Spectroscopic Study of Hyperon Resonances below $K^{bar}N$ Threshold via the (K^-,n) Reaction on Deuteron

H. Noumi, *Osaka Univ. RCNP*, for the P31 collaboration

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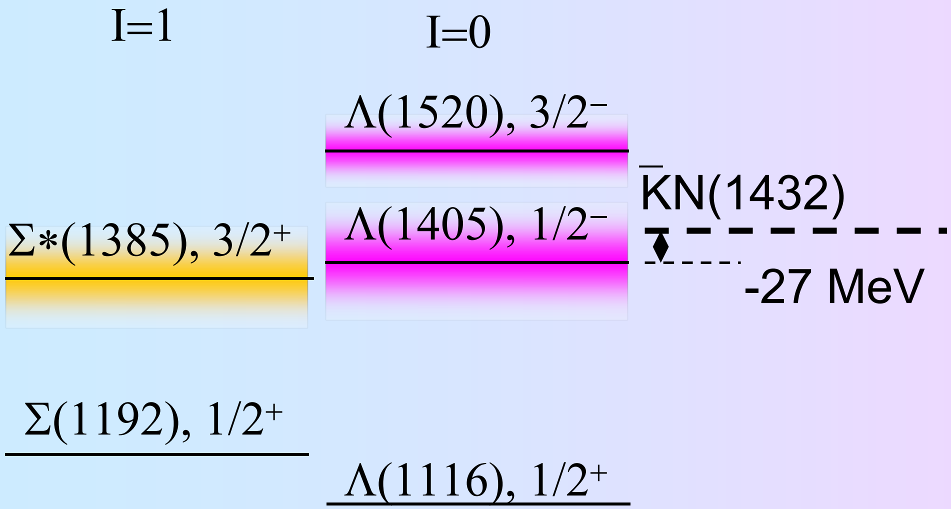
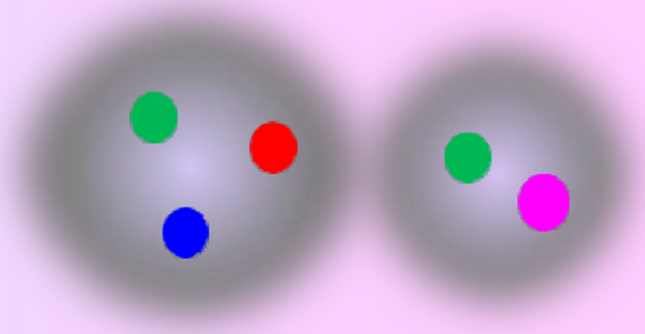
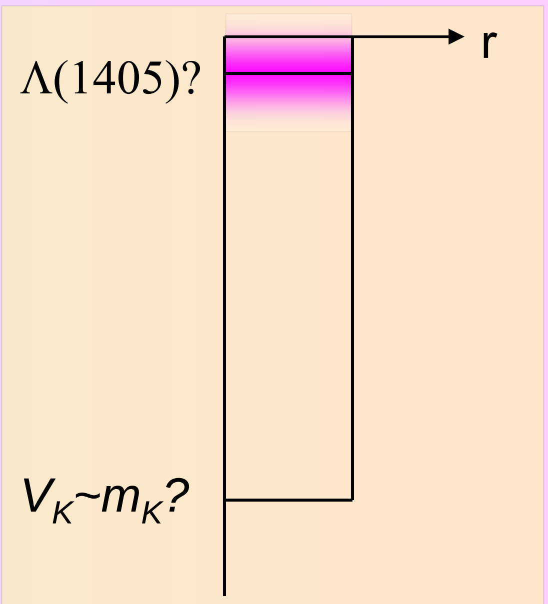
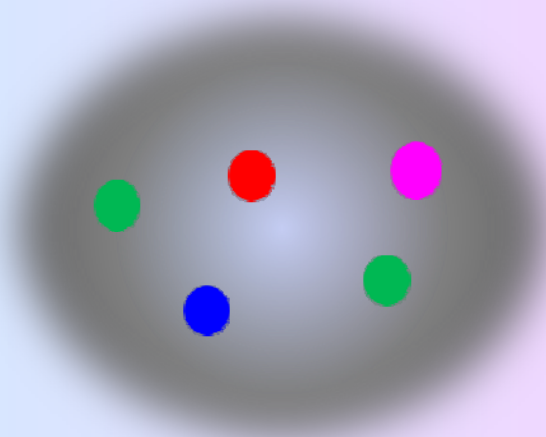
1. Introduction:
   $K^{bar}N$ int. and Λ(1405)
2. Experimental Method
   d(K-,n)$\pi\Sigma$ w/ the E15 setup
3. Summary

What is Λ(1405)?





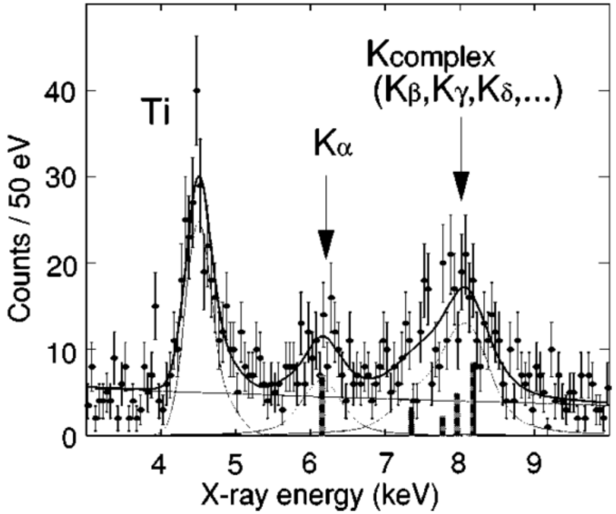




$K^{bar}N$ Interaction

- ✓ Low E K-p scattering data suggest: Attractive (S=0)
- ✓ K-p atomic X-ray shift :
  Repulsive Shift at 1s energy reg.

M.Iwasaki *et al.*, PRL78 (1997) 3067



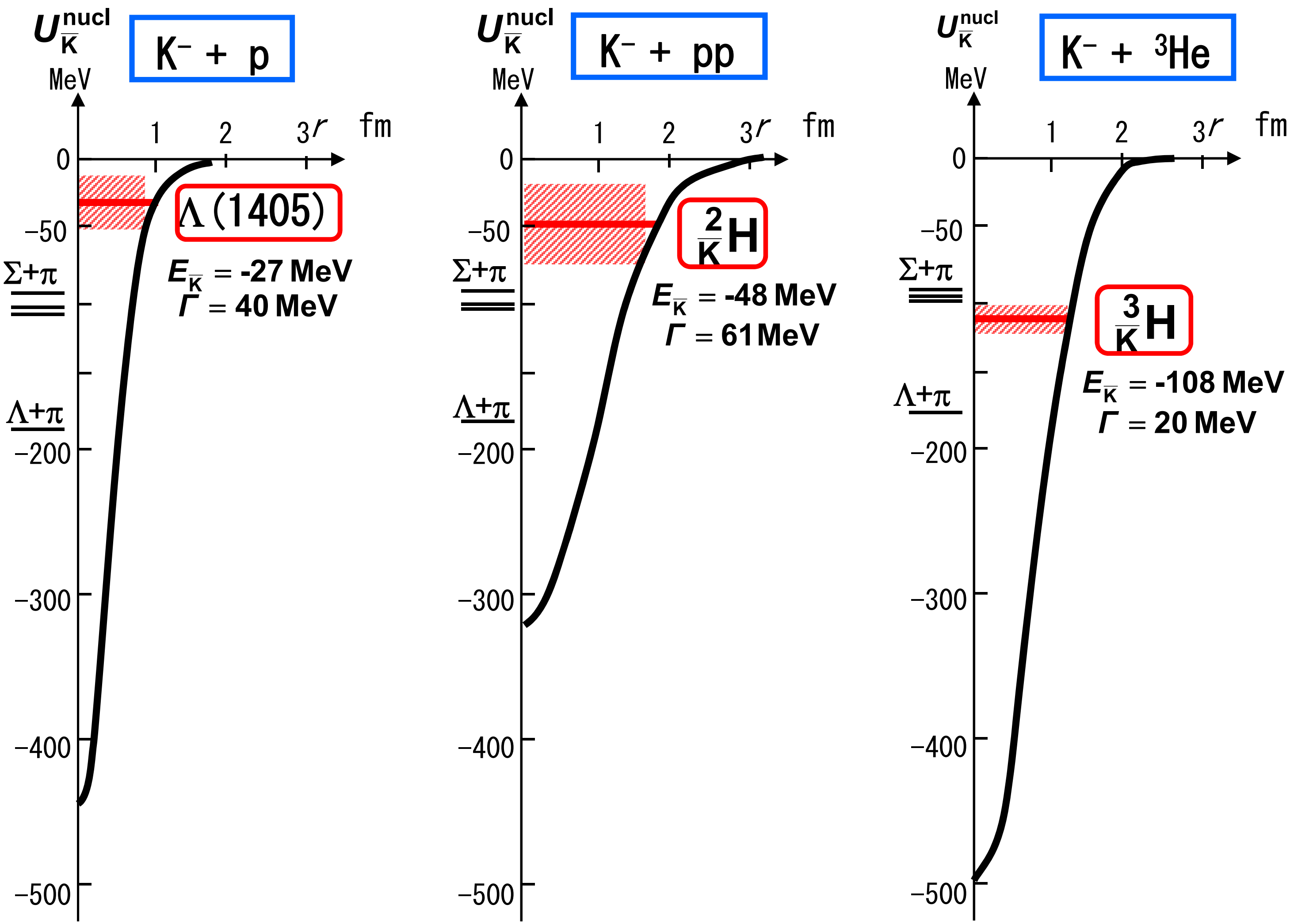
Suggests <u>Strongly Attractive $K^{bar}N$</u> Int.

Is "<u>True" 1s State</u> deeply bound ?

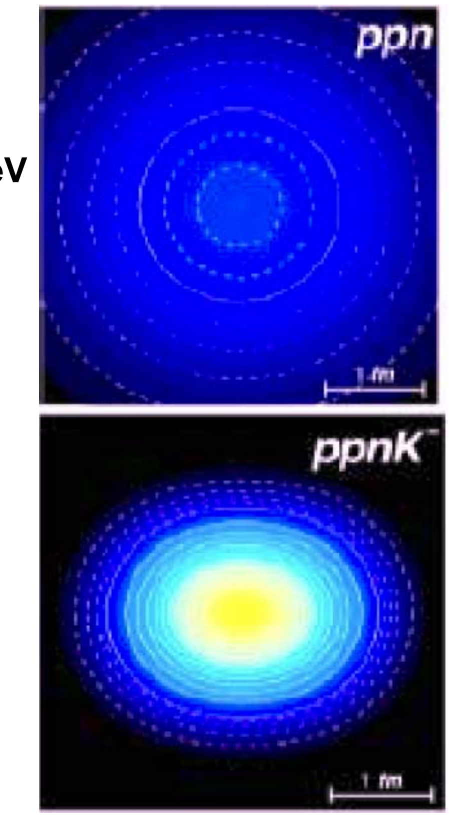
= Λ(1405) : S_{01} ?

If so, deeply bound Kaonic Nucleus…?

Deeply Bound K⁻-Nucleus System ?



Dote et al.



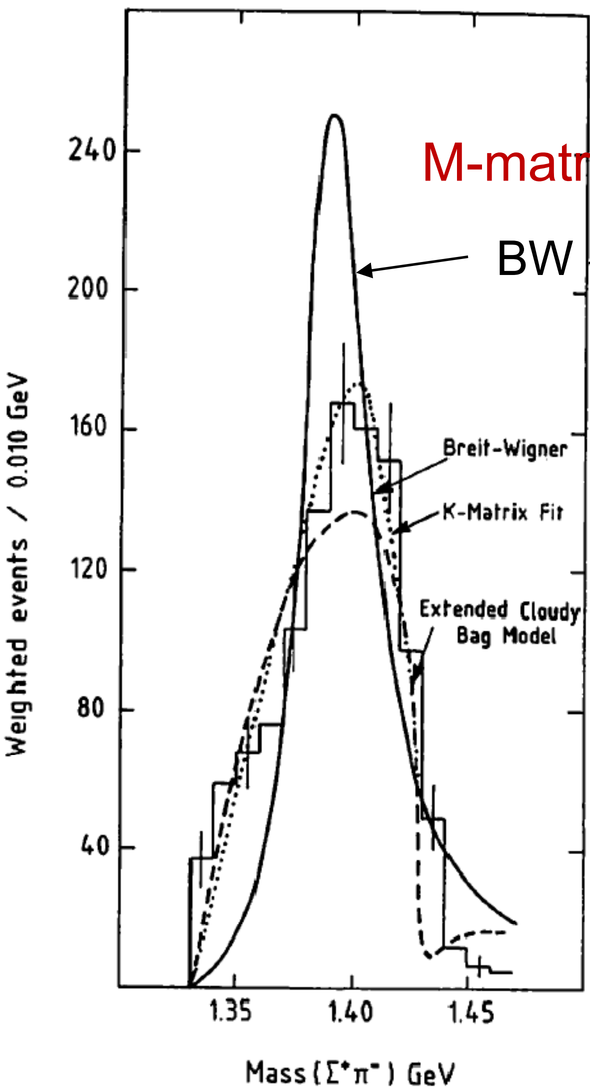
Y. Akaishi & T. Yamazaki, Phys. Rev. C65 (2002) 044005.
Y. Akaishi & T. Yamazaki, Phys. Lett. B535 (2002) 70.

In PDG2007…

$\Lambda(1405)\ S_{01}$

$I(J^P) = 0(\frac{1}{2}^-)$ Status: ∗∗∗∗

See the note on "The $\Lambda(1405)$" in our 2000 edition, Eur. Phys. J. **C15**, p. 748 (2000). For a recent discussion and earlier references on evidence for a 2-pole structure of the $\Lambda(1405)$ see MAGAS 05.



$\Lambda(1405)$ MASS

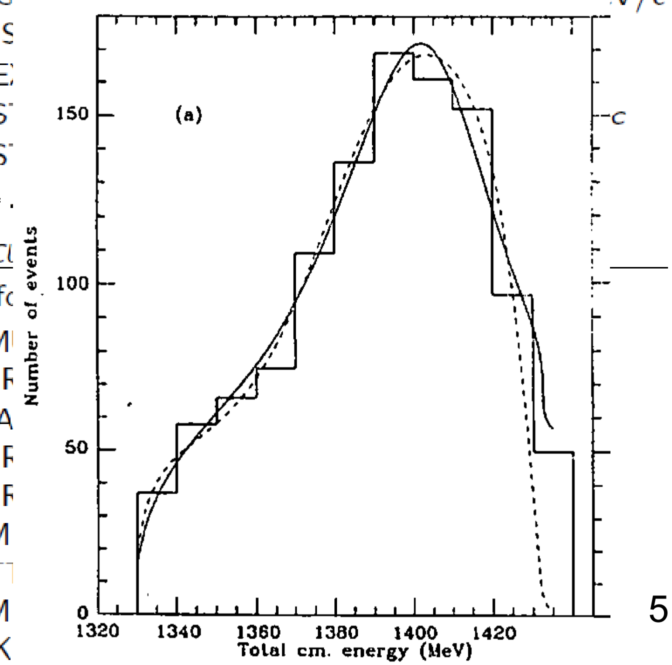
PRODUCTION EXPERIMENTS

M-matrix→

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1406.5±4.0		[1] DALITZ	91		M-matrix fit
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1391 + 1	700	[1] HEMINGWAY	85	HBC	$K^- p$ 4.2 GeV/c
~ 1405	400	[2] THOMAS	73	HBC	$\pi^- p$ 1.69 GeV/c
1405	120	BARBARO-...	68B	DBC	$K^- d$ 2.1–2.7 GeV/c
1400 ± 5	67	BIRMINGHAM	66	HBC	$K^- p$ 3.5 GeV/c
1382 ± 8		ENGLER	65	HDBC	$\pi^- p$, $\pi^+ d$ 1.68 GeV/c
1400 ±24		MUS			
1410		ALE			
1405		ALS			
1405		ALS			

EXTRAPOLATIONS BELOW $N\overline{K}$

VALUE (MeV)	*DOCU*
• • • We do not use the following data fo	
1407.56 or 1407.50	[3] KIM
1411	[4] MAR
1406	[5] CHA
1421	MAR
1416 ±4	MAR
1403 ±3	KIM
1407.5±1.2	[6] KIT
1410.7±1.0	KIM
1409.6±1.7	[6] SAK



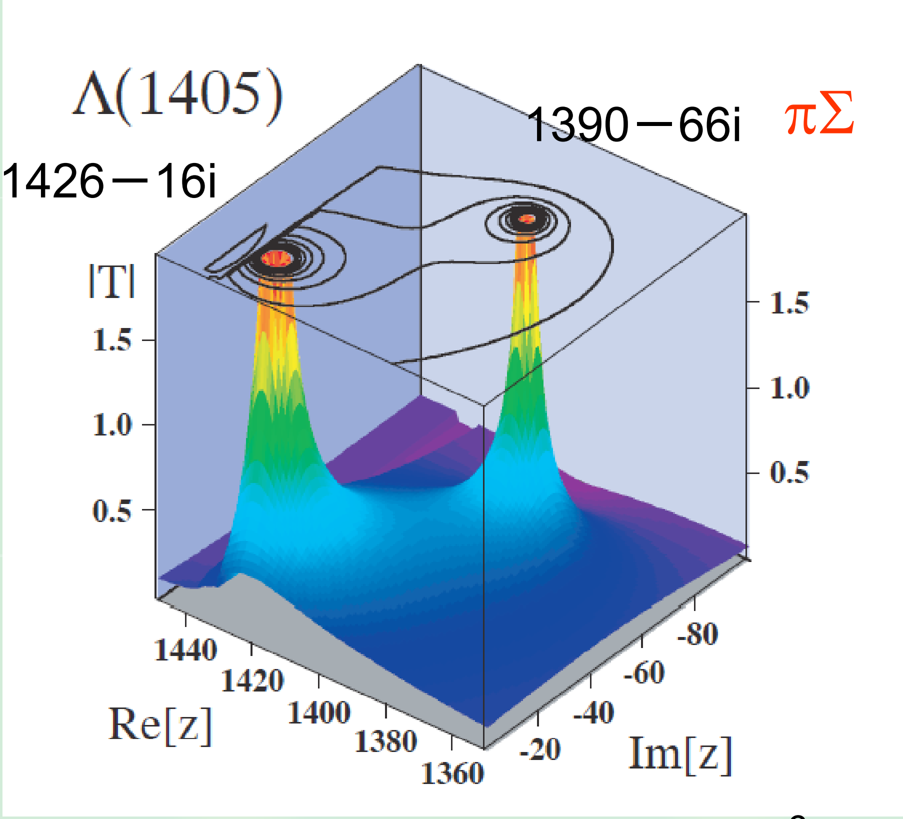
Motivation : Two poles?

T. Hyodo:
presented in SNP04

There are two poles of the scattering amplitude around nominal Λ(1405) energy region.

- **Cloudy bag model**
  J. Fink, *et al.*, PRC41, 2720
- **Chiral unitary model**
  J. A. Oller, *et al.*, PLB500, 263
  E. Oset, *et al.*, PLB527, 99
  D. Jido, *et al.*, PRC66, 025203
  T. Hyodo, *et al.*, PRC68, 018201
  T. Hyodo, *et al.*, PTP112, 73
  C. Garcia-Recio, *et al.*, PRD67, 076009
  D. Jido, *et al.*, NPA725, 181
  T. Hyodo, *et al.*, PRC68, 065203
  C. Garcia-Recio, *et al.*, PLB582, 49
- **Correlated quark model**
  A. Zhang, *et al.*, hep-ph/0403210

$\Lambda(1405) : J^P = 1/2^-, I = 0$

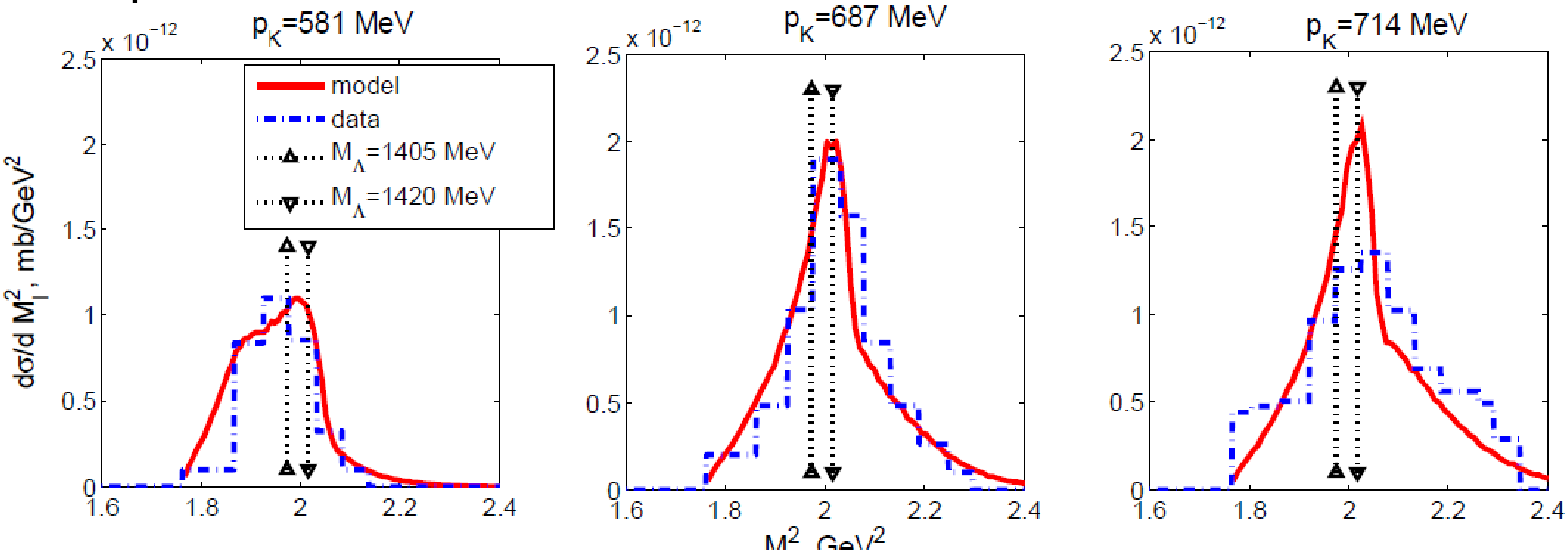


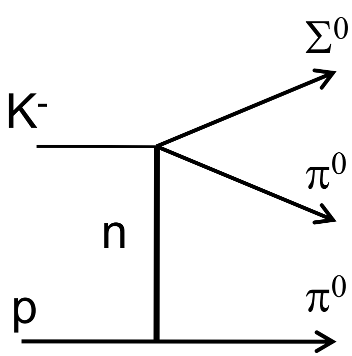
ChU model, T. Hyodo

Evidence for the Two Pole structure of $\Lambda(1405)$!?

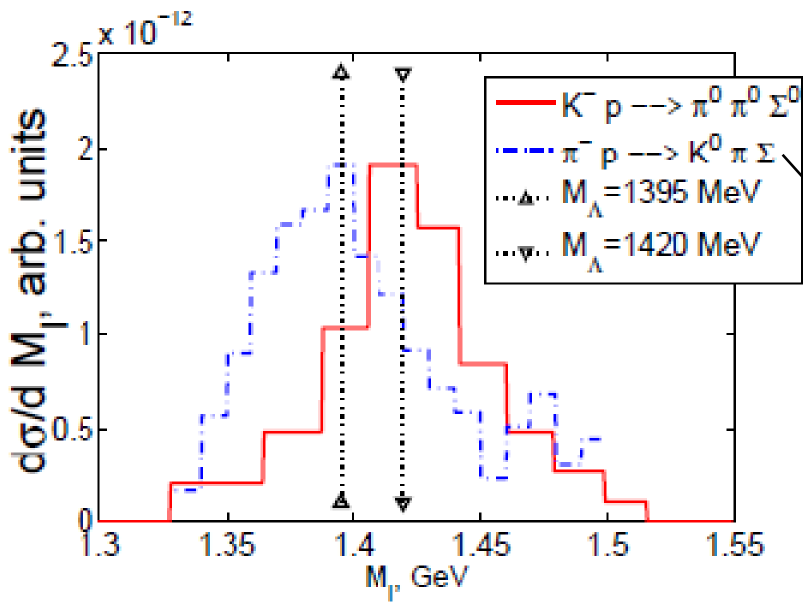
$K^- p \to \pi^0 \pi^0 \Sigma^0$

V.K. Magas, E. Oset, A. Ramos, PRL95, 052301(2005)





n-pole term



S. Prakhov et al., PRC70, 034605('04)
$K^- p \to \pi^0 \pi^0 \Sigma^0$

D. W. Thomas et al., NPB56, 15('73)
$\pi^- p \to K^0 \pi \Sigma$

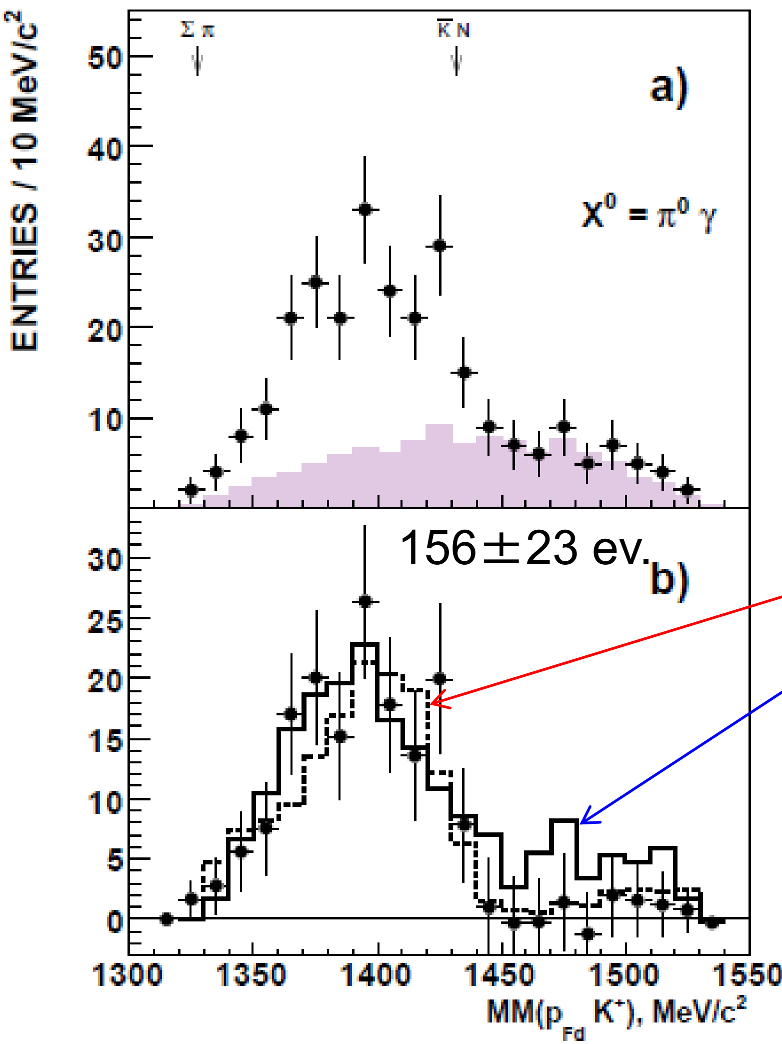
In PDG2009…

$\Lambda(1405)\ S_{01}$

$I(J^P) = 0(\frac{1}{2}^-)$ Status: ∗∗∗∗

It seems to be the universal opinion of the chiral-unitary community that there are two poles in the 1400-MeV region. For recent discussions and earlier references, see for example MAGAS 05 and JIDO 03. ZYCHOR 08 presents experimental evidence against the two-pole model, but this is disputed by GENG 07A.

COSY-ANKE: pp→pK⁺Λ*(→$\pi^0\Sigma^0$)
I. Zychor et al. PLB660, 167(2008)



also the "Note on the $\Lambda(1405)$" in our 2000 edition, The Euro-
n Physical Journal **C15** 1 (2000).

ingle, ordinary three-quark $\Lambda(1405)$ fits nicely into a J^P =
SU(4) $\overline{4}$ multiplet, whose other members are the $\Lambda_c(2595)^+$,
2790)$^+$, and $\Xi_c(2790)^0$; see Fig. 1 of our note on "Charmed
yons."

$\Lambda(1405)$ MASS

ION EXPERIMENTS

	EVTS	DOCUMENT ID		TECN	COMMENT
4.0		[1] DALITZ	91		M-matrix fit
not use the following data for averages, fits, limits, etc. • • •					
1	700	[1] HEMINGWAY	85	HBC	$K^- p$ 4.2 GeV/c
	400	[2] THOMAS	73	HBC	$\pi^- p$ 1.69 GeV/c
	120	BARBARO-...	68B	DBC	$K^- d$ 2.1–2.7 GeV/c
5	67	BIRMINGHAM	66	HBC	$K^- p$ 3.5 GeV/c
3		ENGLER	65	HDBC	$\pi^- p$, $\pi^+ d$ 1.68 GeV/c
4		MUSGRAVE	65	HBC	$\overline{p}p$ 3–4 GeV/c
		ALEXANDER	62	HBC	$\pi^- p$ 2.1 GeV/c
		ALSTON	62	HBC	$K^- p$ 1.2–0.5 GeV/c
		ALSTON	61B	HBC	$K^- p$ 1.15 GeV/c

LATIONS BELOW $N\overline{K}$ THRESHOLD

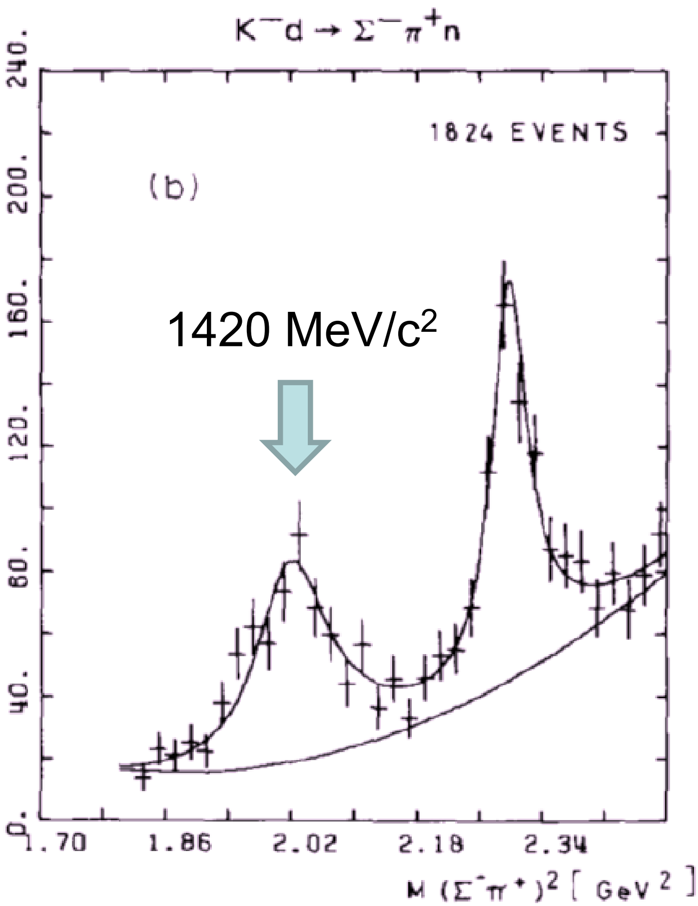
	DOCUMENT ID		TECN	COMMENT
not use the following data for averages, fits, limits, etc. • • •				
407.50	[3] KIMURA	00		potential model

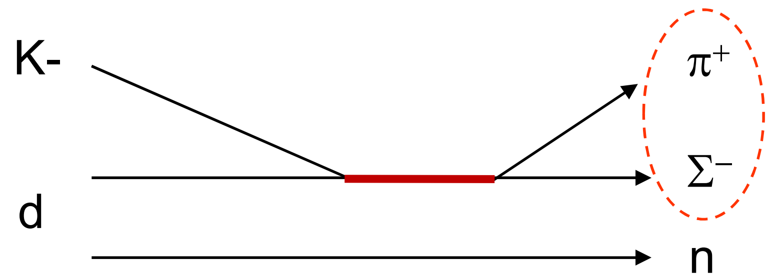
Bubble Chamber Exp. for d(K^-,$\Sigma^-\pi^+$)n at CERN

O. Braun et al., NPB129, 1(1977)

p_K=673~834 MeV/c

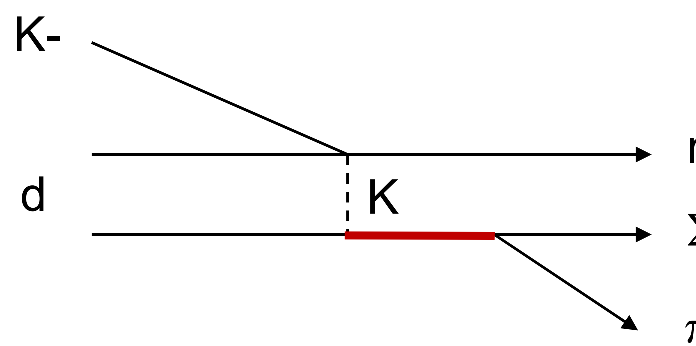
σ=~400 μb





q_n=0.6~1 GeV/c (not reported)

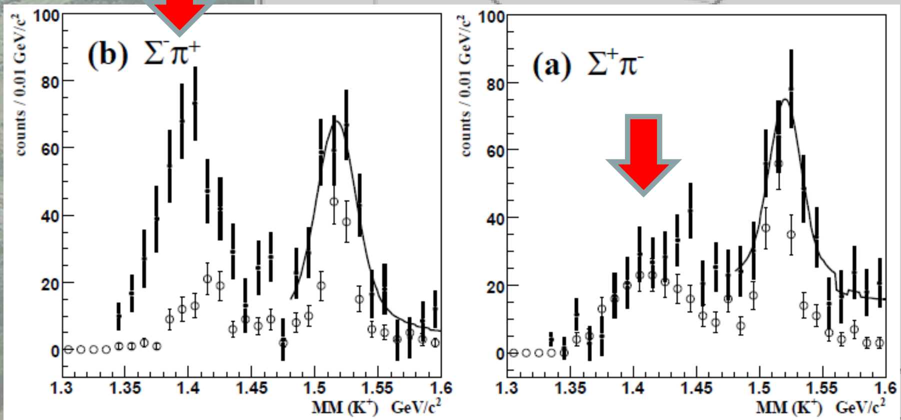
n:spectator?



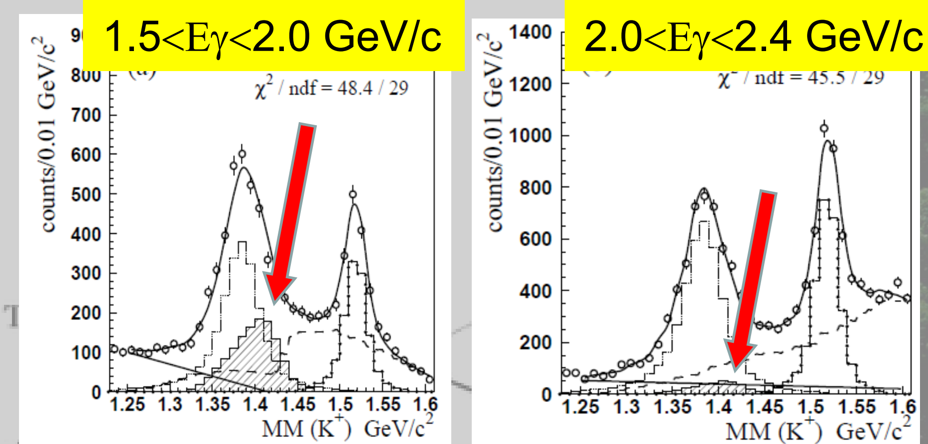
Λ(1405): $\gamma + p \rightarrow K^+ + \pi^+\Sigma^-(\pi^-\Sigma^+)$

M. Niiyama et al., Phys. Rev. C78, 035202 (2008)

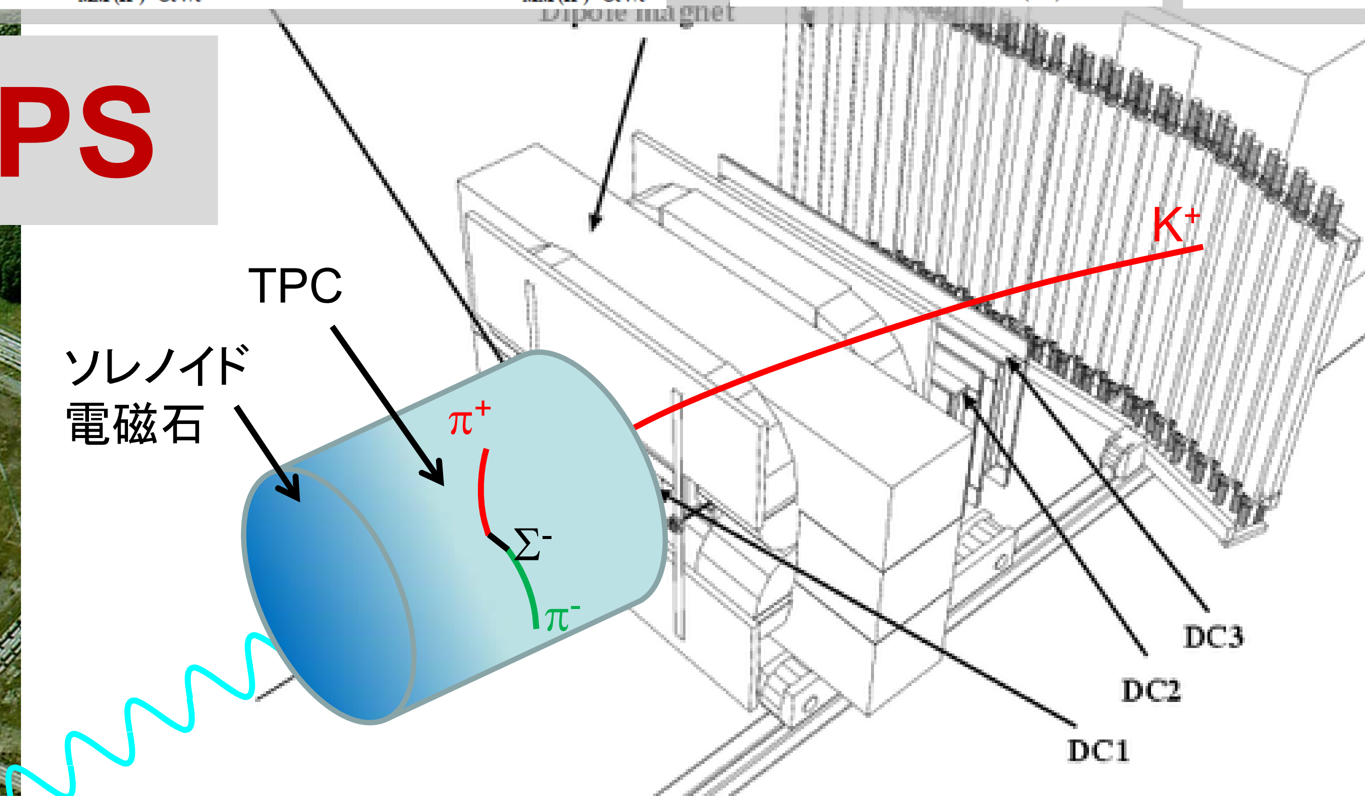
Asymmetric Production in Charged State



Energy Dependence of Λ(1405) Production



LEPS



Λ(1405) Spectrum

- ✓The situation is not conclusive, rather controversial.
- ✓Experimental studies are necessary.
- ✓Approaches to Λ(1405) from different production processes are important.

$\Lambda(1405)$ Spectroscopy via the (K^-,n) reaction on ^2H

Motivation

✓Study of $\Lambda(1405)$ structure
clarify if it is a K^{bar}N resonance (K^{bar}N bound state)

What do we need?

✓K^{bar}N scattering below K^{bar}N threshold
Virtual Kaon Beam

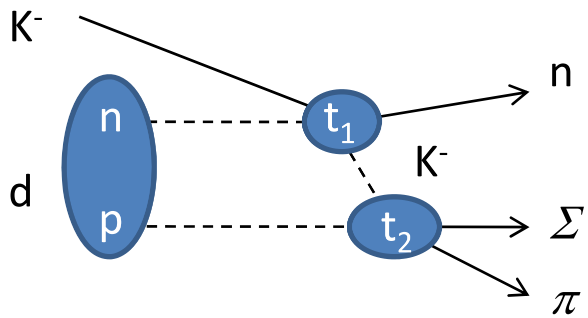
Employ $d(K^-,n)\Lambda^*$

✓Identify I=0 state in K^{bar}N -> $\pi\Sigma$ process

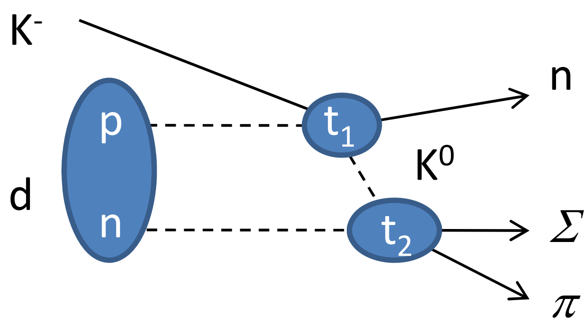
S-wave, I=0 $\rightarrow$ $\Lambda^*(1405)$ $\rightarrow \pi^0\Sigma^0$, $\pi^{+/-}\Sigma^{-/+}$
S-wave, I=1 $\rightarrow$ non-resonant
P-wave, I=1 $\rightarrow$ $\Sigma^*(1385)$ $\rightarrow \pi^0\Lambda, \pi^{+/-}\Sigma^{-/+}$

Reaction Diagram

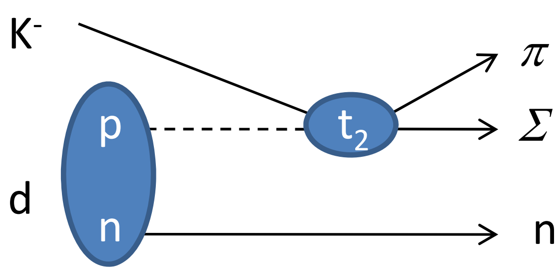
D. Jido, E. Oset, and T. Sekihara, arXiv:0904.3410



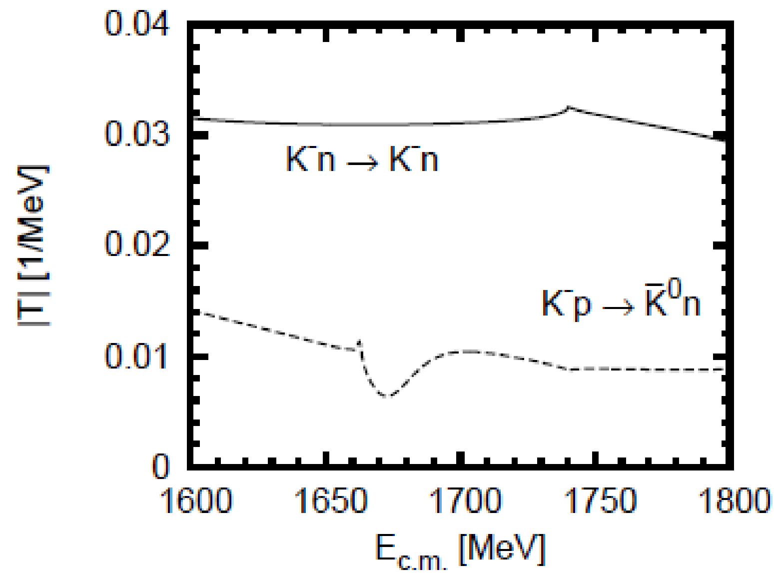
dominant

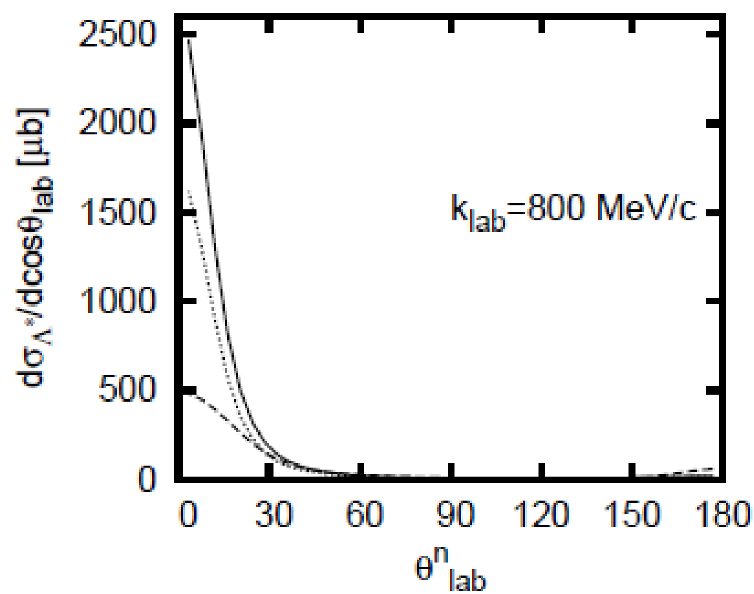


Interference



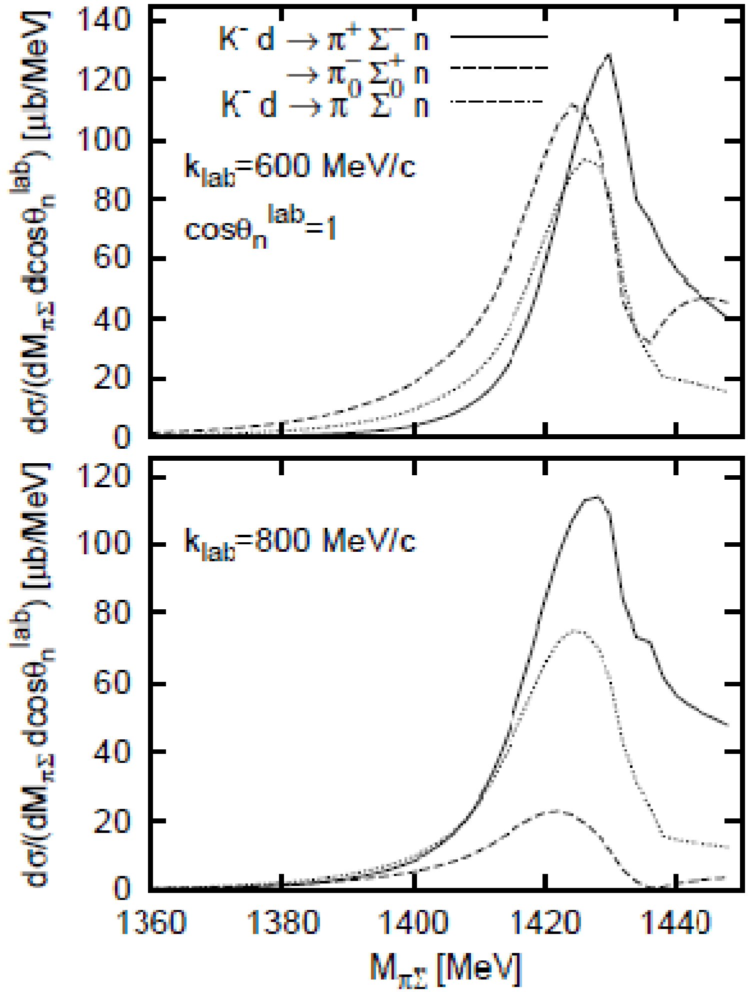
small

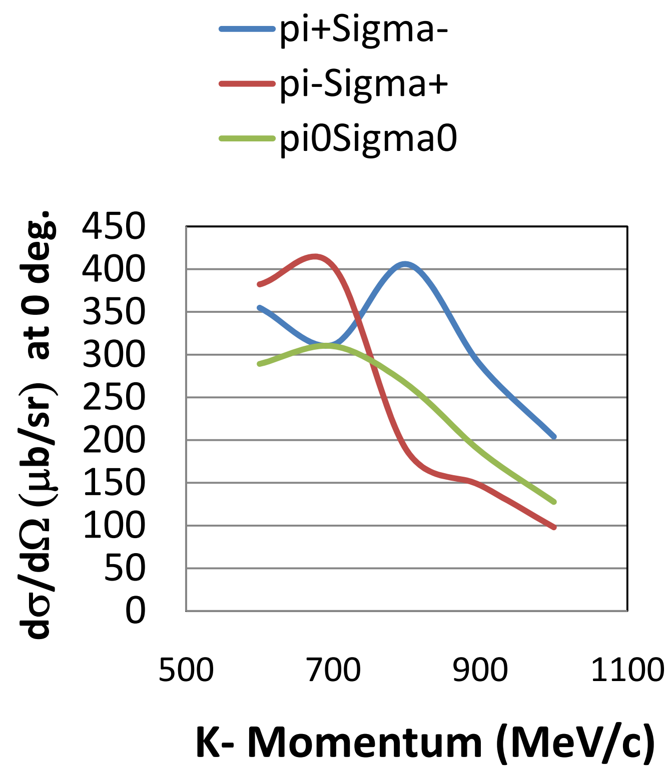




Calculated Cross Sections and Spectra for $K^- d \to \pi\Sigma n$

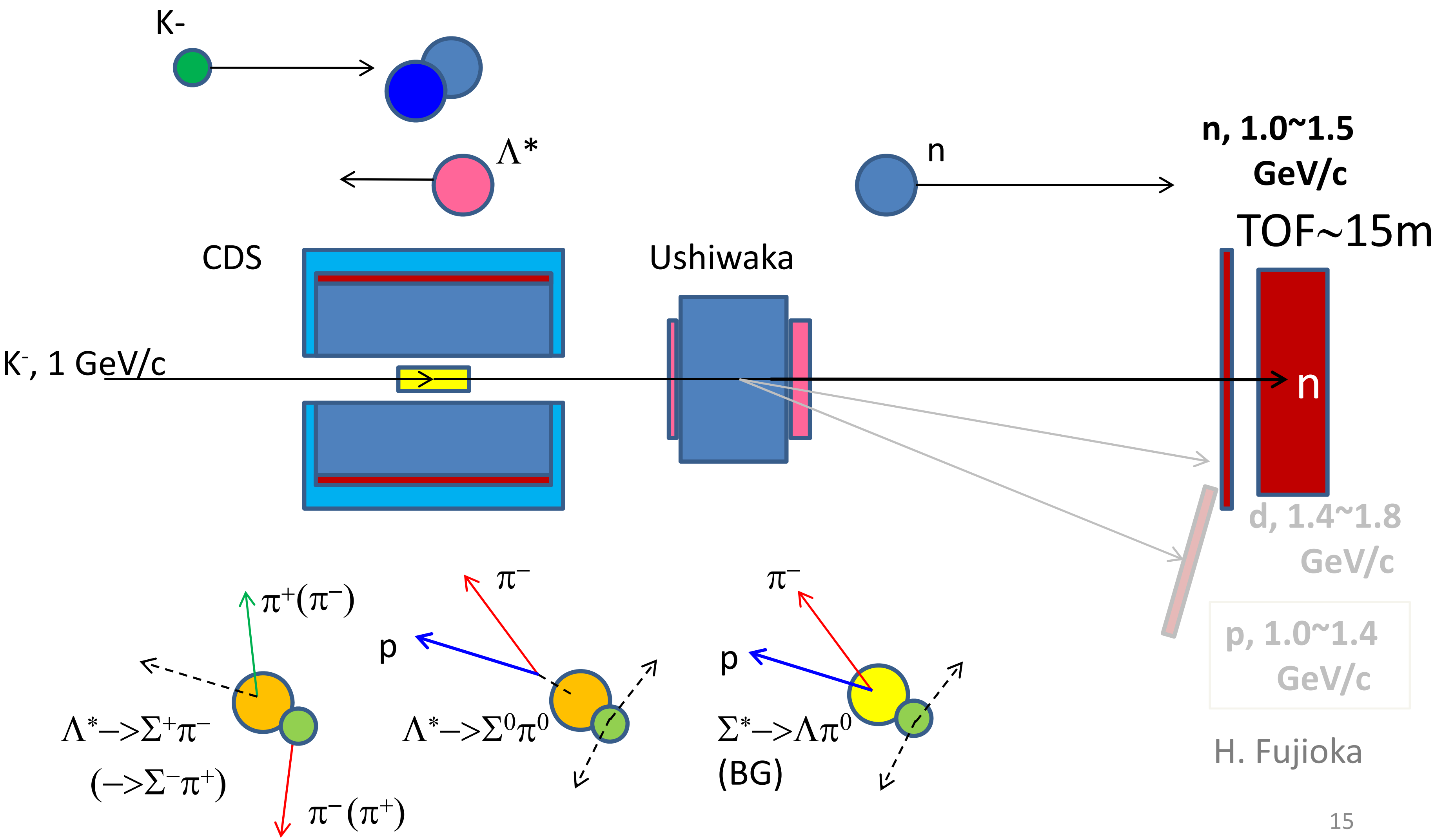
ChUM By D. Jido, E. Oset, and T. Sekihara, arXiv:0904.3410





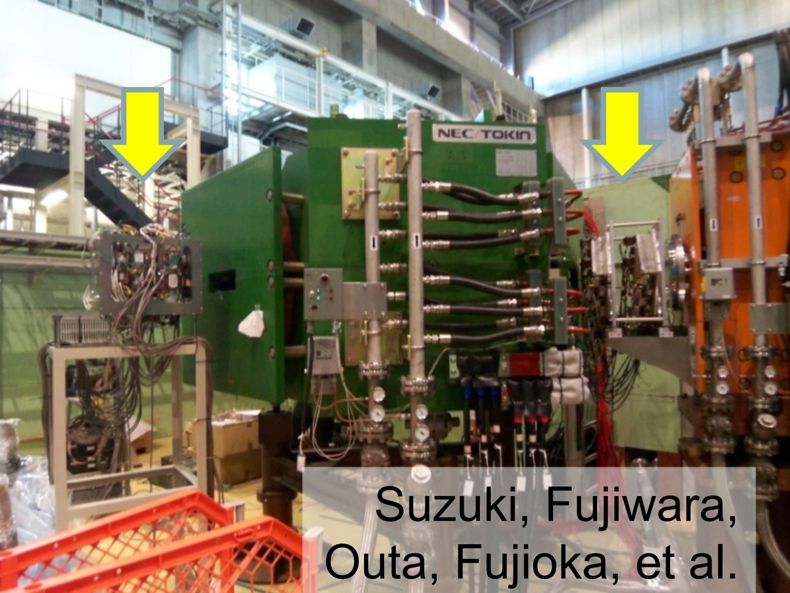
Λ(1405) Spectroscopy via the (K^-,n) reaction on ^{2}H

$^2H(K^-,p)\Sigma^{*-}$



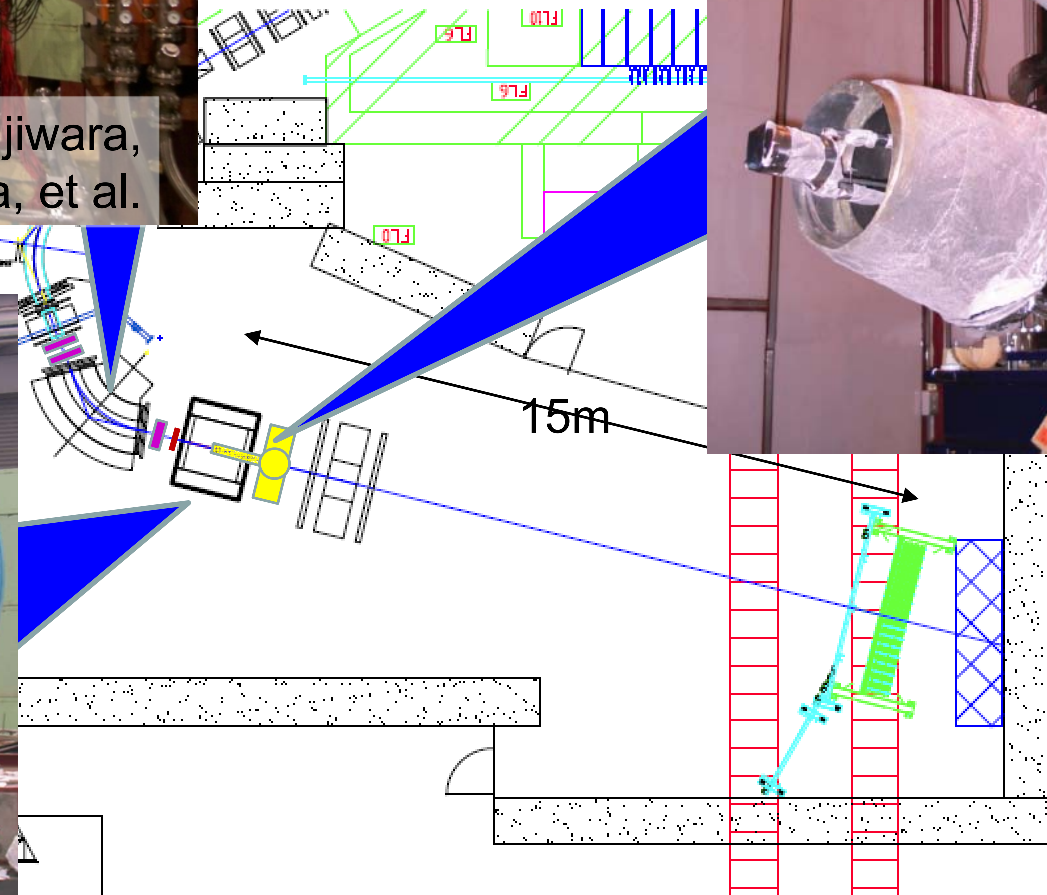
H. Fujioka

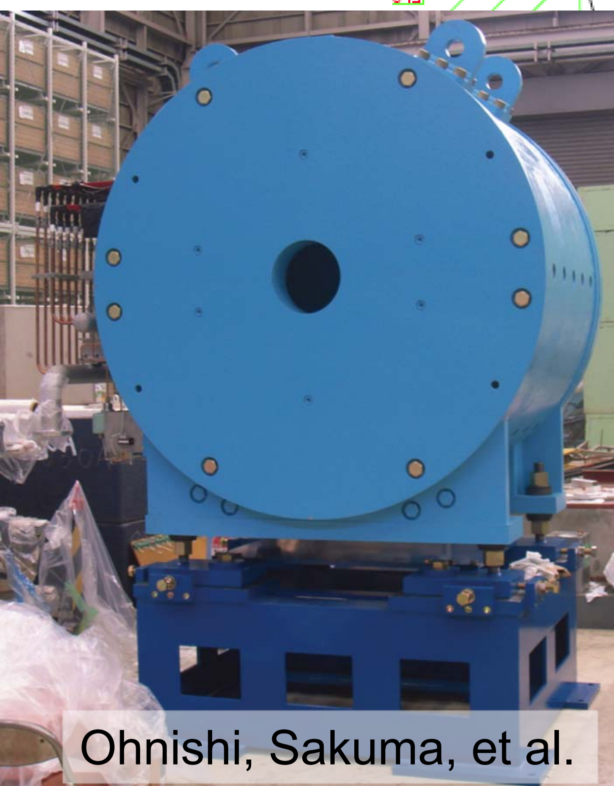
K1.8BR



Suzuki, Fujiwara, Outa, Fujioka, et al.


Ishimoto, Iio, et al.



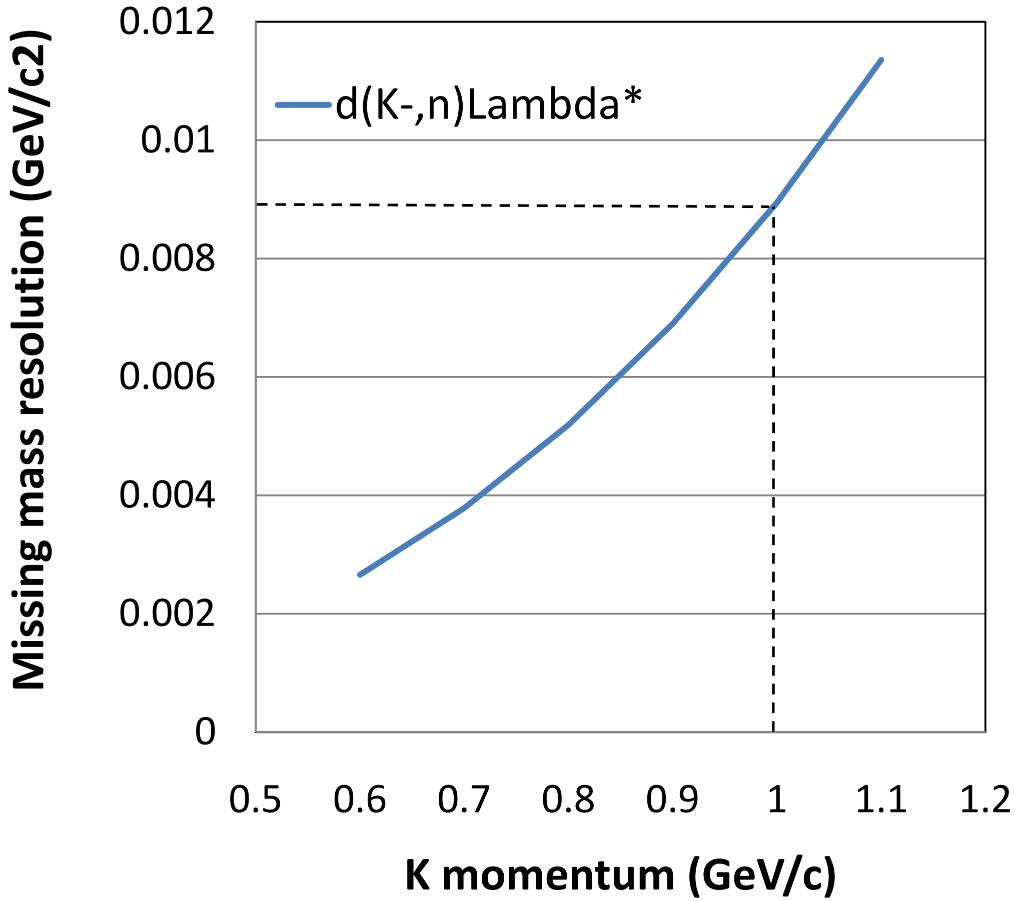

Ohnishi, Sakuma, et al.

Missing Mass Resolution in the d(K-, n)X reaction

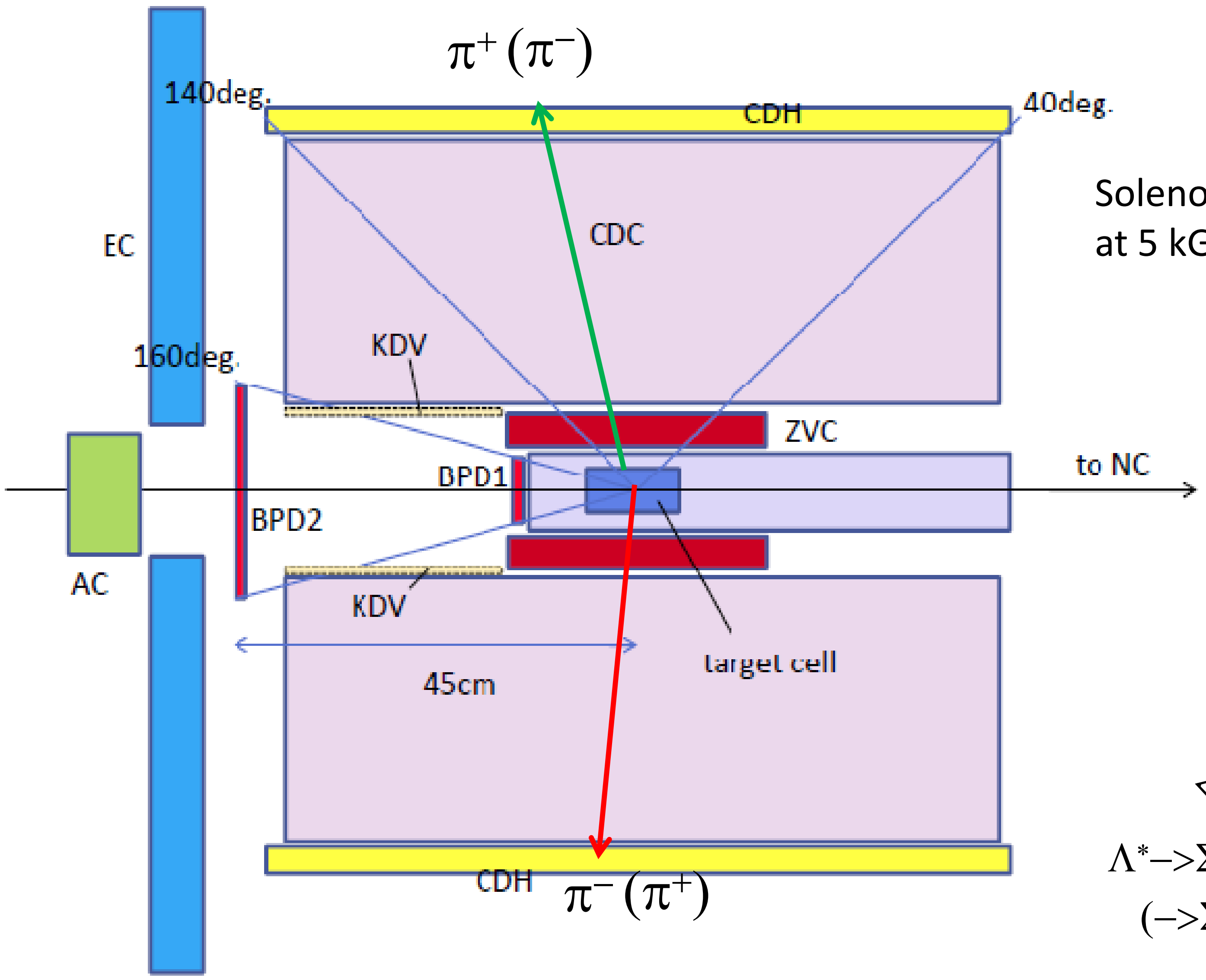
Dominant sources of ambiguity…

dt~120 ps (NC) dL_V~2cm, dL_T~5cm, F.L.=15m ⇒ dβ -> dp

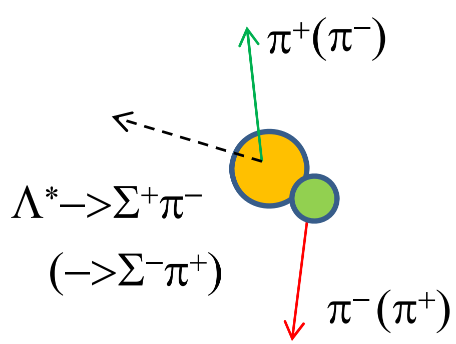
dMM ~ 9 MeV/c (sigma) at p_{K-}=1 GeV/c



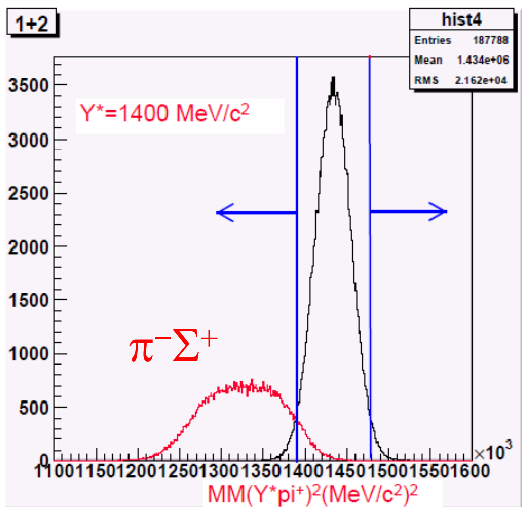
Detection of the Λ^* -> $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ modes

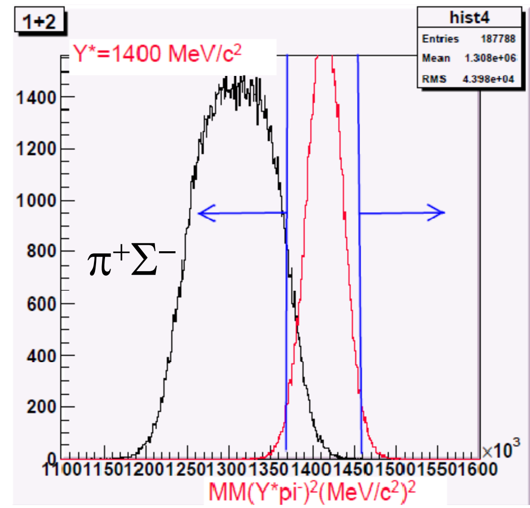


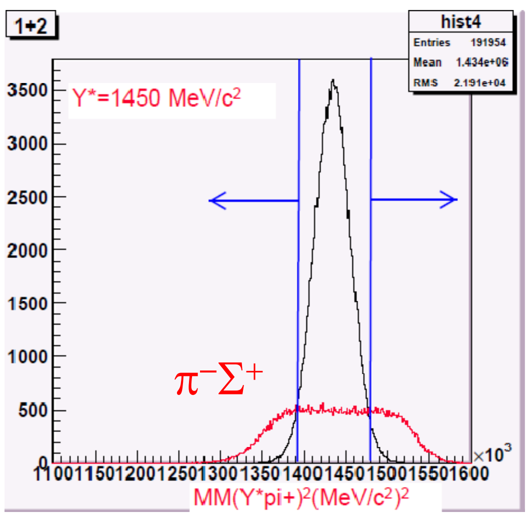
Solenoid Field
at 5 kG

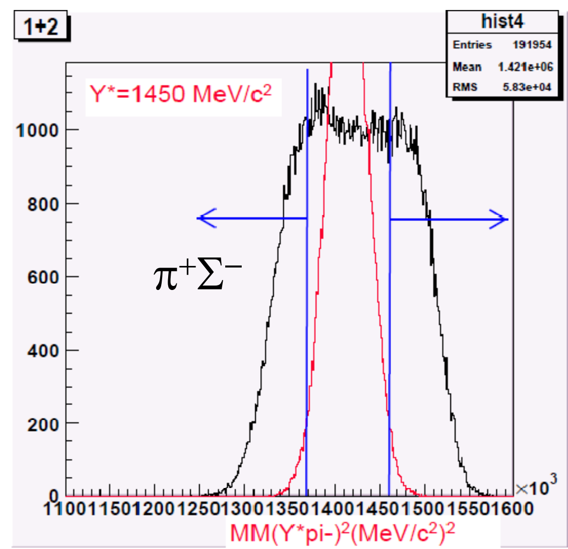


Identification of Λ* -> $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ modes



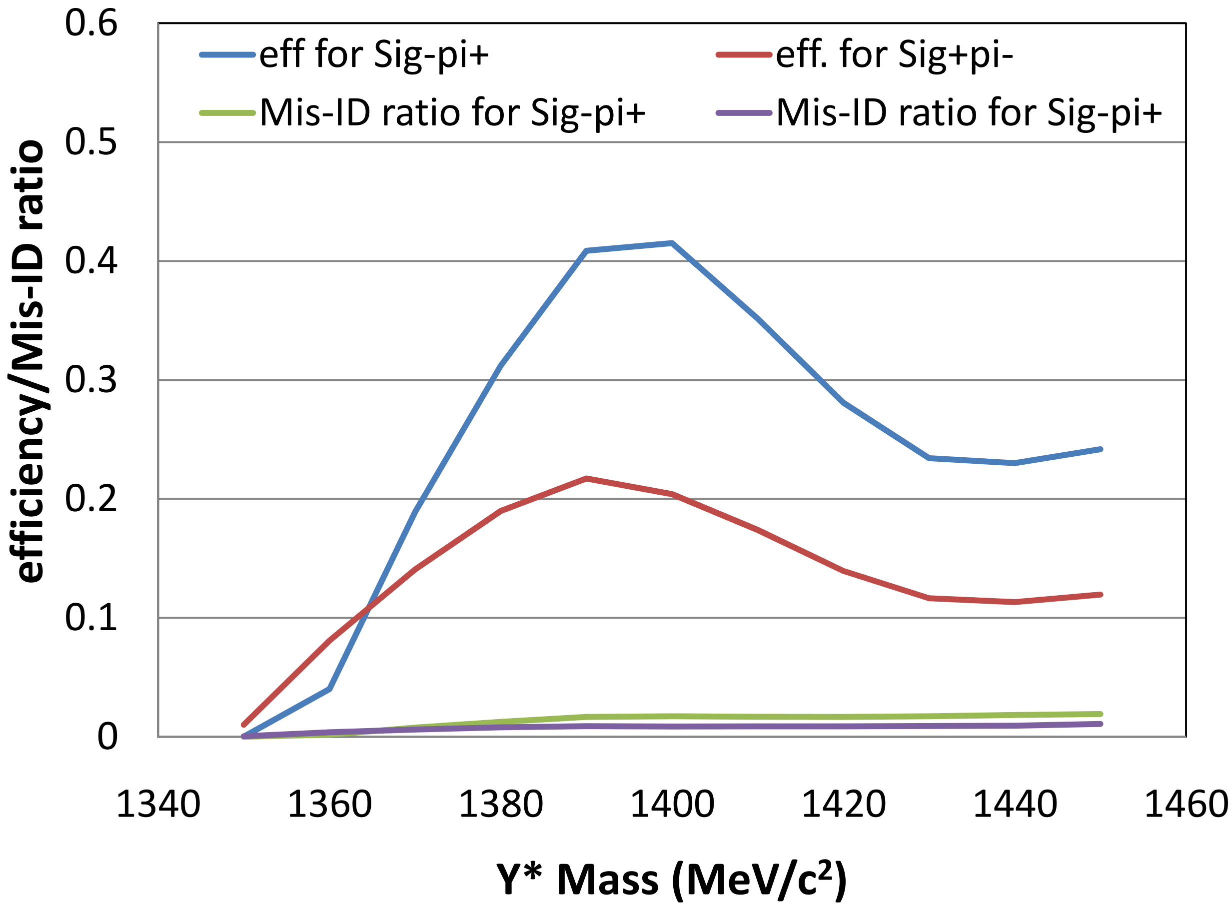




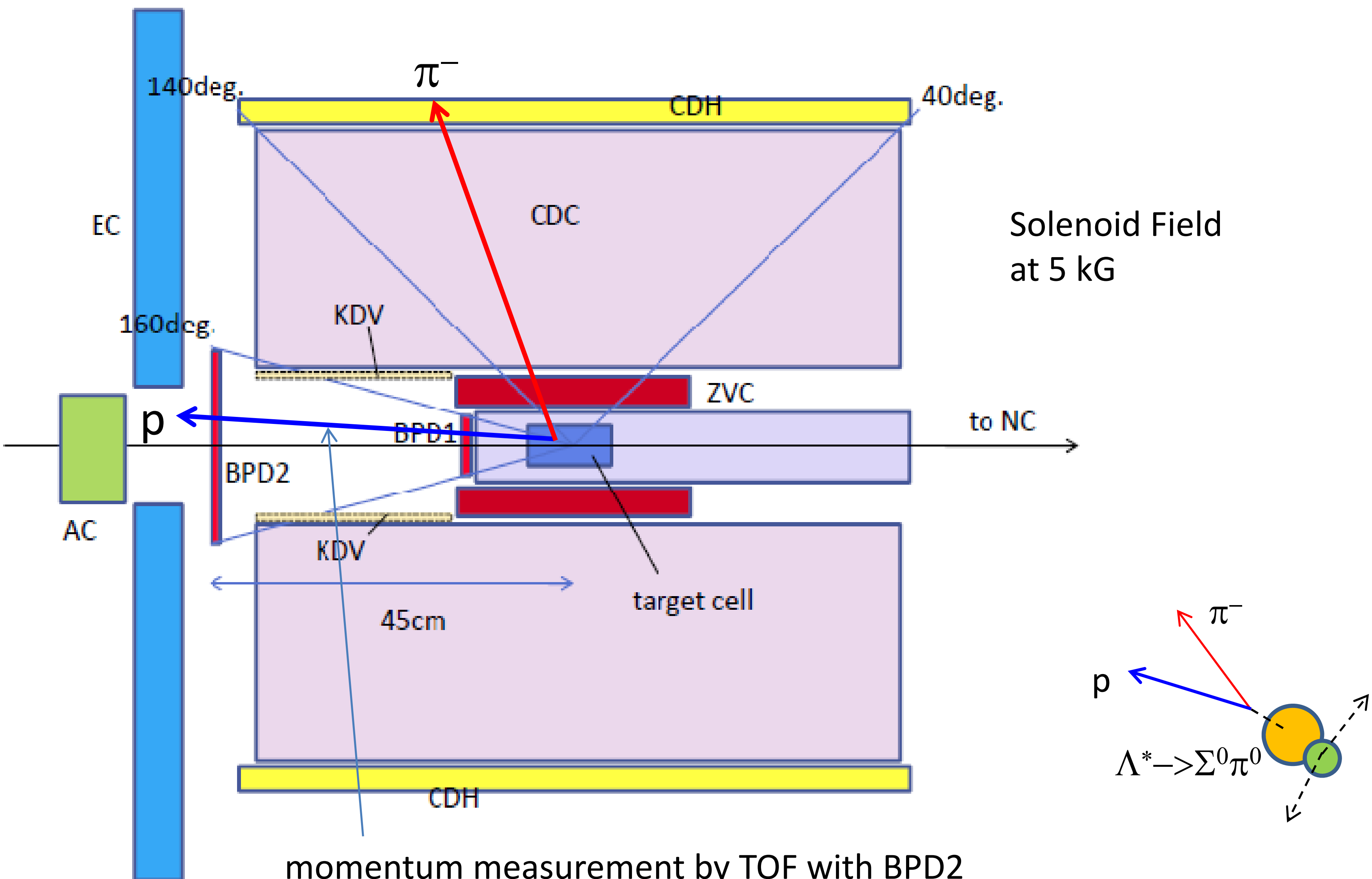


Detection Efficiency of Λ^* -> $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ modes

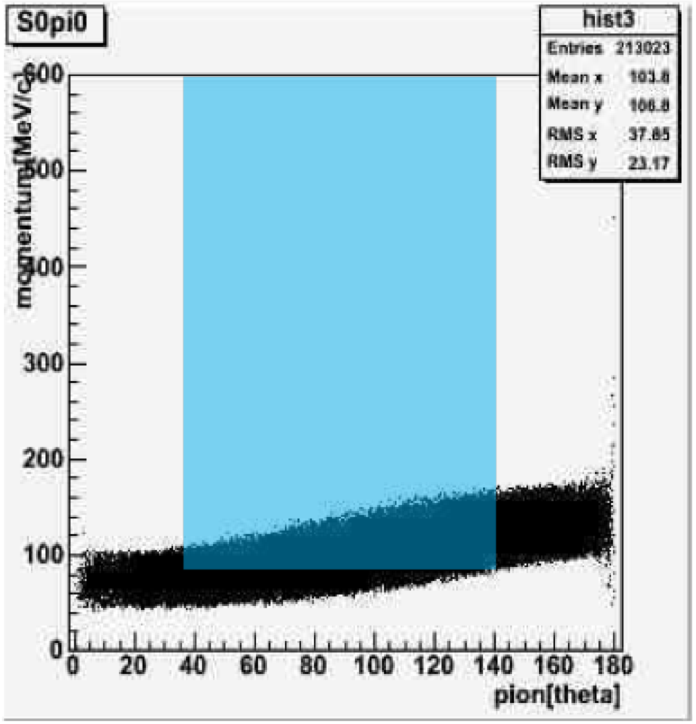
Contamination (Mis-identification) ~ a few%

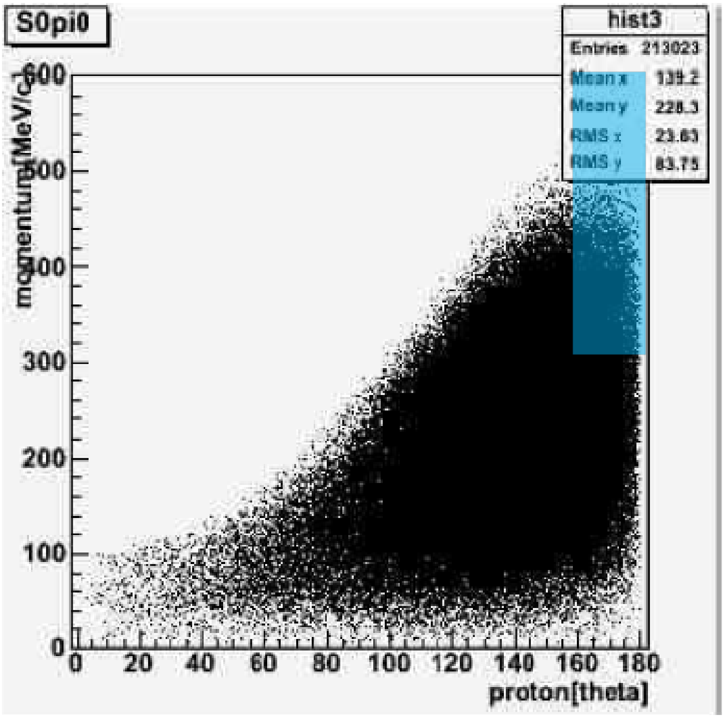


Backward Proton Detectors for the Λ^* -> $\pi^0\Sigma^0$ mode

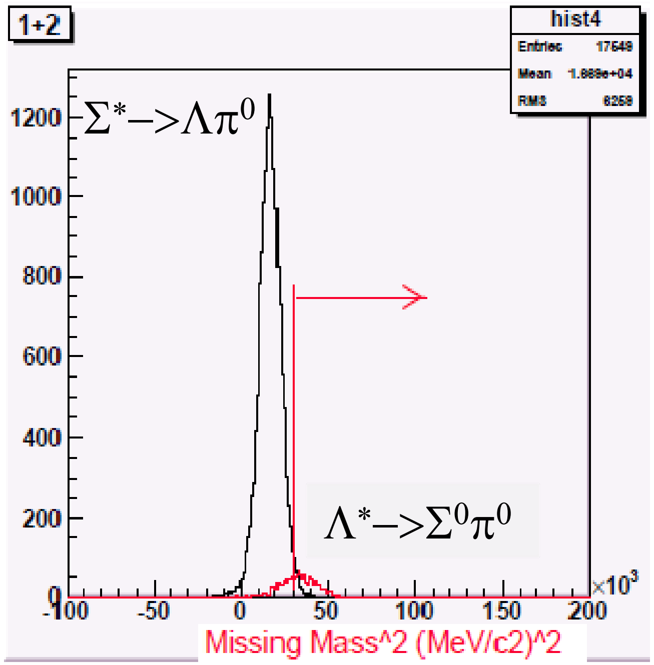


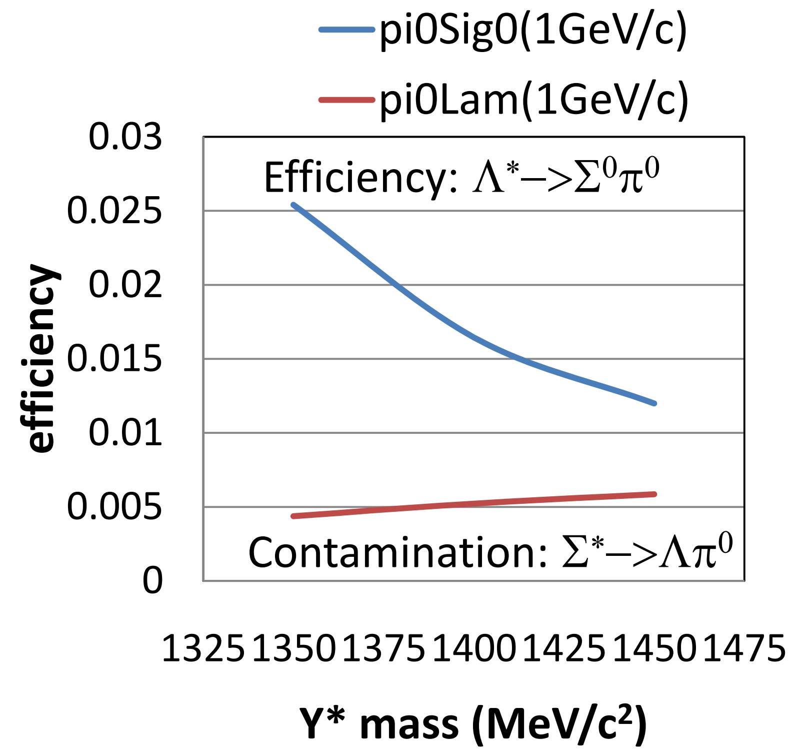
momentum measurement by TOF with BPD2


S0pi0
hist3
Entries 213023
Mean x 103.8
Mean y 106.8
RMS x 37.85
RMS y 23.17
momentum[MeV/c]
0
100
200
300
400
500
600
0 20 40 60 80 100 120 140 160 180
pion[theta]


S0pi0
hist3
Entries 213023
Mean x 139.2
Mean y 228.3
RMS x 23.63
RMS y 83.75
momentum[MeV/c]
0
100
200
300
400
500
600
0 20 40 60 80 100 120 140 160 180
proton[theta]

ID & Efficiency for Λ^* -> $\pi^0\Sigma^0$





Cut Condition:

Proton: >300 MeV/c, θ > 160deg.

Pion: >80 MeV/c, 40<θ < 140deg.

$MM^2 > 30000$ for $\Lambda^* \rightarrow \Sigma^0\pi^0$

ΔMM ~ 50 MeV/c^2, σ_t~200ps, L~0.45m

Simulation by S. Enomoto

Yield Estimation

Item	Mnemonic		Comment
Intensity	I_b	2.0E+5 ppp	30GeV-27kW(6s)
# of target nuclei	n	4.1E+23	D:8cm, 0.169g/cc
Reaction X section	$d\sigma/d\Omega$	220 μb/sr 97 128	$\Lambda^* \to \pi^+\Sigma^-$ $\Lambda^* \to \pi^-\Sigma^+$ $\Lambda^* \to \pi^0\Sigma^0$
Solid angle	$\Delta\Omega$	0.020 sr	
Reconstruction eff. DAQ Beam Tracking Neutron detection	ε_P	0.2	 0.9 0.9 0.3
Decay mode eff.	ε_M	0.32 0.16 0.015	$\Lambda^* \to \pi^+\Sigma^- \to \pi^+\pi^- n$ $\Lambda^* \to \pi^-\Sigma^+ \to \pi^-\pi^+ n$ $\Lambda^* \to \pi^0\Sigma^0 \to \pi^0\pi^- p$
Analysis eff.	ε_A	0.8	
Yield	Y	~19200 ~4800 ~350	$\Lambda^* \to \pi^+\pi^- n$ (120 shifts) $\Lambda^* \to \pi^-\pi^+ n$ (120 shifts) $\Lambda^* \to \pi^0\pi^- p$ (120 shifts)

Summary

✓We propose to study $\Lambda(1405)$ hyperon resonance via the $d(K^-, n)\pi\Sigma$ reactions.

✓We expect to investigate $\Lambda(1405)$ in the coupled chanel $K^{bar}N$ – $\pi\Sigma$ sytem.

The E15 setup is quite suitable to carry out the present experiment.

The $\pi^0\Sigma^0$ final I=0 state as well as $\pi^{+/-}\Sigma^{-/+}$ are to be identified.

The proposed experiment can improve statistics for each mode very much:

1~2 orders of magnitude for $\pi^{+/-}\Sigma^{-/+}$

a factor 2 or more for $\pi^0\Sigma^0$

Backward Proton Detectors:

- ✓ development of BPD

  BPD1:K(charged) –beam ID/vertex
  BPD2: TOF for protons
  -> Scintillator Hodescopes with MPPC

- ✓ Vertex Detector for Λ->pπ^-
  -> determine the reaction z vertex
  for better p_n measurement in Λ*-> $\pi^0\Sigma^0$

  MWPC/GEM/SSD/Fiber Hodoscopes

- ✓ d(K-,p)Σ^{-*}

  -> using proton arm of P28 Setup(Fujioka et al)

Misc.

Comment on $^3He(K^-,d)$

Compared w/ $d(K^-,n)$

Merit

✓ Slower d: better momentum resolution
-> better missing mass resolution

✓ Larger recoil Momentum: ~500 MeV/c
-> backward p-detection much better.

Demerit

✓ Small cross section: 1/100 ~ 1/10 of $d(K^-,n)$?
but feasible for $\pi^+\Sigma^-$ and $\pi^-\Sigma^+$ modes

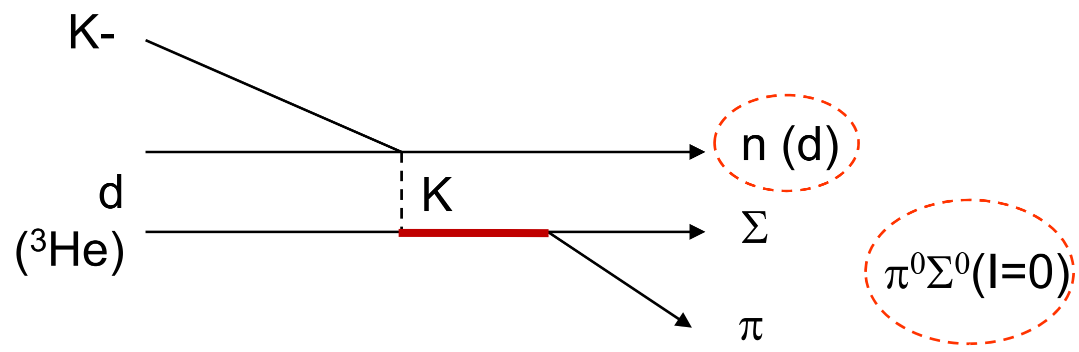
Could be a parasitic to E15

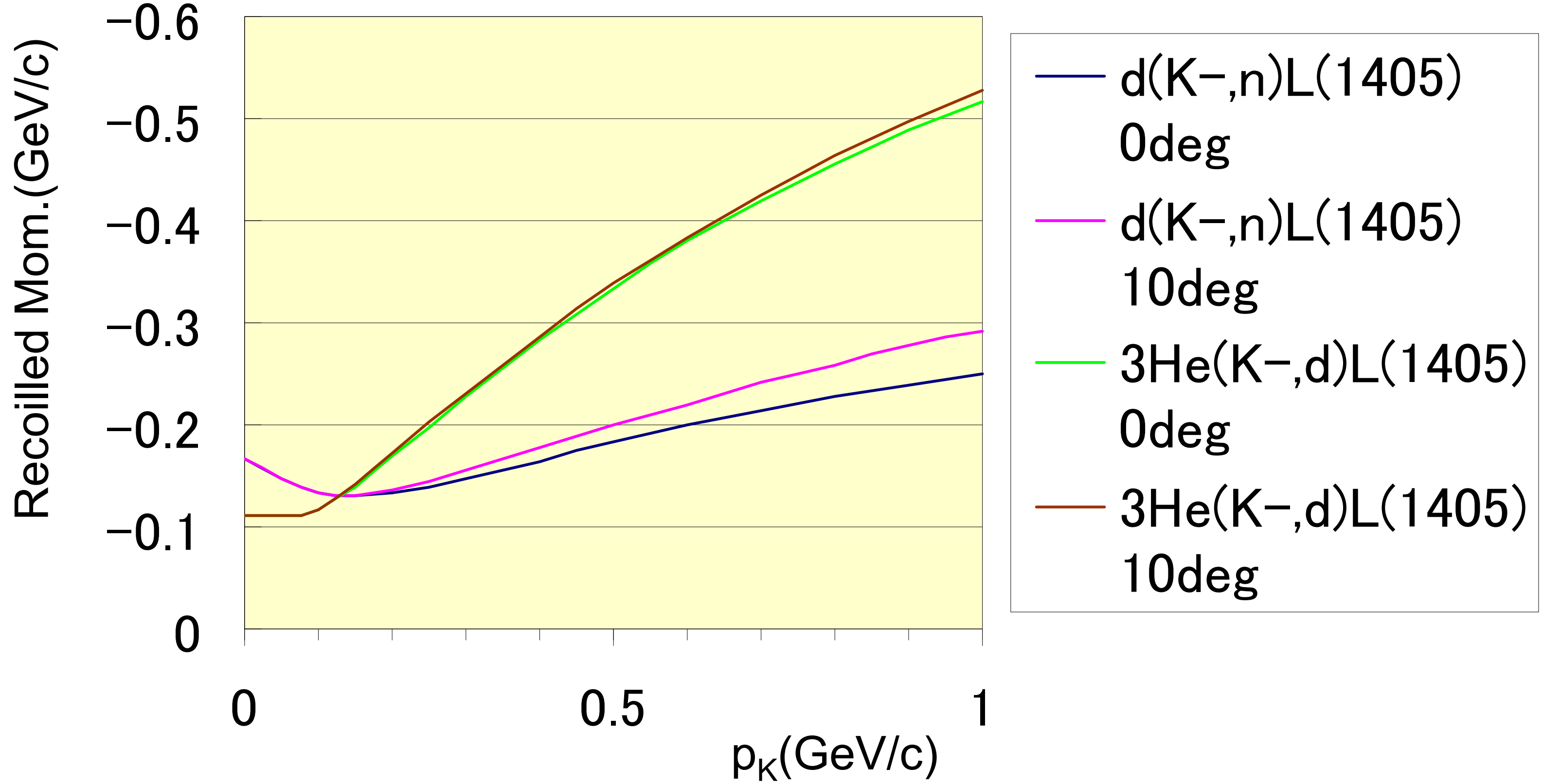
-> be a good pilot experiment for $d(K^-,n)$

Exp. to form S-Wave $\bar{K}N$ state and I=0 state in final state with low-E K- Beam at J-PARC

K-d → nπΣ

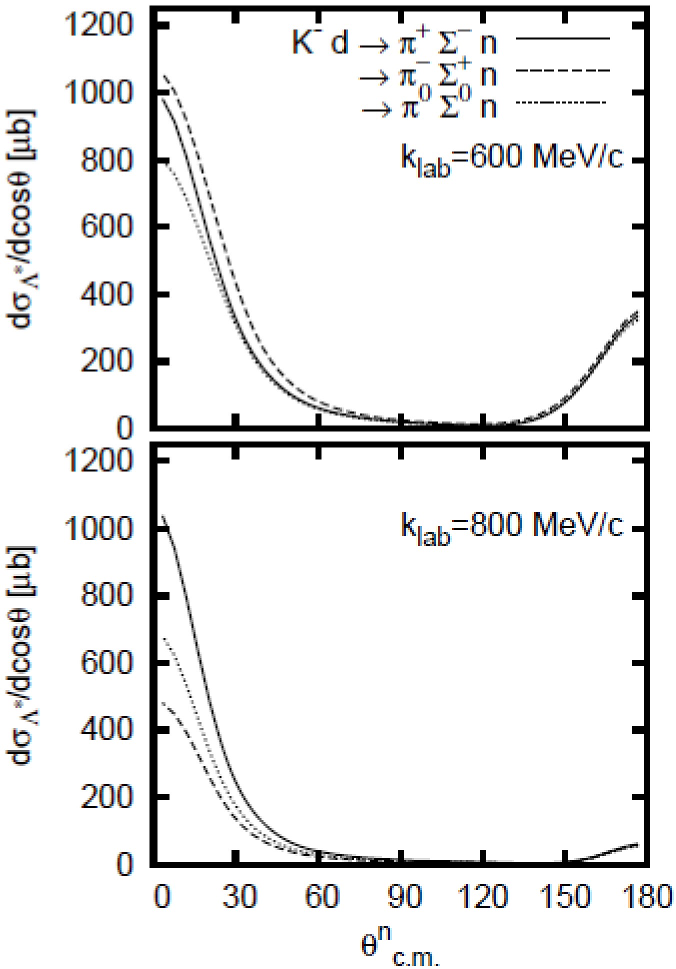
K-^{3}He → dπΣ

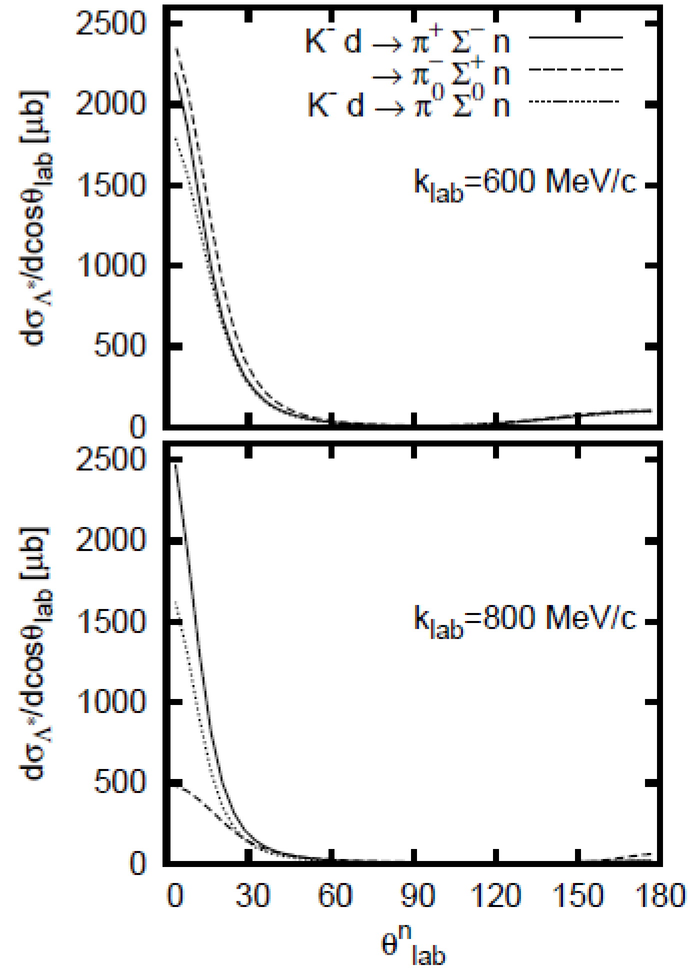




backup

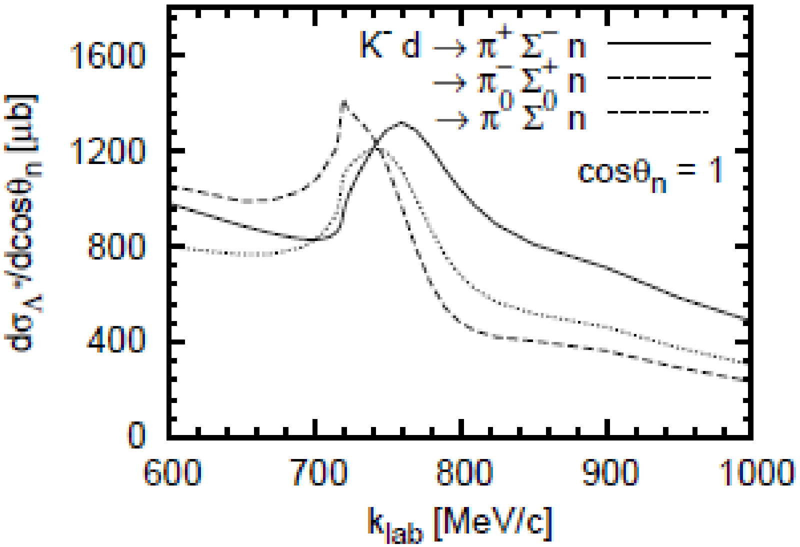
D. Jido, E. Oset, and T. Sekihara, arXiv:0904.3410

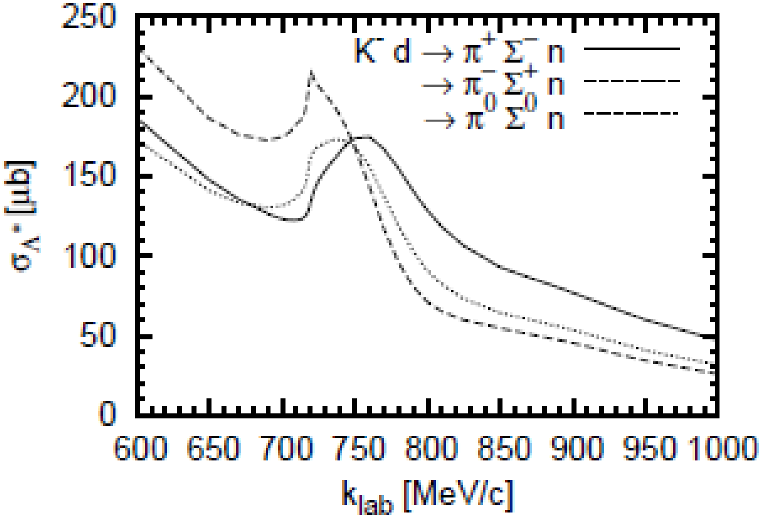




D. Jido, E. Oset, and T. Sekihara, arXiv:0904.3410

p





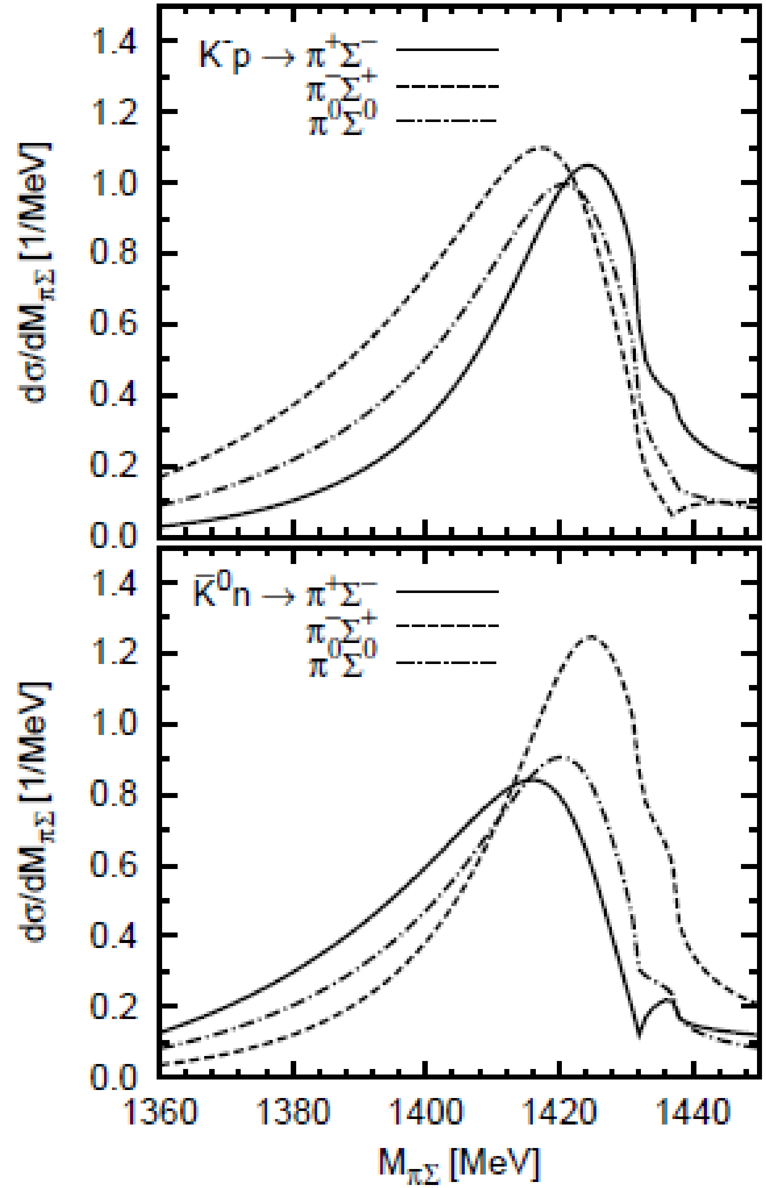
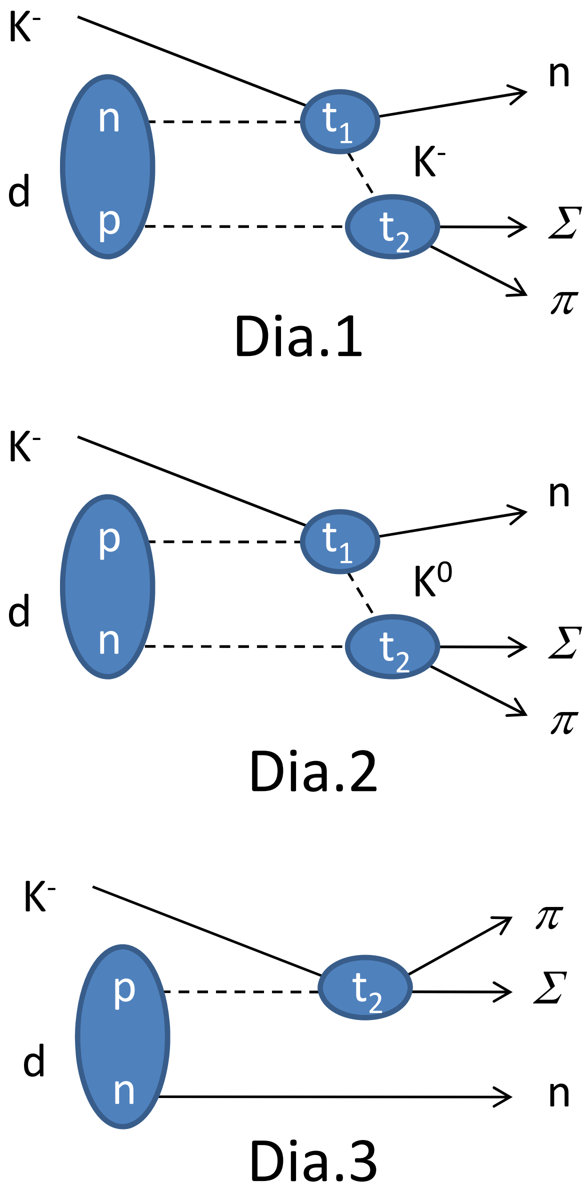
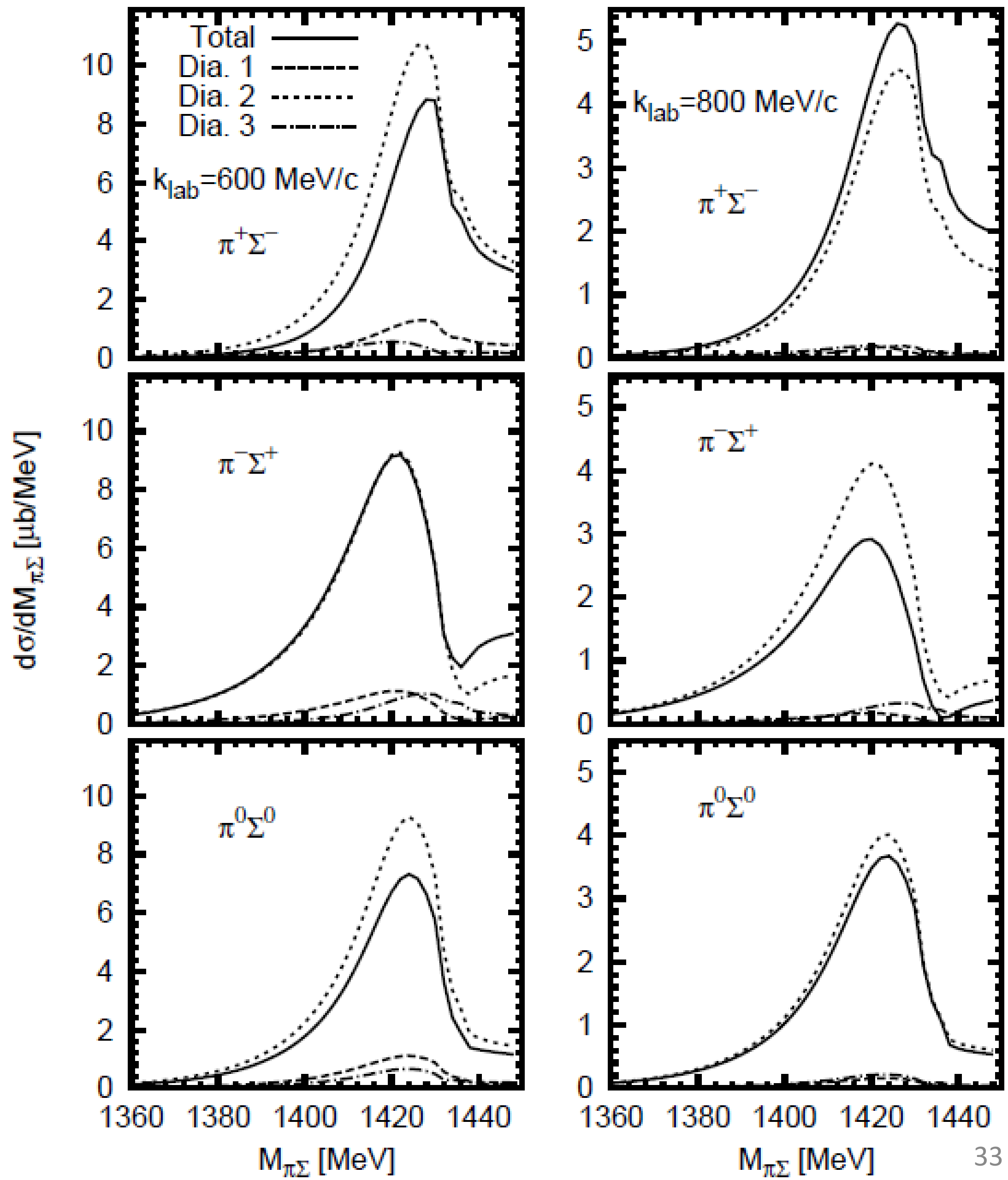


Diagram Contribution（no Interf’ce）

D. Jido, E. Oset, and T. Sekihara, arXiv:0904.3410





Y. Ikeda and T. Sato, PRC79:035201,2009.

$dN/dW_{cm}=C|t_{\pi\Sigma\to\pi\Sigma}|^2 p_{cm}$

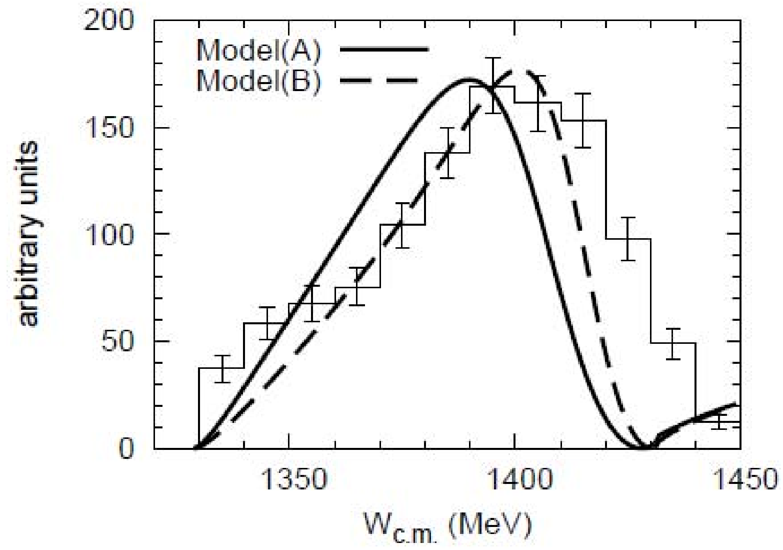


FIG. 2: Invariant mass distribution of the $\pi\Sigma$.

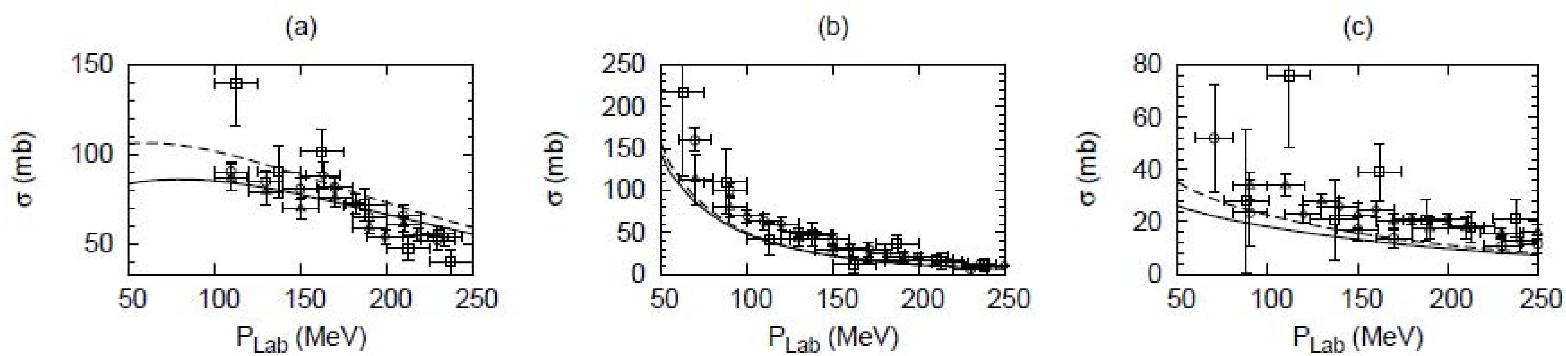
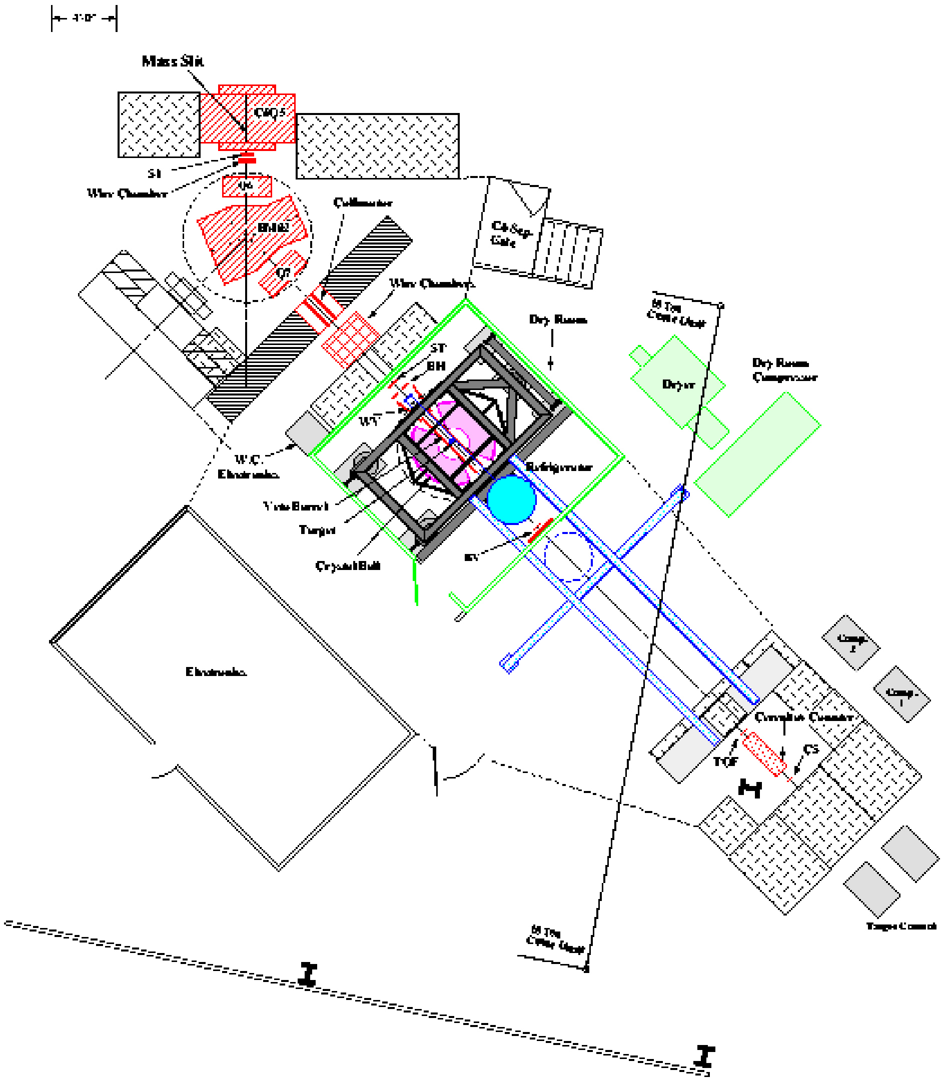
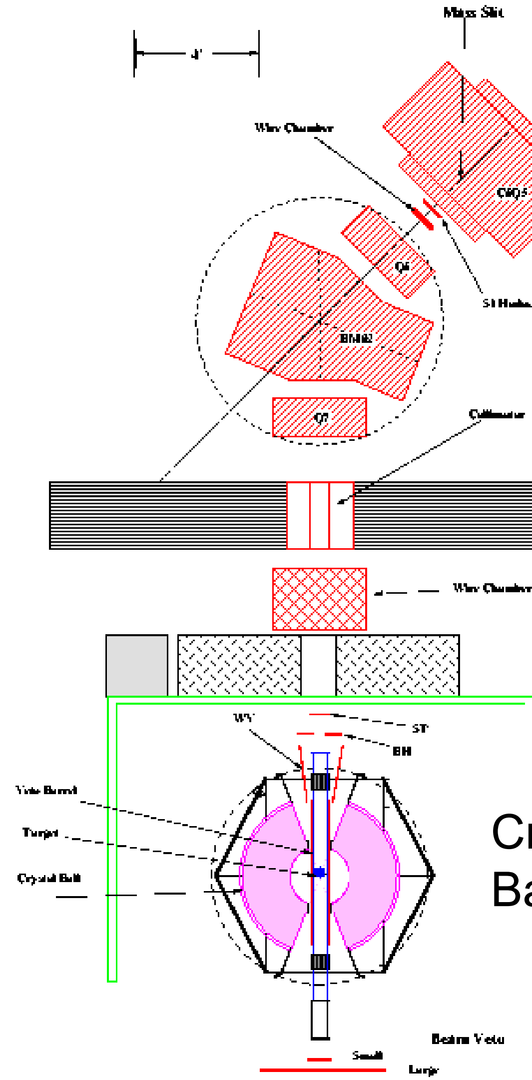


FIG. 3: The total cross section of (a) $K^-p \to K^-p$, (b) $K^-p \to \pi^+\Sigma^-$, and (c) $K^-p \to \pi^-\Sigma^+$ reactions. The solid (dashed) curve shows cross section calculated by using Model (A)((B)). Data are taken from Ref. [29, 30, 31, 32, 33].





Crystal Ball

AGS-E913 Setup

S. Prakhov et al., PRC70, 034605('04)

$K^{-}p \rightarrow \Sigma^{*} \rightarrow \pi^{0}\pi^{0}\Sigma^{0}$

S. Prakhov et al., PRC70, 034605('04) $K^{-}p \rightarrow \Sigma^{*} \rightarrow \pi^0\pi^0\Sigma^0$

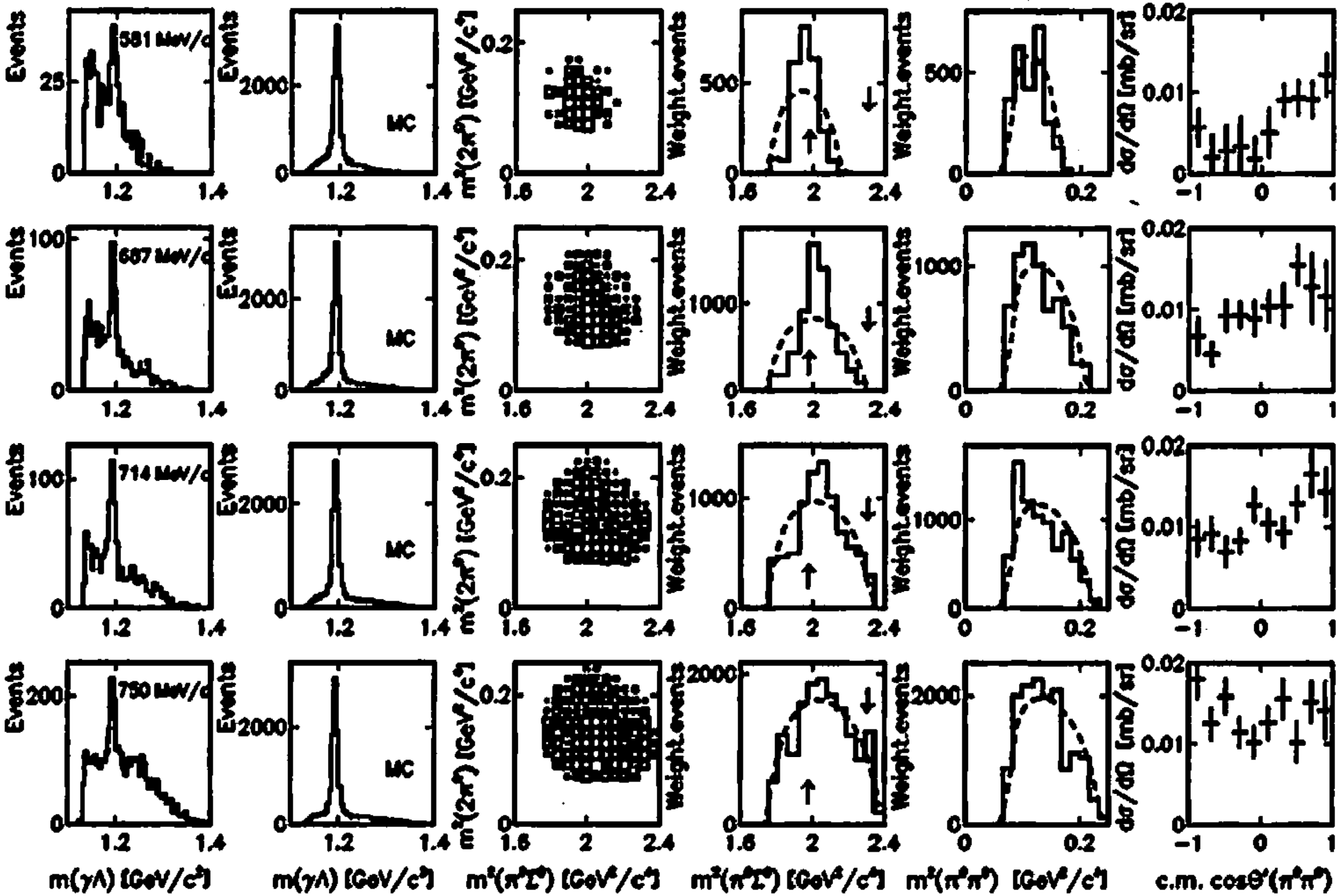
$s^{1/2}$=

1.598 GeV

1.647 GeV

1.659 GeV

1.676 GeV

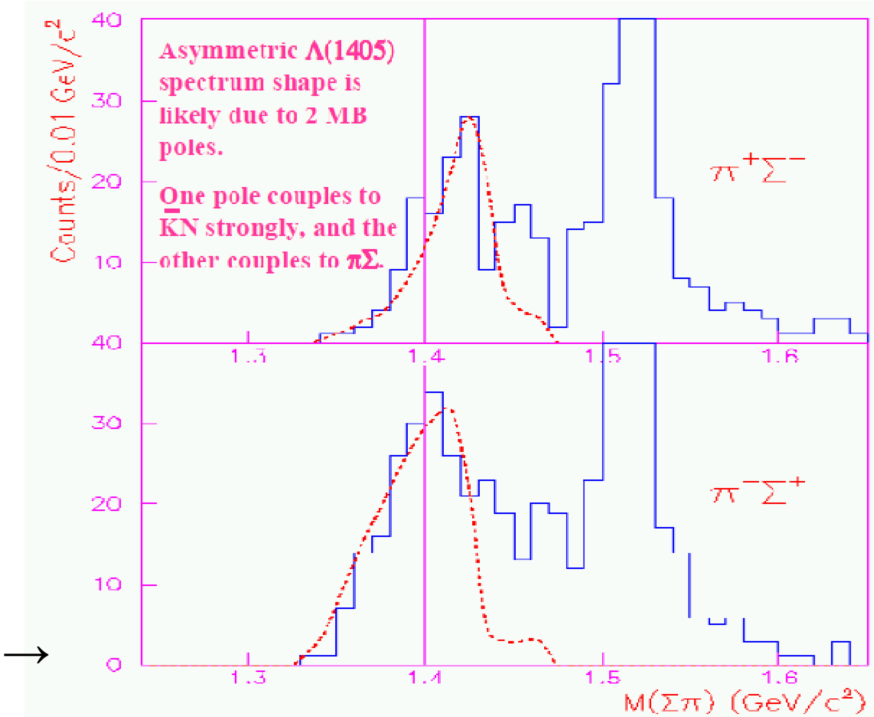


Σ^*: **** $\Sigma(1670)$ D_{13}, Γ~60MeV, ***S(1660)P_{11}, Γ~100MeV

LEPS Exp.

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

$\rightarrow \pi^{\pm}\Sigma^{\mp}$

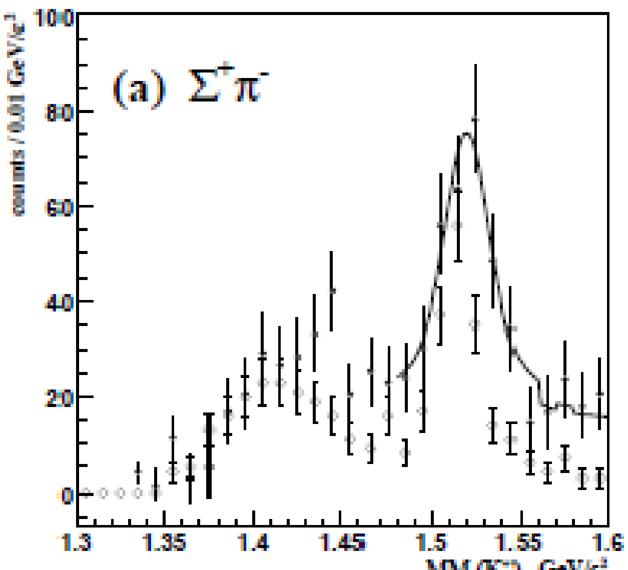


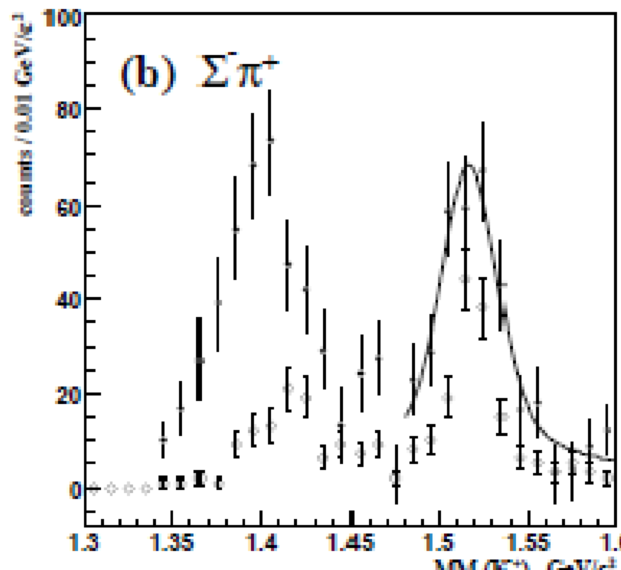
$$\frac{1}{2}|T^{(1)}|^2 + \frac{1}{3}|T^{(0)}|^2 + \frac{2}{\sqrt{6}}Re(T^{(0)}T^{(1)*})\,; \quad \pi^+\Sigma^-$$

$$\frac{1}{2}|T^{(1)}|^2 + \frac{1}{3}|T^{(0)}|^2 - \frac{2}{\sqrt{6}}Re(T^{(0)}T^{(1)*})\,; \quad \pi^-\Sigma^+$$

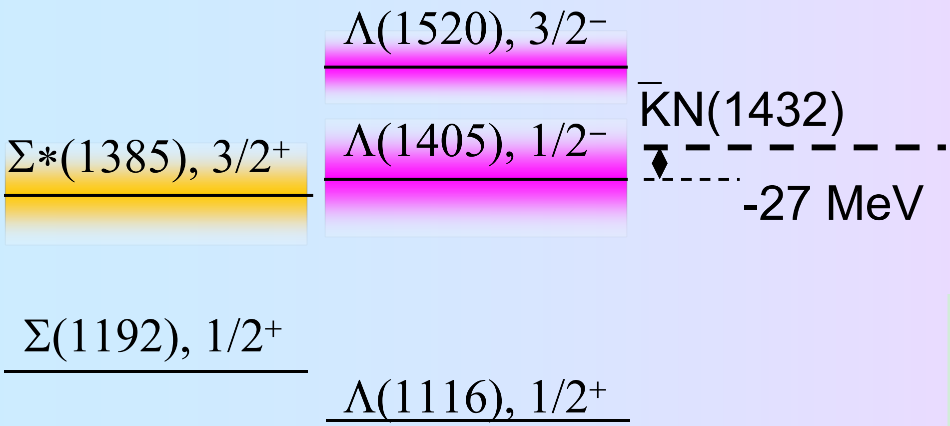
$$\frac{1}{3}|T^{(0)}|^2\,; \quad \pi^0\Sigma^0$$

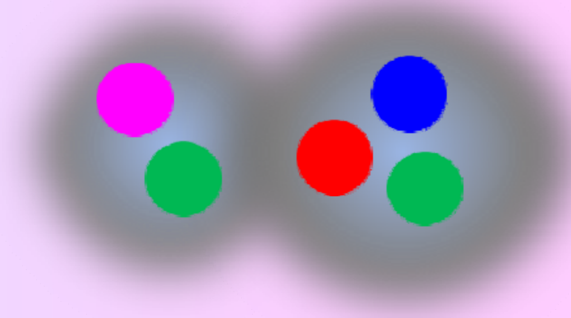
Q014 Exp.→



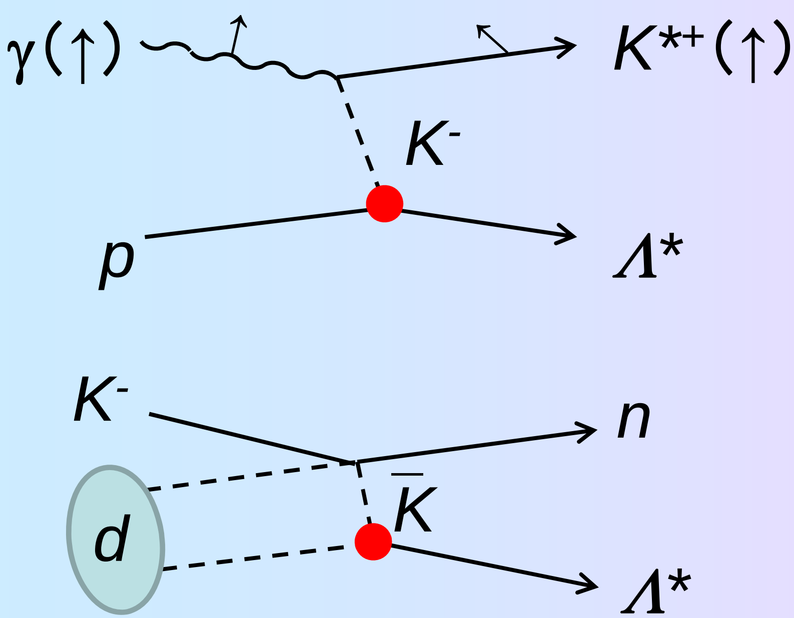


Λ(1405):分子共鳴的構造の解明

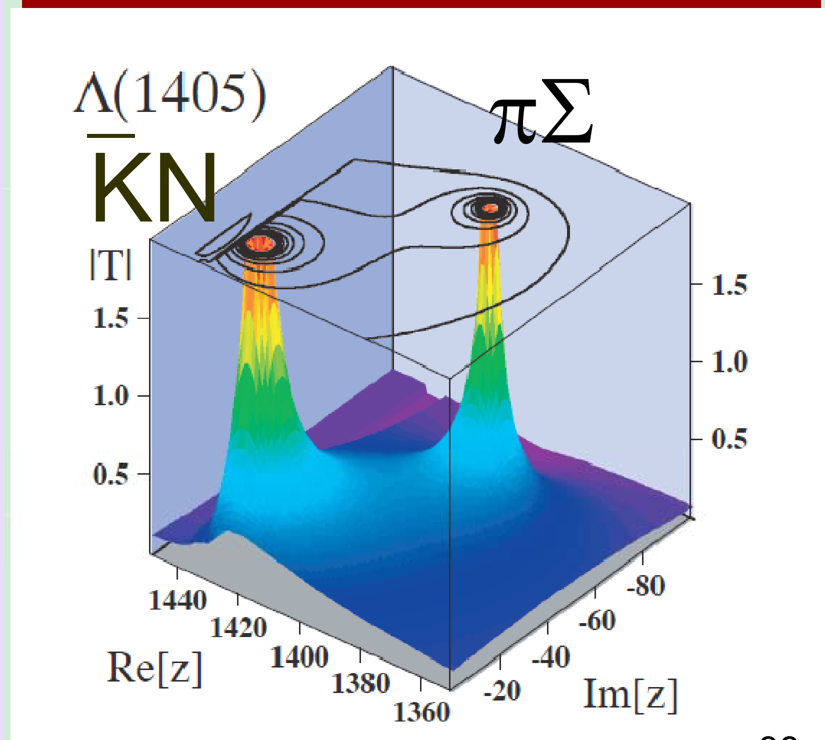




K̄NΛ*結合を選択的に調べる



$\Lambda(1405) : J^P = 1/2^-, I = 0$



ChU model, T. Hyodo