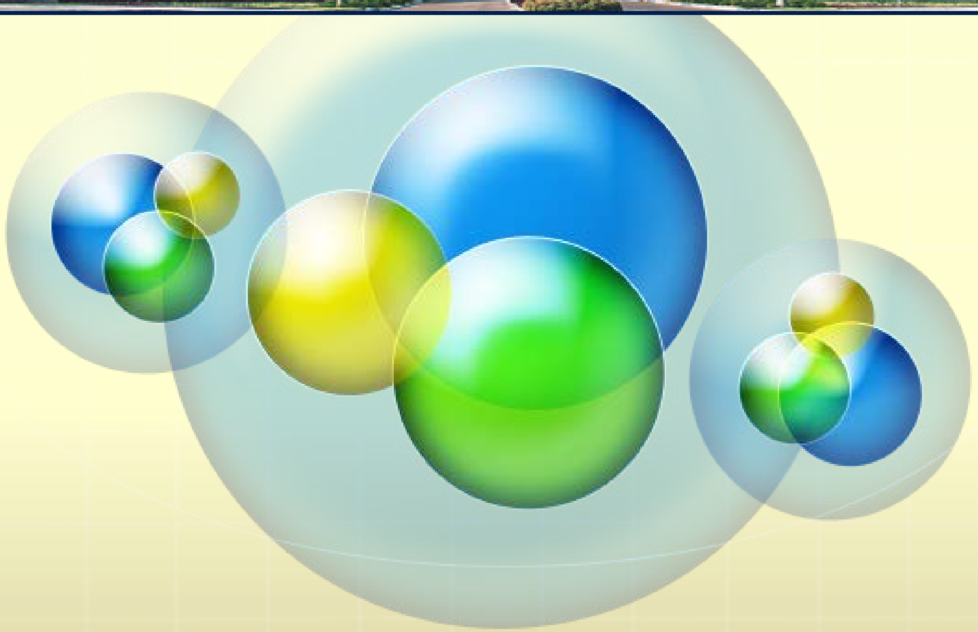


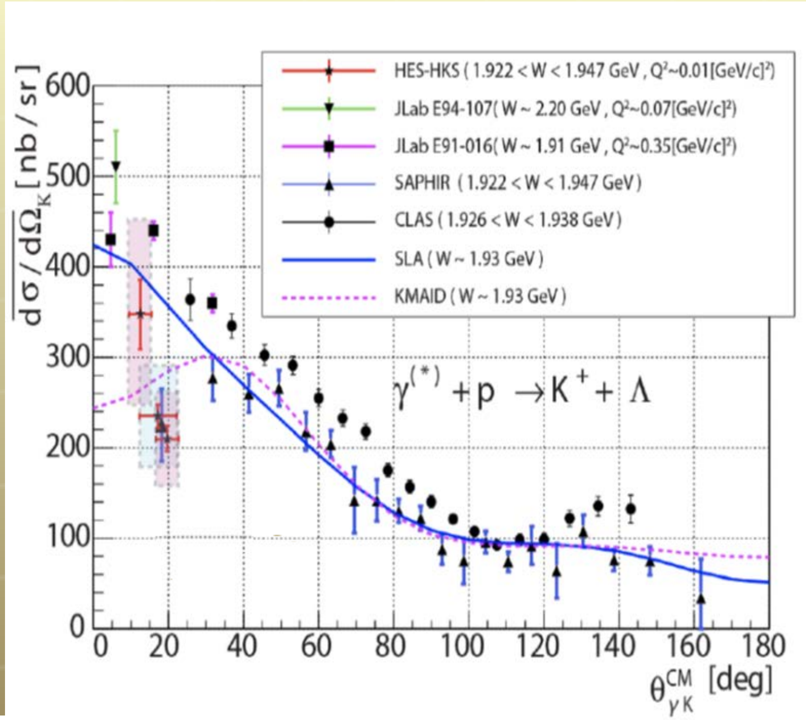
Spectroscopic Study of Light Hypernuclei

Pete Markowitz
Florida International University

$H(e,e'K^+)\Lambda/\Sigma$

Forward angle data both important and missing

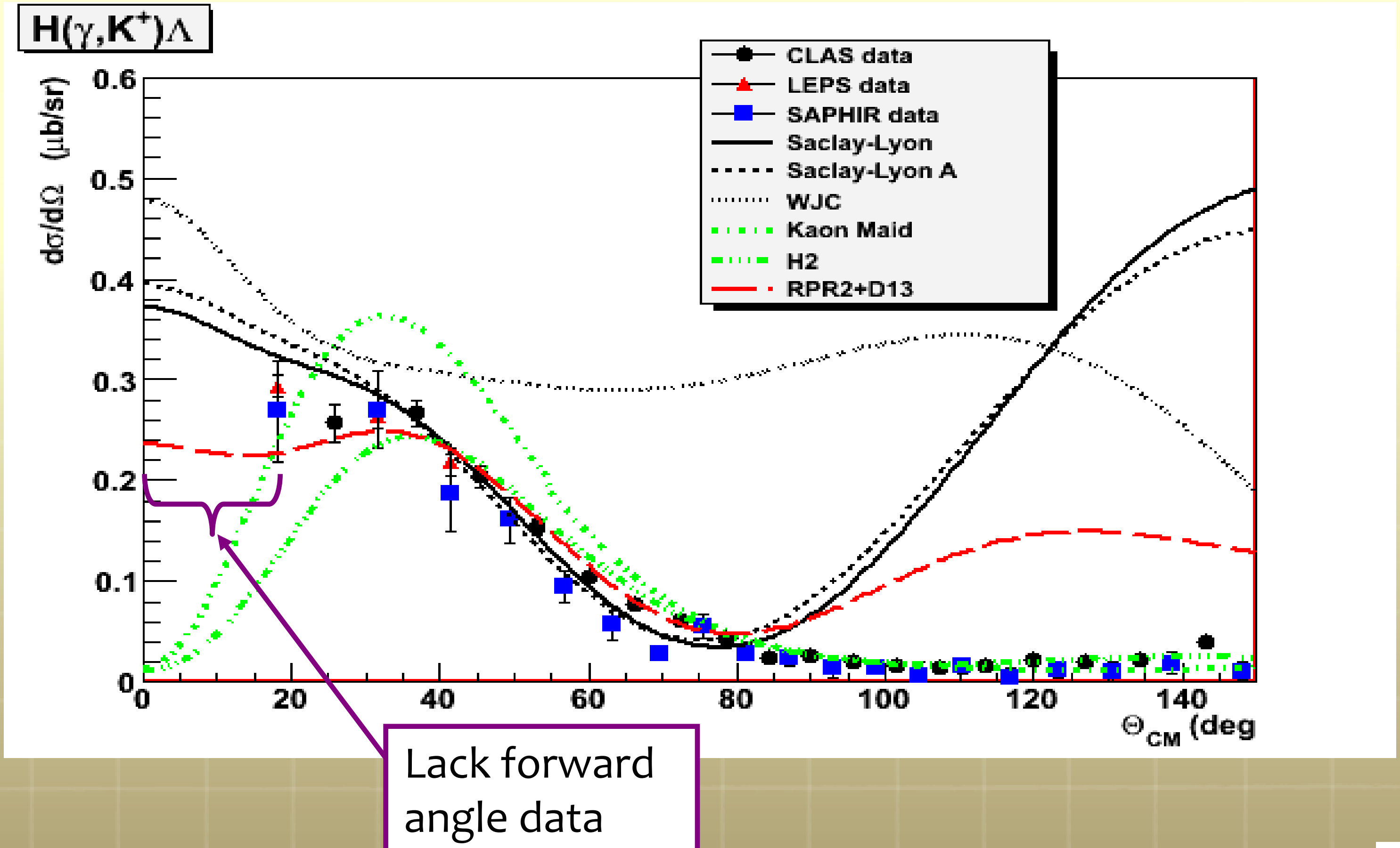
- **Energy calibration for hypernuclear measurements**
  - Can use cryogenic, waterfall or CH2 target
- **Important to understand angular distribution**
  - Sensitive discriminant of models
  - Required input for hypernuclei
  - Measure at identical kinematics



E94-107 electro-production result with $Q^2 \sim 0.07$ (GeV/c)^2, W=2.2 GeV and θ_{CM} =6°

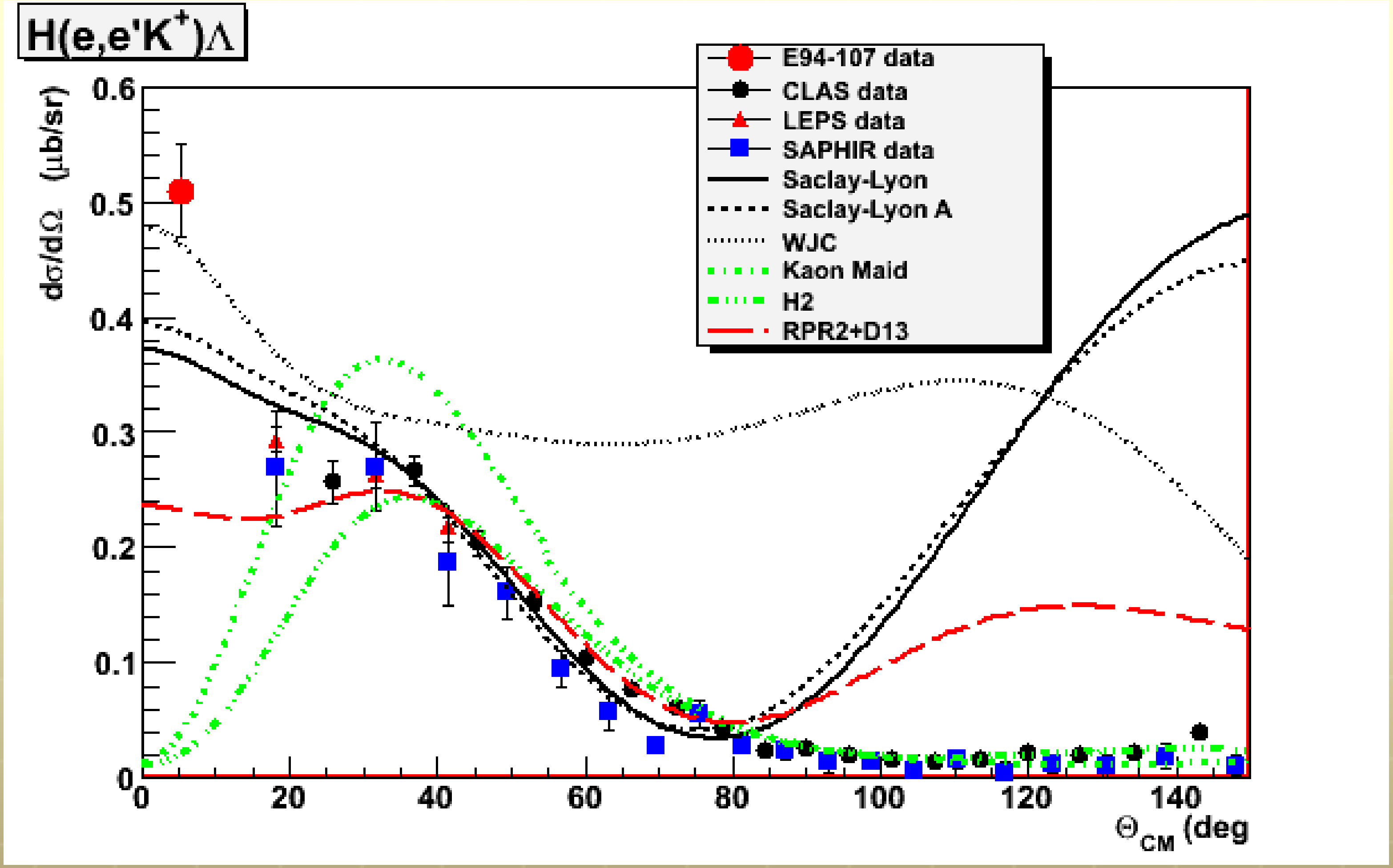
H target – The elementary process $^1H(e,e'K)\Lambda$

JLab hypernuclear experiments detect K^+ at small angles & low Q^2 (**close to photon-point).**
Region not covered existing photo- and electroproduction data CLAS, SAPHIR, and LEPS.



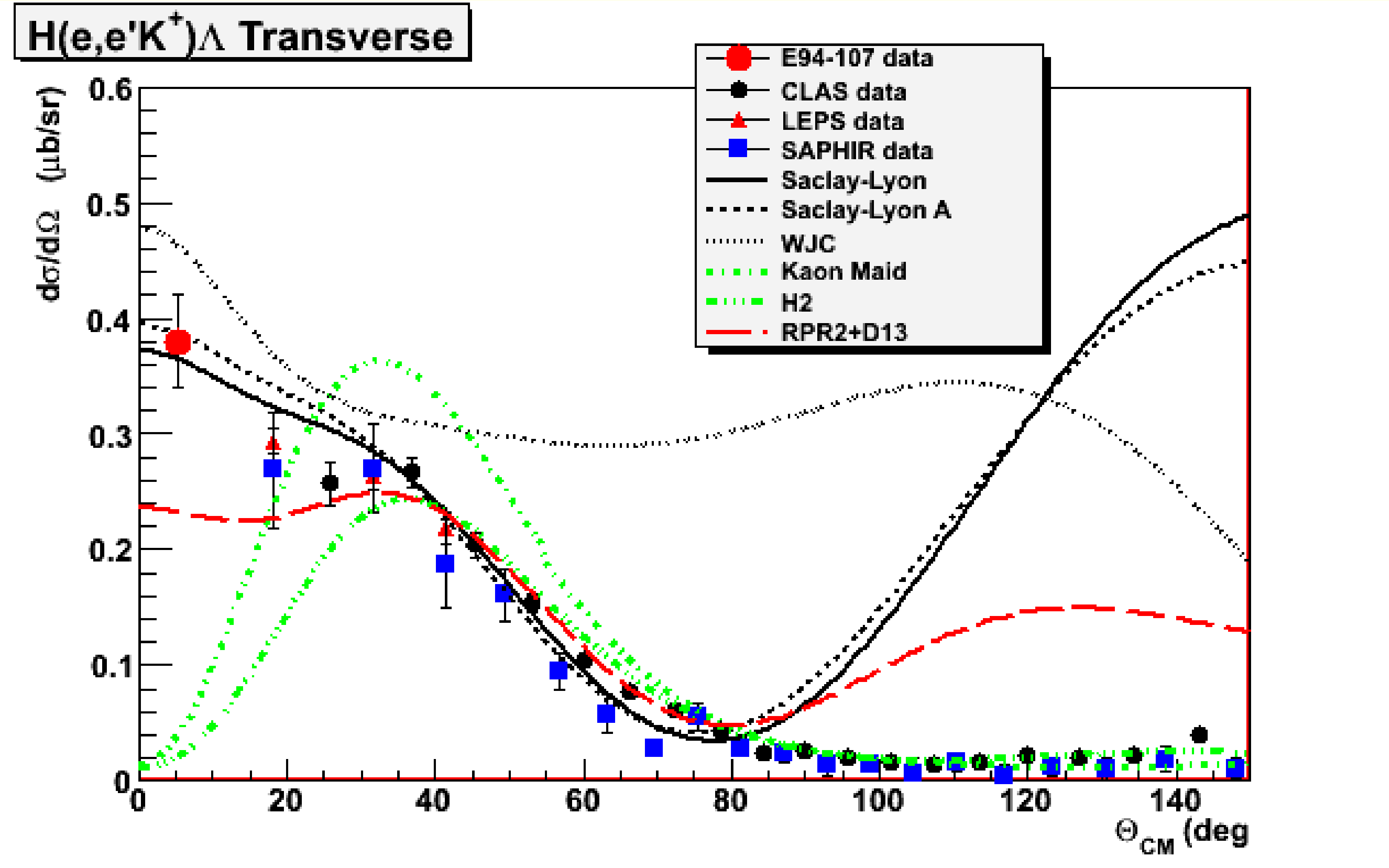
Models differ at very forward angles.
Also makes interpretation of obtained hypernuclear spectra difficult.

Results on H target – Angular distribution

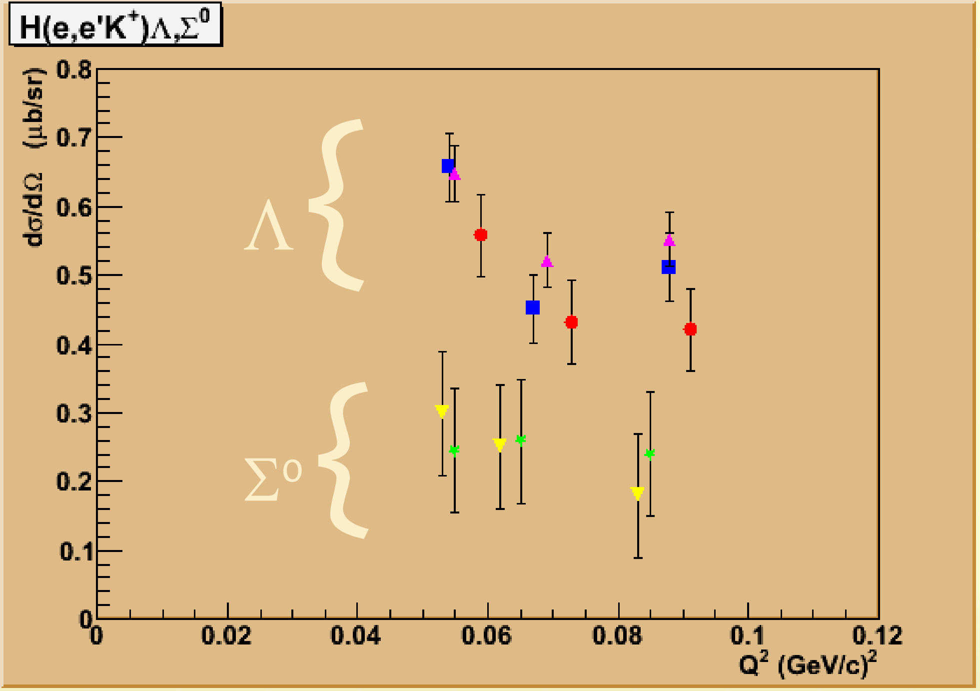


•None of the models is able to describe the data over the entire range
E94-107 data is electroproduction – could longitudinal amplitudes play a role?

Results on **H** target – Transverse estimate

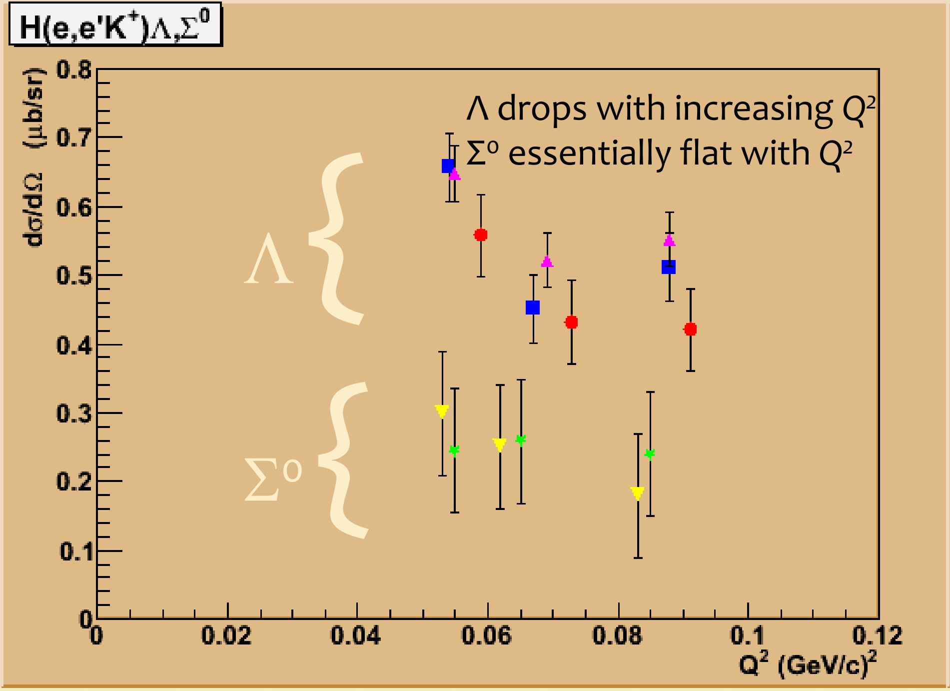


- Estimate of purely transverse amplitudes
- Still greater than most models predict

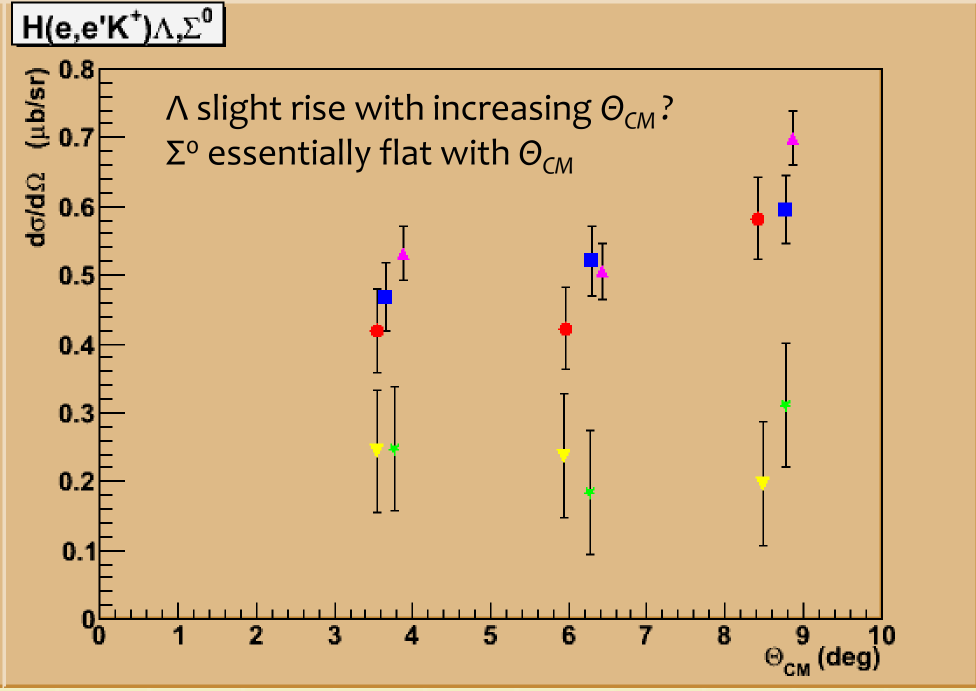


Λ drops with increasing Q^2

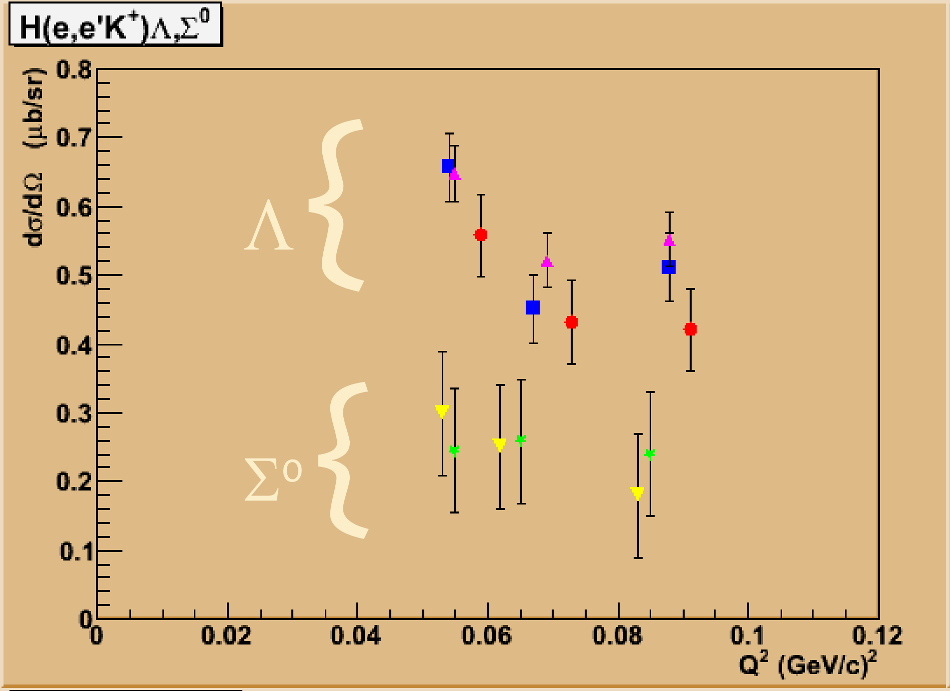
Σ^0 essentially flat with Q^2

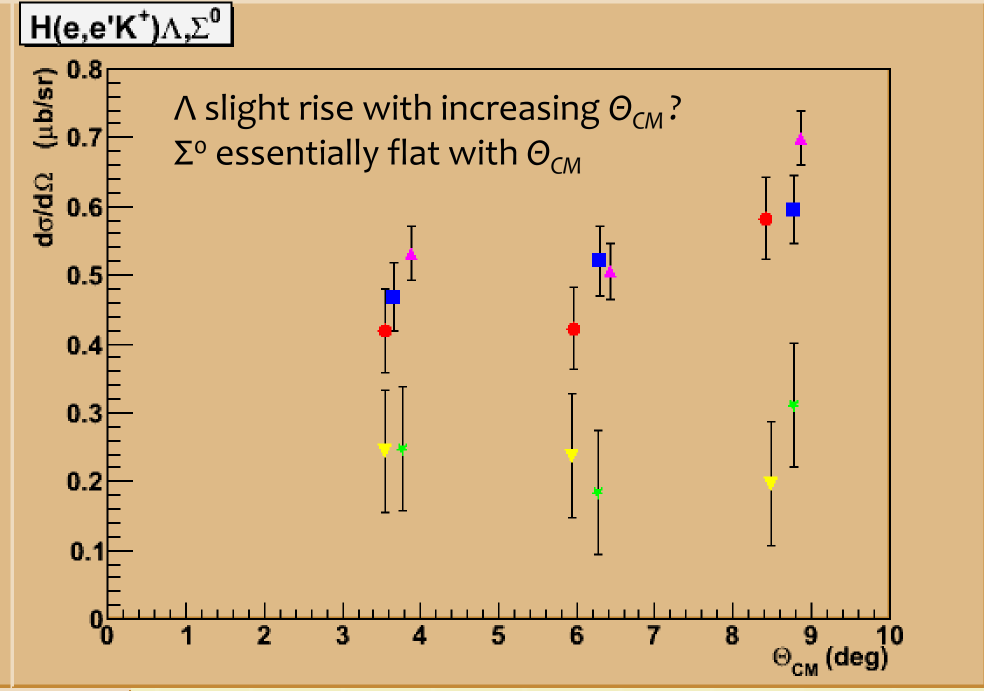


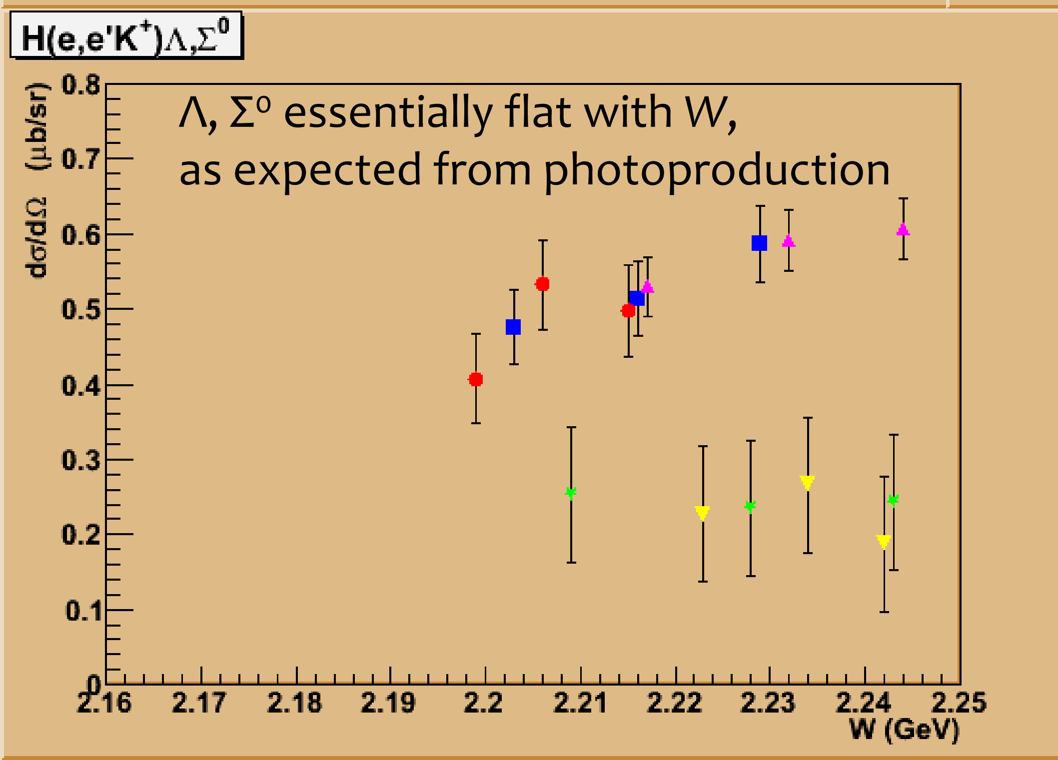
H(e,e'K+)Λ,Σ0
Λ drops with increasing Q2
Σ0 essentially flat with Q2
Λ
Σ0
dσ/dΩ (μb/sr)
Q2 (GeV/c)2

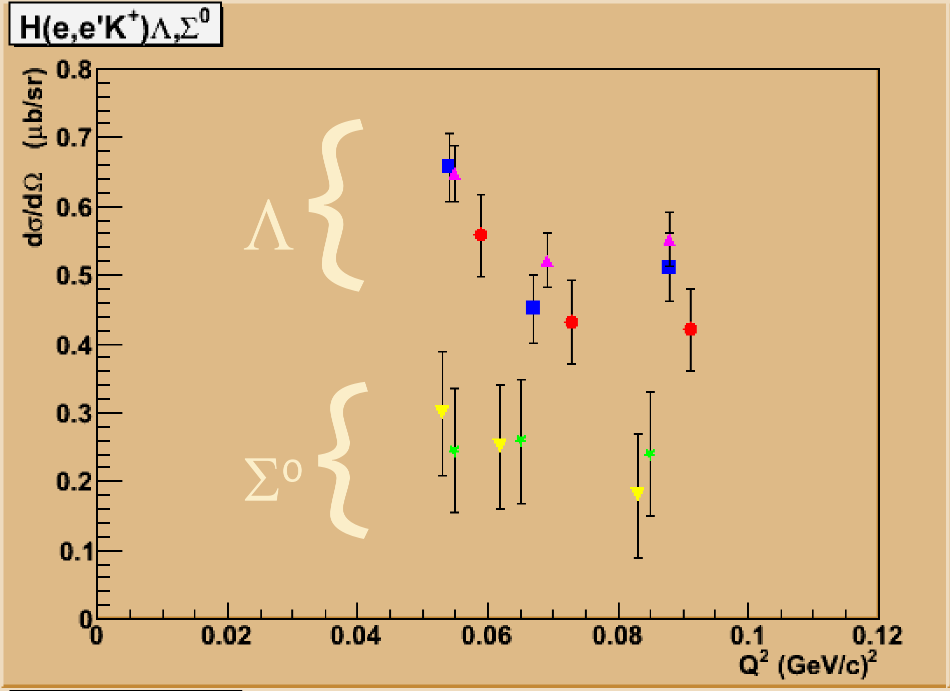


H(e,e'K+)Λ,Σ0
Λ slight rise with increasing ΘCM ?
Σ0 essentially flat with ΘCM
dσ/dΩ (μb/sr)
ΘCM (deg)

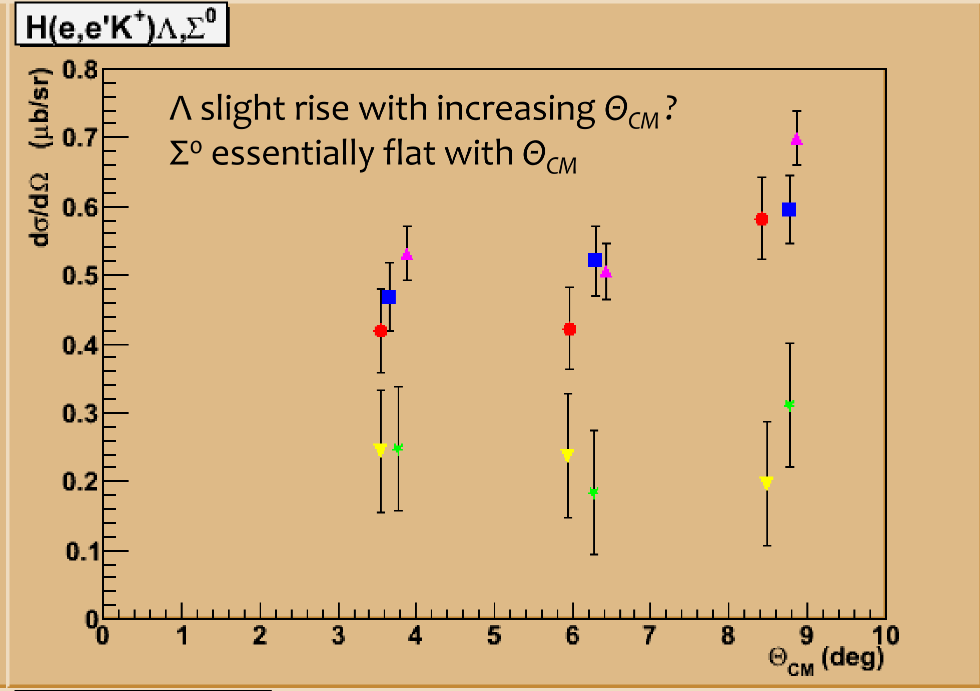

H(e,e'K+)Λ,Σ0
dσ/dΩ (μb/sr)
Λ
Σ0
Q2 (GeV/c)2
0 0.02 0.04 0.06 0.08 0.1 0.12
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8


H(e,e'K+)Λ,Σ0
Λ slight rise with increasing ΘCM ?
Σ0 essentially flat with ΘCM
dσ/dΩ (μb/sr)
ΘCM (deg)
0 1 2 3 4 5 6 7 8 9 10
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

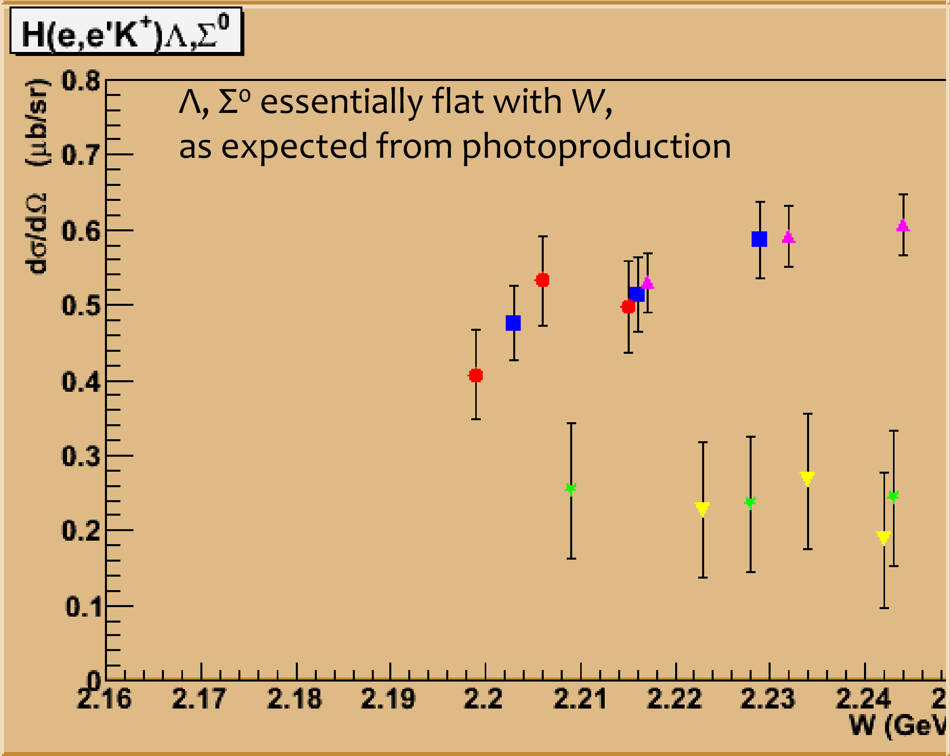

H(e,e'K+)Λ,Σ0
Λ, Σ0 essentially flat with W,
as expected from photoproduction
dσ/dΩ (μb/sr)
W (GeV)
2.16 2.17 2.18 2.19 2.2 2.21 2.22 2.23 2.24 2.25
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8



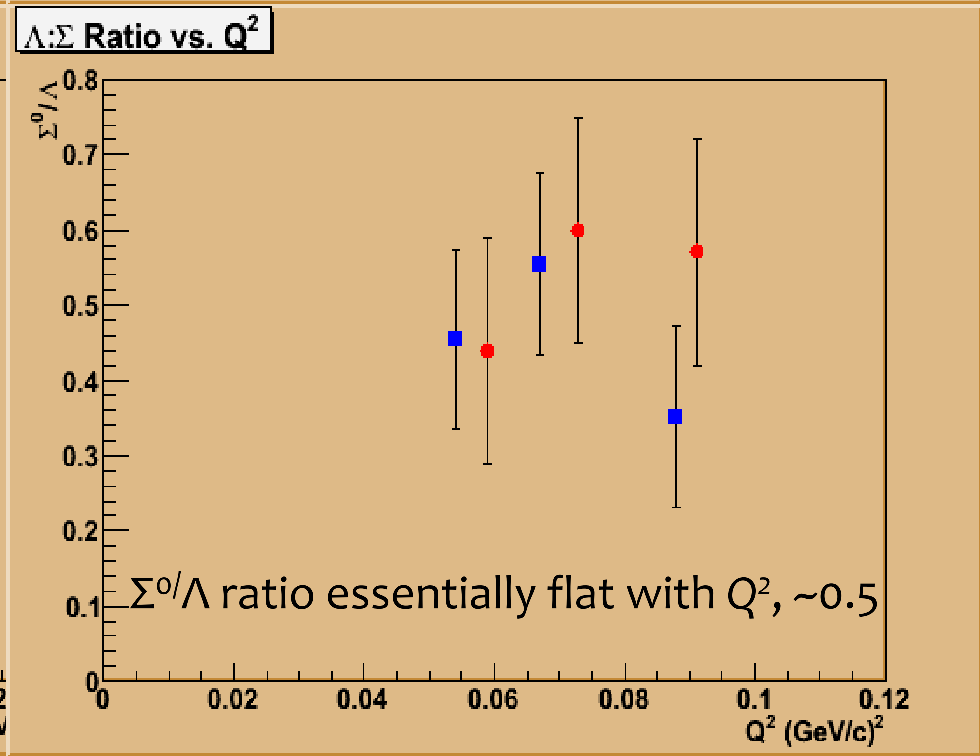
H(e,e'K+)Λ,Σ0
dσ/dΩ (μb/sr)
Λ
Σ0
Q2 (GeV/c)2



H(e,e'K+)Λ,Σ0
dσ/dΩ (μb/sr)
Λ slight rise with increasing ΘCM ?
Σ0 essentially flat with ΘCM
ΘCM (deg)

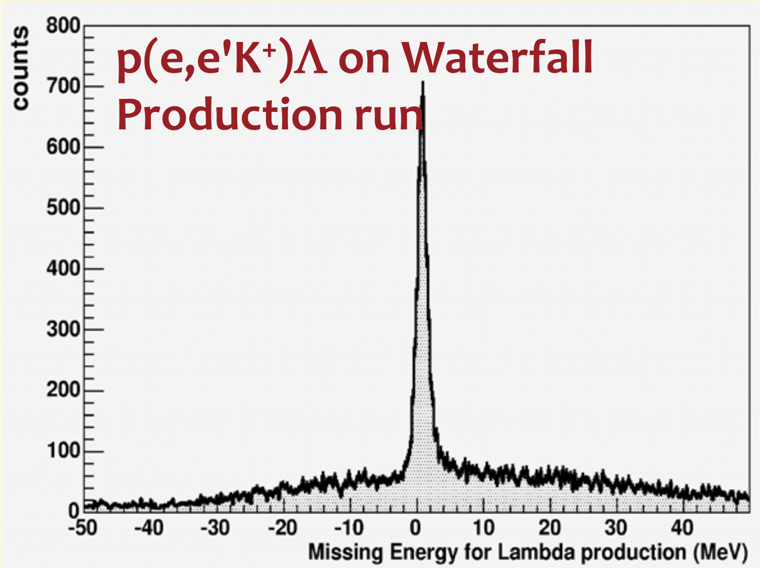


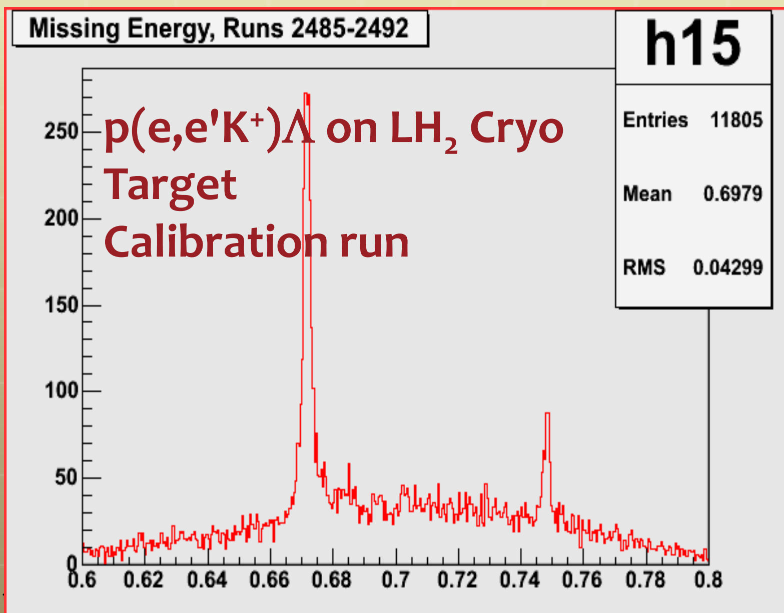
H(e,e'K+)Λ,Σ0
dσ/dΩ (μb/sr)
Λ, Σ0 essentially flat with W,
as expected from photoproduction
W (GeV

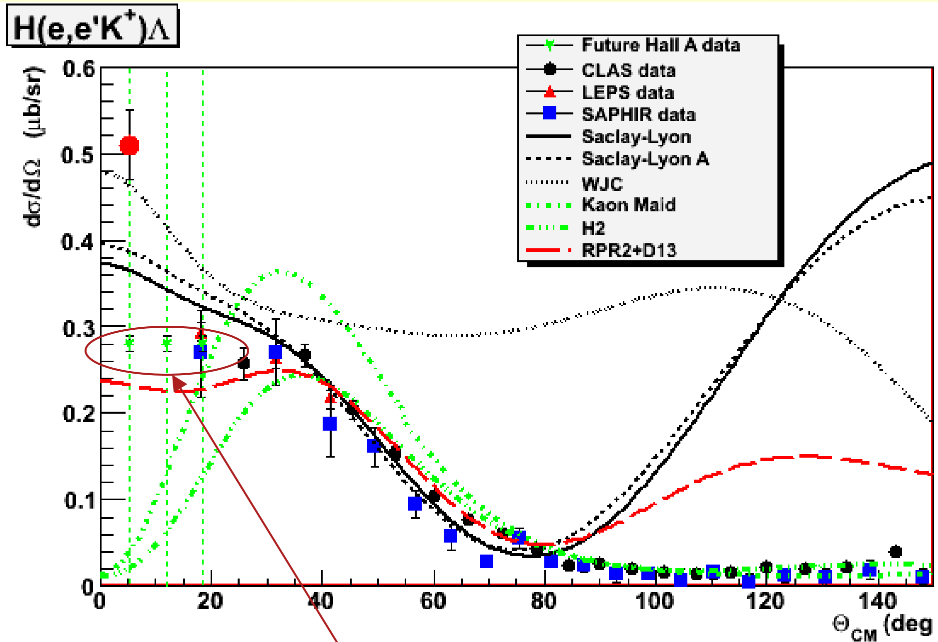


Λ:Σ Ratio vs. Q2
Σ0/Λ
Σ0/Λ ratio essentially flat with Q2, ~0.5
Q2 (GeV/c)2

Results on H target – The p(e,e'K)Λ Cross Section







Expected data from E07-012,
Never ran
(but we could get similar data)

The $H(e,e'K^+)\Lambda/\Sigma$

Low Q^2 at small angles

- **Same kinematics as hypernuclear spectroscopy**

  Elementary reaction is an ingredient of hypernuclear calculation

  Typically start w/ photoproduction and extend to electroproduction

  Intrinsically interesting however:

  ϑ dependence at small angles not measured

  W dependence still open

  Ratio of Λ:Σ^0 could probe nature of diquarks

- **Hypernuclear setup**

  Utilized cryogenic, waterfall or CH2 targets

  Very clean spectra with low backgrounds

  ➔ Luminosity well understood but acceptances take work

  Precise cross sections obtained

- **Odd piece of phase space**

  Critical for interpreting hypernuclear measurements

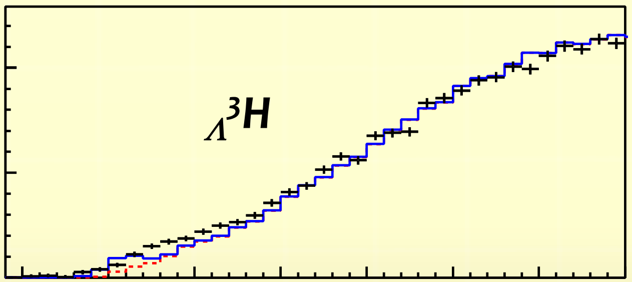
  Almost real photons but …

  Possible to do very limited Q^2 (slope?)

The $^{3}H(e,e'K^{+})\ {}_{\Lambda}^{3}n$

The $^3He(e,e'K^+)\ _{\Lambda}^{3}H$

Jlab has seen the A=3 and A=4 hypernuclear states without optimal resolution.



$_{\Lambda}^{4}H$

The $^{3}H(e,e'K^{+})\ {}_{\Lambda}^{3}n$

Surprise?

- **Unexpected resonance in ^{6}Li + ^{12}C scattering**

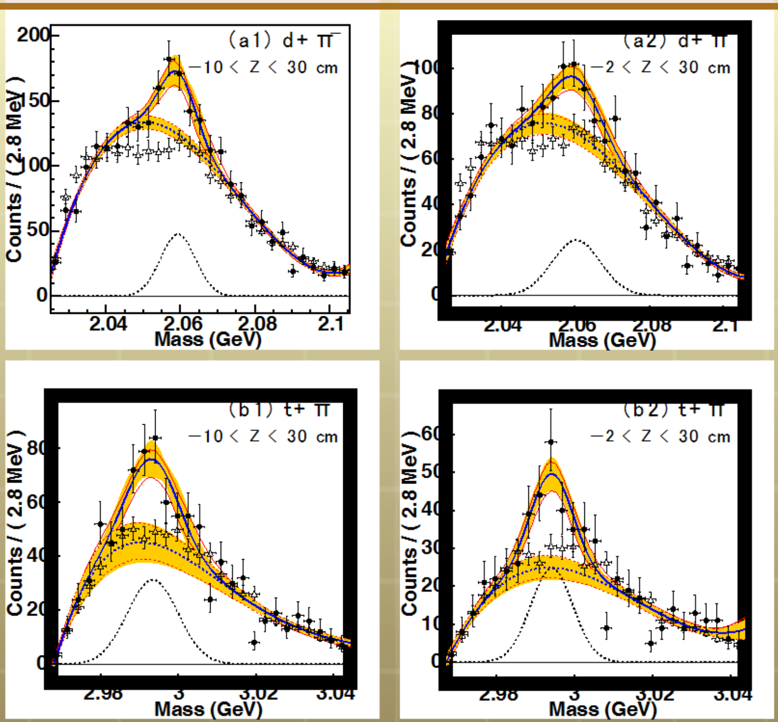
  d+ π^{-} and t+ π^{-} both exhibit additional strength

  Interpreted as 3-body and 2-body decay of ${}_{\Lambda}^{3}n$ state

- **If verified, would have serious impact**

  Downs & Dalitz suggested no bound isospin triplet state, PhyRev 114 (1958)

  "Straightforward" to measure, only possible currently at Jlab



$^{3}H(e,e'K^{+})\ {}_{\Lambda}^{3}n$

"Even" a resonance could still teach us a lot

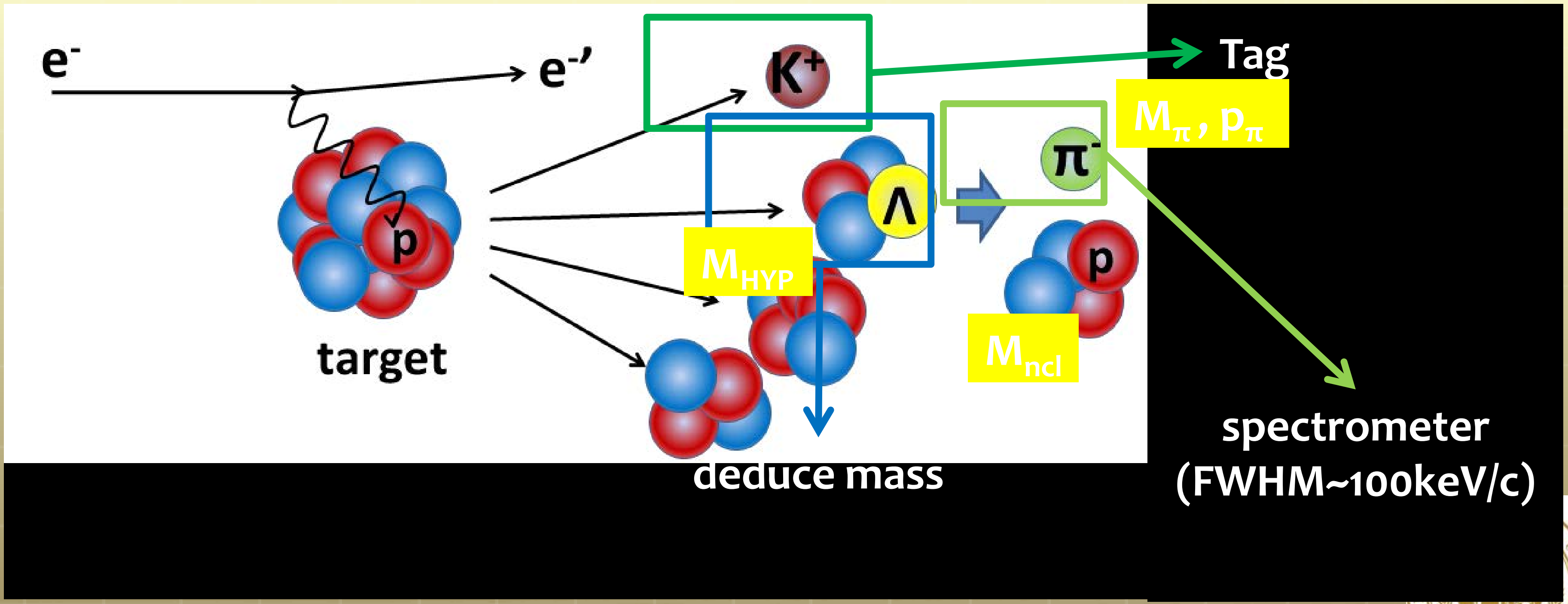
- **CSB**
  - Fundamental symmetry breaking or 3-body force?
  - *Λnn* state could tell us about the *Λn* without the pesky protons
  - Would the 2-body force need $^{2}H(e,e'K^{+})\ {}_{\Lambda}^{2}n$ to subtract it?
- **If verified, would have serious impact**
  - Downs & Dalitz suggested no bound isospin triplet state, PhyRev 114 (1958)
  - More recent calculations also cannot describe a bound ${}_{\Lambda}^{3}n$
  - "Straightforward" to measure, only possible currently at JLab
  - Since I=0 already exists, is the $^{3}He(e,e'K^{+})\ {}_{\Lambda}^{3}H$ measurement "clean"?

- **Target Issues**
  - Would be a new target (could be longer – 40 cm?)
  - May also want other cryogenic targets in same measurement
- **Separate Proposal**
  - Explaining hypernuclear proposals is always hard
  - Keep proposals to one simple topic for the PAC

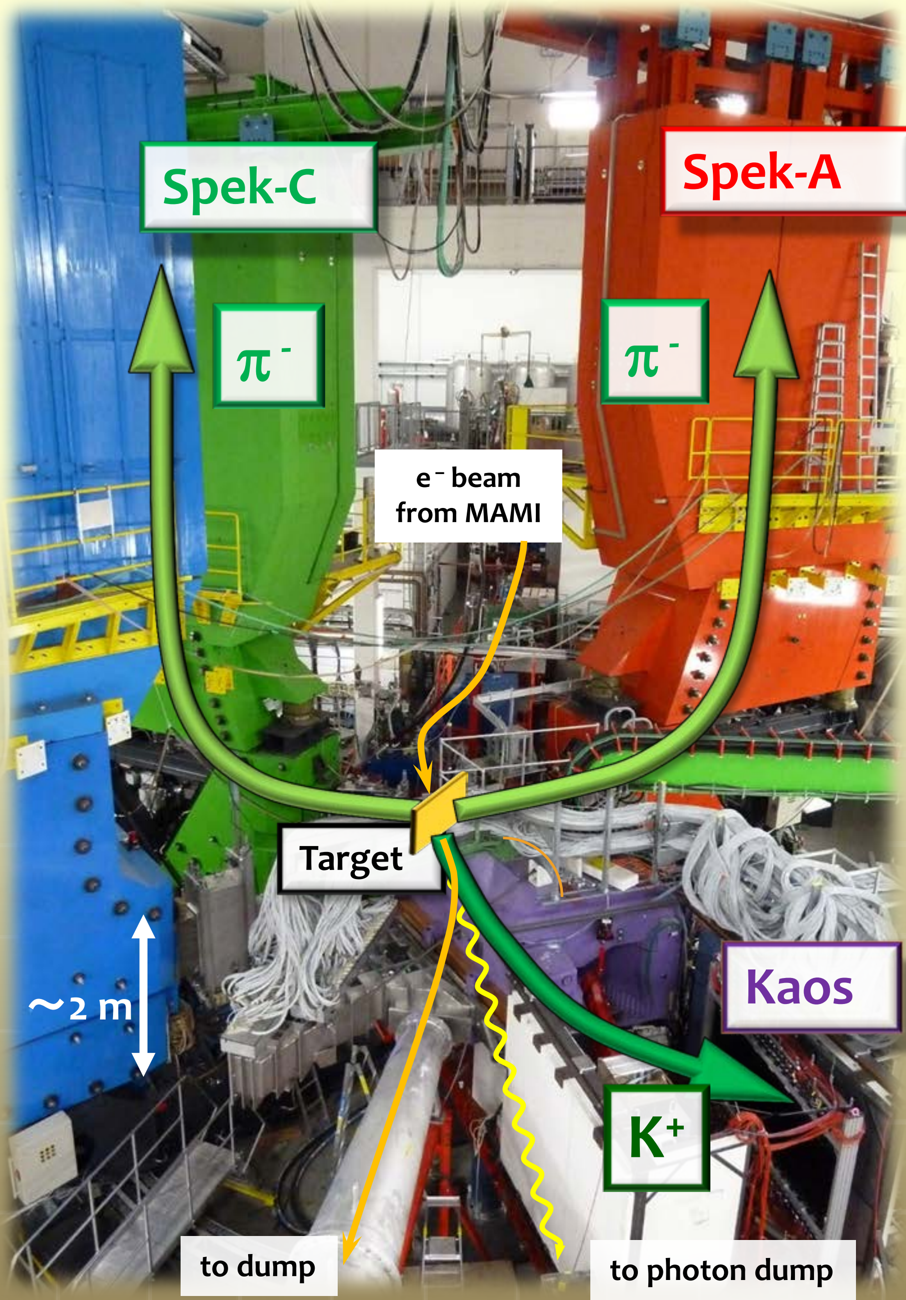
CSB in A=4

Decay π Spectroscopy of Electroproduced Hypernuclei (JLab E10-001 and MAMI-C KaoS project)

Study of $^{4}_{\Lambda}H$ ground state



KaoS at MAMI-C (Mainz Univ.)



Beam

Energy	1.5 GeV

Target

Material	^{9}Be
Thickness	125 μm (54° tilted)

Kaos (Kaon tagger)

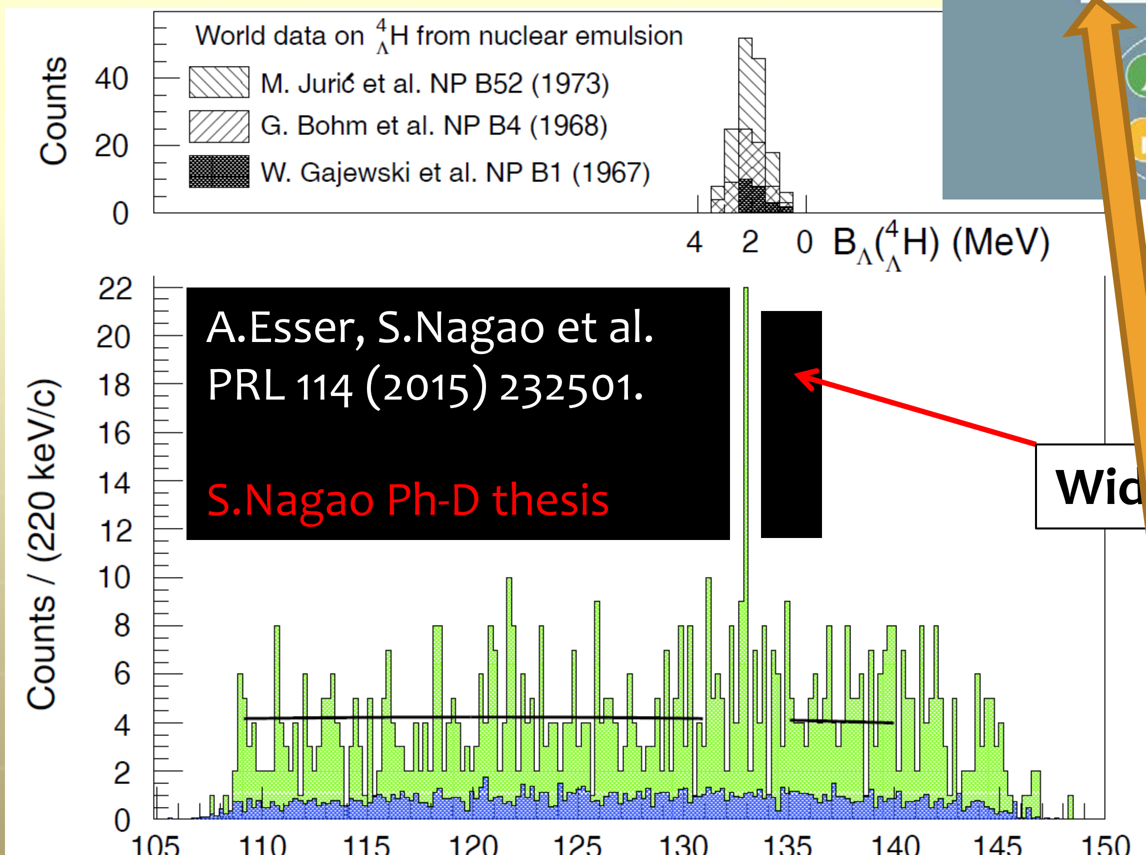
Cent.Mom	+900 MeV/c
Solid angle	~ 15 msr
K^+ survival ratio	~ 40%

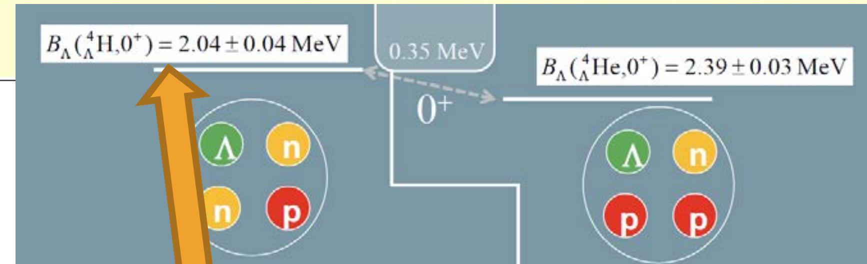
Spek-A, C (Pion spectrometer)

Cent.Mom	Spek-A = -115 MeV/c Spek-C = -125 MeV/c
Mom. res	$\Delta p/p < 10^{-4}$
Solid angle	28 msr

π^- spectrum tagged by K^+

Kaos + Spek-C (2011,2012)





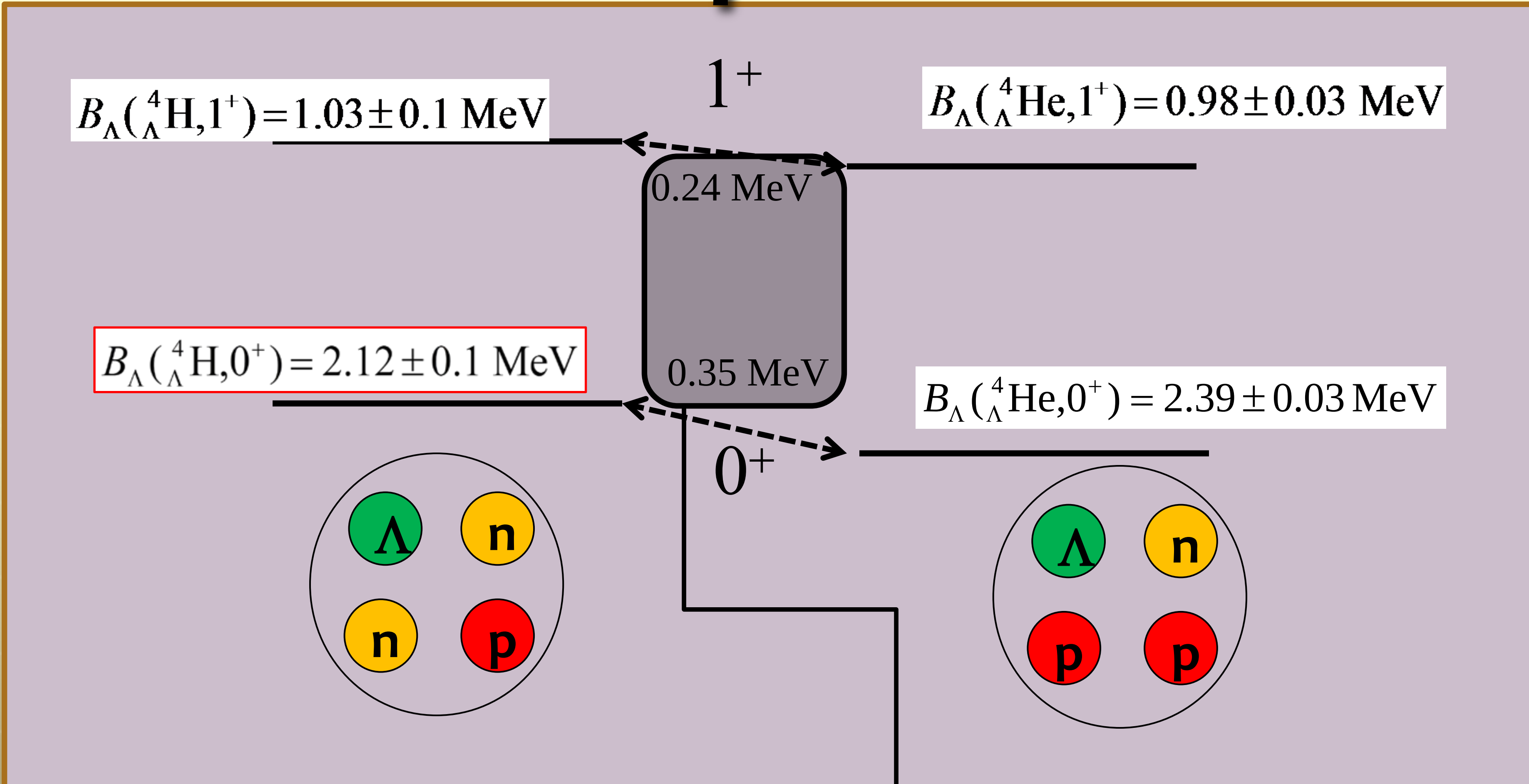
Wid h 230 keV/c (FWHM)

$$B_\Lambda = 2.12 \pm 0.01 \pm 0.09\ MeV$$

Pion momentum (MeV/c)

Collaboration took additional data in 2014. Analysis is in progress.

A=4 system
CSB ΛN potential



Coulomb effect is very small.

$$-\Delta B_c = 0.050\pm0.02 \text{ MeV},$$

$$-\Delta B_c^* = 0.025\pm0.015 \text{ MeV}$$

Charge Symmetry Breaking

cf) B(^{3}H)-B(^{3}He)-ΔB_c ~ 70 keV

A=4 system
CSB ΛN potential

Best accessible by Jlab!

$B_\Lambda({}^4_\Lambda\mathrm{H},1^+) = 1.03 \pm 0.1\ \mathrm{MeV}$

1^+

$B_\Lambda({}^4_\Lambda\mathrm{He},1^+) = 0.98 \pm 0.03\ \mathrm{MeV}$

0.24 MeV

γ-ray : level spacing

Decay π: ground state

Mainz New data :

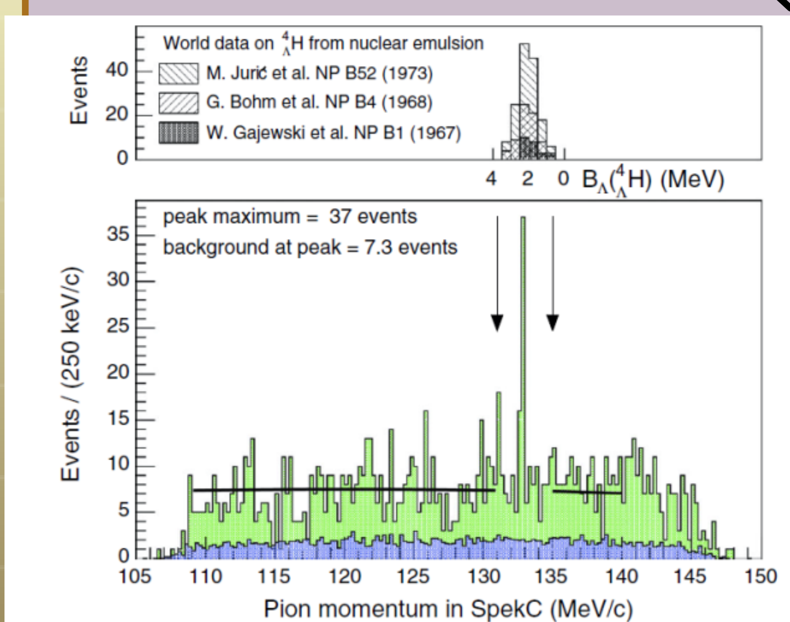
***PRL* 114, 232501 (2015)**

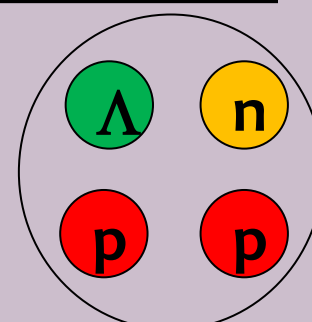
$B_\Lambda({}^4_\Lambda\mathrm{H},0^+) = 2.12 \pm 0.1\ \mathrm{MeV}$

0.35 MeV

$B_\Lambda({}^4_\Lambda\mathrm{He},0^+) = 2.39 \pm 0.03\ \mathrm{MeV}$

0^+





Charge Symmetry Breaking

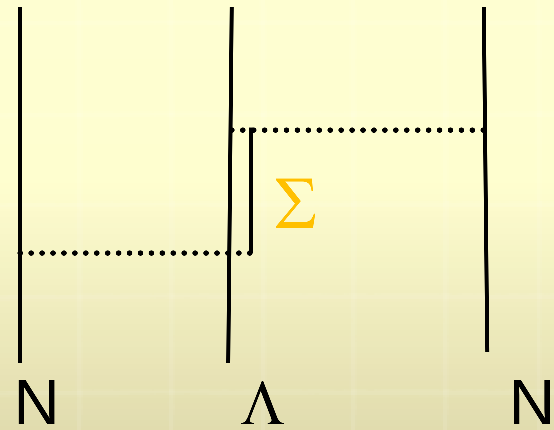
cf) $B({}^3\mathrm{H}) - B({}^3\mathrm{He}) - \Delta B_c \sim 70$ keV

Three-body ΛNN force

Modern ChPT-NLO calculation predicts 3NF effect is < 100keV

NLO calculation cannot explain experimental results for A=4, T=1/2, hypernuclei.

(Nogga, HYP2012)



ΛΣ mass difference ~ 80 MeV < NΔ mass difference ~ 300MeV

$M(\Sigma^+) < M(\Sigma^0) < M(\Sigma^-)$, $\Delta M(\Sigma^- - \Sigma^+) \sim 8\,\text{MeV}$

No consistent understanding of 0^+, 1^+ of ${}^4_\Lambda H$, ${}^4_\Lambda He$?

Phenomenological potential :

A.R.Bodmer&Q.N.Usmani, PRC 31(1985)1400.

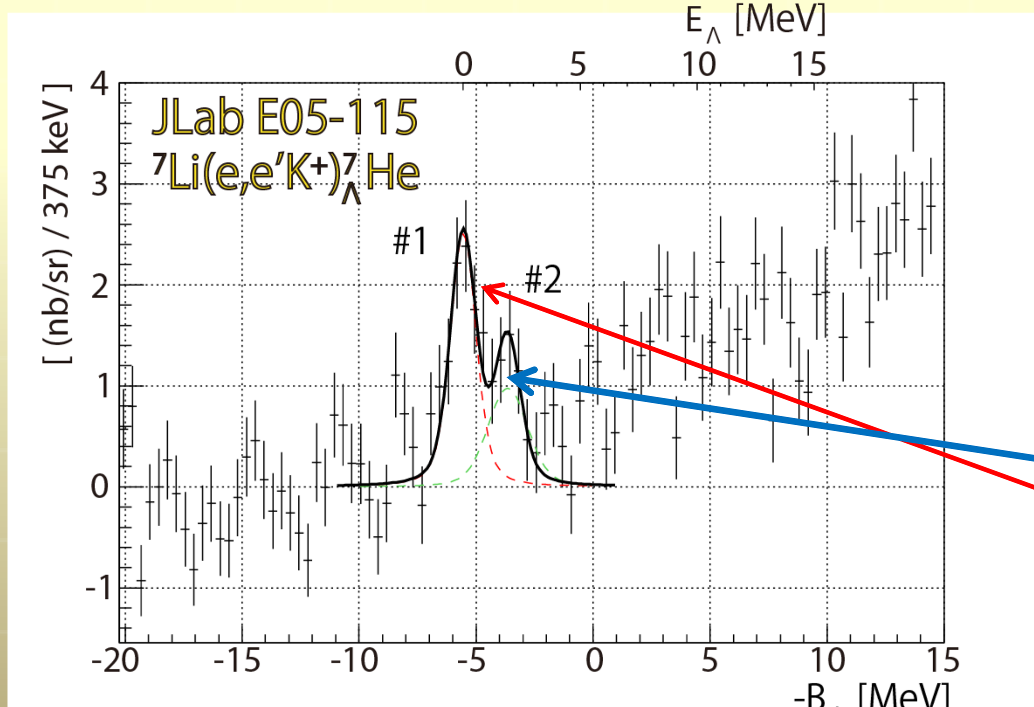
$$V^{CSB} = -\tau_3 T_\pi^2 \tfrac{1}{8}[(0.568\Delta B_\Lambda + 0.756\Delta B^*_\Lambda) + (0.568\Delta B_\Lambda - 0.756\Delta B^*_\Lambda)\sigma_\Lambda \cdot \sigma_N]$$

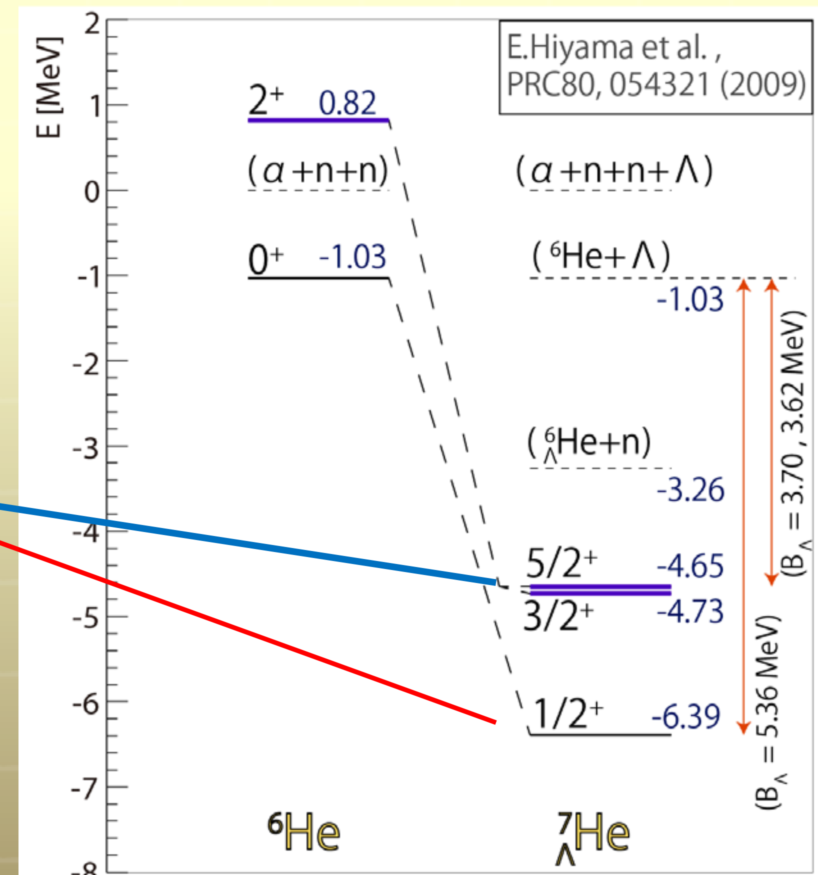
CSB in A=7

- **Uses data from multiple experiments to address physics**

$^{7}Li(e,e'K)^{7}_{\Lambda}He$ from JLab E05-115: Case study for the impact

T.Gogami, Doctor Thesis (2014) Tohoku Univ.



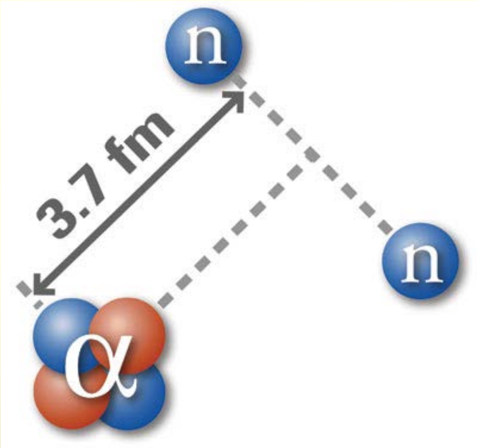


E01-011(HKS) 90 counts

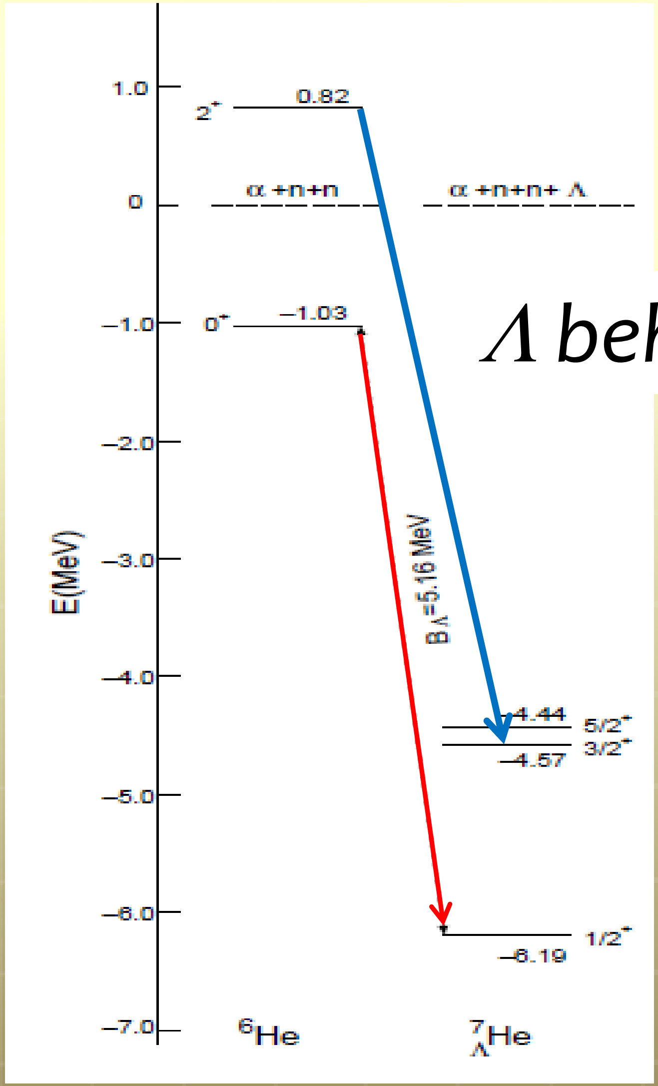
E05-115(HKS-HES) >500 counts

unbound ^{6}He excited state + Λ = bound $^{7}_{\Lambda}He$ excited state

$^{7}_{\Lambda}He = {}^{6}He + \Lambda$



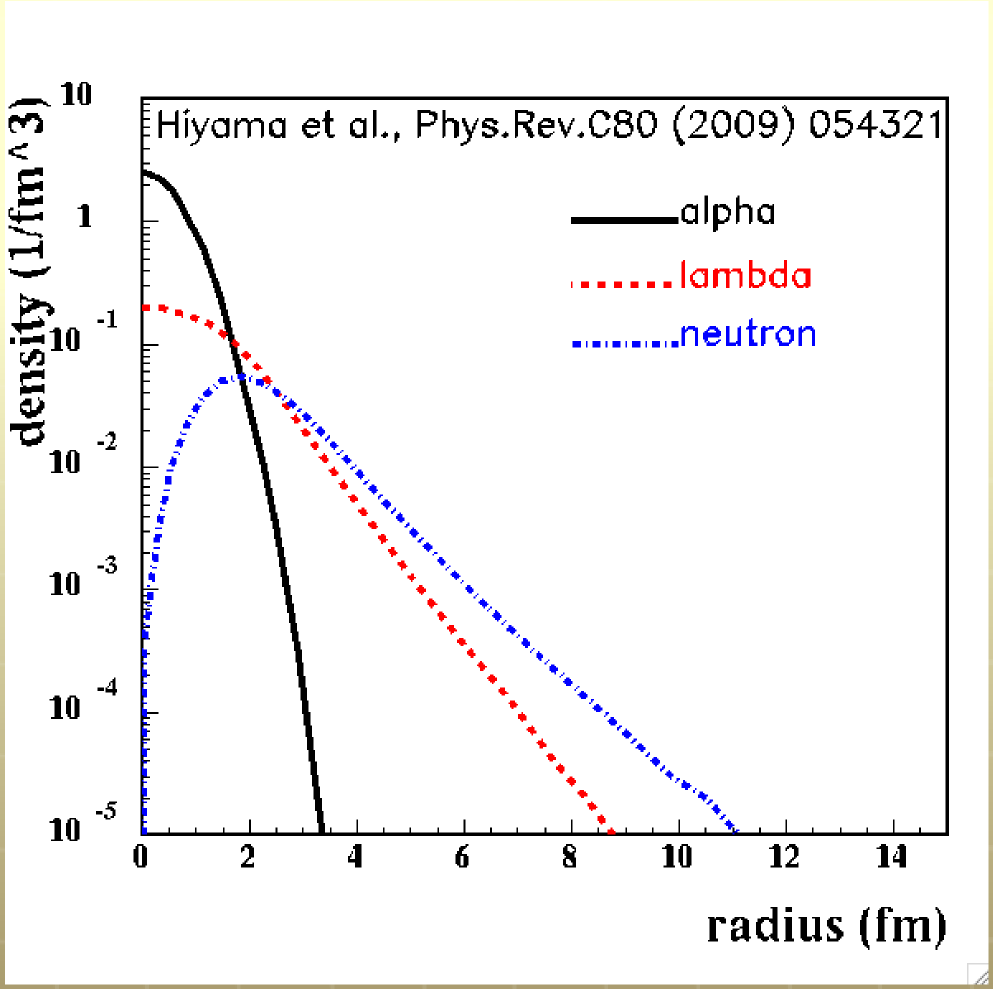
^{6}He : 2n halo

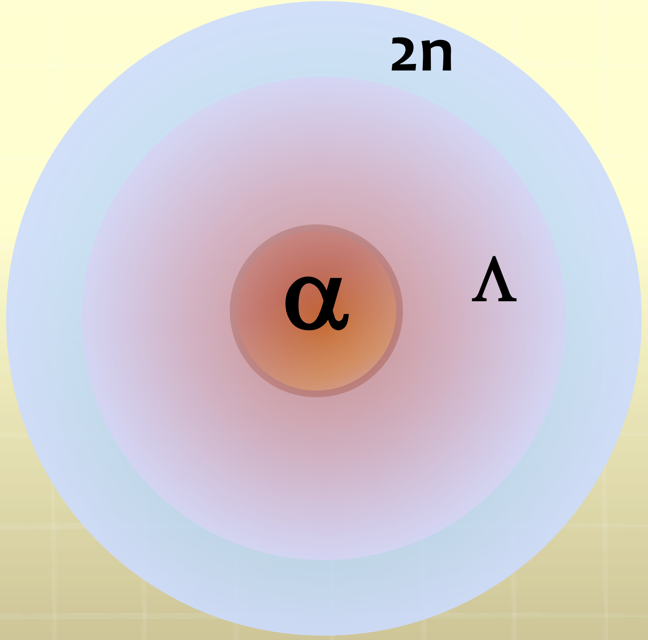


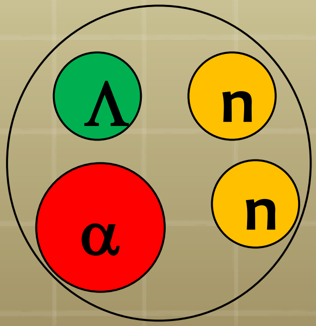
Λ behaves like glue

E.Hiyama et al. PRC 80, 054321 (2009)

$^{7}_{\Lambda}He$ Density Distributions

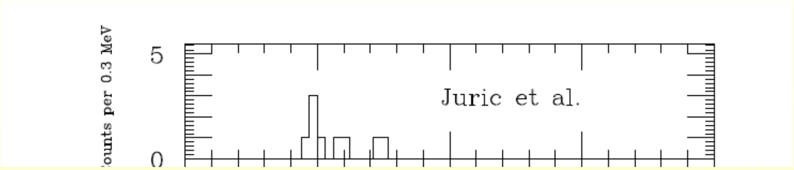




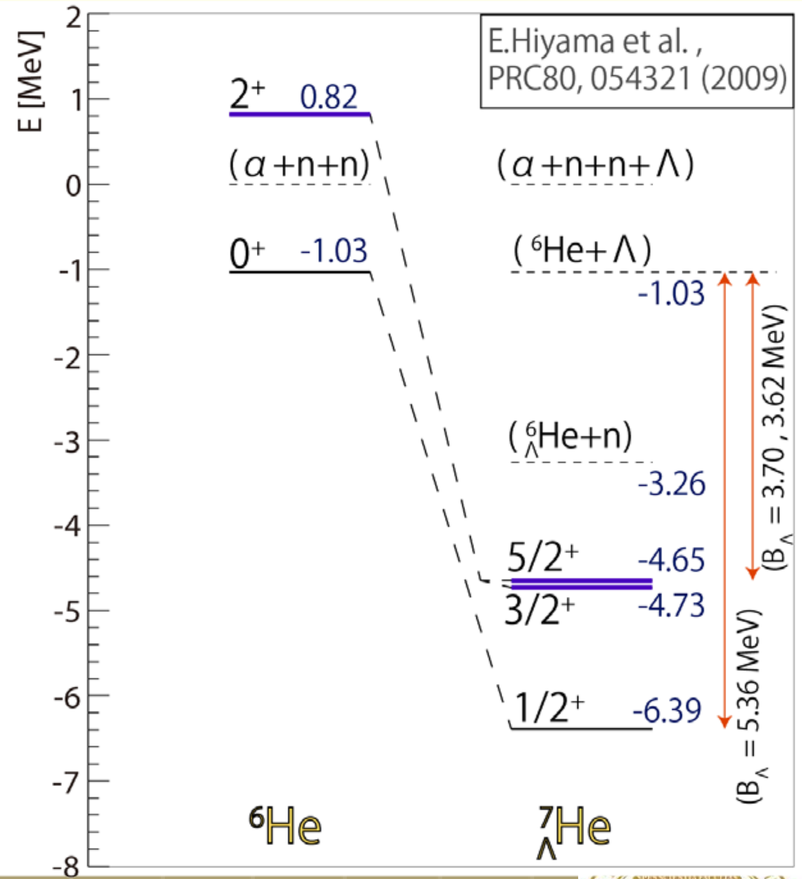


$^{7}_{\Lambda}$He spectrum

Juric et al., Nucl. Phys. A484 (1988) 520

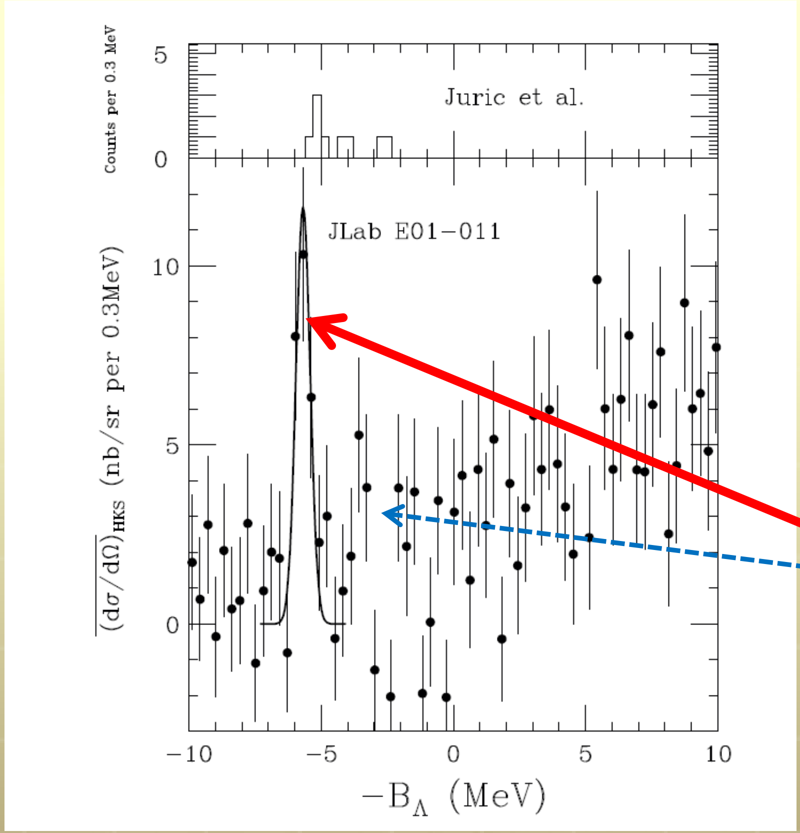


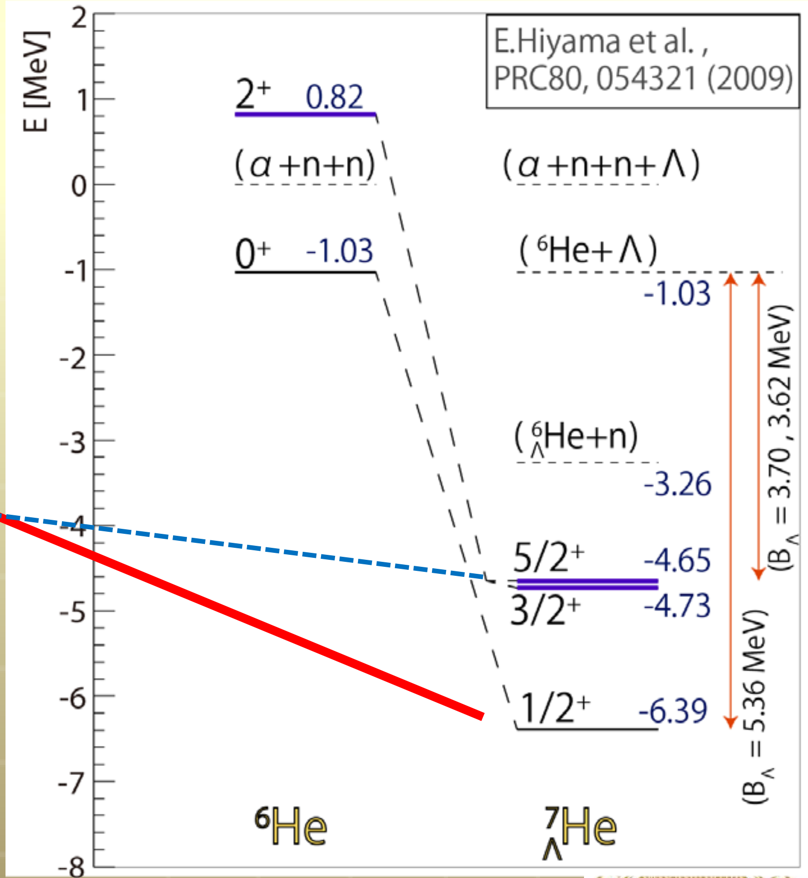
No B_{Λ} was obtained.



$^{7}_{\Lambda}$He spectrum of E01-011

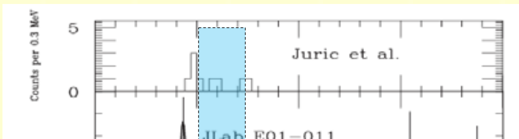
SNN et al., PRL 110, 012502 (2013)



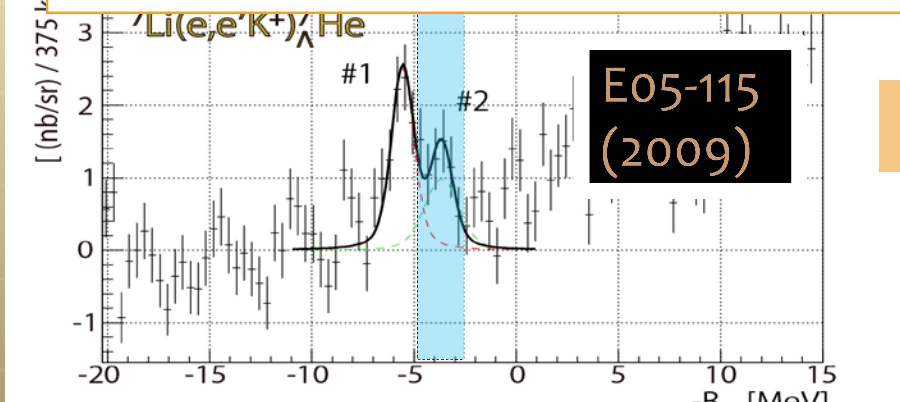


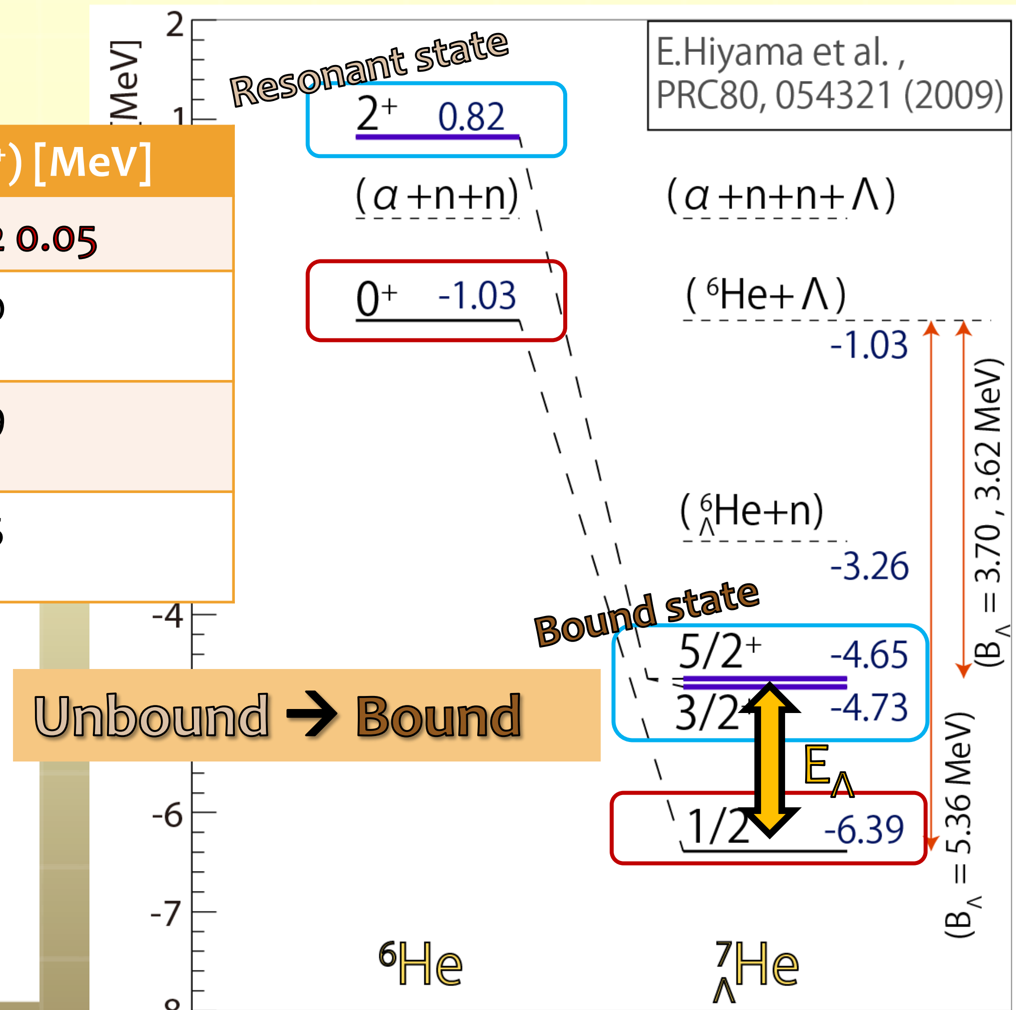
E01-011(HKS)   90 counts

Observation of excited states



	E_Λ (3/2⁺,5/2⁺) [MeV]
JLab E05-115	**1.900.22 0.05**
E.Hiyama et al., PRC 80, 054321 (2009)	1.70
M.Sotona et al., PTP 117 (1994)	1.79
D.J.Millener Private communication	1.75

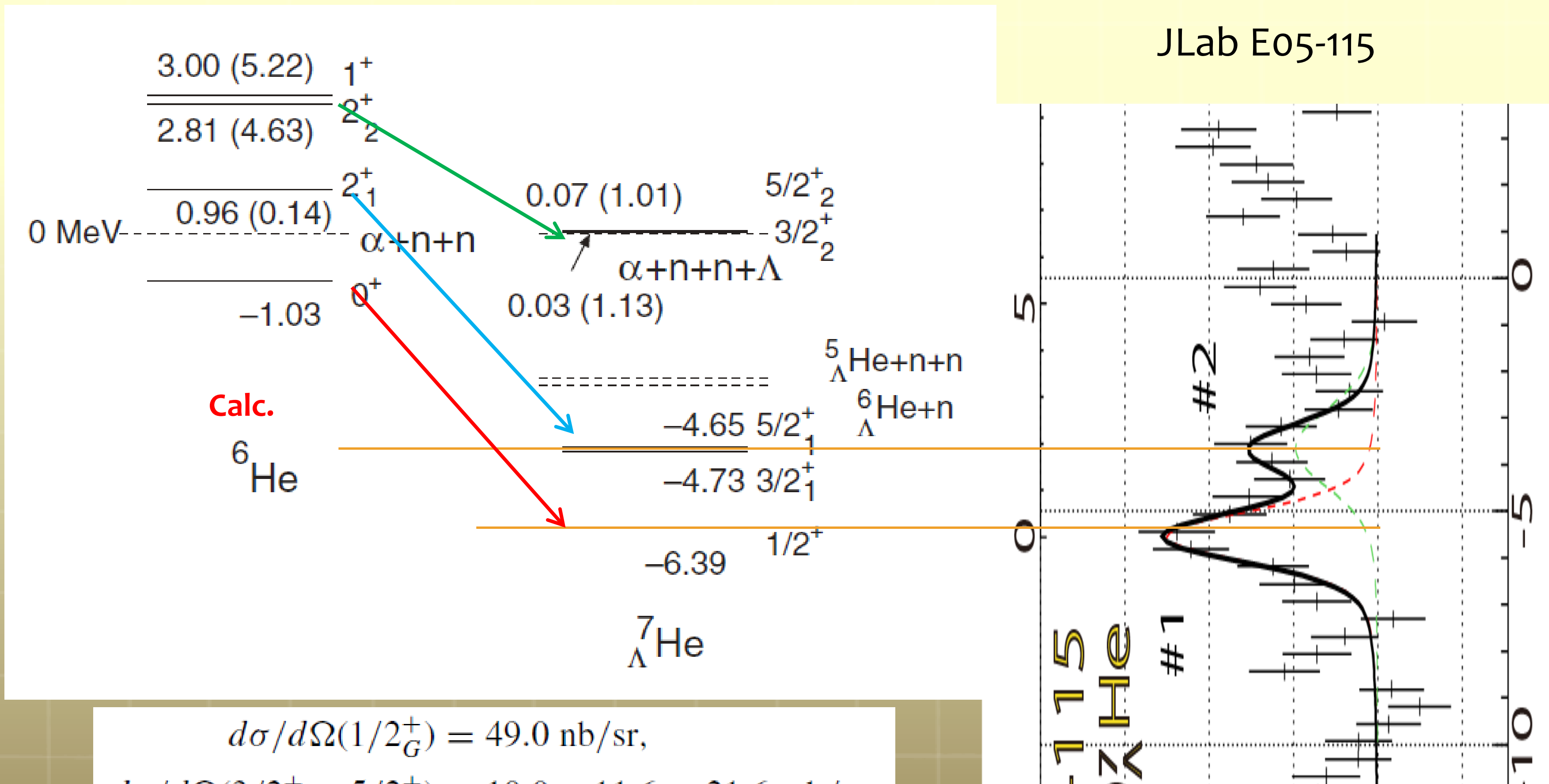




T.Gogami, Doctor Thesis (2014) Tohoku Univ.

E.Hiyama et al. PRC 91 054316 (2015)

JLab E05-115



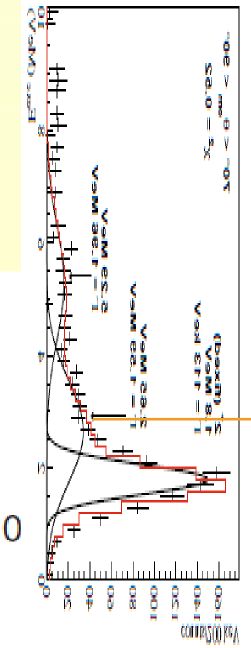
$$d\sigma/d\Omega(1/2^+_G) = 49.0\ \mathrm{nb/sr},$$

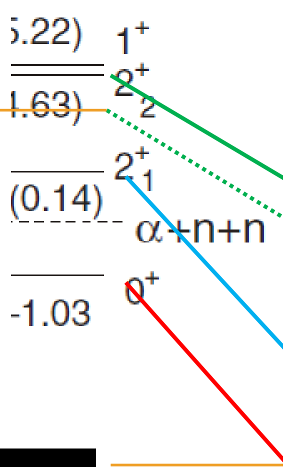
$$d\sigma/d\Omega(3/2^+_1 + 5/2^+_1) = 10.0 + 11.6 = 21.6\ \ \mathrm{nb/sr},$$

$$d\sigma/d\Omega(3/2^+_2 + 5/2^+_2) = 3.4 + 4.3 = 7.7\ \ \mathrm{nb/sr}.$$

X.Mougeot et al., PLB 718 (2012) 441.   p(^{8}He,t)^{6}He

yama et al. PR





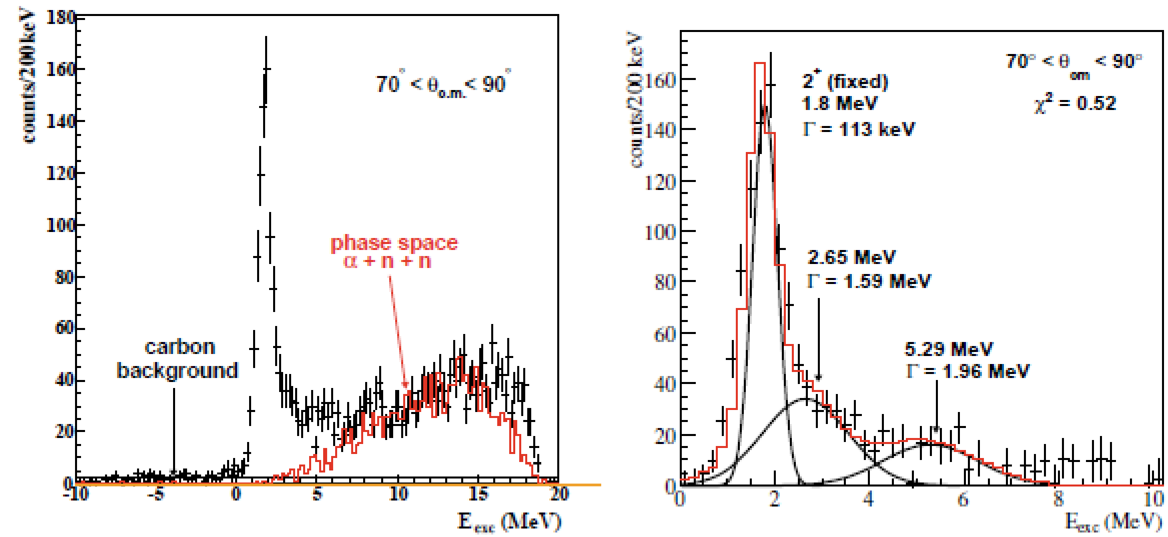
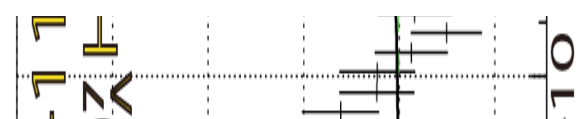


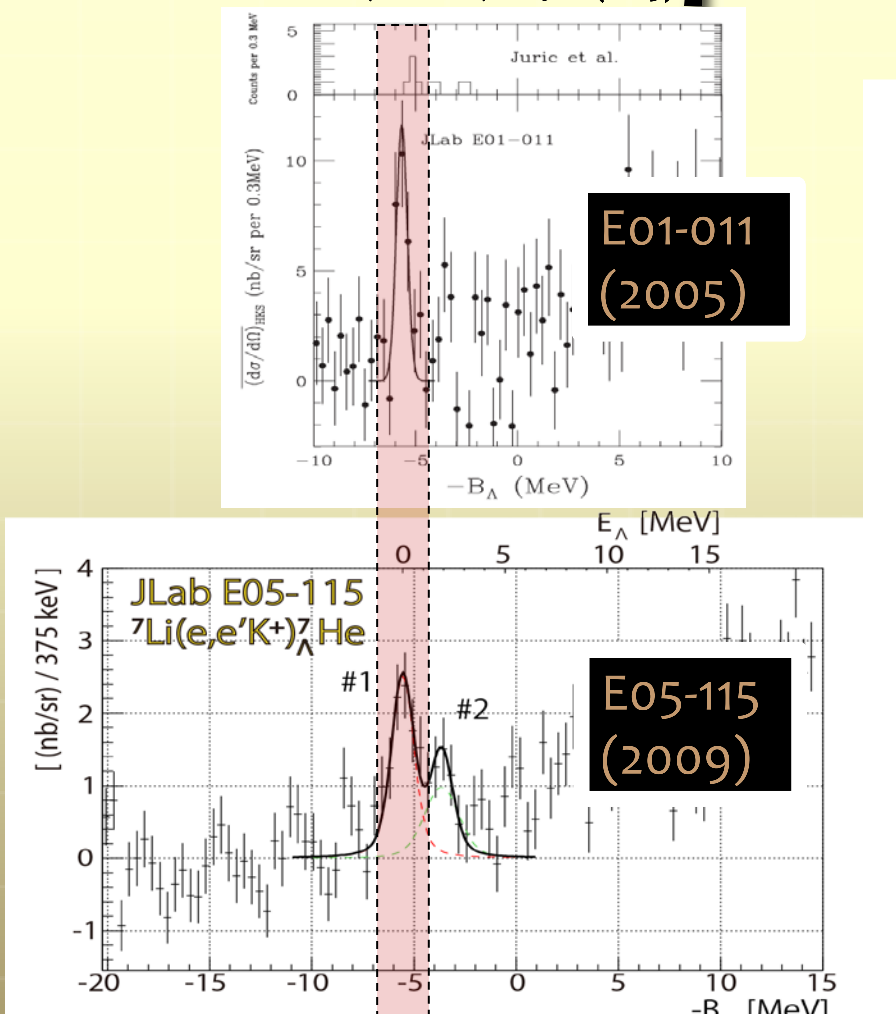
Figure 2: ^{6}He E_x spectrum obtained with a gate between 70-90$^\circ_{c.m}$ from the triton kinematics detected in coincidence with an α: (left part) with the components of the physical background due to the carbon content (black curve) and to the few-body processes (α+n+n) in exit channel (red curve); (right) after subtraction of the physical background, and analysis (in the 0 to 8 MeV range) with the resonances discussed in the text.



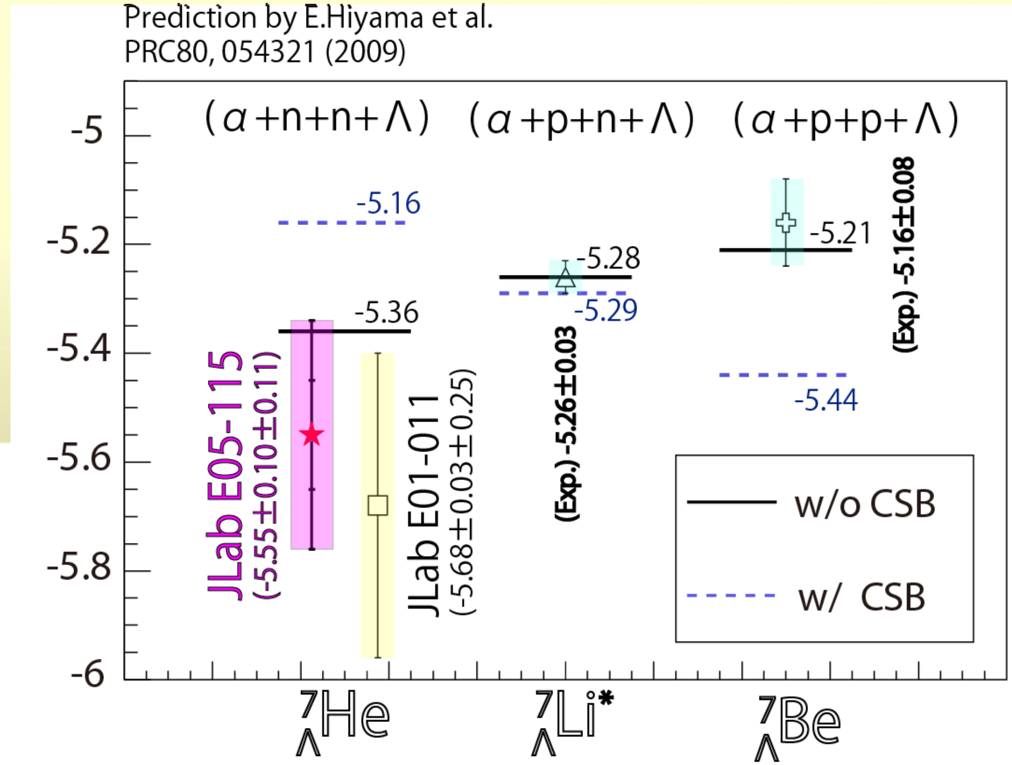
$$d\sigma/d\Omega(1/2^+_G) = 49.0 \text{ nb/sr},$$
$$d\sigma/d\Omega(3/2^+_1 + 5/2^+_1) = 10.0 + 11.6 = 21.6 \text{ nb/sr},$$
$$d\sigma/d\Omega(3/2^+_2 + 5/2^+_2) = 3.4 + 4.3 = 7.7 \text{ nb/sr}.$$

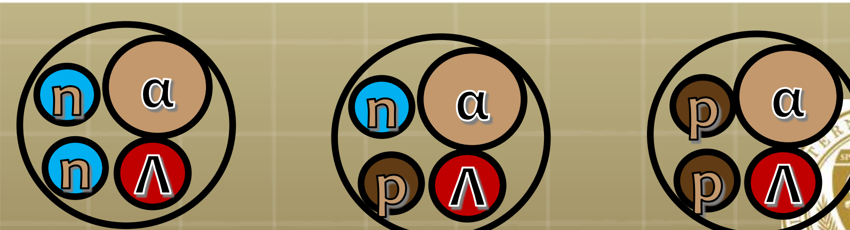
CSB interaction test in A=7 iso-triplet comparison

SNN et al., PRL 110, 012502 (2013)



T.Gogami, Doctor Thesis (2014) Tohoku Univ.

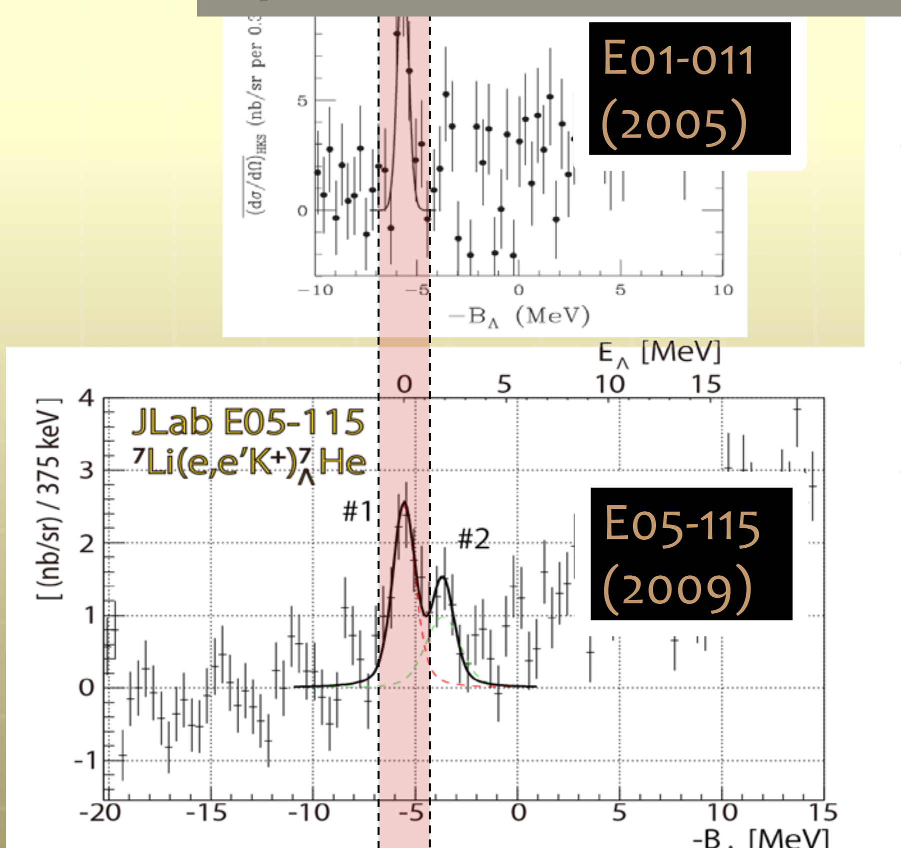




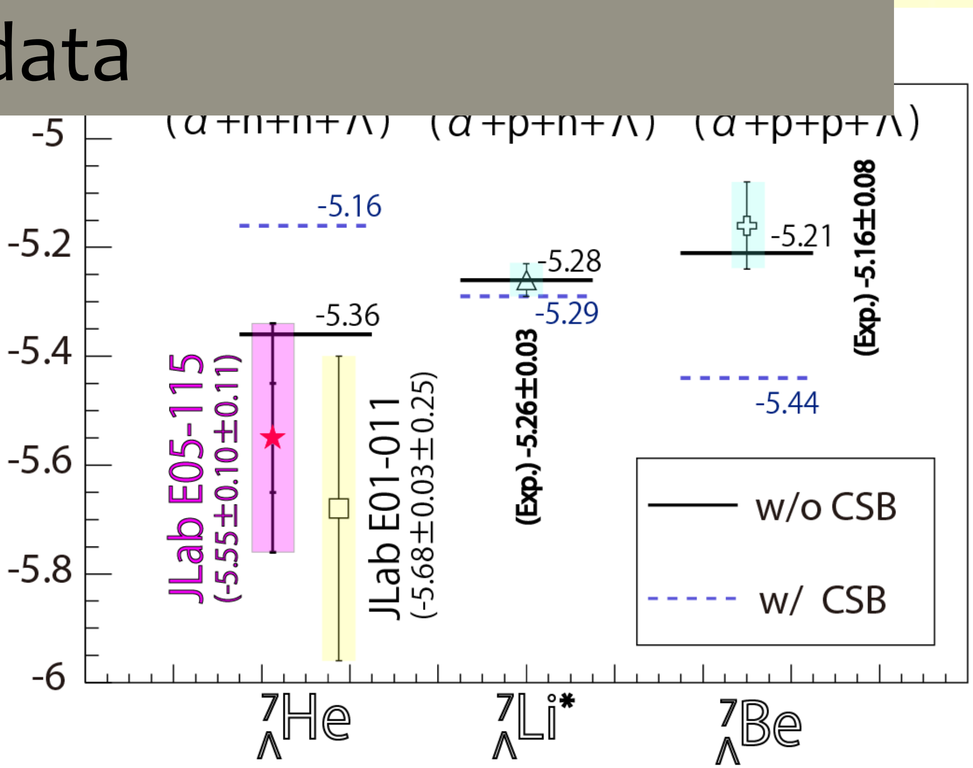
CSB interaction test in A=7

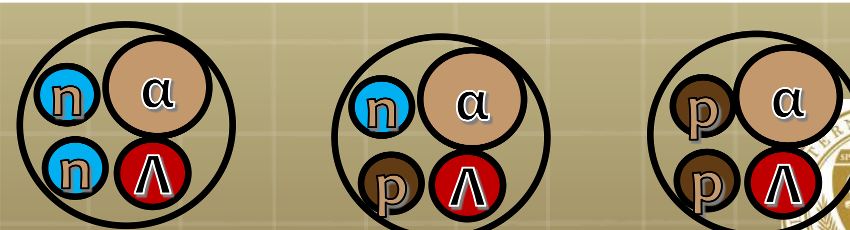
CSB potential is not necessary for A=7

Assumed CSB potential is too naïve or problem for A=4 data



T.Gogami, Doctor Thesis (2014) Tohoku Univ.





Summary

- Light Spectroscopy well suited for measurements of Charge Symmetry Breaking
  - CSB not well understood
- Require precision measurements since effects are small
- To maximize range in isospin, likely need JPARC, Mainz, Jlab:
  - Reaction (e,e'K) spectroscopy
    - complementary targets, absolute energy calibration
    - good energy resolution
  - decay pions
    - excellent resolution, determine g.s. energies
  - γ-ray
    - excellent resolution, level spacing of excited states