Kaonic Atoms and $\Lambda(1405)$

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$\Lambda(1405)$ Qspires : ~ 400 entries
6 new experimental results s in recent 3 years

- brief reminder of theories

- the profile of $\Lambda(1405)$ in $\Sigma\ \pi$ channels -new experiments

- the profile of $\Lambda(1405)$ in $\bar{K}$ channel - kaonic atoms and nuclei

The essential theoretical models are:
(a) Quark model - problems with fine structure
(b) Quasi-bound I =0 $\bar{K}$N state decaying to $\Sigma\ \pi$.
(c) a superposition of both

Essential problem : continuation from physical region to resonant region is parameter unstable

Σ(1385) Λ(1405) KN (experiments)

Look below threshold

Experiments : Σπ- final state spectra

bound K-meson -K atoms, nuclear capture

Models : potentials, effective (chiral) approach,

selfconsistent dispersion relations

profile of $\Lambda(1405)$ in $\Sigma\ \pi$ channels

observed with the initial $\mathrm{K}^-\ p$

$$T(K^-\ p\ \rightarrow \Sigma^+\ \pi^-) = \frac{1}{\sqrt{6}}\ T_0\ +\ \frac{1}{2}\ T_1$$

$$T(K^-\ p\ \rightarrow \Sigma^-\ \pi^+) = \frac{1}{\sqrt{6}}\ T_0\ -\ \frac{1}{2}\ T_1$$

$$T(K^-\ p\ \rightarrow \Sigma^0\ \pi^0)\ = \frac{1}{3}\ T_0$$

three separate maxima

observed with an initial $\Sigma\ \pi$

$$F(\Sigma^+\ \pi^-\ \rightarrow \Sigma^+\ \pi^-) = \frac{1}{3}\ F_0\ +\ F_1\ \frac{1}{2}\ +\ F_2\ \frac{1}{6}$$

$$F(\Sigma^-\ \pi^+\ \rightarrow \Sigma^-\ \pi^+) = \frac{1}{3}\ F_0\ +\ F_1\ \frac{1}{2}\ +\ F_2\ \frac{1}{6}$$

$$F(\Sigma^0\ \pi^0\ \rightarrow \Sigma^0\ \pi^0)\ = \frac{1}{3}\ F_0\ + \frac{2}{3}\ F_2$$

two separate maxima

Recent experiments

TABLE I: Maxima in the $\Sigma\pi$ spectra, recent experiments

channel	$\gamma p \to K^+ \Sigma \pi$ CLAS	$pp \to p K^+ \Sigma \pi$ ANKE, HADES
	E_{max}	E_{max}
Σ^+, π^-	1420	1400
Σ^0, π^0	1415	1390
Σ^-, π^+	1410	1400

CLAS: K.Moriya R. Schumacher arXiv: 0911270v1
HADES: J.Siebenson arXiv: 1009.0946v1
ANKE: I. Zychor et al, Phys. Lett. B660(2008)167

TABLE II: Maxima in the $\Sigma\pi$ spectra

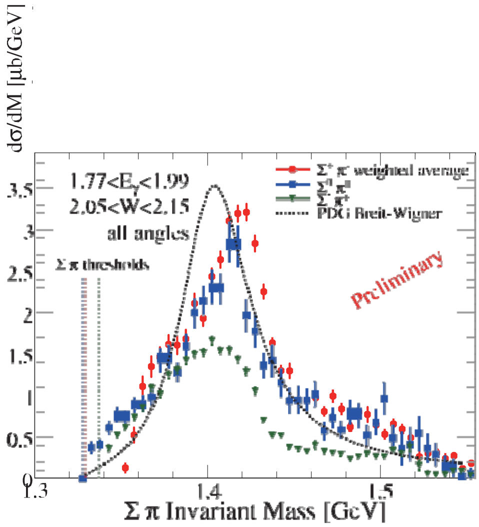
channel	$\gamma p \to K^+ \Sigma \pi$ CLAS		$pp \to K^+ \Sigma \pi$p ANKE, HADES
	E_{max}	$(coupling)^2$ to $K^*(892)$	E_{max}
Σ^+, π^-	1420	2/3	1400
Σ^0, π^0	1415	1/3	1390
Σ^-, π^+	1410	0	1400

ELECTRO-PRODUCTION $ep \to K^+ \Sigma^- \pi+$
CLAS: M. Lu, R. Schumacher et al arXiv: 1108.1809v1

Conclusion

Accessible final states contain 3 or more strongly interacting particles,
precise description is difficult.

It makes sense to look into alternative elastic KN interactions with bound N or bound K



photoproduction CLAS : Moriya, Schumacher , arXive 0911.2705v1

Extraction of absorptive KN amplitudes from atomic level widths

Ω = atomic –nuclear overlap is small

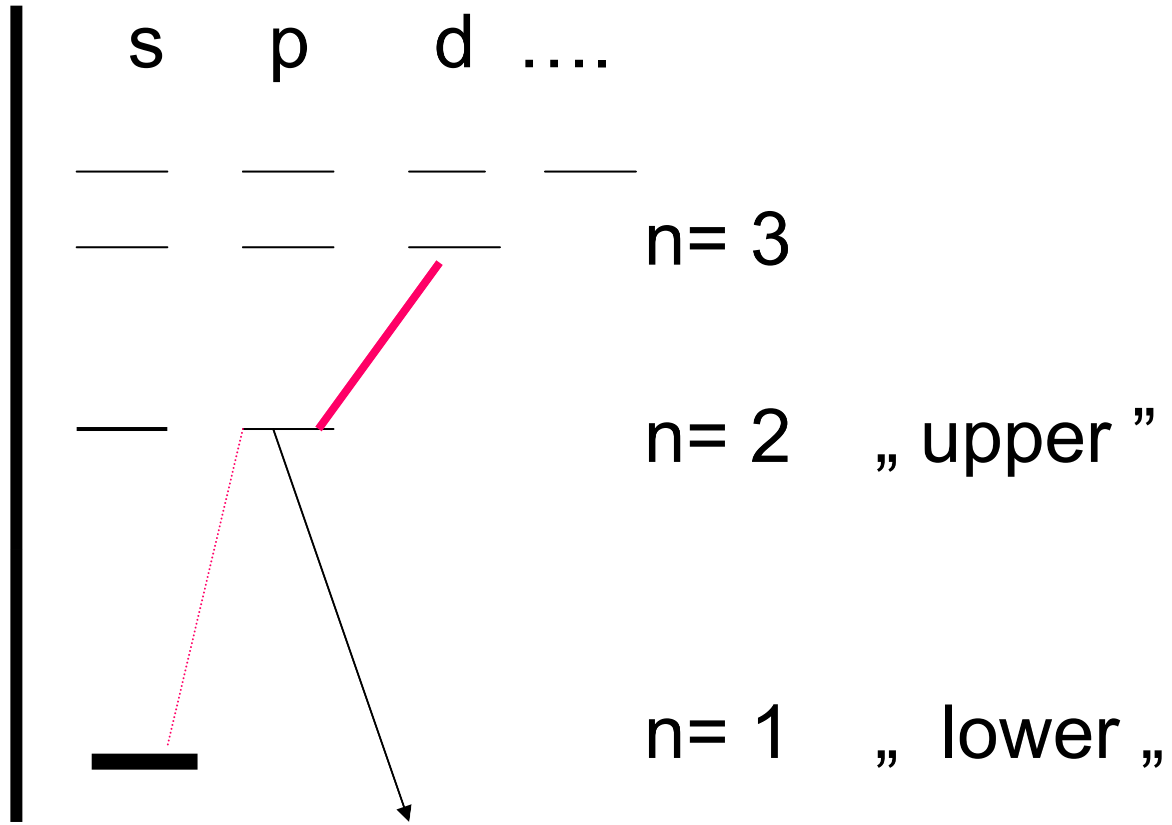
$\Gamma = \mathrm{Im}\, \Sigma_i\ a_{KN}\,(E_i = -\,\mathrm{BINDING}_i - \mathrm{RECOIL}\,)\ \Omega_i$

almost correct

Involve subthreshold energies (-40 – 0) MeV

Optimum : one valence nuclear shell
few MeV spread by recoil

„upper levels „



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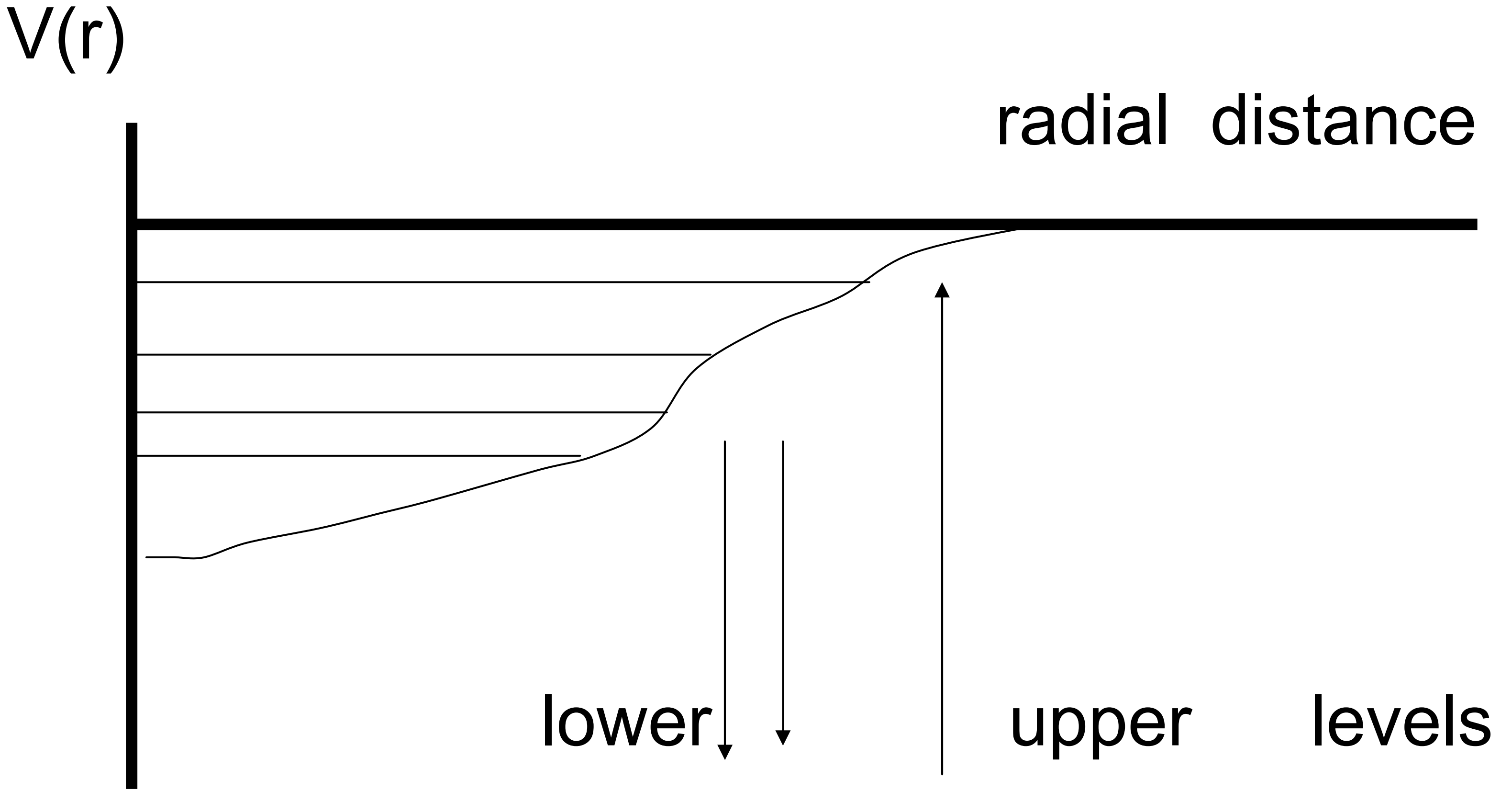
Nucleon levels „seen” in atoms



Upper levels „do not fit „

E. Friedman , A.Gal

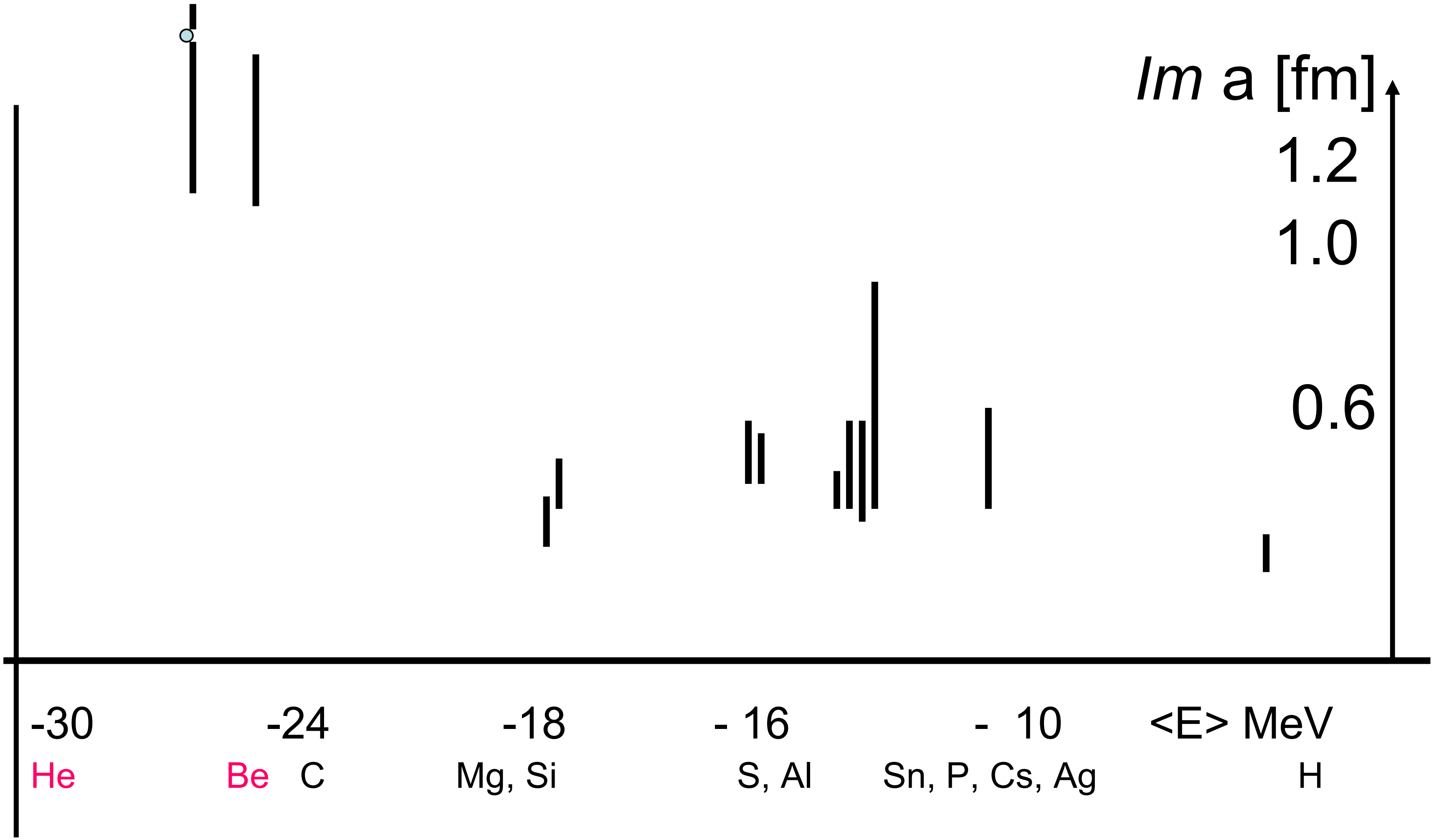
Im a= 0.37 fm   upper levels
Im a= 0.94 fm   lower levels

$\Gamma \sim \; Im \quad a_{KN}(E = -BINDING \; - RECOIL \;)$

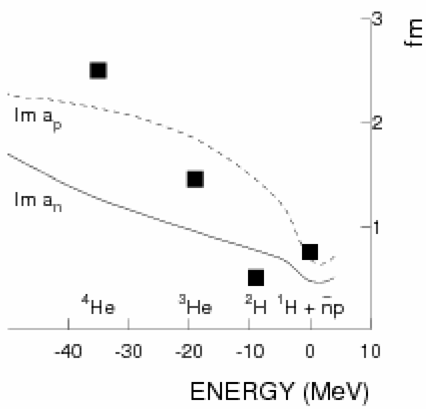
5 - 25 % accurate   in upper levels

impulse approx. not valid
in lower levels

Im $\langle a_{KN} \rangle$ extracted from upper atomic levels



Im a(E) extracted from light antiprotonic atoms - PS 207 data



Paris model

Im a(KN) extracted from upper widths

nucleus	E_S	$\Gamma[eV]$	Im $a[fm]$	Im $a[fm]$	Im $a[fm]$	Im $a[fm]$
			impulse	Re $a = 0$	Re $a = -0.5$	Re $a = -0.7$
^{4}He	20	-	-	-	-	-
^{9}Be	16.9	0.04(.02)	1.39(0.70)	-	-	-
^{12}C	15.9	0.98(.16)	1.23(0.25)	1.45	1.18	1.04
^{24}Mg	11.7	0.08(.03)	0.40(0.15)	-	-	-
^{28}Si	11.6	0.53(.06)	0.52(0.06)	-	-	-
^{32}S	8.6	3.10(.36)	0.74(0.08)	0.95	0.66	0.52
^{27}Al	8.3	0.30(.04)	0.62(0.08)	-	-	-
^{112}Sn	7.5	15.1(4.4)	0.52(0.15)	-	-	-
^{31}P	7.3	1.44(.41)	0.64(0.18)	0.79	0.52	0.35
^{37}Cl	6.4	5.7 (1.5)	0.60(0.23)	0.78	0.47	0.32
^{65}Cu	6.1	7.0(3.8)	0.850(0.45)	-	-	-
^{113}In	6.1	11.4(3.7)	0.51(0.33)	-	-	-
^{107}Ag	5.8	7.3(4.7)	0.61(0.39)	-	-	-
^{108}Cd	5.8	6.2(2.8)	0.32(0.14)	-	-	-

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Favourite situation for studying Γ_{upper}

one or few nucleon orbitals

perfect P,D,He,

good Li, Be, C, N,O,

resonable in almost all atoms

2 parameters to extract

Im $a_{0\ \Lambda(1405)}$ (E) , Im $a_{K,neutron}$

P wave from Σ(1385) – known

corrected by central optical potential

K-neutron dominated widths

Upper widths due mostly to Kn , S + P w

Pb → *Im* a (K^-n)

U →

^{208}Pb	8.0	4.1(2.0))	**1.24(0.60)**
^{238}U	7.6	15.1(4.4)	**1.36(0.39)**

Large part due to Σ(1385)

Another possibility to study sub-threshold elastic KN or K-nucleus amplitude

an old idea

K-hydrogen $\rightarrow \Lambda(1405) + \gamma$

Kaons lost in cascade

Kaonic Hydrogen ~ 95% lost

How many go to $\Lambda(1405) + \gamma$?

Old BNL experiment

$K^- p \rightarrow \Sigma(1190)\ \gamma$

Found on the level of 1/1000

D.A.Whitehouse ..PRL.63(89)1352; K.D.Larsen.. Phys.Rev D47(93)799

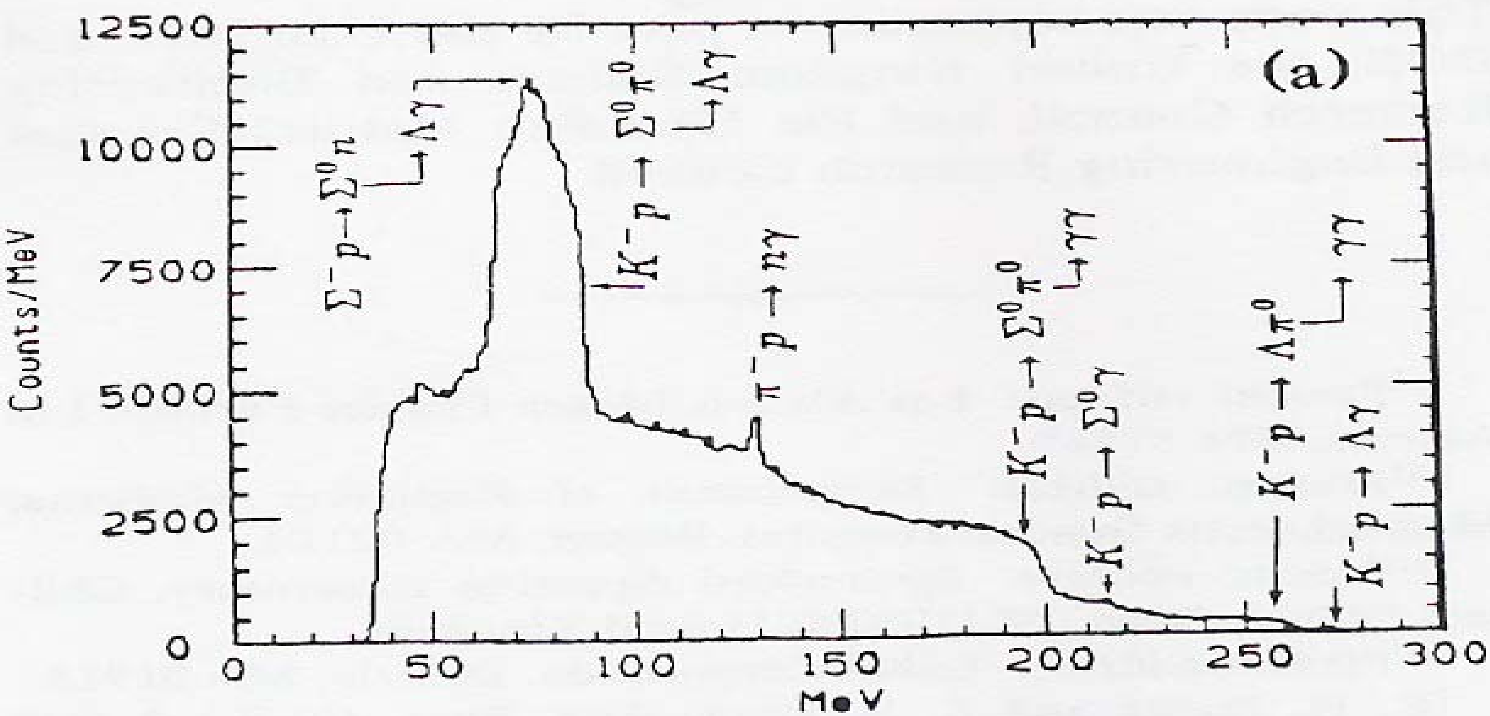
$K^- p \rightarrow \Lambda(1405)\ \gamma$

Is it feasible ?

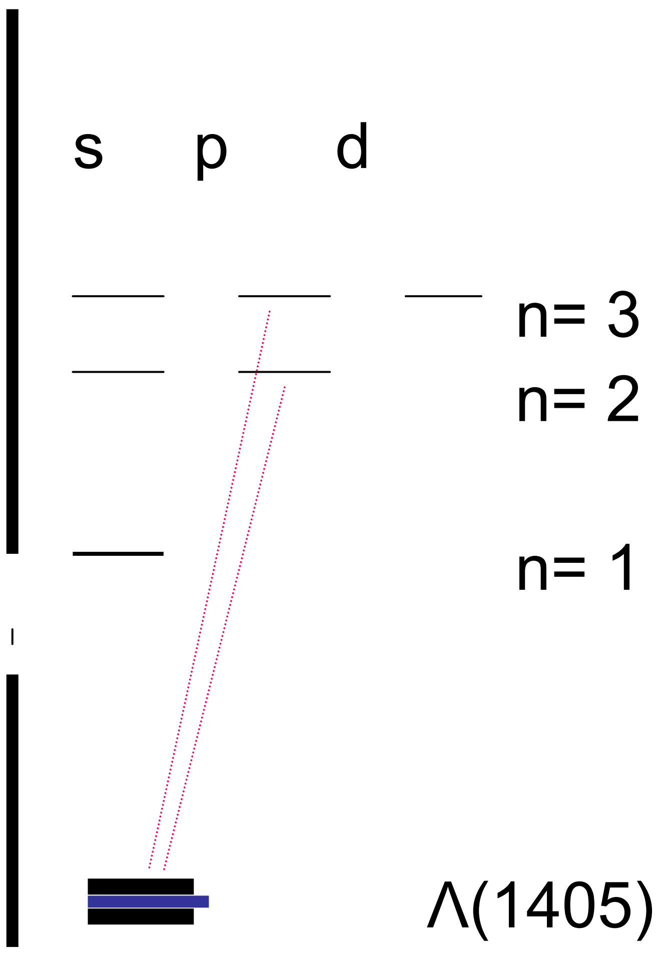
What is the line shape ?

High energy photons from K^- p atom

VOLUME 63, NUMBER 13 PHYSICAL REVI



Gamma rays to Λ(1405) make ~5 10^{-3} of captures from (n P) levels



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Occupation and capture from all (n,P) states

estimated captures from n P states in gas targets

~ few % of stopped K mesons

Total chance for γ transition

~ 0.001-0.0001

per stopped kaon

Kaonic deuterium atom → KNN

Deep state ~100 MeV (FINUDA, DISTO)

Very small chance

Weakly bound or virtual state ~ 47 MeV

P+Σ(1385) sw Phys. Rev C 79

Good chance

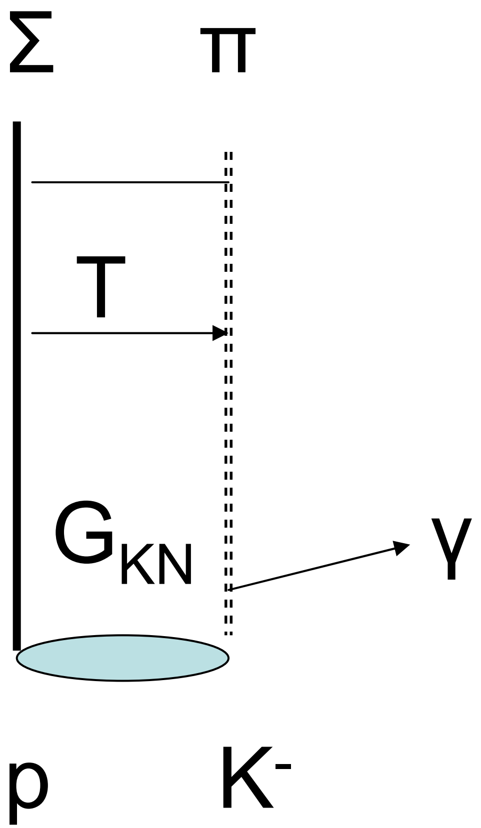
Line shape

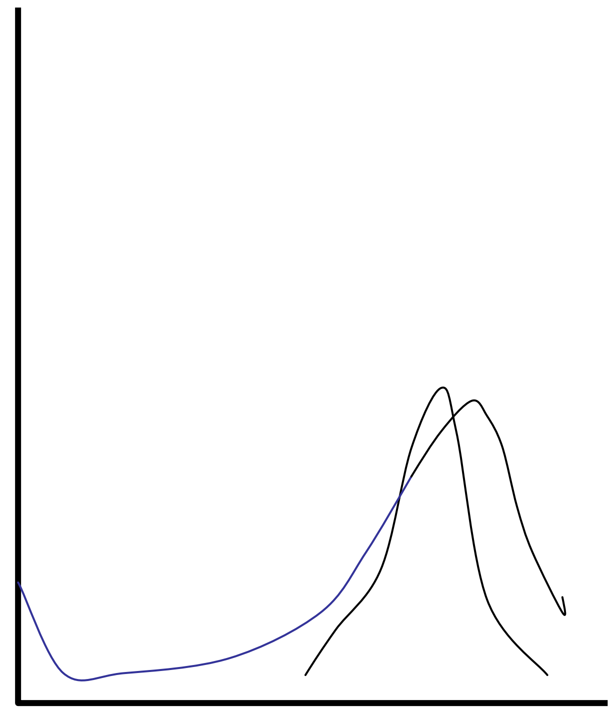
$\Gamma = \int dk \ \ S(k)$

$S(k) = Im \quad T_{KN,KN} \ (E_o - k) \quad k \quad G_{KN}(k)$

LINE SHAPE

resonance●propagator●phase space





Summary

- extraction of Λ(1405) from Σπ spectrum seems difficult

- Upper widths in K atoms allow to find *Im* $T_{KN,KN}$ (E)
to -40 MeV down below threshold

- K -Atom → K-Nuclear + γ
in hydrogen may give elastic
Im T_{KN}(E)
Experiments are difficult

Upper levels –suggestions

Interesting measurements

- He (2p)
- Be , C , repetition
- Sn 112,116,118,124 – different proton bindings

Pb 208 Kn parameters in addition to D