KBAR-NUCLEUS BOUND STATE SPECTROSCOPY

- A New Paradigm of Strangeness Nuclear Physics

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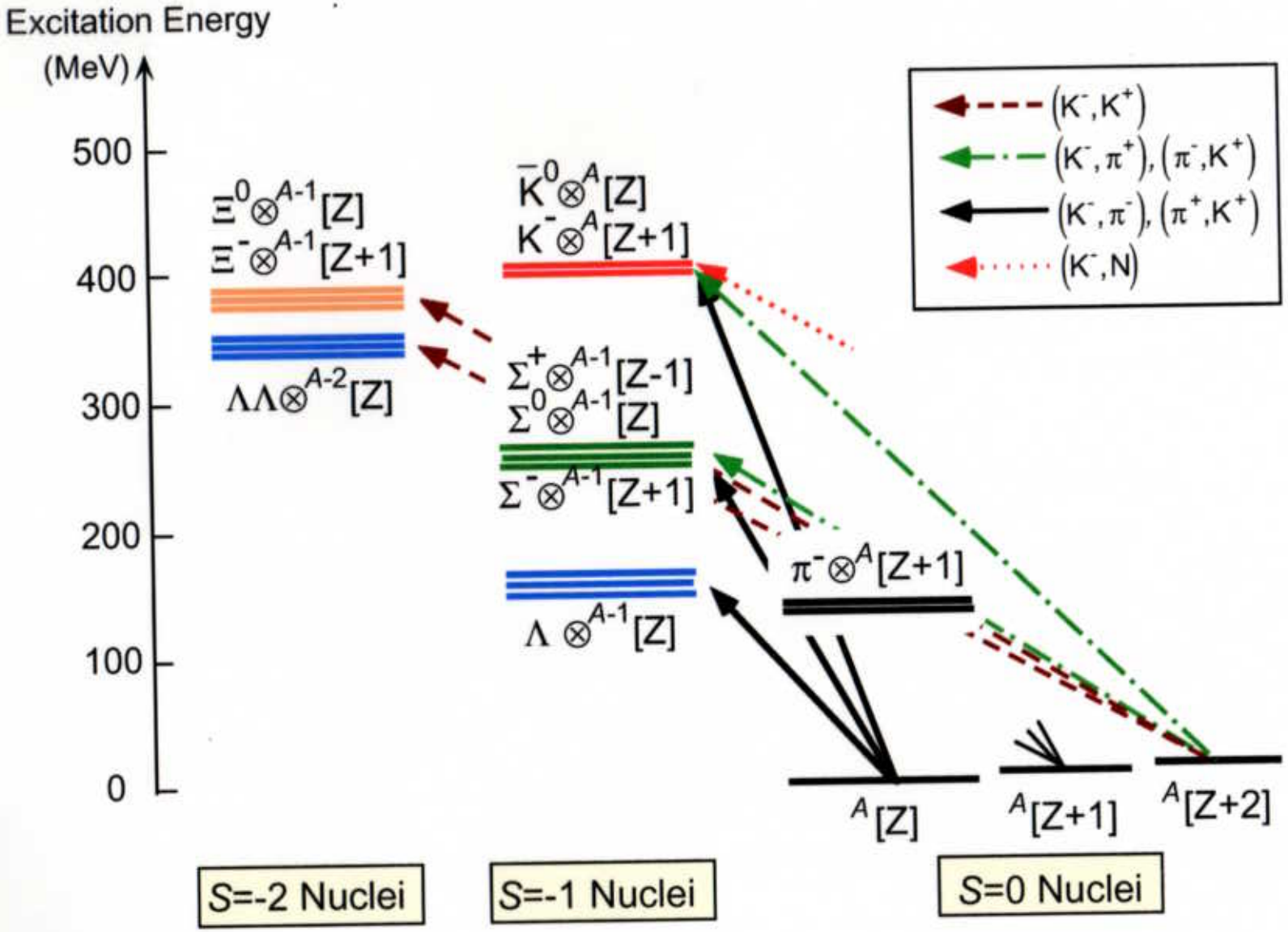

Excitation Energy
(MeV)
500
400
300
200
100
0
$\Xi^0 \otimes^{A-1}[Z]$
$\Xi^- \otimes^{A-1}[Z+1]$
$\Lambda\Lambda \otimes^{A-2}[Z]$
$\bar{K}^0 \otimes^{A}[Z]$
$K^- \otimes^{A}[Z+1]$
$\Sigma^+ \otimes^{A-1}[Z-1]$
$\Sigma^0 \otimes^{A-1}[Z]$
$\Sigma^- \otimes^{A-1}[Z+1]$
$\Lambda \otimes^{A-1}[Z]$
$\pi^- \otimes^{A}[Z+1]$
$^{A}[Z]$
$^{A}[Z+1]$
$^{A}[Z+2]$
(K^-,K^+)
$(K^-,\pi^+),(\pi^-,K^+)$
$(K^-,\pi^-),(\pi^+,K^+)$
(K^-,N)
S=-2 Nuclei
S=-1 Nuclei
S=0 Nuclei

$\bar{K}$ - Nuclear Production by (K^-, π^-)

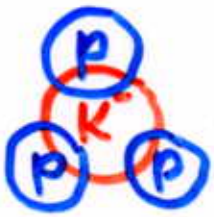
"n" $(K^-, \pi^-)\ \Lambda_{1405}$ as a door way

"seed"

proton-rich $\bar{K}$ nuclei

low momentum transfer ~ 300 MeV/c

Target	Reaction	Door way state	K^- state
p	(K^-,π^0)	Λ^*	K^--p
d	(K^-,π^-)	Λ^*-p	K^--$(p)^2$
^{3}He	(K^-,π^-)	Λ^*-$(p)^2$	K^--$(p)^3$
^{4}He	(K^-,π^-)	Λ^*-$(p)^2$n	K^--$(p)^3$n
^{6}Li	(K^-,π^-)	Λ^*-$(p)^3(n)^2$	K^--$(p)^4(n)^2$
^{7}Li	(K^-,π^-)	Λ^*-$(p)^3(n)^3$	K^--$(p)^4(n)^3$
^{9}Be	(K^-,π^-)	$\Lambda^* - (\alpha)^2$	K^--p-$(\alpha)^2$
^{10}B	(K^-,π^-)	Λ^*-$(p)^5(n)^4$	K^--$(p)^6(n)^4$
^{11}B	(K^-,π^-)	Λ^*-$(p)^5(n)^5$	K^--$(p)^6(n)^5$
^{12}C	(K^-,π^-)	Λ^*-$(p)^6(n)^5$	K^--$(p)^7(n)^5$



Few-Body $\bar{K}N$ Systems

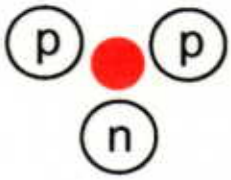
Strange Baryon

$\Lambda^*(1405)$

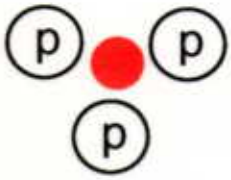
Di-baryon

$^{2}_{\bar{K}}H$

Tri-baryon



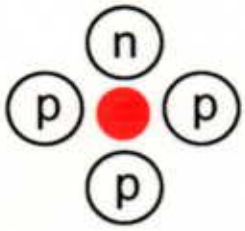
$^{3}_{\bar{K}}H$



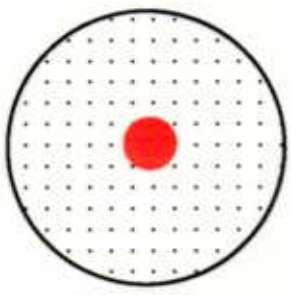
$^{3}_{\bar{K}}He$

Tetra-baryon

$^{4}_{\bar{K}}H$

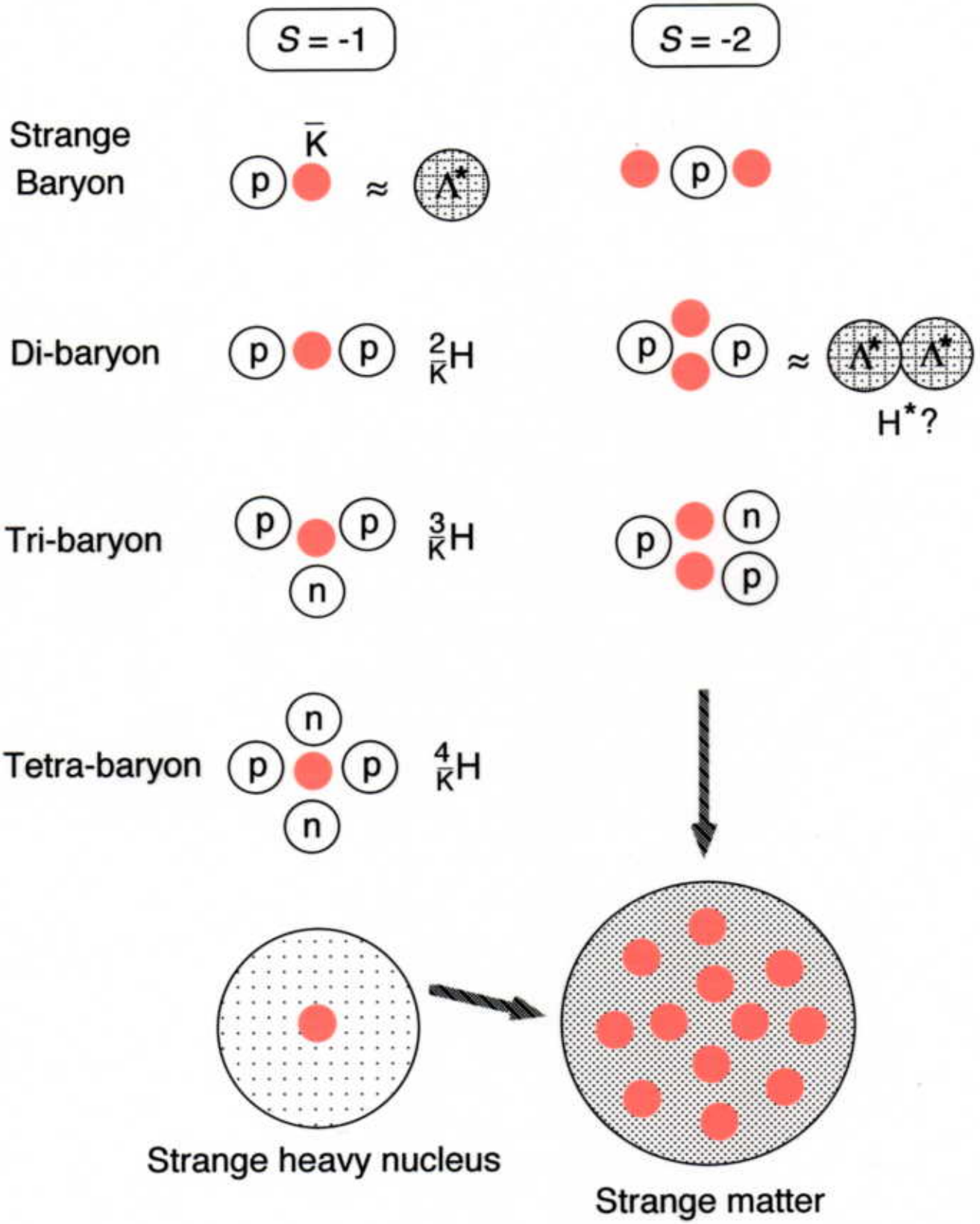


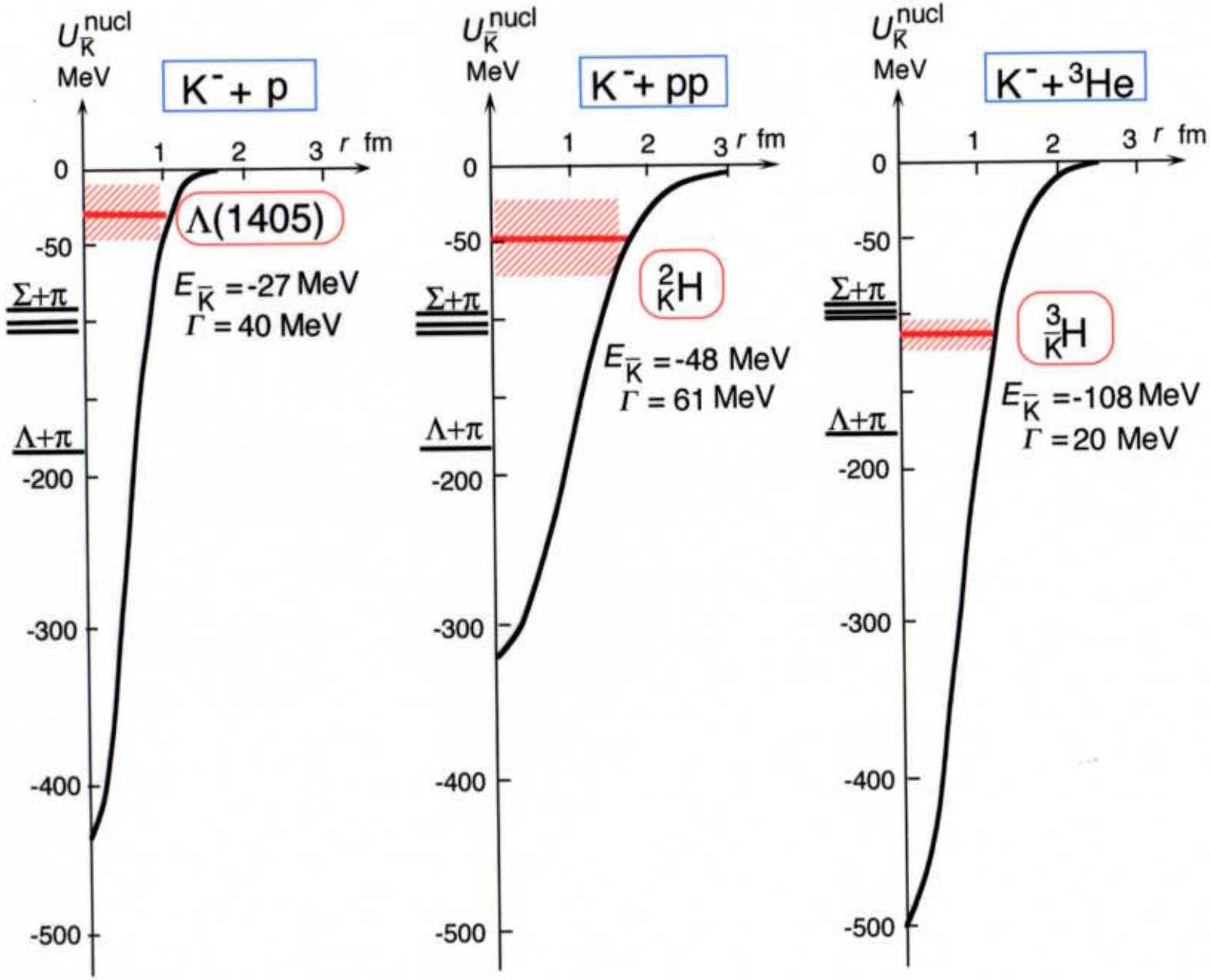
$^{4}_{\bar{K}}He$

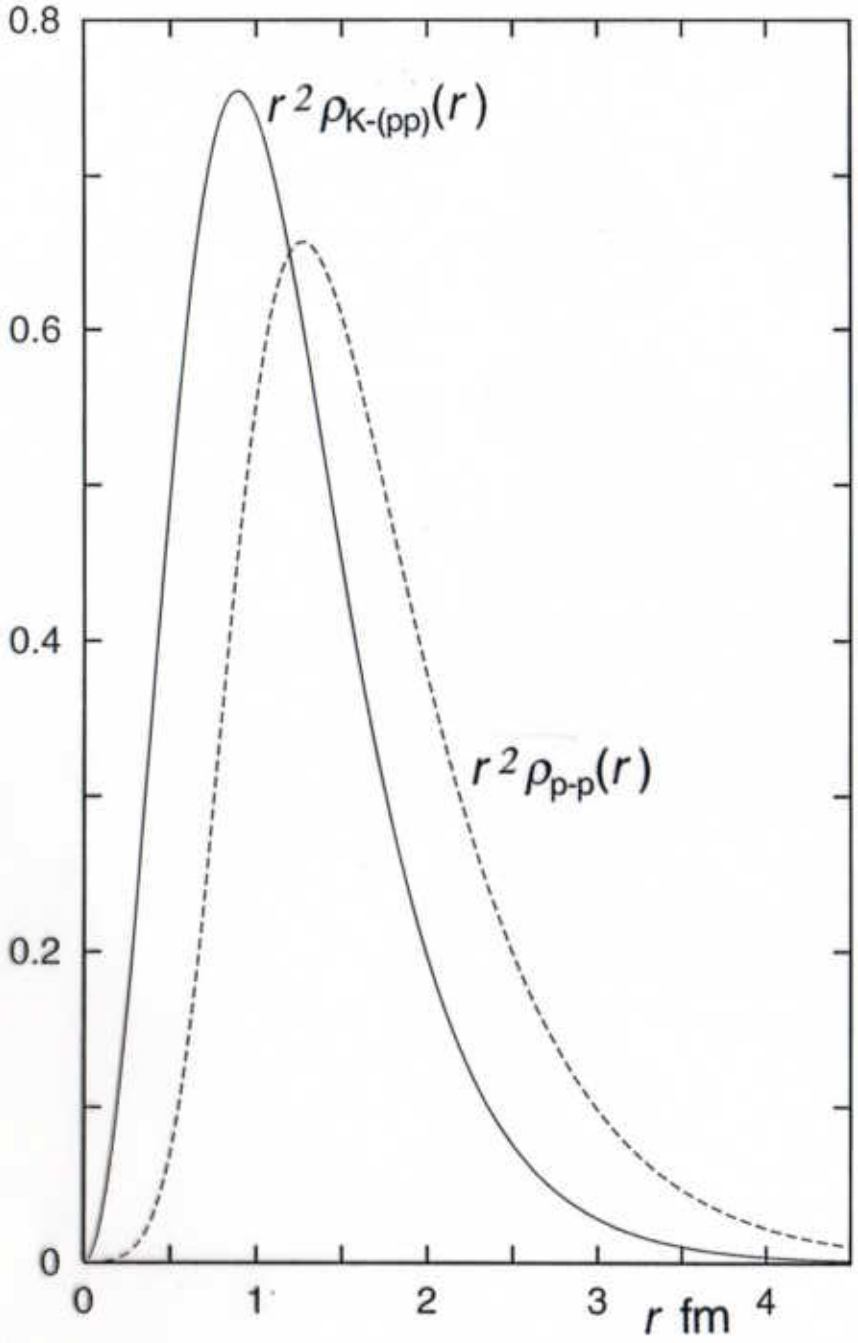


Strange heavy nucleus

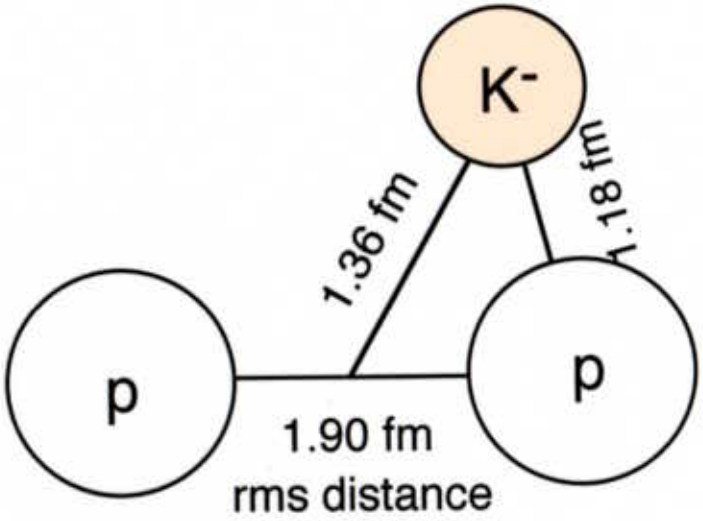
Few-Body $\bar{K}N$ Systems




$U_{\bar{K}}^{nucl}$
MeV
K⁻ + p
r fm
1
2
3
0
-50
Σ+π
Λ+π
-200
-300
-400
-500
Λ(1405)
$E_{\bar{K}}$ = -27 MeV
Γ = 40 MeV
$U_{\bar{K}}^{nucl}$
MeV
K⁻ + pp
r fm
$^{2}_{\bar{K}}$H
$E_{\bar{K}}$ = -48 MeV
Γ = 61 MeV
$U_{\bar{K}}^{nucl}$
MeV
K⁻ + ^{3}He
r fm
$^{3}_{\bar{K}}$H
$E_{\bar{K}}$ = -108 MeV
Γ = 20 MeV



Structure of ppK$^-$



Nuclear $\bar{K}NN$ bound states

$K^- \otimes nn$ $\qquad 2\{v^{T=1}\}$

$T=3/2$ Unbound

$K^- \otimes d$ $\qquad 2\left\{\frac{1}{4}v^{T=0}+\frac{3}{4}v^{T=1}\right\}$

$T=1/2$ $E_{0s} =$ MeV $\quad \Gamma_{0s} =$ MeV

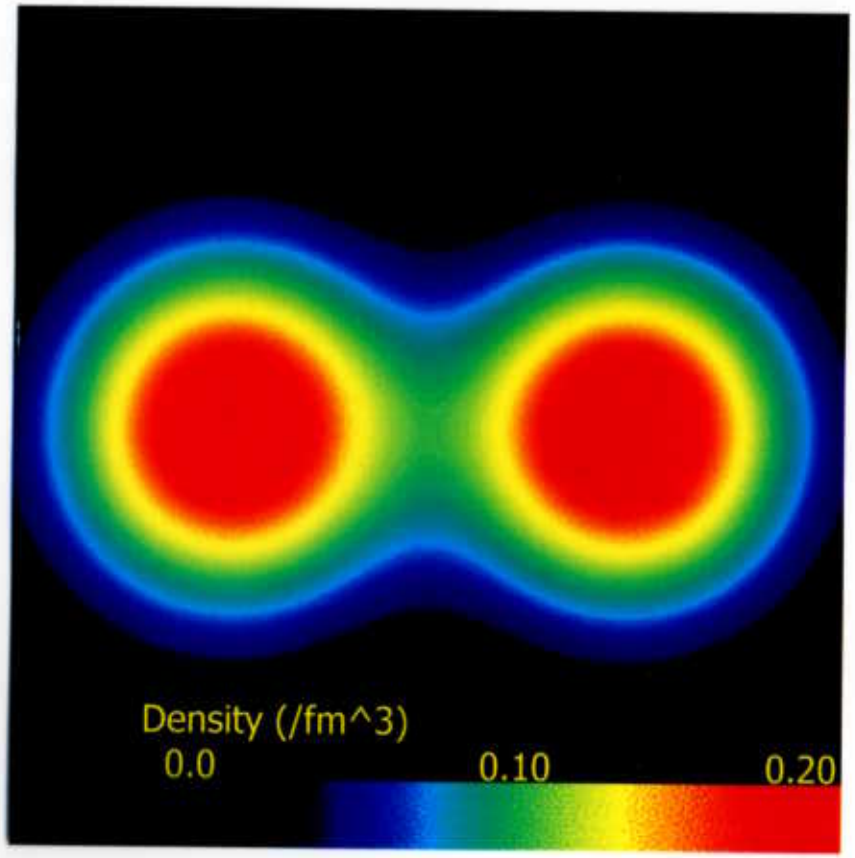
Above the $\Lambda(1405)$+n threshold

"$K^- \otimes pp$" $\qquad 2\left\{\frac{3}{4}v^{T=0}+\frac{1}{4}v^{T=1}\right\}$

$T=1/2$ $E_{0s} = -48$ MeV $\quad \Gamma_{0s} = 61$ MeV

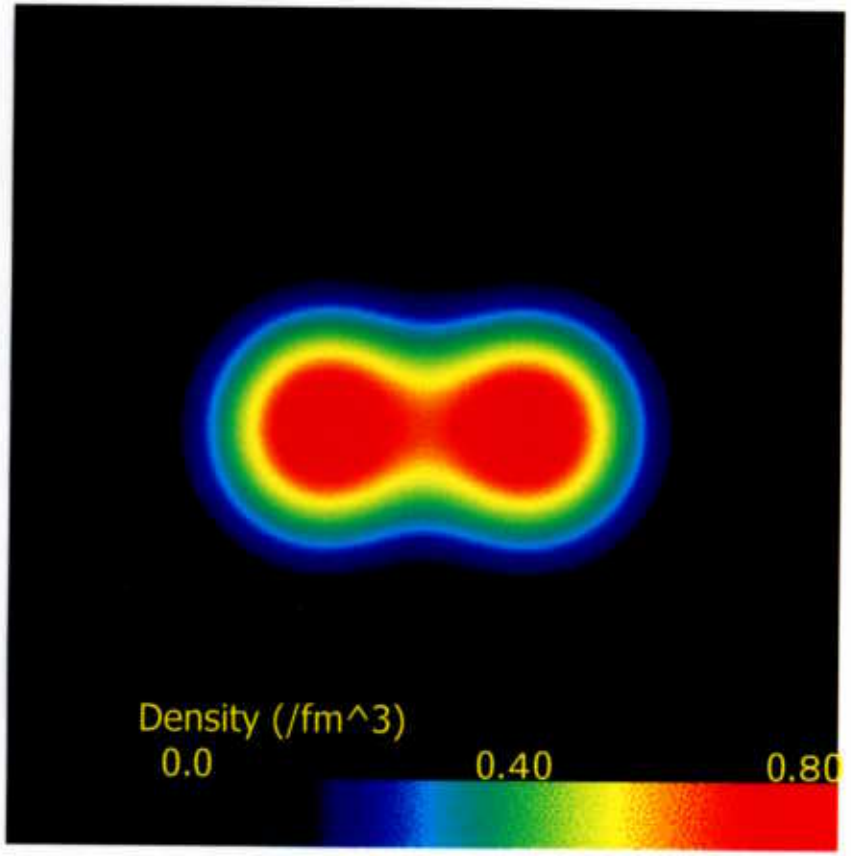
$V_{NN}(^1S_0) \rightarrow V_{NN}(^3S_1)$	-64 MeV	69 MeV
$M_N \rightarrow 1.5\ M_N$	-76 MeV	75 MeV
Both	-98 MeV	82 MeV

^{8}Be



7 fm

$K^{-}+^{8}$Be



7 fm

V. Hepp et al. 1977 intriguing data

D_2 bubble chamber

$K^- + d \to \pi^- \underline{\Sigma^- \pi^+}\ p_s$

$\to$ "n" $(K^-, \pi^-) Y^*$

Our hypothesis:

$d(K^-, \pi^-)\ \underline{K^- pp}$ M ~2320 MeV

$\hookrightarrow \underline{\Sigma^- \pi^+ p}$

discrete

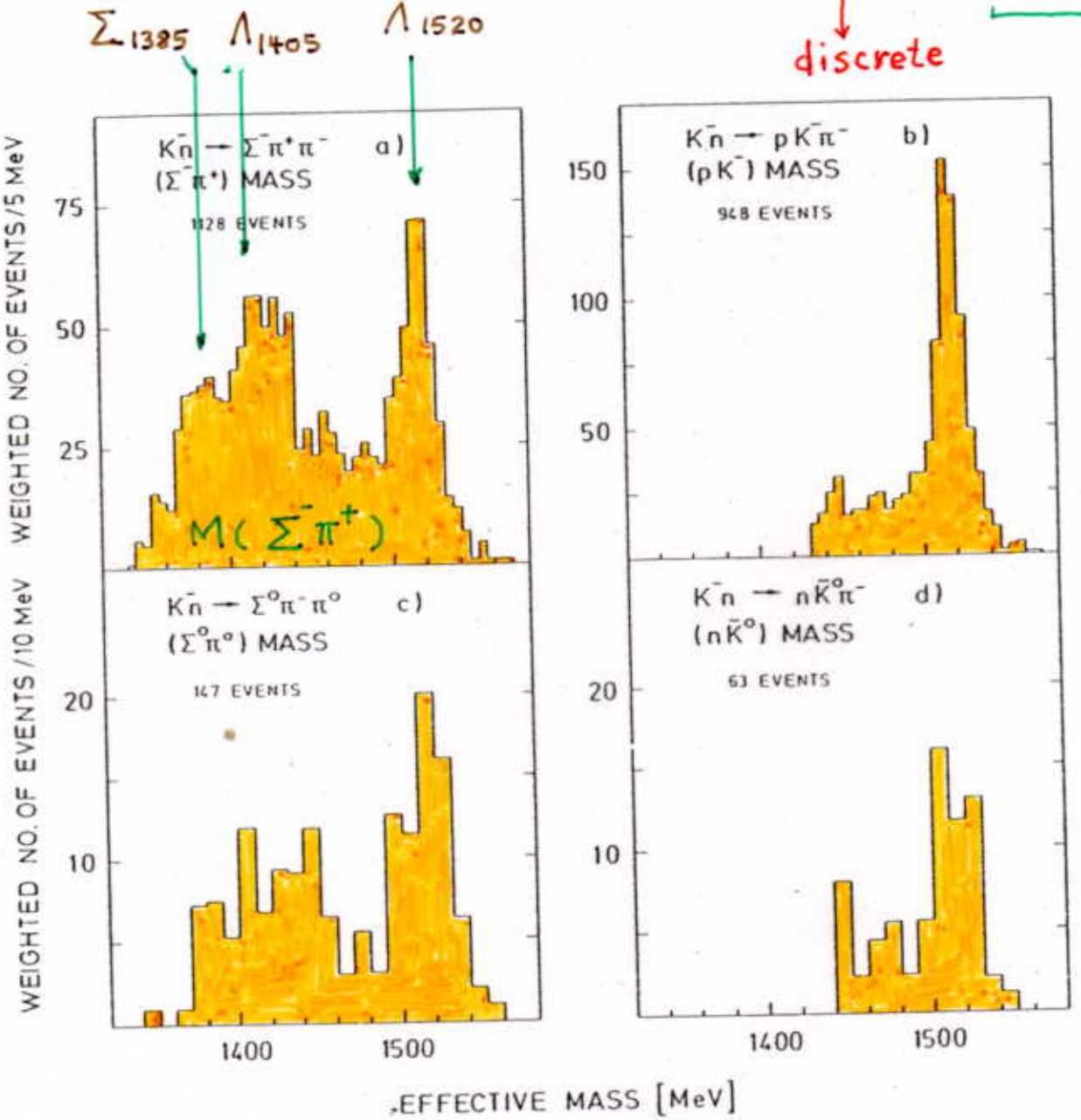


Fig. 11. Distribution of invariant masses: (a) $\Sigma^-\pi^+$ in the reaction $K^-n \to \Sigma^-\pi^+\pi^-$; (b) pK^- in the reaction $K^-n \to pK^-\pi^-$; (c) $\Sigma^0\pi^0$ in the reaction $K^-n \to \Sigma^0\pi^-\pi^0$; (d) $n\bar{K}^0$ in the reaction $K^-n \to n\bar{K}^0\pi^-$.

Hepp et al. (1976)

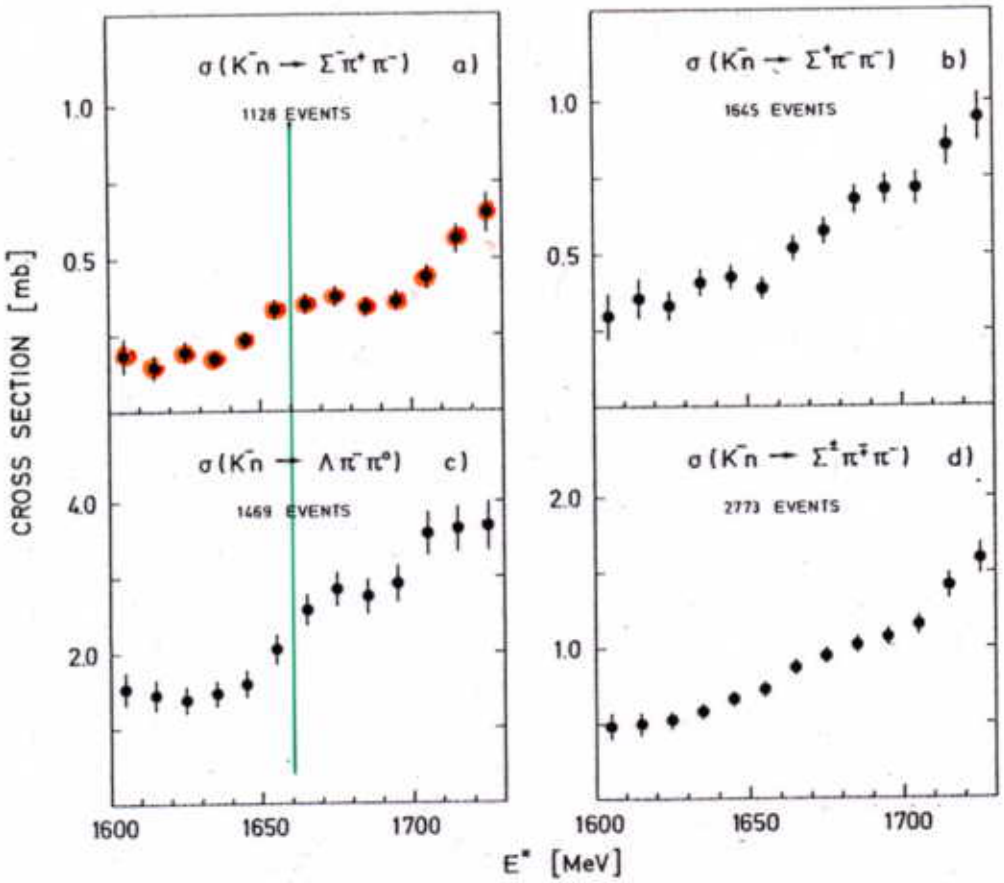


Fig. 8. Cross sections for the three-body reactions (4) to (6). The points in fig. 8d are the sum of the corresponding points in figs. 8a and 8b.

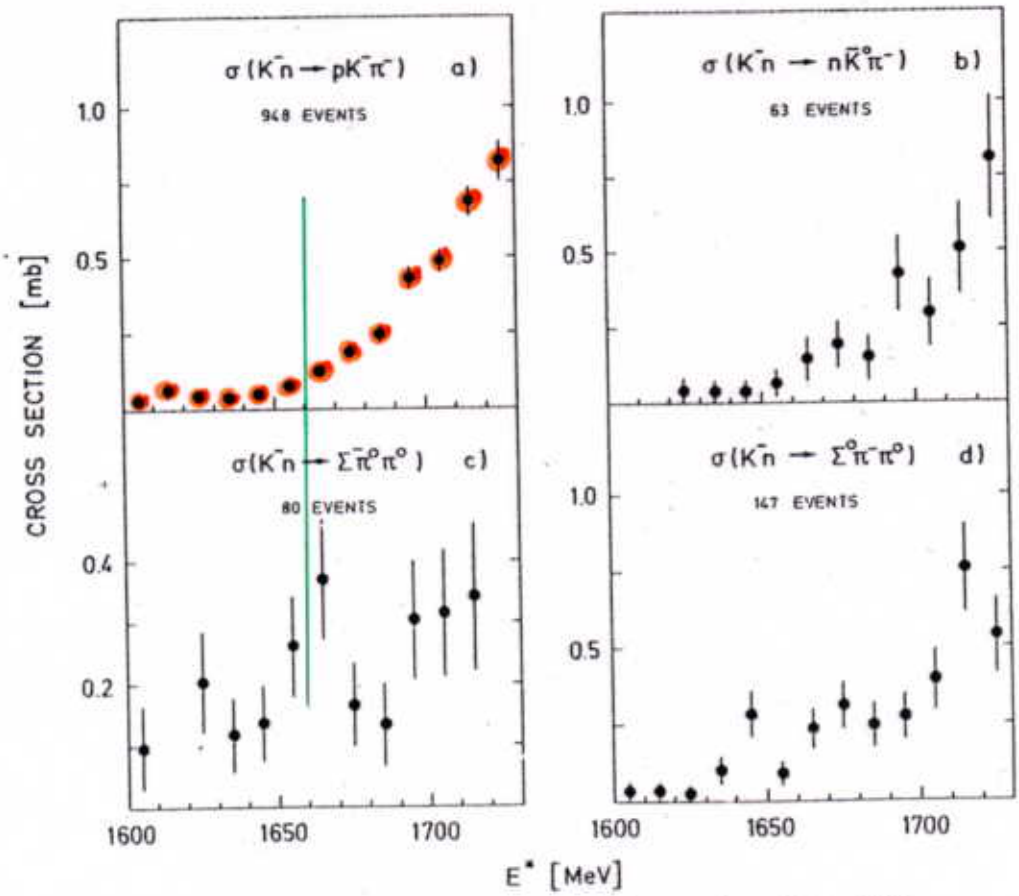


Fig. 9. Cross sections for the three-body reactions (7) to (10).

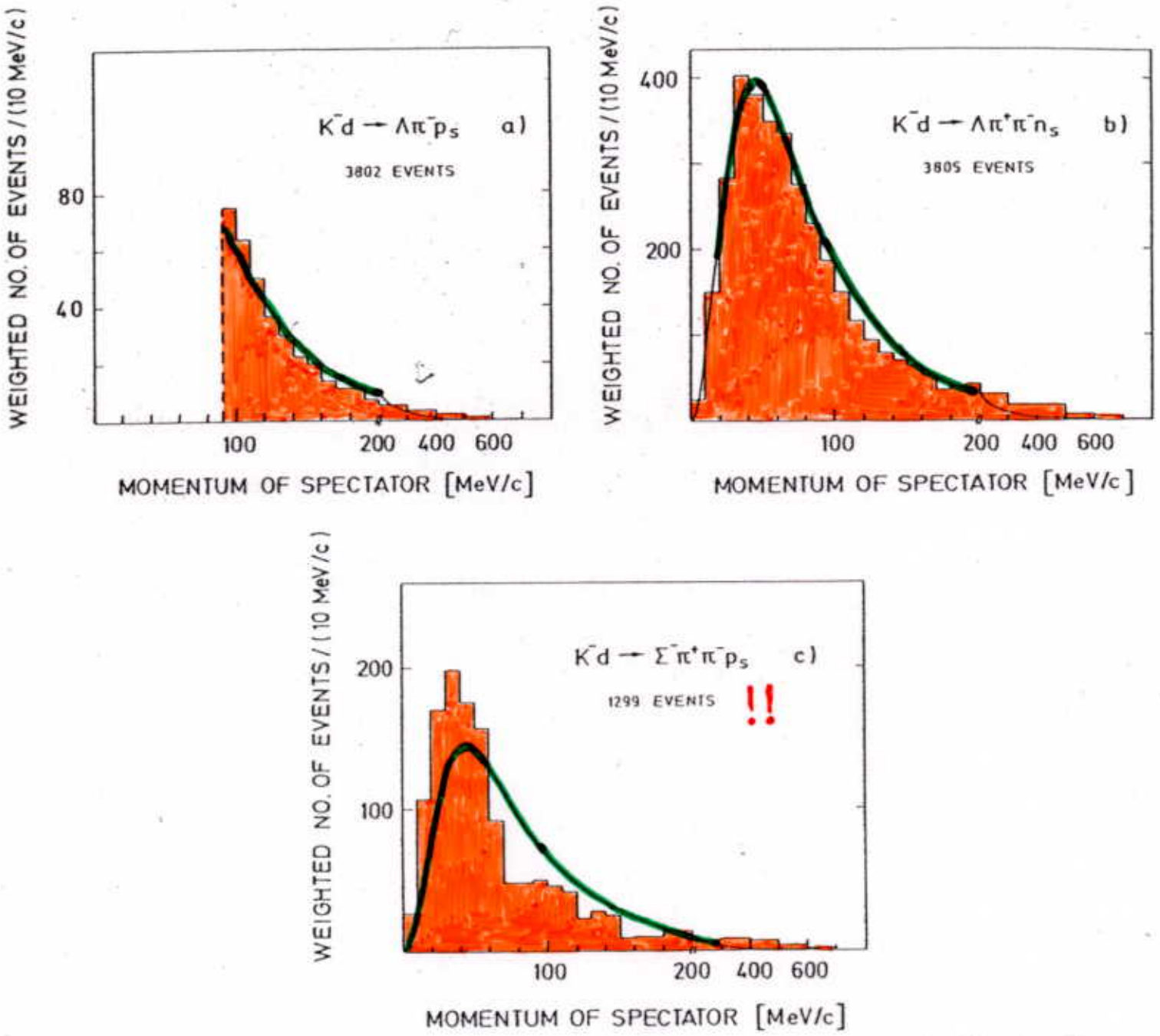
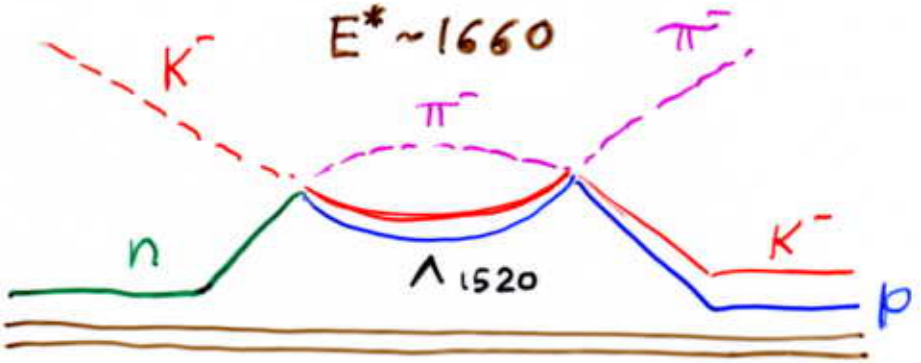
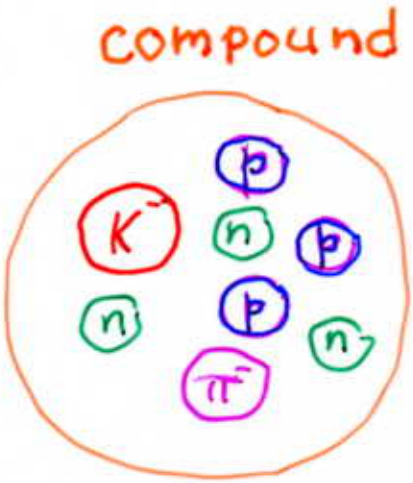


Fig. 3. Momentum distribution for the spectator particle for the reactions: (a) $K^-d \to \Lambda\pi^-p_S$; (b) $K^-d \to \Lambda\pi^+\pi^-n_S$, (c) $K^-d \to \Sigma^-\pi^+\pi^-p_S$. The curves represent the momentum distribution derived from the Reid wave function of the deuteron. The curves are normalized to the number of events below 300 MeV/c.

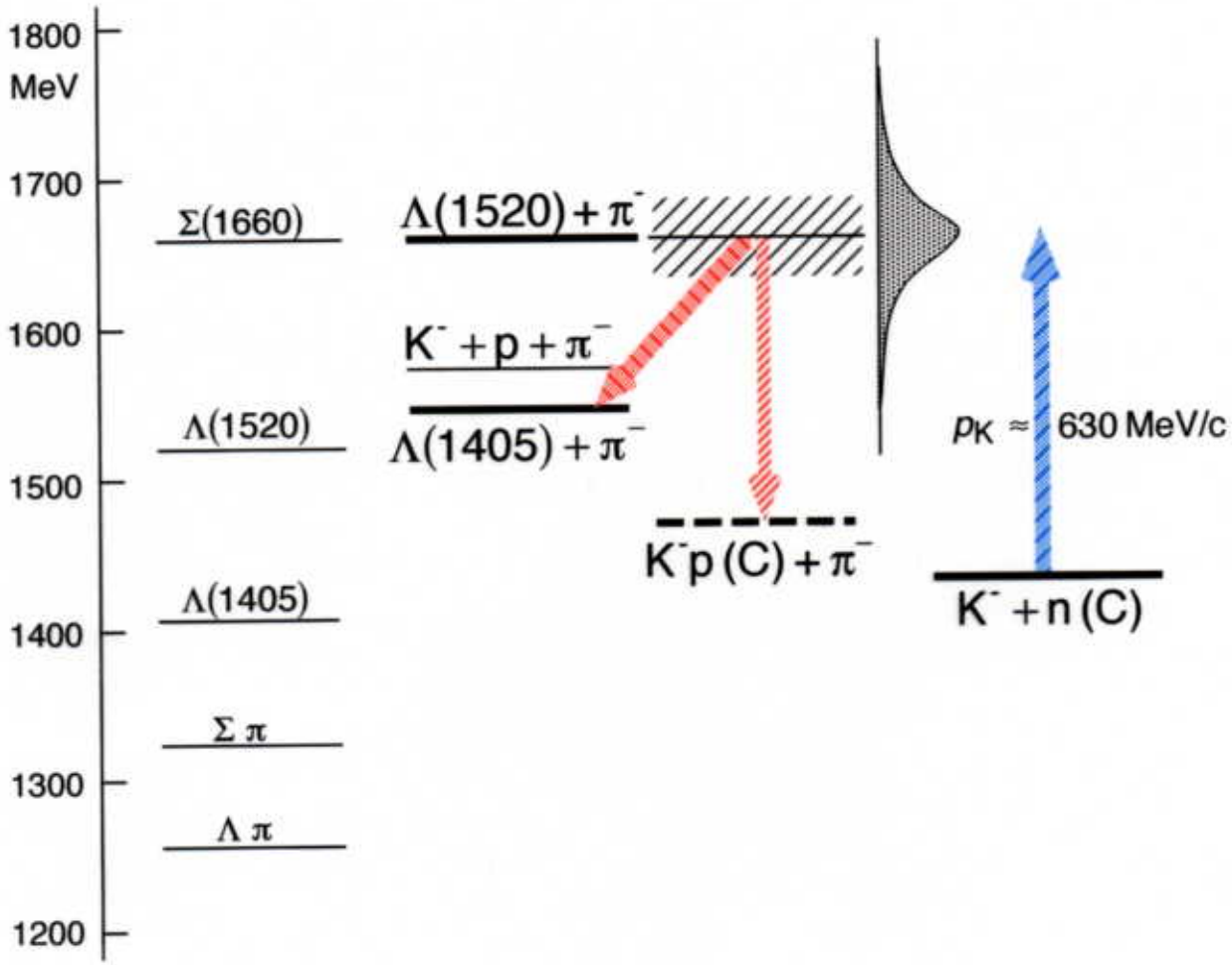
Resonant Formation of $\bar{K}$ Compound Nucleus





$\Lambda_{1405} + \pi^-$

$\bar{K}$-nucleus $+ \pi^-$


1800
MeV
1700
1600
1500
1400
1300
1200
Σ(1660)
Λ(1520)
Λ(1405)
Σ π
Λ π
Λ(1520) + π⁻
K⁻ + p + π⁻
Λ(1405) + π⁻
K⁻p (C) + π⁻
pK ≈ 630 MeV/c
K⁻ + n (C)

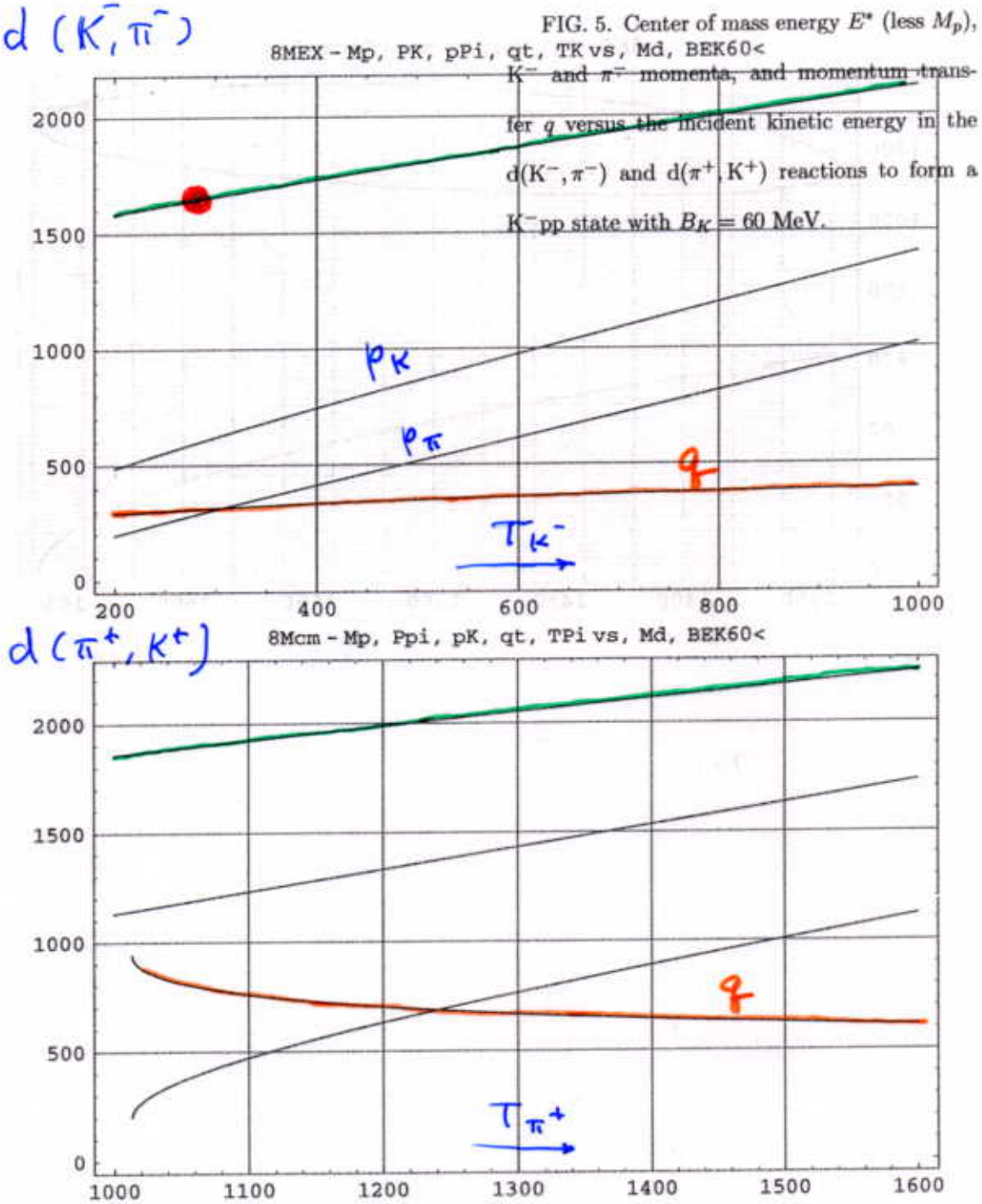
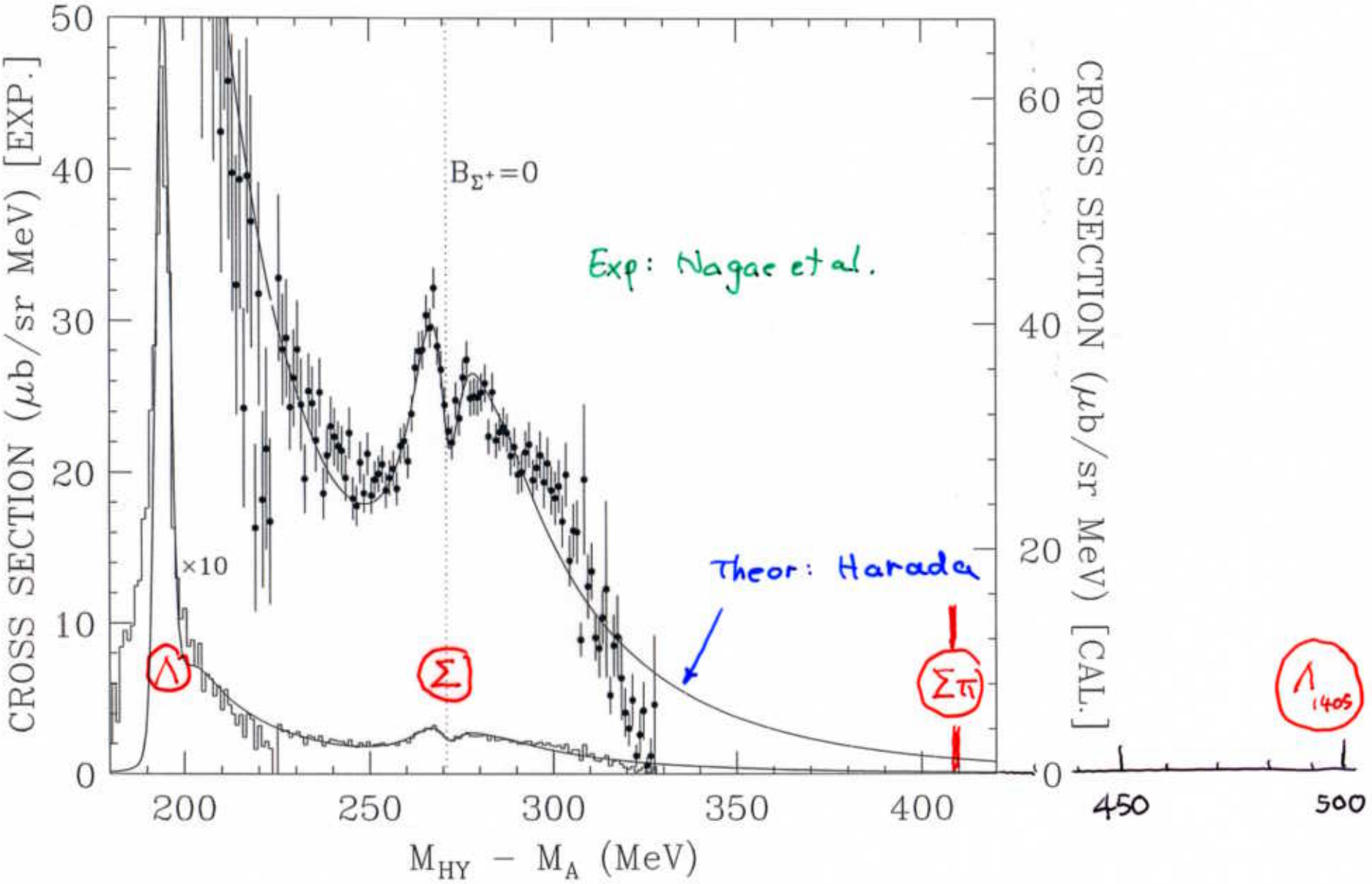
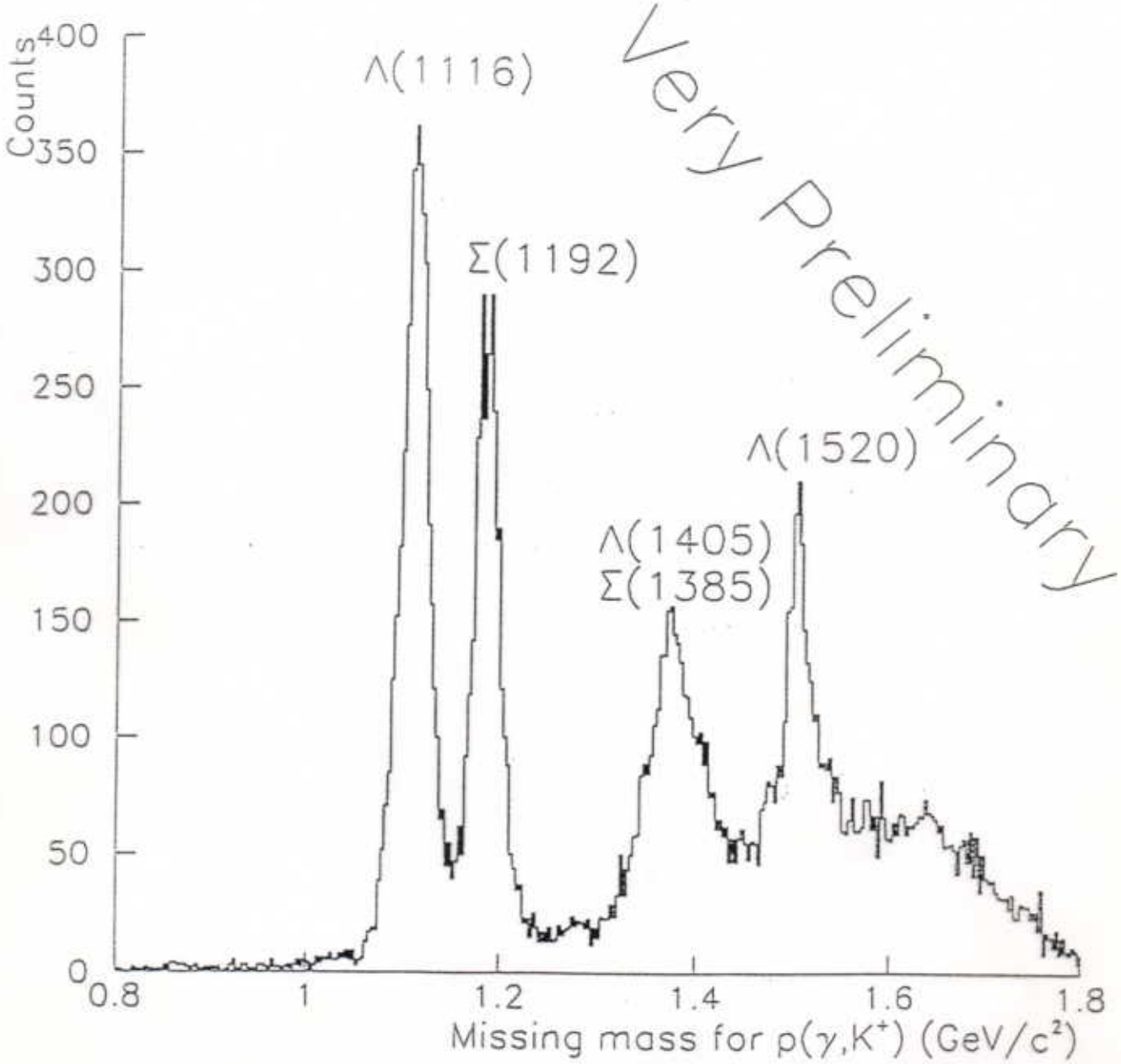


FIG. 5. Center of mass energy E^* (less M_p), K^- and π^- momenta, and momentum transfer q versus the incident kinetic energy in the $d(K^-,\pi^-)$ and $d(\pi^+,K^+)$ reactions to form a K^-pp state with $B_K = 60$ MeV.

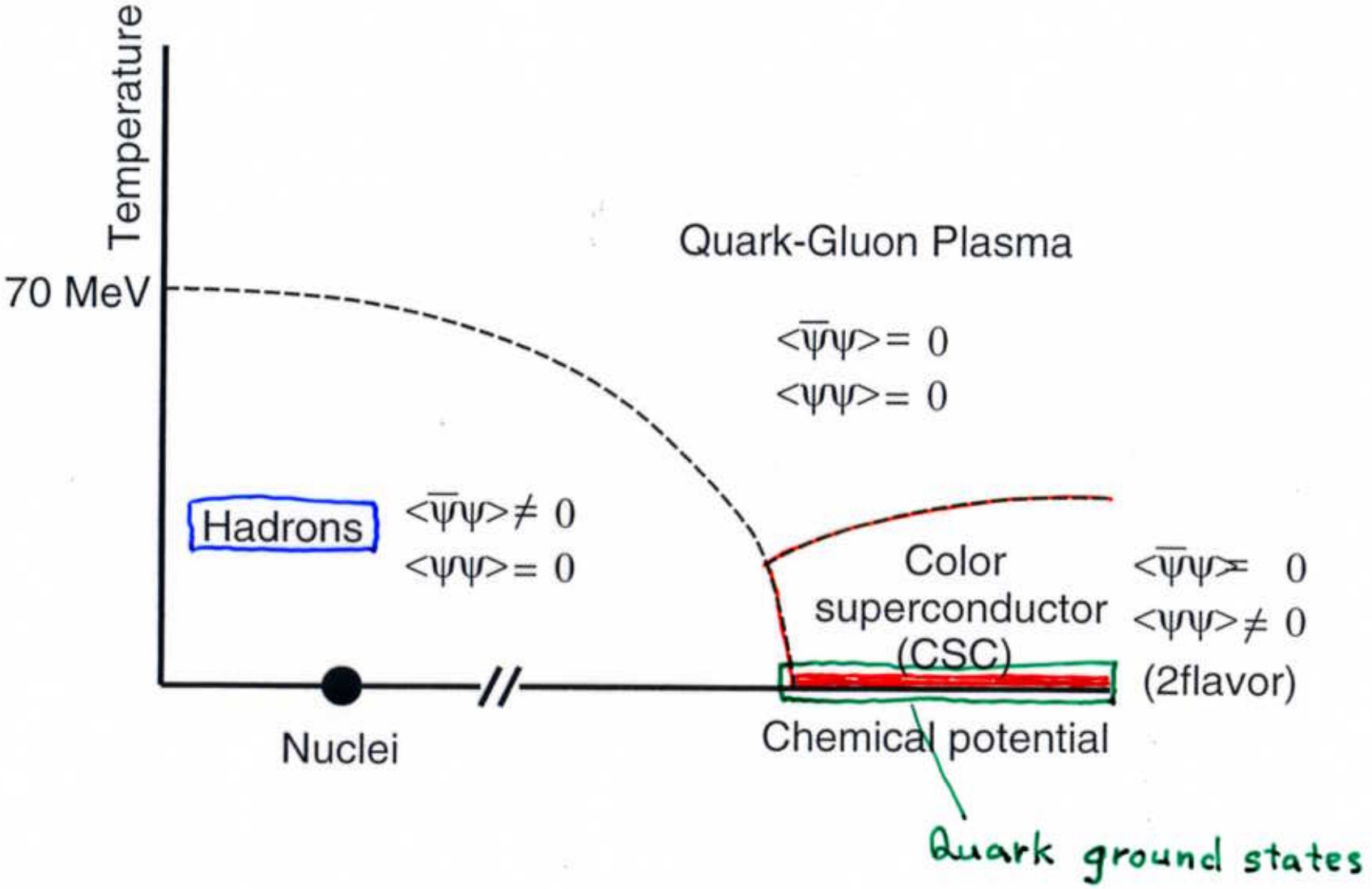
^{4}He(K^-, π^-) ~ 600 MeV/c K^-





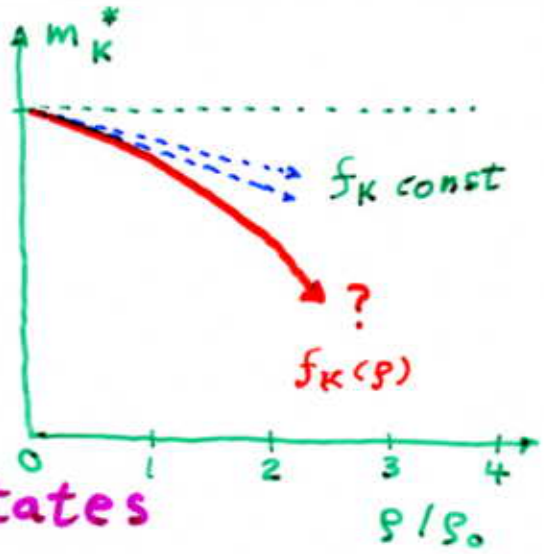
SPring8

J.K.Ahn


Temperature
70 MeV
Quark-Gluon Plasma
$\langle\bar{\psi}\psi\rangle = 0$
$\langle\psi\psi\rangle = 0$
Hadrons
$\langle\bar{\psi}\psi\rangle \neq 0$
$\langle\psi\psi\rangle = 0$
Color superconductor (CSC)
$\langle\bar{\psi}\psi\rangle = 0$
$\langle\psi\psi\rangle \neq 0$
(2flavor)
Nuclei
Chemical potential
Quark ground states

A new paradigm

$\bar{K}$ NUCLEI



Very deep discrete states

$B_{\bar{K}} \gtrsim 100$ MeV

Highly excited resonance states

$E_{\bar{K}N} - E_\Lambda \sim 200$ MeV

→ In-medium $\bar{K}N$ interaction

f_K restored ? $f_K(\rho)$

→ High-density nuclear matter formed around $\bar{K}$ at T = 0

→ Quark-gluon phase ?

→ Kaon condensation, Strange matter

→ Nuclear dynamics under extreme conditions

proton-neutron segregation

compression

To be investigated

KEK, BNL, DAΦNE, ...

JHF