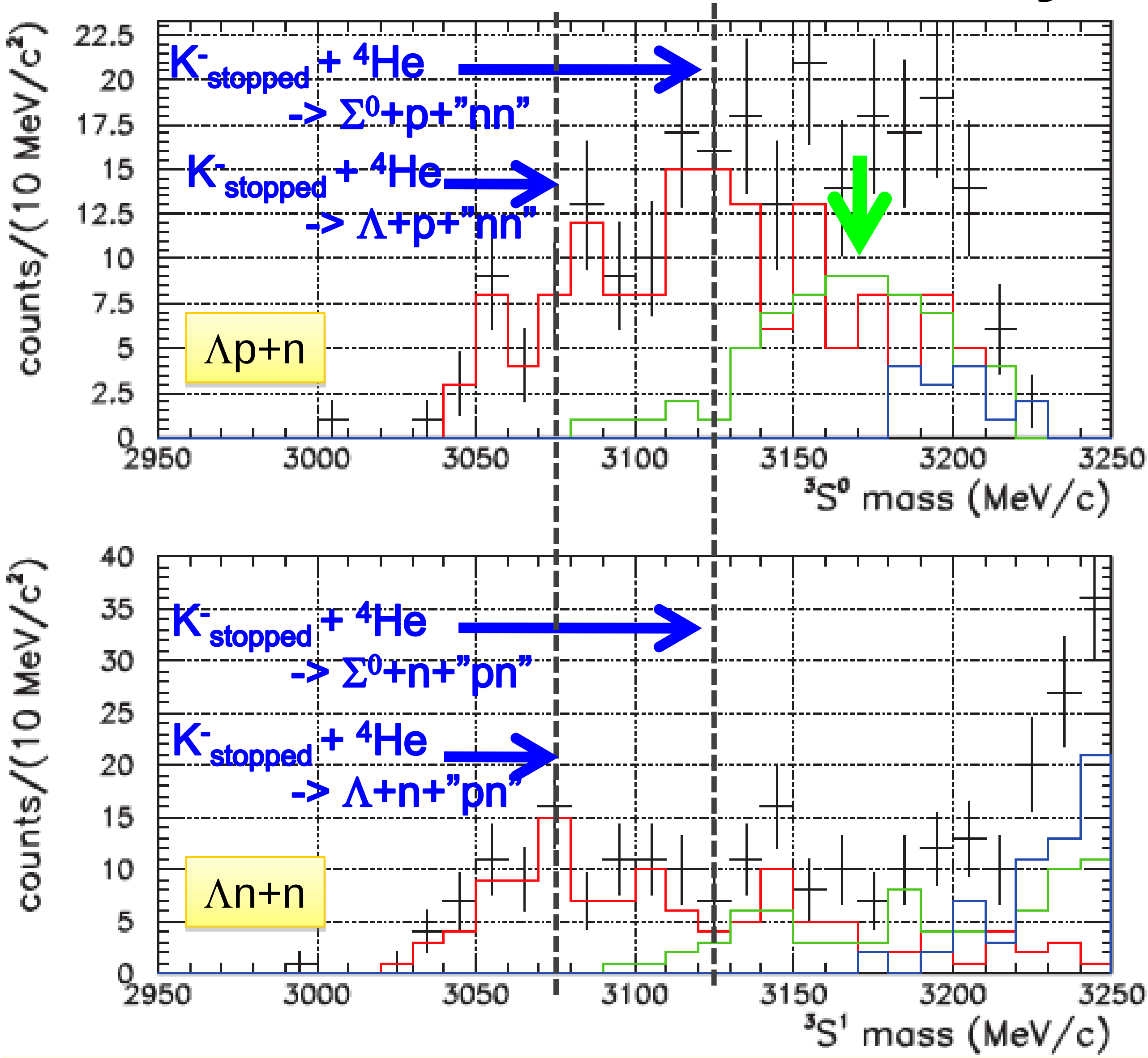


✓By detecting an additional neutron in coincidence with back-to-back ΛN, we can separate ΛNNN/ΛγNNN/ΛπNNN final states.

~30% of Bp component is now found to be occupied by Σ^0pnn events.

Study of Σ^0pnn events allows us more unambiguous search of multibaryon intensity (we can forget the possibility of ΣΛ conversion).

ΛN+n semi-exclusive analysis 2
– observation of multibaryon strength



Green : Σ^0NNN
Red : ΛNNN

- No 2NA strength is seen for Σ^0p events !!
- Peak of tribaryon mass spectrum by Σ^0p final state is **shifted from expectation of 2NA process by ~40 MeV/c^2 !!**
- All conventional explanations are unlikely to account for the peak at 3170 MeV/c^2 !!

Observation of Σ^0nn decay mode of $^3S^0$ tribaryon.

Conclusions

1. The spin-isospin dependence of 2NA process of negative kaon has been observed for the first time.

2. The 2NA process accounts for ***only ~30%*** of non-mesonic Λ branch.

3. A large fraction of the remaining ~70% (7~9%/$K^-_{stopped}$) does not allow any interpretation **except for multibaryon formation.**

4. The $K^-[pp]_{I=1,S=0}$ hypothesis of Λp spectrum (FINUDA interpretation) is, however, ***unlikely*** from observed spin-isospin property of the 2NA process at 0-energy.

5. The Λp spectrum suggests $^3S^0_{T=1}$, while the Λn suggests $^3S^+_{T=0/1}$. The Λn spectrum would be interpreted as an unpredicted dibaryon $K^-[pn]_{I=0,S=1}$.

6. ***Observed*** tribaryon mass is ~3140 MeV/c^2 (Σ^0 and Λ modes overlap). **The dependence of the peak position on the decay mode was now observed.**