The experimental search for strange multi-baryonic systems in ^{4}He(stopped K^-, YN) reaction

1. Introduction
2. Experiment
3. ΛN correlations
4. ΣN correlations
5. Discussion and prospect

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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.

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(in-flight K^-,N) -> *no narrow sates !*

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) with $^{6/7}$Li/ ^{12}C(stopped K^-,Λp)

-> *evidence for deeply bound ppK$^-$ state*(PRL **94** 210323 (2005))

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)) ***:talk by M.Sato***

Broad states? ***-> This talk***

Original aim of the Experiment - *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

$K^-_{stopped}$ + ^{4}He -> p + $S^0_{T=1}$ ->PLB **659** 107:***talk by M.Sato***

-> n + $S^+_{T=0,1}$

$S^+_{T=0,1}$ -> Y(π)NN ->H. Yim, under preparation

Y -> πN

Very strict upper limits for narrow(Γ< ~40 MeV/c^2) states

Insensitive to broad (Γ> ~40 MeV/c^2) states

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

Semi-exclusive missing mass spectroscopy via

This talk.

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

(Y:Λ->arXiv:0711.4943)

$^3S^{0/+}_{T=0,1}$ -> Y(π)NN

Small statistics, but well resolved final states. Dibaryon?

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

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

Inclusive measurement for

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

Semi-exclusive measurement for

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

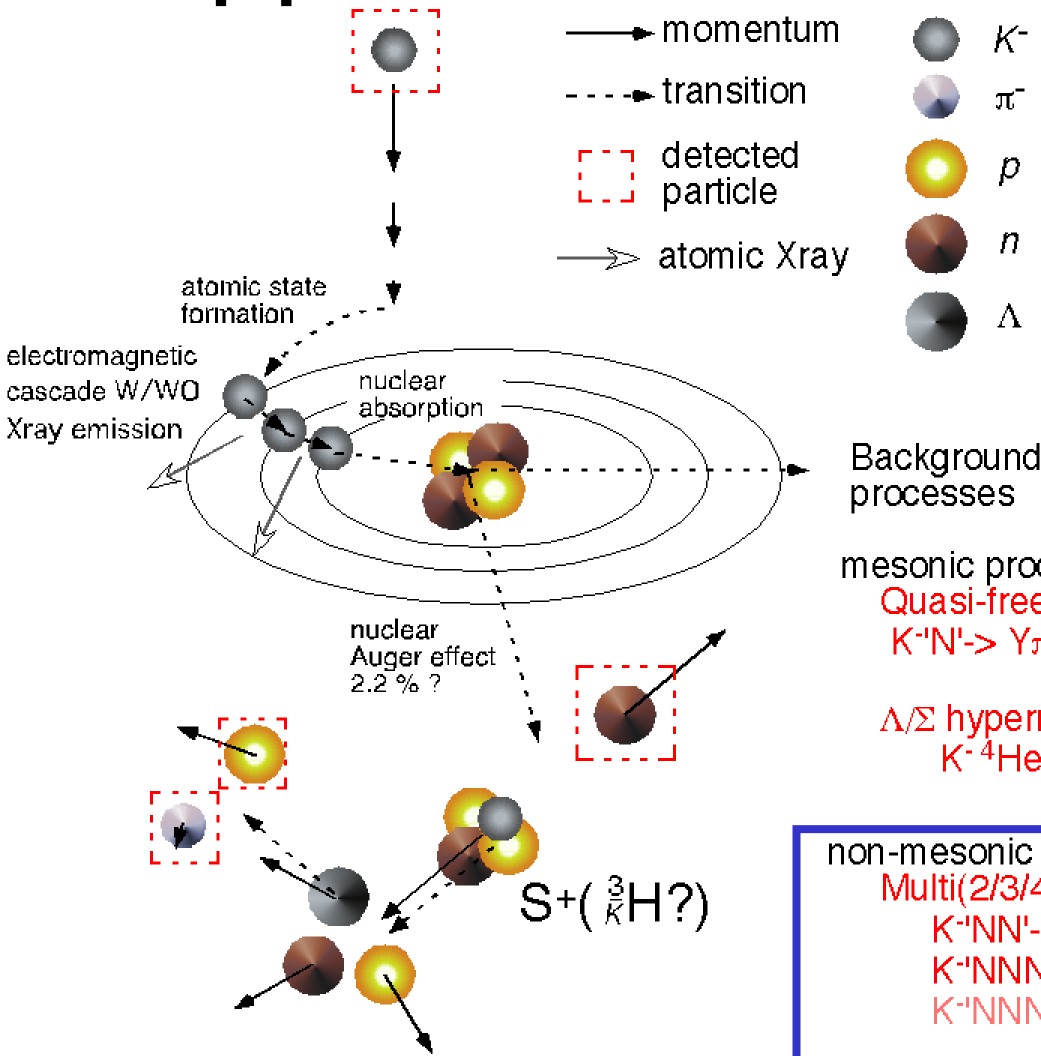
$^2S^0_{T=1/2}$ -> Yn

-> $^3S^+_{T=0,1}$ + n

$^3S^+_{T=0,1}$ -> Yd

Y:Λ->PRC **76** 068202

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'-> YN (2NA)

K-NNN'-> YNN (3NA)

K-NNNN'-> YNNN (4NA)

Dibaryon production+ its non-mesonic decay?

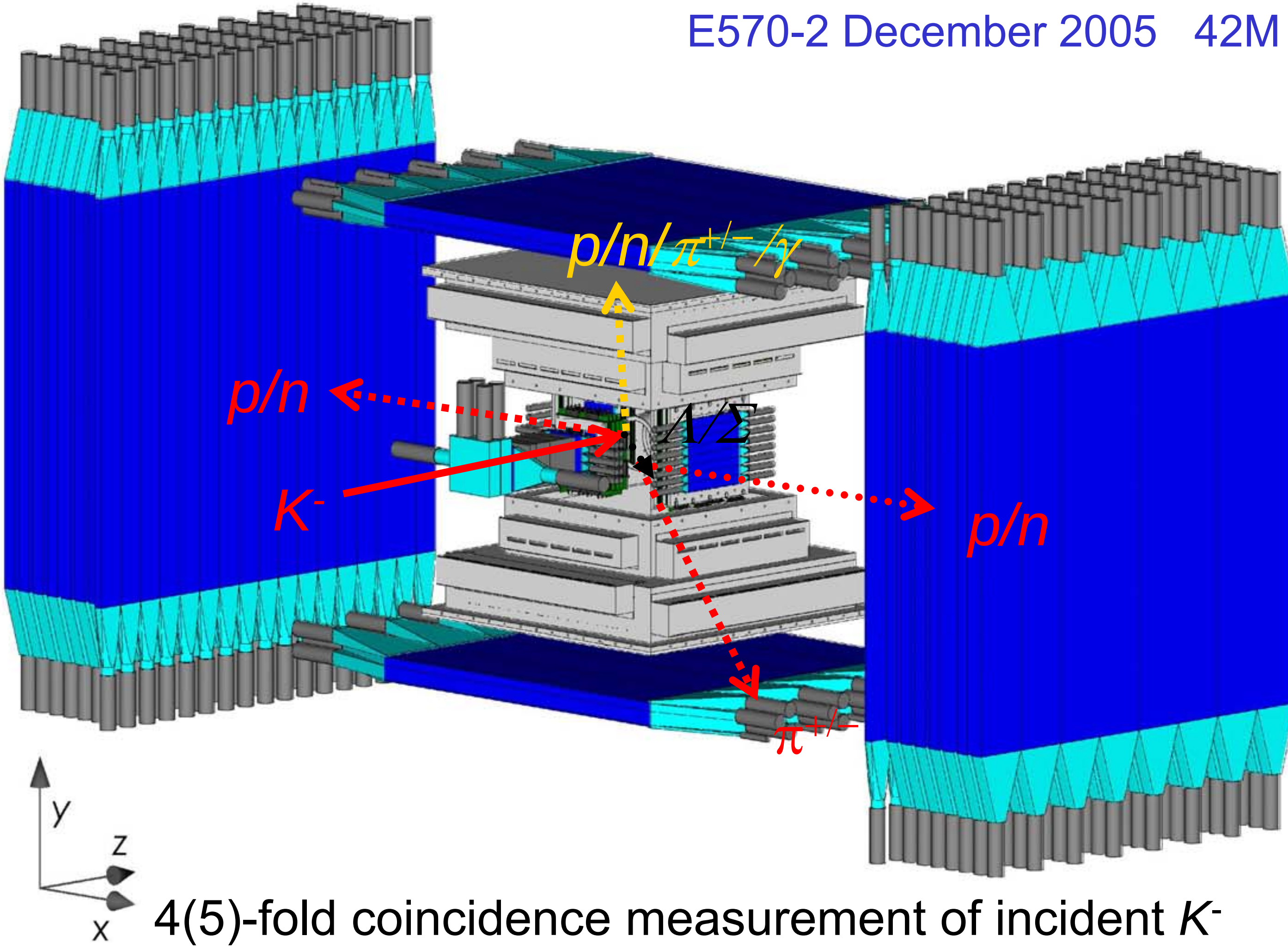
$K^- {}^4He \to XNN$

$X \to YN$

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

Measurement

E549 June 2005 95M stopped K^-
E570-1 October 2005 108M stopped K^-
E570-2 December 2005 42M stopped K^-



4(5)-fold coincidence measurement of incident K^- (+X)+back-to-back 2 nucleons+charged π

Momentum decision by track detection+TOF method for π/p/n

^{4}He(stopped K^-, ΛN) missing mass

Regardless of the medium states,

$K^-_{stopped}$ + ^{4}He -> Λ + N + N + N + π
$K^-_{stopped}$ + ^{4}He -> Λ + N + N + N
$K^-_{stopped}$ + ^{4}He -> Λ + n + d

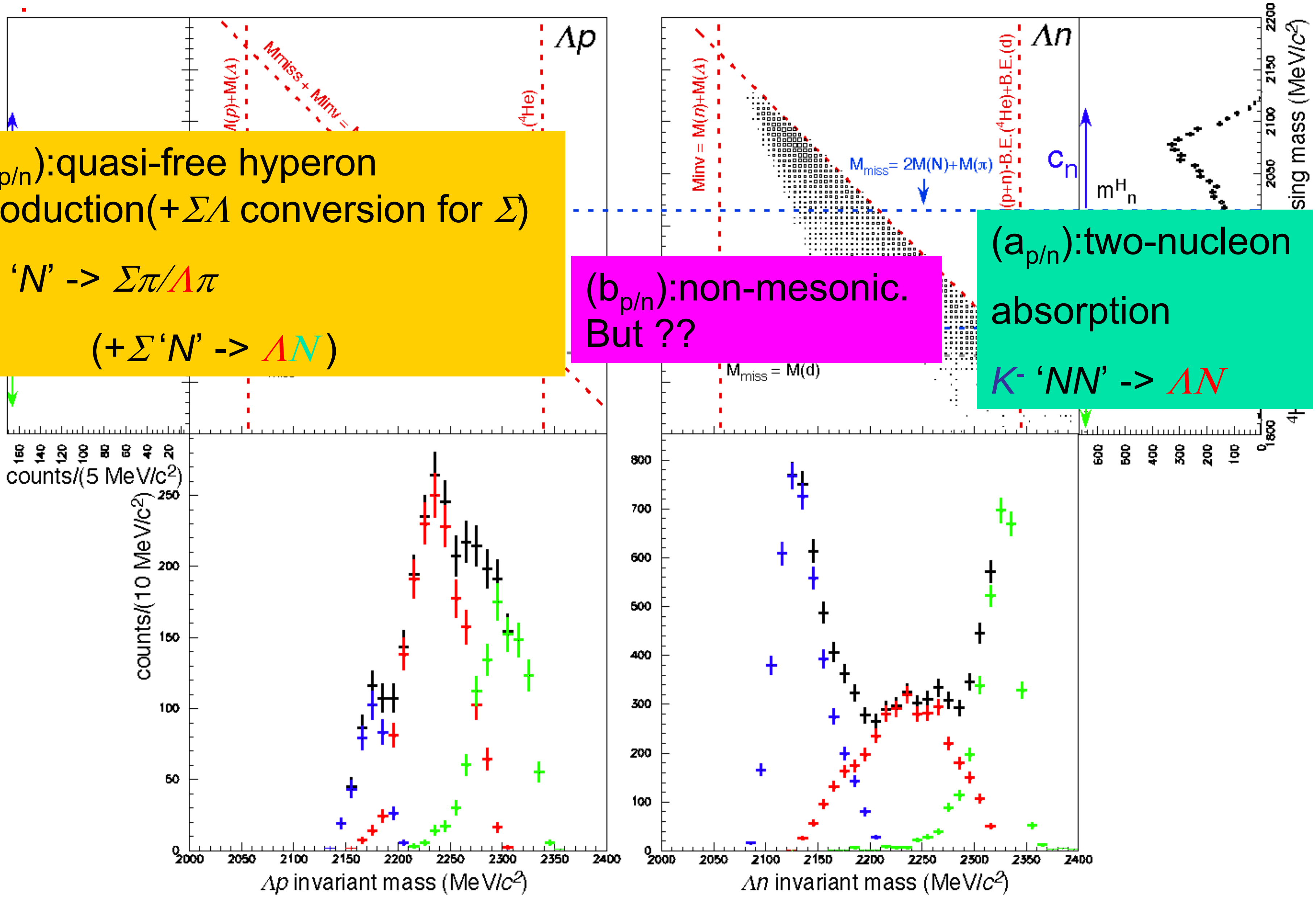
final states can be separated by

^{4}He($K^-_{stopped}$, ΛN) missing mass,

$$M_{NN^*} = \sqrt{(p_{init} - p_\Lambda - p_N)^2},$$

which is actually ***internal energy*** of reaction residual.
Internal energy can give important information to interpret observed strength.

ΛN invariant mass VS ^{4}He(stopped K^-, ΛN) missing mass



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

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

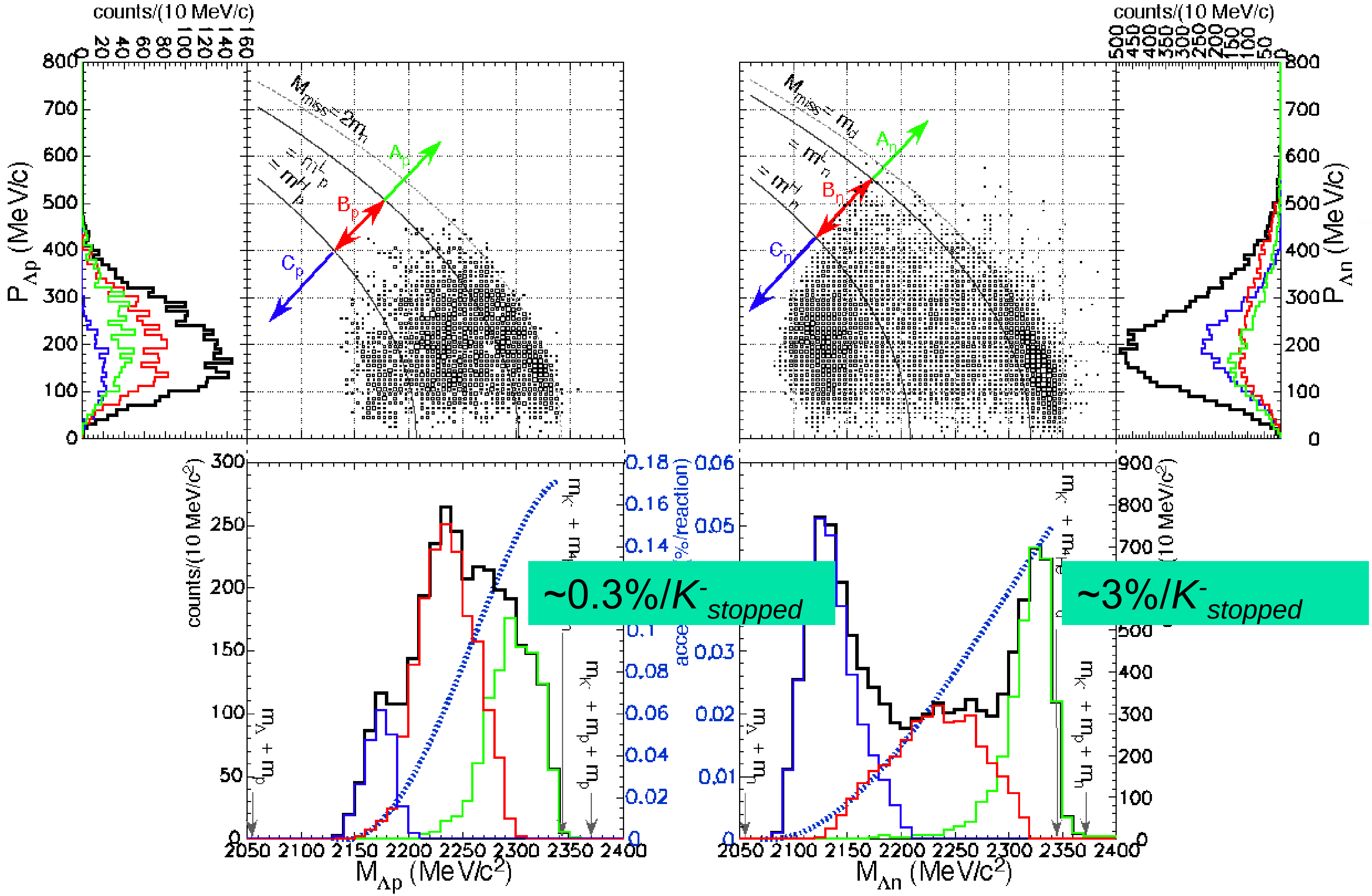
(+Σ'N' -> ΛN)

($b_{p/n}$):non-mesonic. But ??

($a_{p/n}$):two-nucleon absorption

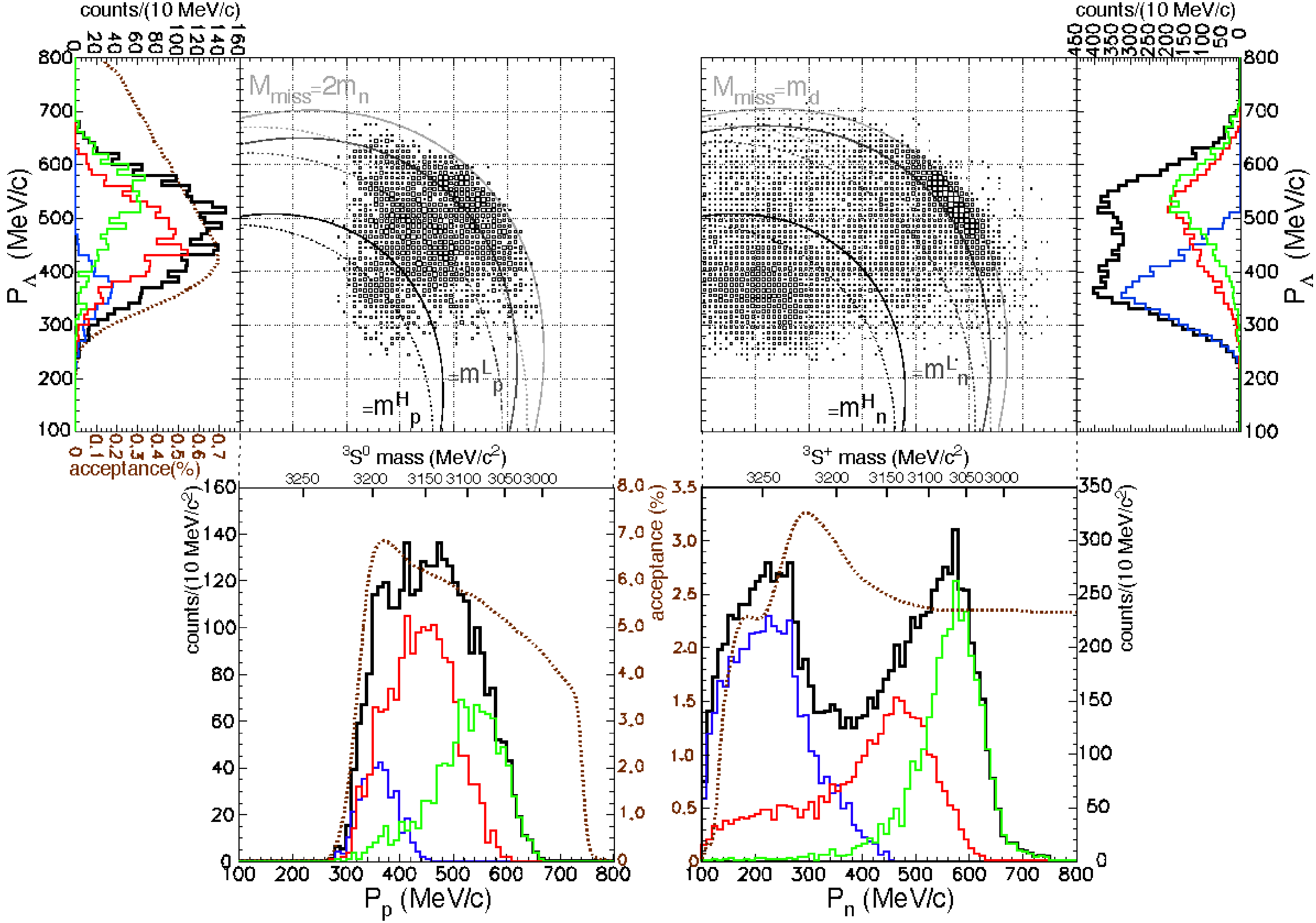
K^- 'NN' -> ΛN

ΛN invariant mass VS ΛN total momentum



1. **'NN'$_{I=0,S=1}$ dominance of** K^- 'NN'$_{I,S}$ -> ΛN
2. **More intense contribution of $B_{p/n}$**

Λ momentum VS N momentum



($b_{p/n}$) -> Unresolved ***broad strength peaked at ~3140 MeV/c²***.

Discussion of a_p/a_n :2-nucleon-absorption (2NA) components

Clear observation of "two"-nucleon absorption,

K^- '*pp*' $_{I=1,S=0}$ -> Λp (a_p~0.3%/$K^-_{stopped}$)

K^- '*pn*' $_{I=1,S=0/I=0,S=1}$ -> Λn (a_n ~3%/$K^-_{stopped}$)

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. ***Suppression*** of

(K^- [*pp*] $_{I=1,S=0}$)-> Λp

decay mode of strongly bound K^-pp system (cf. K^-d-> Λn :~0.4%)

Properties of b_p/b_n components

1. Presence of intense(***~70% of ΛNNN final states***) b_p/b_n components.

2. b_n could be explained by the elastic re-scattering effect(PRC **74** 025206).

3. Much different a_p:b_p,a_n:b_n intensity ratio.
-> simultaneous explanation of b_p and b_n by elastic re-scattering effect is almost impossible…

4. b_p cannot be explained by the re-scattering effect from ***the 2D spectrum shape***.
-> b_p is extremely peculiar.

Interpretation of b_p component

Possible contibutions to component b_p…

1. Σbranch of"two"-nucleon absorption and successive ΣΛ conversion process

K^- 'NN' -> Σp

Σ 'N' -> Λp

Possible contribution from

K^- 'pp' -> $\Sigma^0 p$

Σ^0 -> $\Lambda\gamma$

2. ΛNN branch of "three-nucleon absorption" cf. PRC **76** 068202)

K^- 'NNN' -> ΛpN ← *Expected brach* is 0.1% order…

3. $^2S^+_{T=1/2}$ dibaryon (K^- [pp] $_{I=1,S=0}$) production and its Λp decay (for ^{6}Li + ^{7}Li + ^{12}C, FINUDA collaboration, PRL **94** (2005) 212303)

$K^-_{stopped}$ + ^{4}He -> $^2S^+_{T=1/2}$ + n + n

$^2S^+_{T=1/2}$ -> Λ + p ← Spin-isospin suppressed…

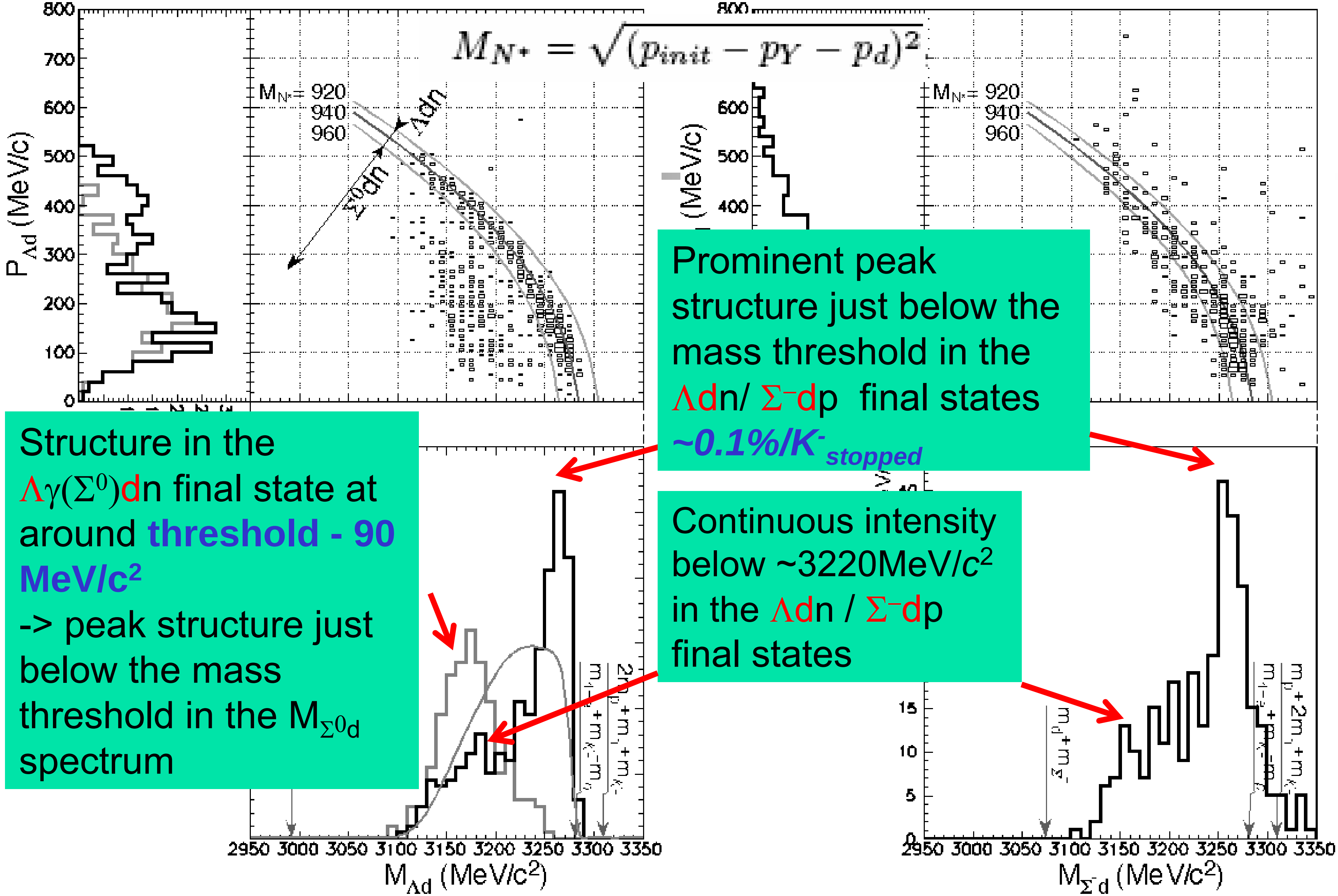
4. $^3S^0_{T=1}$ tribaryon production and its Λnn decay

$K^-_{stopped}$ + ^{4}He -> $^3S^0_{T=1}$ + p

$^3S^0_{T=1}$ -> Λ + n + n

Three-nucleon absorption (Yd branch)

$$M_{N^*} = \sqrt{(p_{init} - p_Y - p_d)^2}$$



Structure in the $\Lambda\gamma(\Sigma^0)$dn final state at around **threshold - 90 MeV/c²**

-> peak structure just below the mass threshold in the $M_{\Sigma^0 d}$ spectrum

Prominent peak structure just below the mass threshold in the Λdn/ Σ^-dp final states ***~0.1%/$K^-_{stopped}$***

Continuous intensity below ~3220MeV/c^2 in the Λdn / Σ^-dp final states

Interpretation of b_n component

Possible contributions to component (b_n)…

1. Σ branch of "two"-nucleon absorption and successive ΣΛ conversion process

Unseen on ΣN spectra.

K^- 'NN' -> Σn

Σ 'N' -> Λn

Possible contribution from

K^- 'pn' -> $\Sigma^0 n$

Σ^0 -> $\Lambda\gamma$

2. Elastic re-scattering

K^- 'NN'(NN) -> $\Lambda n(NN)$

$\Lambda(n)$-> Λn

K^- 'NN'(NN) -> $\Lambda n(NN)$

$n(N)$-> nN

3. $^2S^0_{T=1/2}$ dibaryon (K^- $[pn]_{I=0,S=1}$) production and its Λn decay

$K^-_{stopped}$ + ^4He -> $^2S^0_{T=1/2}$ + p + n

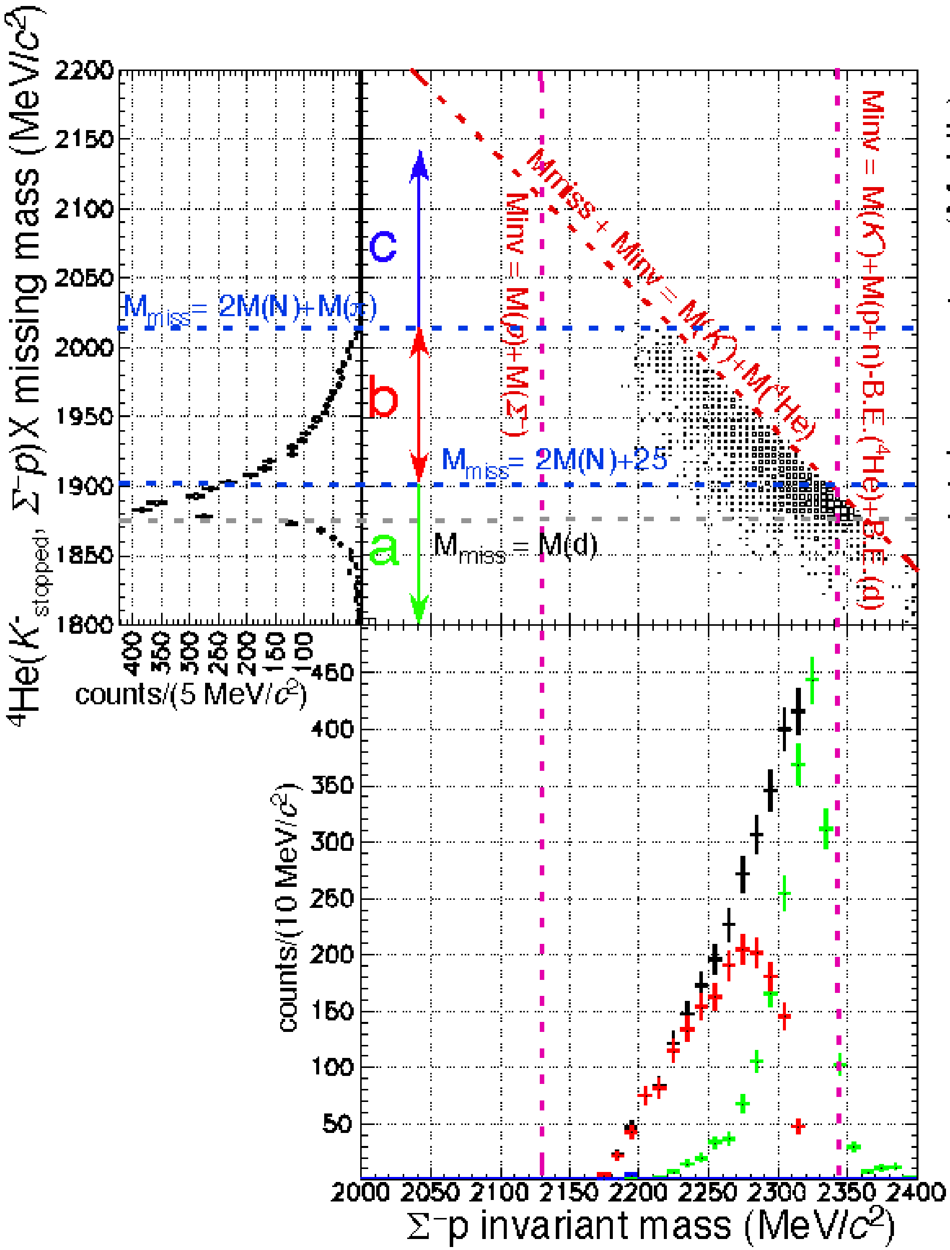
$^2S^0_{T=1/2}$ -> Λ + n

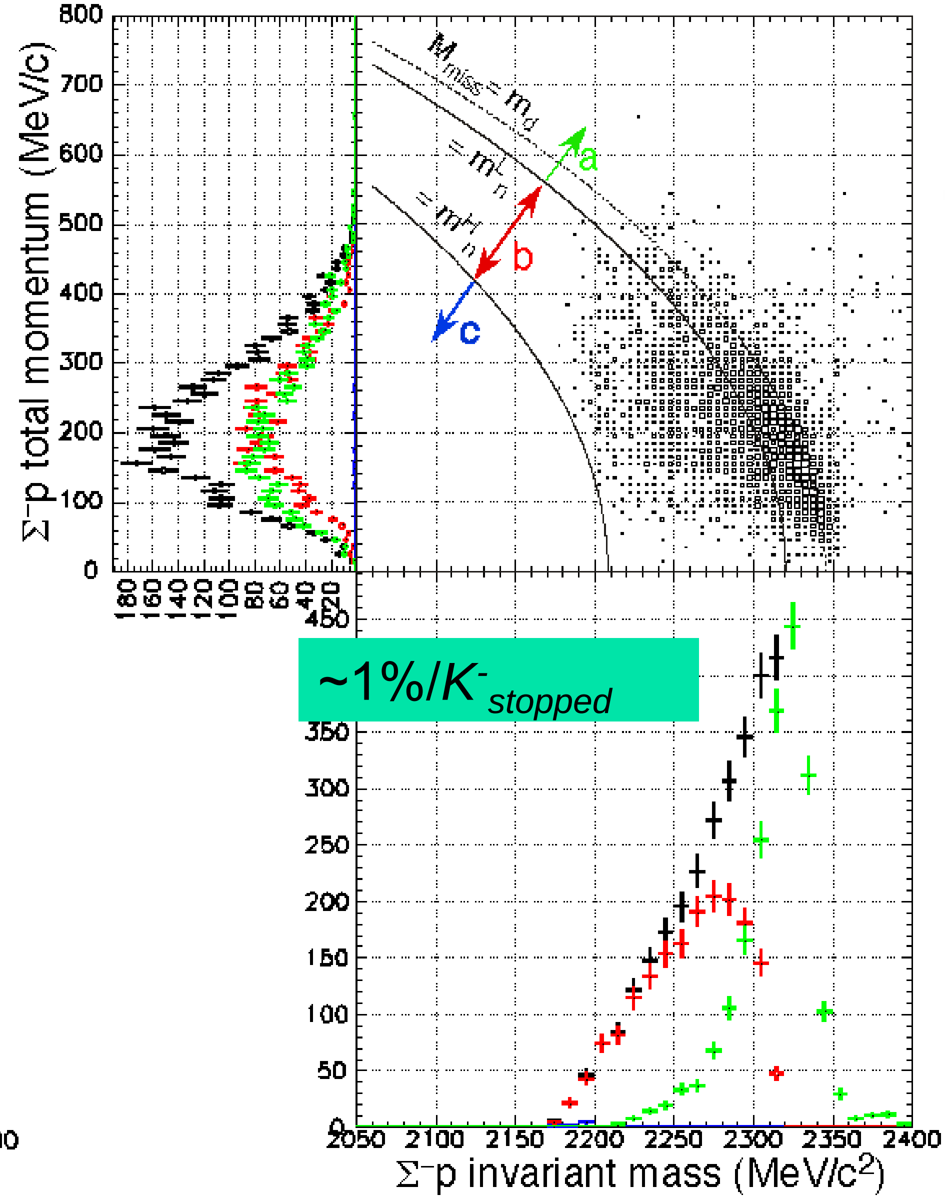
4. $^3S^+$ tribaryon production and its Λpn decay

$K^-_{stopped}$ + ^4He -> $^3S^+$ + n

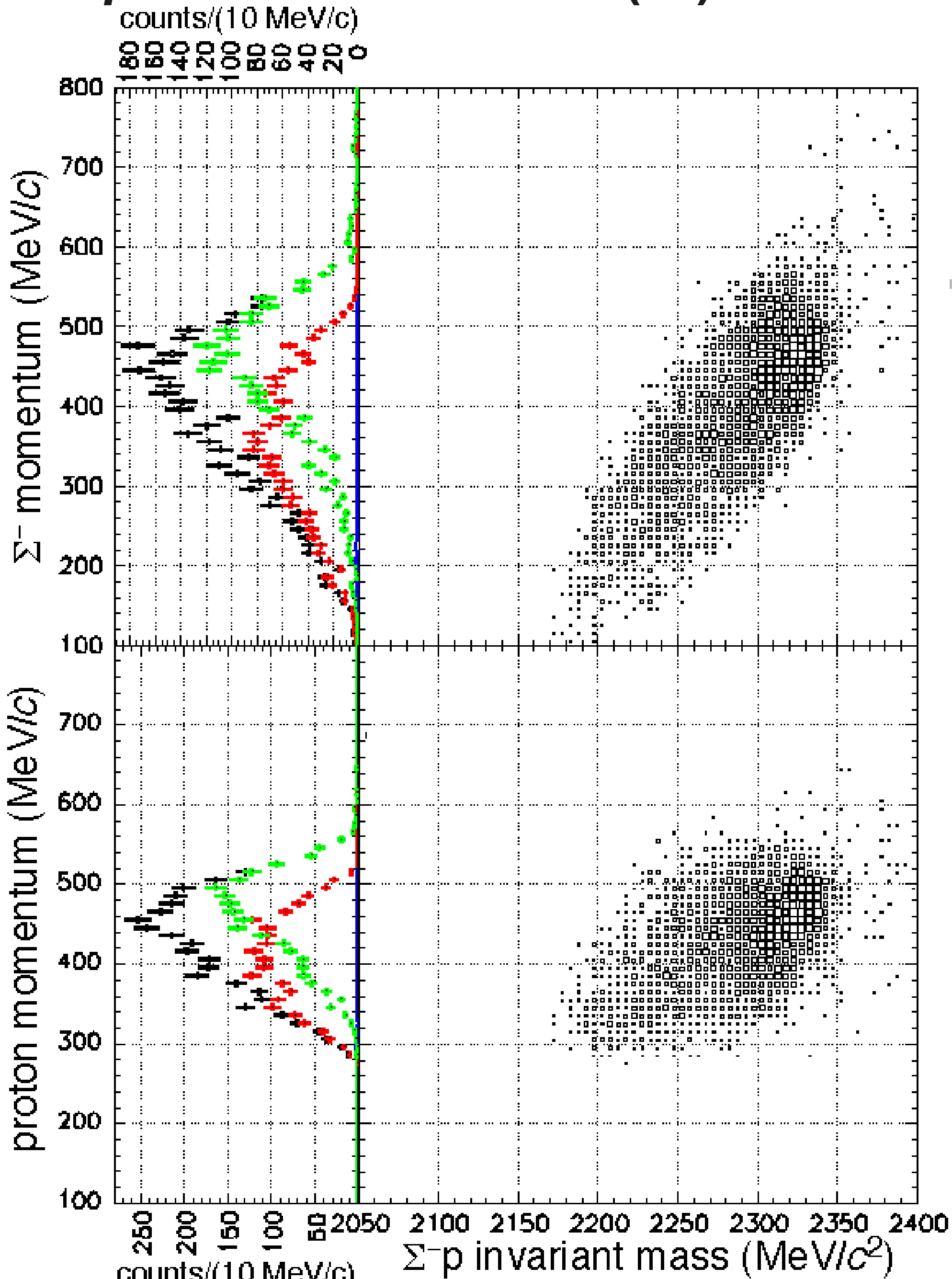
$^3S^+$ -> Λ + p + n

$\Sigma^{-}p$ correlations (1)





$\Sigma^- p$ correlations (2)



2NA: ~1 % out of 3.6 +- 0.9 % of Σ^-ppn/Σ^-pd final state

Σ^- momentum distribution for non-2NA component is ***never explained by elastic re-scattering!!!***

$K^-_{stopped} + {}^4He$

$\rightarrow {}^2S^0_{T=1/2}\,(K^-\,[pn]_{I=0,S=1}) + p + n$

${}^2S^0_{T=1/2} \rightarrow \Sigma^- + p$

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

${}^3S^0_{T=1} \rightarrow \Sigma^- + pn/d$

Conclusions

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

2. The remaining ~70% could include the signal of non-mesonic decay of strange multibaryons.

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

4. The Λp spectrum suggests $^3S^0_{T=1}$, while the Λn suggests $^2S^0_{T=1/2}/^3S^+_{T=0/1}$.

5. $\Sigma^{-}p$ correlations suggest $^2S^0_{T=1/2}/^3S^0_{T=1}$ even more strongly.

6. All suggested multibaryons have large width or as continuum.

Prospects

1. Whole spectrum shapes will be examined after the acceptance correction.

2. Important theoretical information to identify the kaonic nucleus experimentally is not the binding energy, but ***branching ratio of the decay***.

3. The (K^-,N) experiments with A=3/4 targets (cf. J-PARC E15 -> **M. Iwasaki's prenary talk**), by which Λ/Σ channels are ***exclusively*** studied in wide angular/momentum range, are awaited at J-PARC K1.8BR/K1.1.