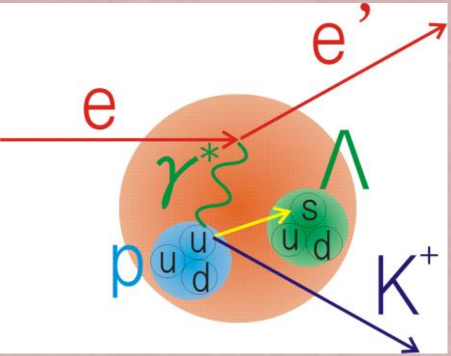
Recent Spectroscopic Investigation of Λ-Hypernuclei by the $(e,e'K^+)$ Reaction

-Analysis Status of E01-011 & E05-115-

Chunhua Chen
Hampton University

Nov. 05, 2013

Λ HYPERNUCLEAR SPECTROSCOPY VIA (e,e'K$^+$)



Merits of the (e,e'K$^+$) experiment

☺ Large momentum transfer

→ Excitation of deeply-bound state

☺ p to Λ reaction → Mirror and Neutron-rich hypernuclei

☺ Spin-flip/non-flip production

☺ High Energy Resolution due to CEBAF beam's quality

2005(E01-011) 2nd Experiment :

$^{7}_{\Lambda}$He $^{12}_{\Lambda}$B, $^{28}_{\Lambda}$Al

- ❖ Newly-constructed **HKS** for K$^+$ side
- ❖ Apply **"Tilt Method"** for e' side

2009(E05-115) 3rd Experiment:

$^{12}_{\Lambda}$B , $^{7}_{\Lambda}$He, $^{10}_{\Lambda}$Be, $^{9}_{\Lambda}$Li and $^{52}_{\Lambda}$V

- ❖ Beam Energy 1.8 →2.344 GeV
- ❖ Brand-new e' spectrometer, HES

Calibration by the elementary process

p(e,e'K$^+$)Λ or Σ: CH_2

CEBAF Bird's−eye photo

INTRODUCTION

Physical Goals:

- To understand YN and YY interactions
- To explore and understand nuclear structure using Λ as a probe
  - **Model the baryonic many body system**
  - **Study the role of Λ in the nuclear medium**

- Shell Model with Λ-N Effective Potential ($p_N s_\Lambda$) for p-shell hypernuclei

$$V_{\Lambda N} = V_0(r) + V_\sigma(r)\boldsymbol{s}_N \cdot \boldsymbol{s}_\Lambda + V_\Lambda(r)\boldsymbol{L}_{N\Lambda} \cdot \boldsymbol{s}_\Lambda + V_N(r)\boldsymbol{L}_{N\Lambda} \cdot \boldsymbol{s}_N + V_T(r)S_{12}$$

$\bar{V}$ Δ S_Λ S_N T

Radial Integrals
Coefficients of operators

- Additional Contribution: Λ-Σ coupling ← $V_{\Lambda\Sigma}$

Our results with precise B_Λ are important in helping to determine these parameters as well as to explore the full spectroscopy with unseen core states.

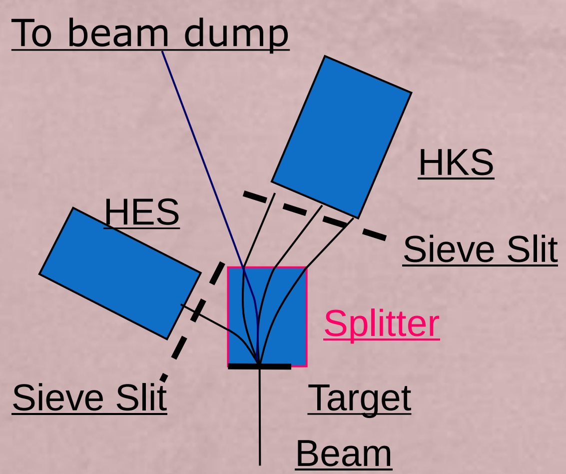
Spectrometer System Calibration

Spectrometer system calibration: key to reach sub-MeV energy resolution

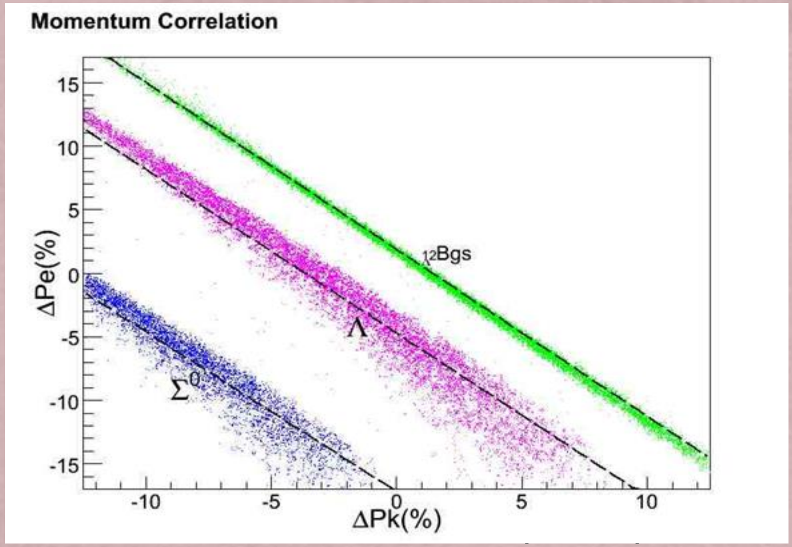
- Common splitter : Separated single arm calibration is impossible
- Technique: 2-arm coupled calibration for both kinematics and optics

Using known masses of Λ, Σ^0 from CH_2 target and identified known hypernuclear bound states ($^{12}{}_{\Lambda}B$ g.s.) for spectrometer calibration

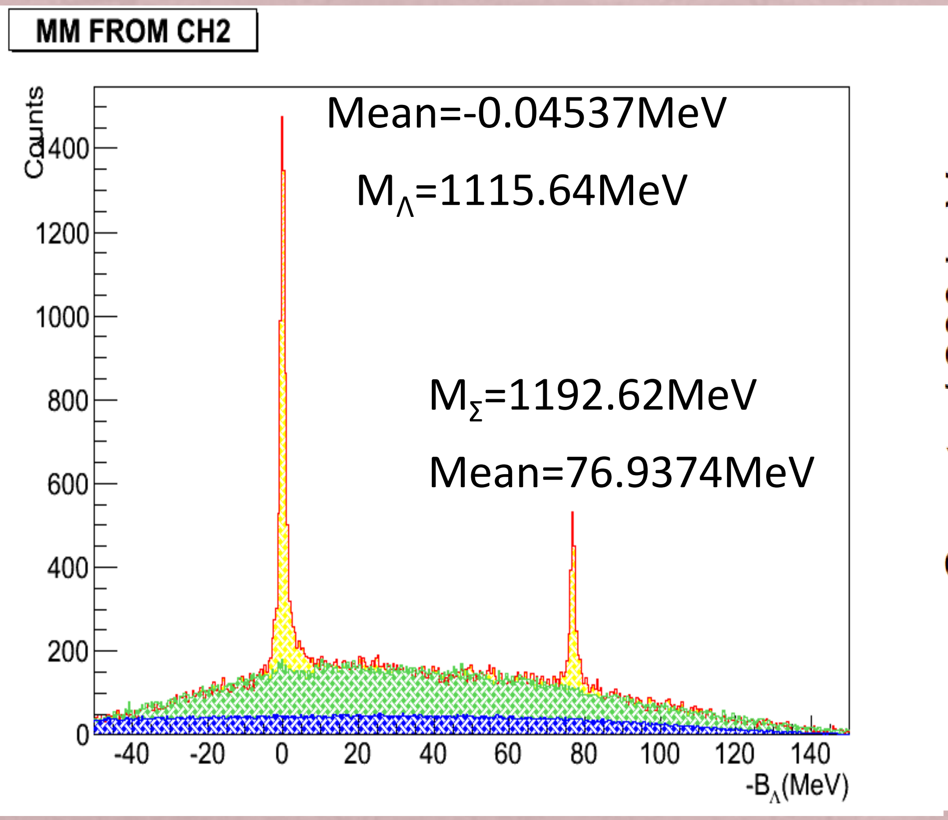
HES spectrometer system



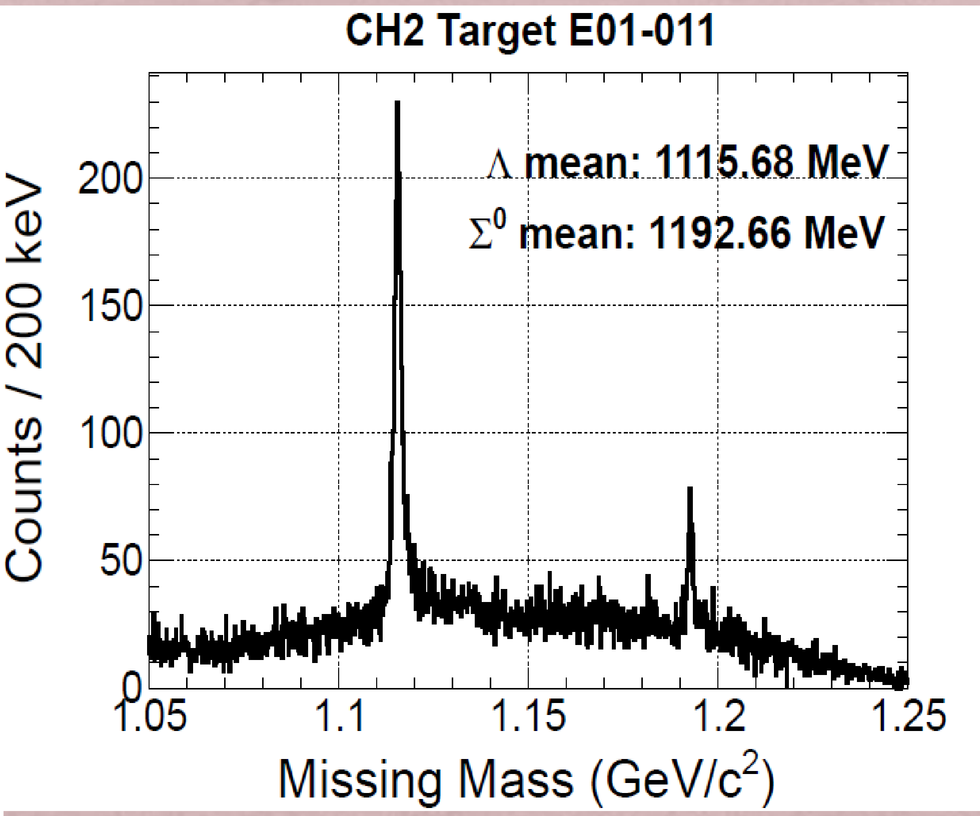
Kinematics coverage



CALIBRATION DATA RESULT



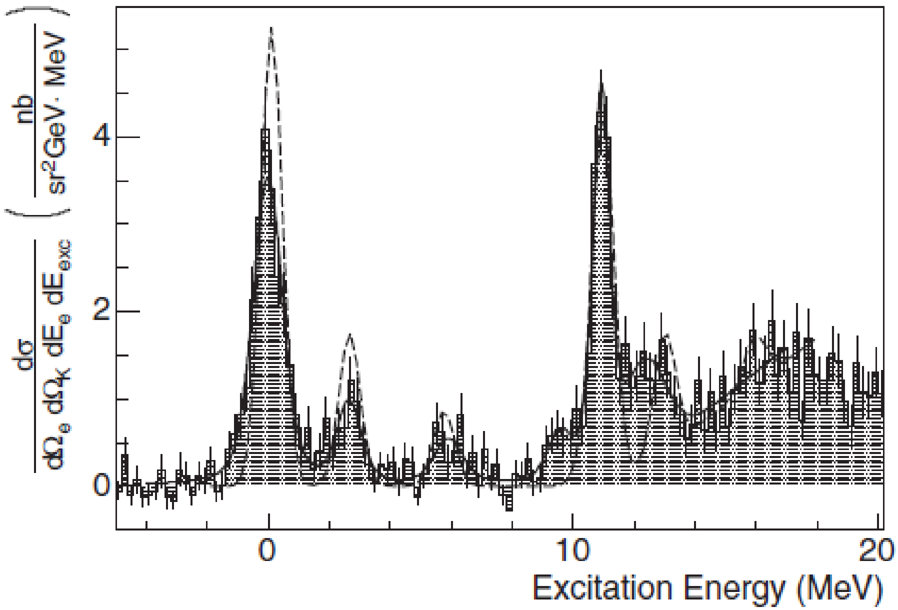
E05-115

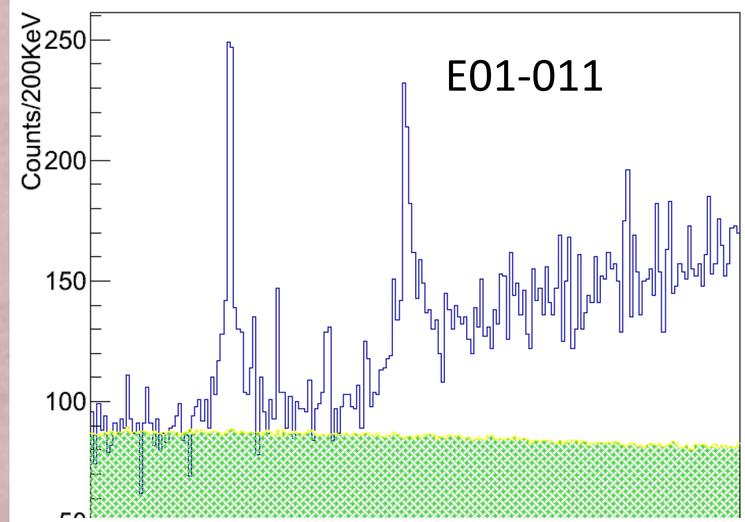


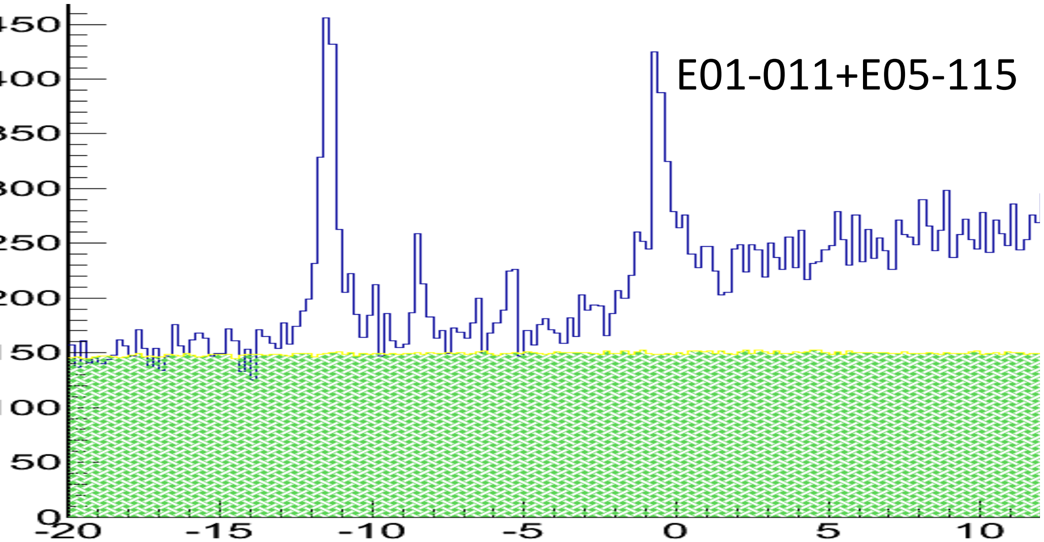
E01-011

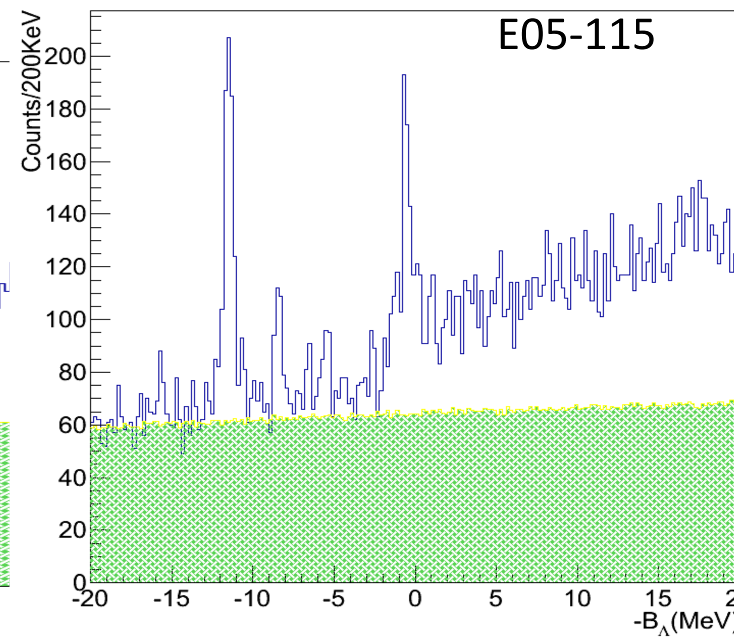
$^{12}_{\Lambda}B$

Phys. Rev. Lett. 99, 052501 (2007) (HallA data)



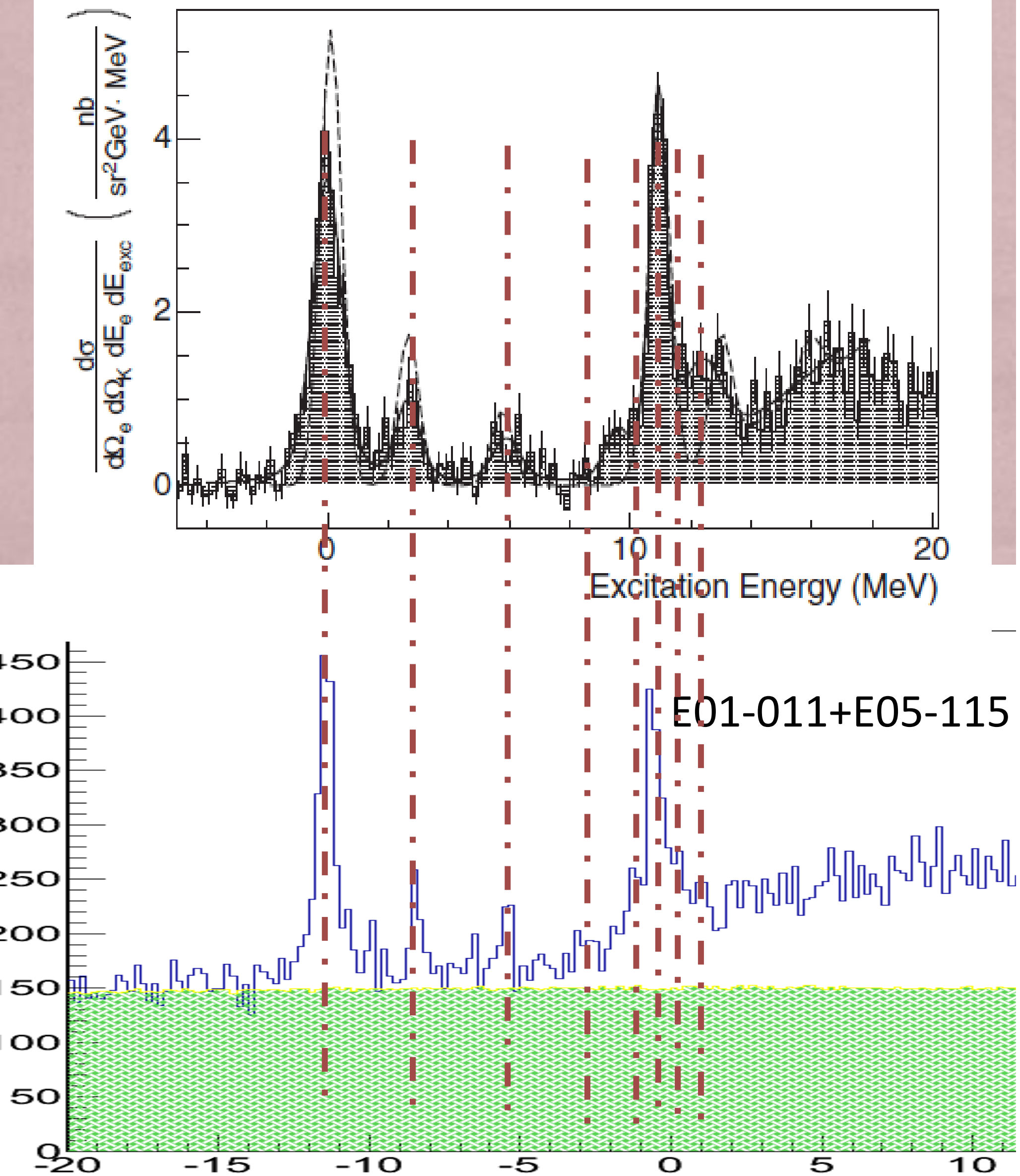


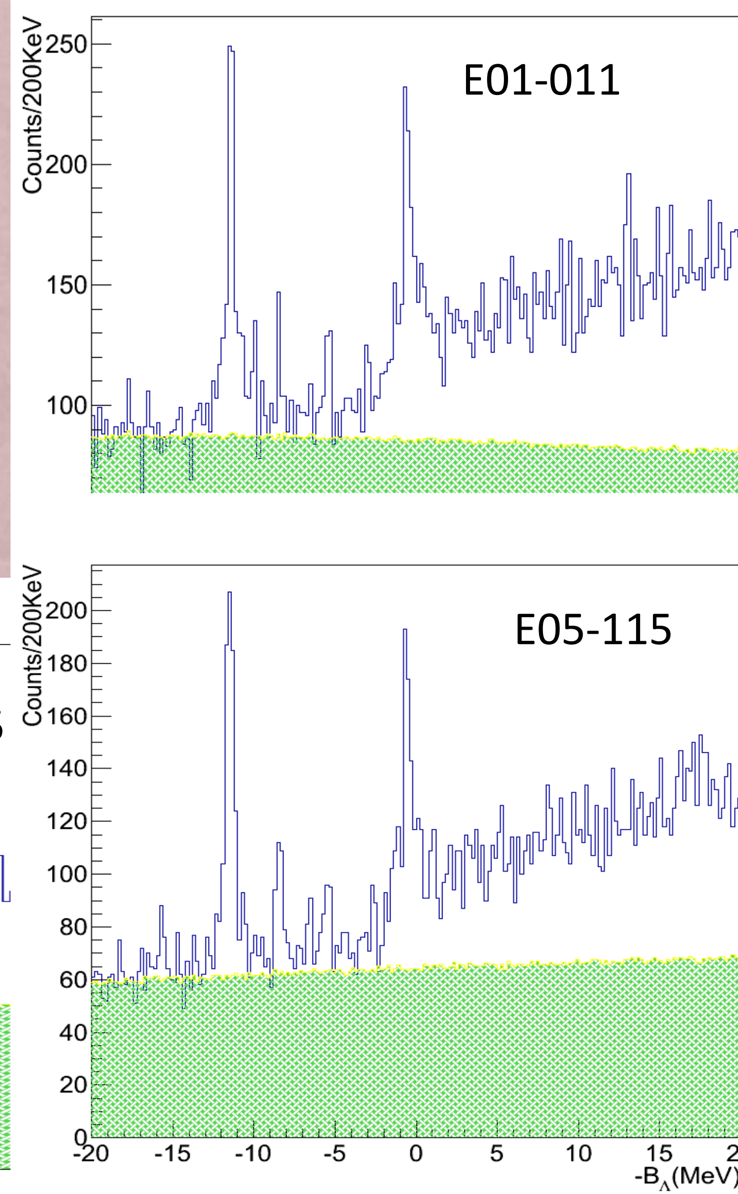




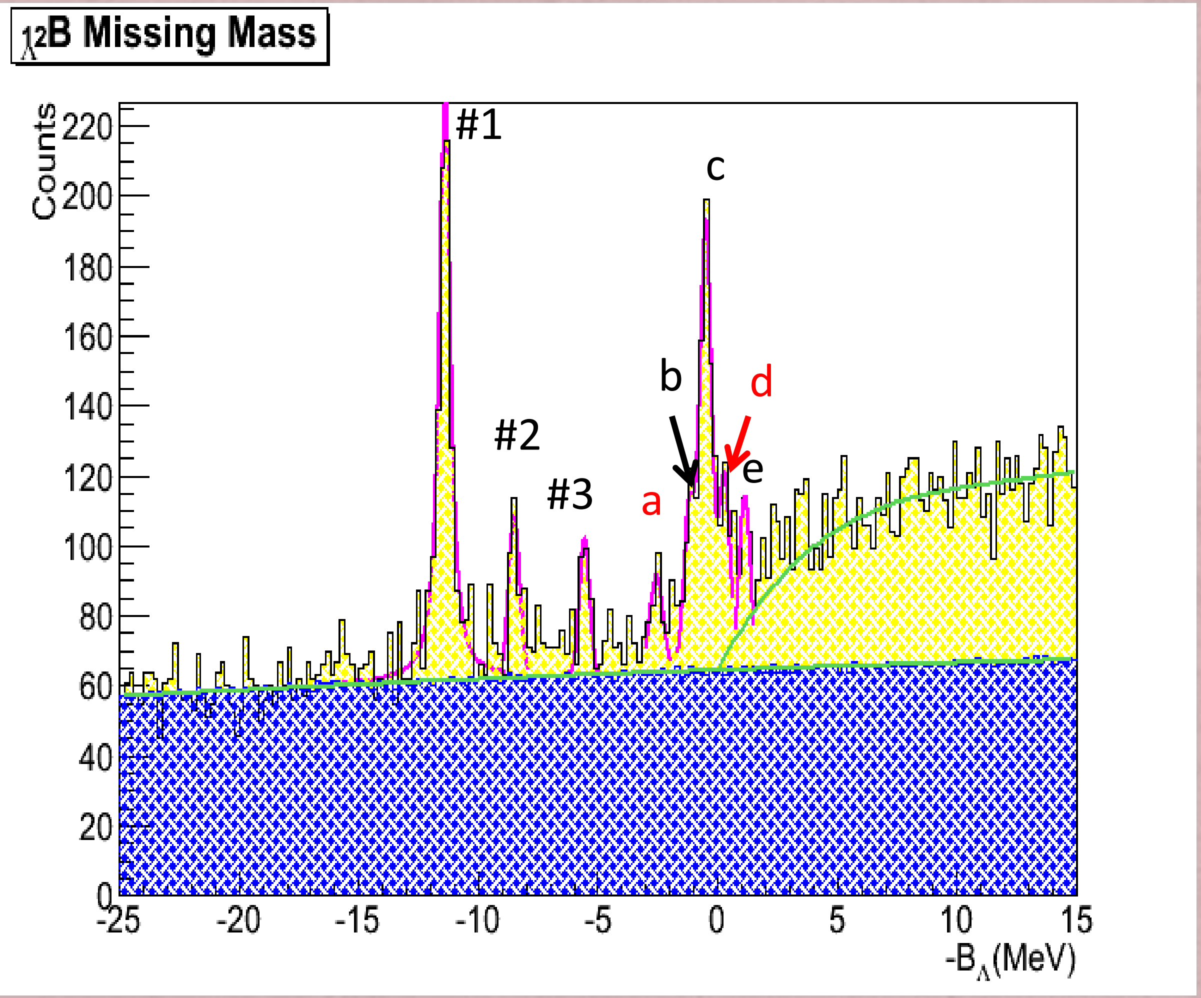
$^{12}_{\Lambda}B$

Phys. Rev. Lett. 99, 052501 (2007) (HallA data)





$^{12}{}_{\Lambda}B$

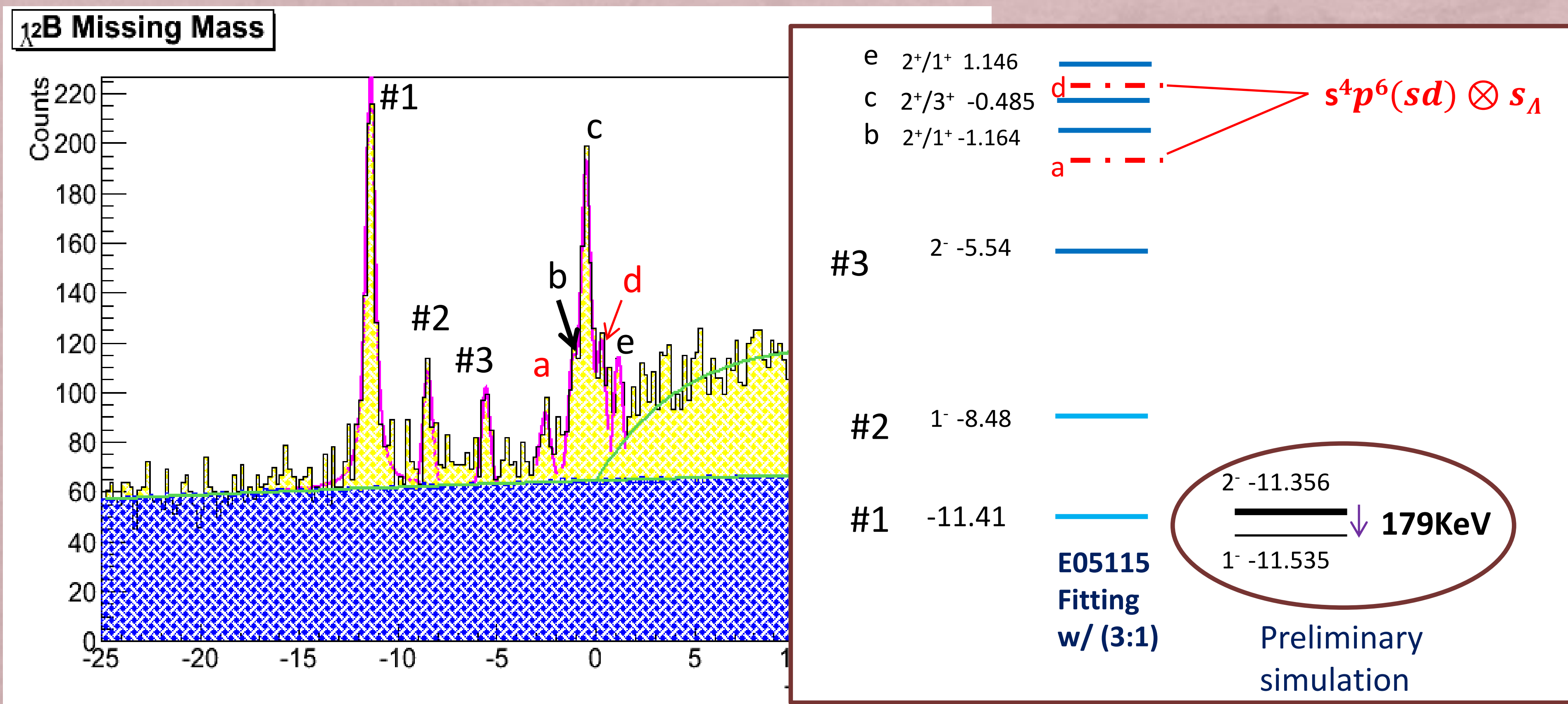


peak	Mean (MeV)	σ (KeV)
1	-11.41	265
2	-8.48	231
3	-5.54	210
a	**-2.539**	**281**
b	-1.164	240
c	-0.485	240
d	**0.295**	**240**
e	1.146	234

Resolution:

σ = ~240 keV or ~ 565 keV FWHM

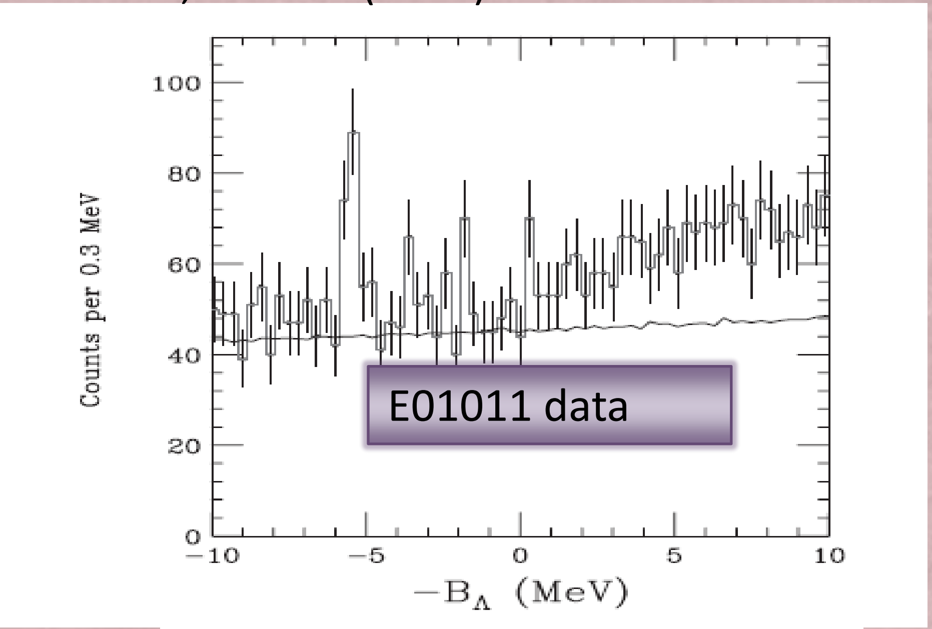
$^{12}{}_{\Lambda}B$

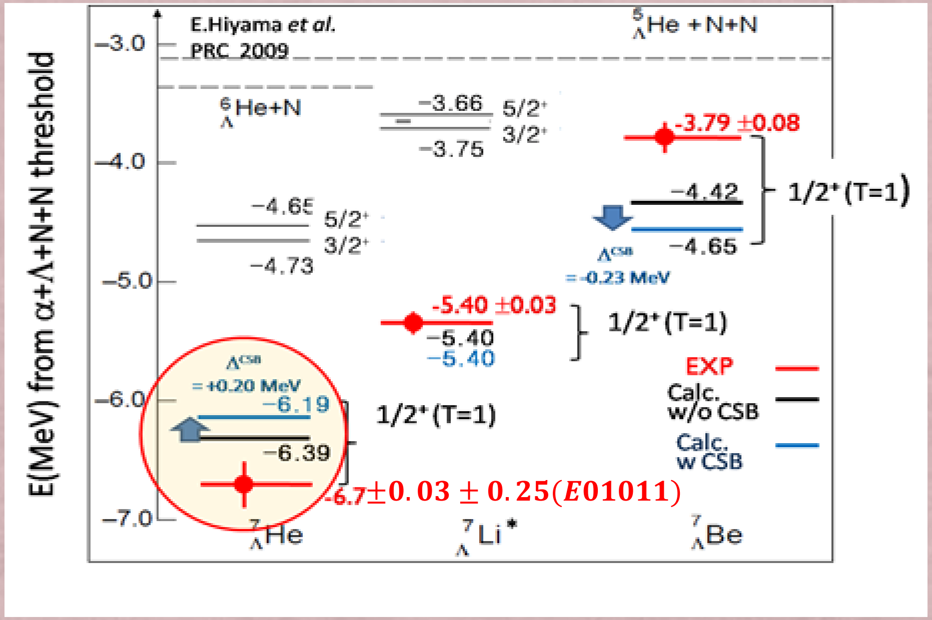


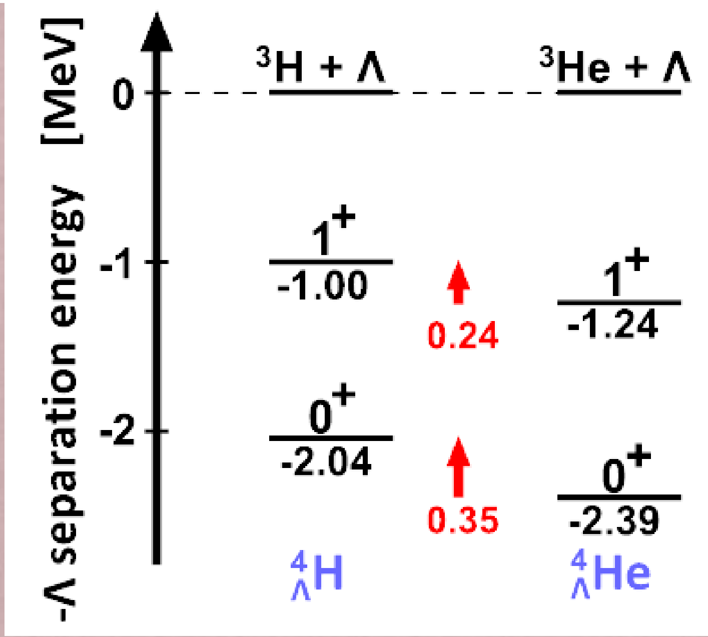
12ΛB Missing Mass
Counts
#1
#2
#3
a
b
c
d
e
e 2+/1+ 1.146
c 2+/3+ -0.485
b 2+/1+ -1.164
d
a
$s^4p^6(sd) \otimes s_\Lambda$
#3 2- -5.54
#2 1- -8.48
#1 -11.41
2- -11.356
179KeV
1- -11.535
E05115 Fitting w/ (3:1)
Preliminary simulation

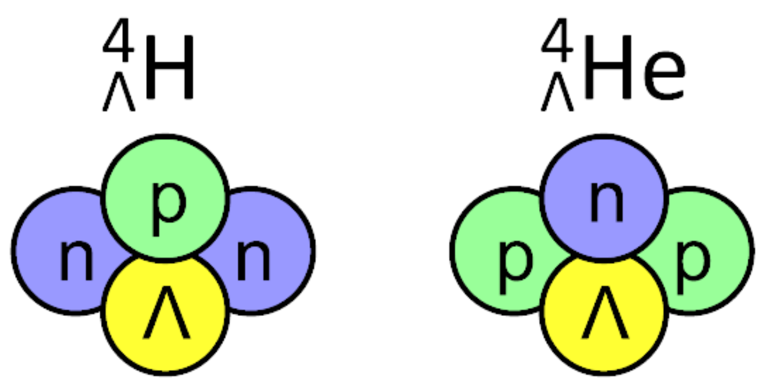
$^{7}_{\Lambda}He$

PRL 110, 012502 (2013)



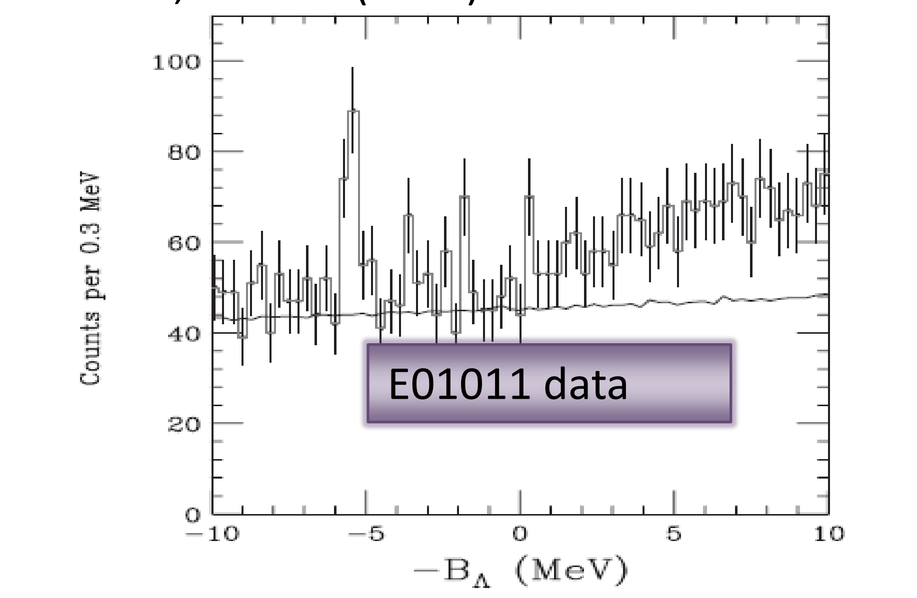


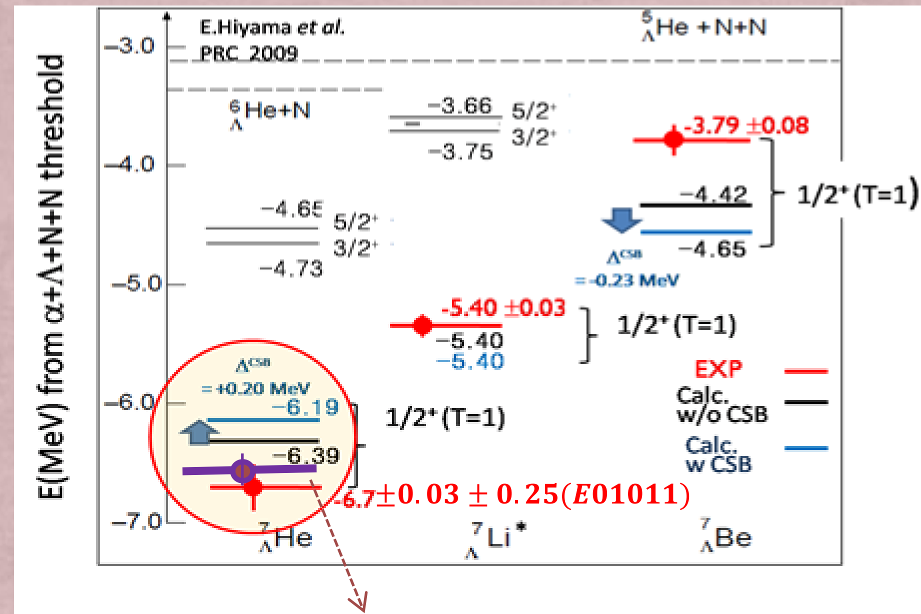




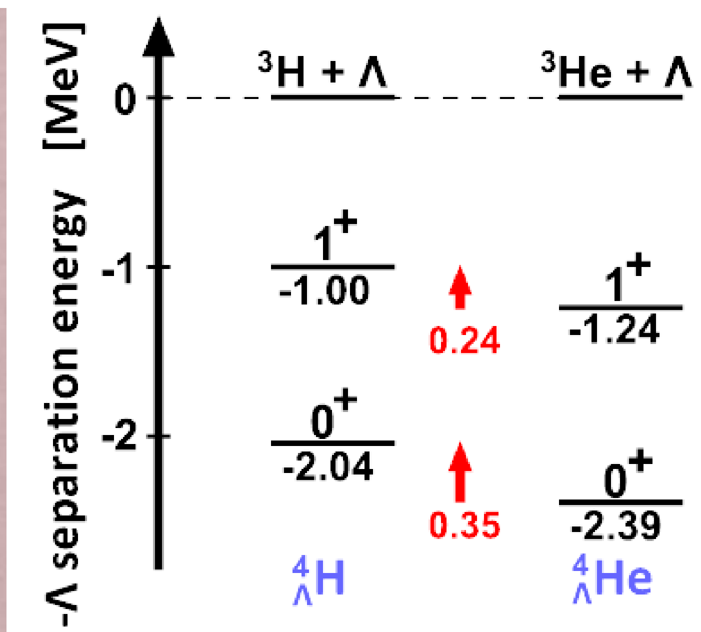
$^{7}_{\Lambda}He$

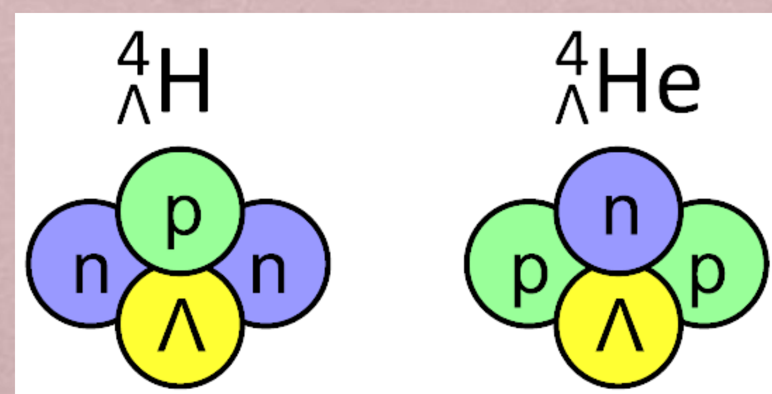
PRL 110, 012502 (2013)





E05-115 with 4 time more statistics and better precision



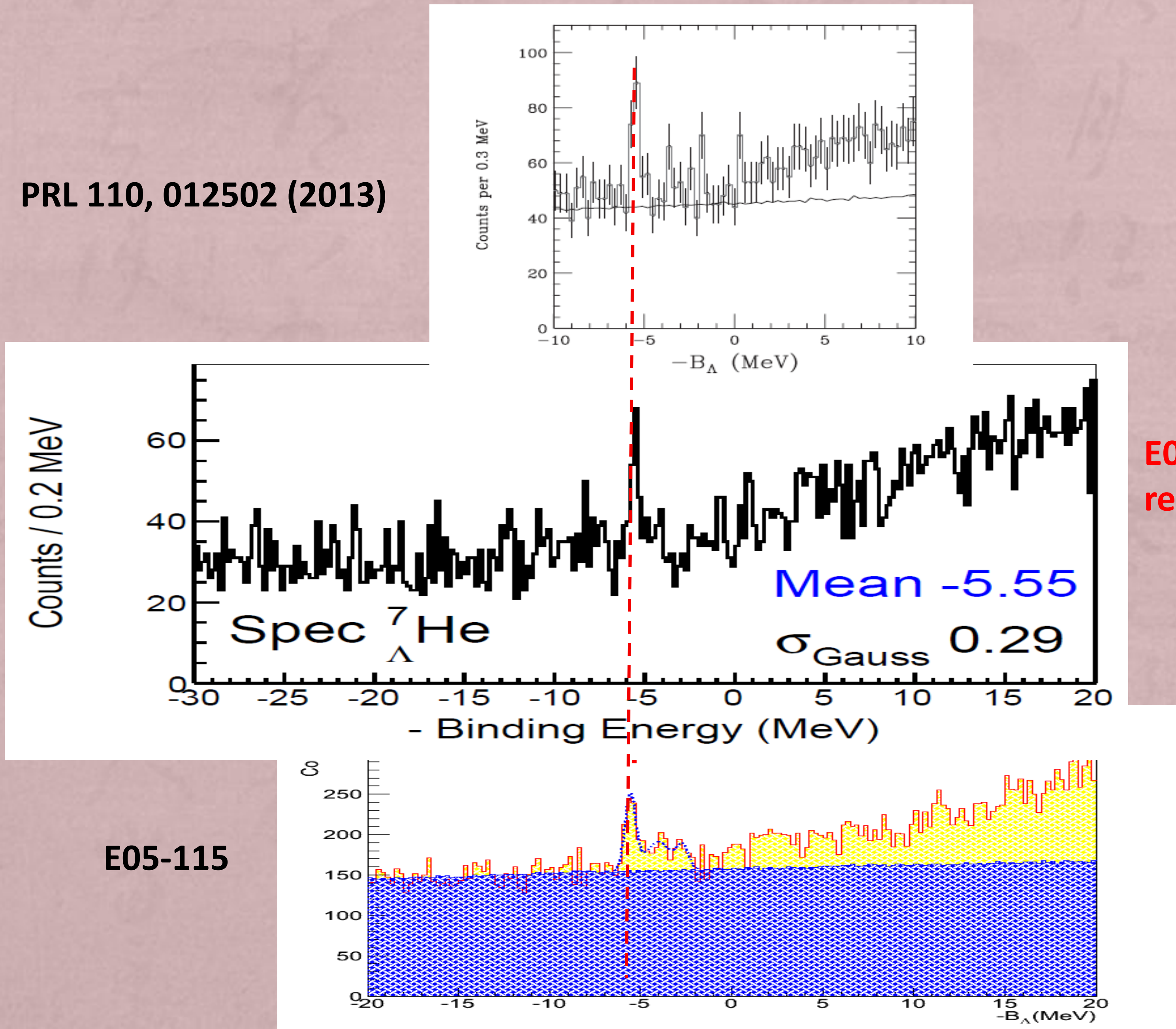


$^{7}_{\Lambda}He$

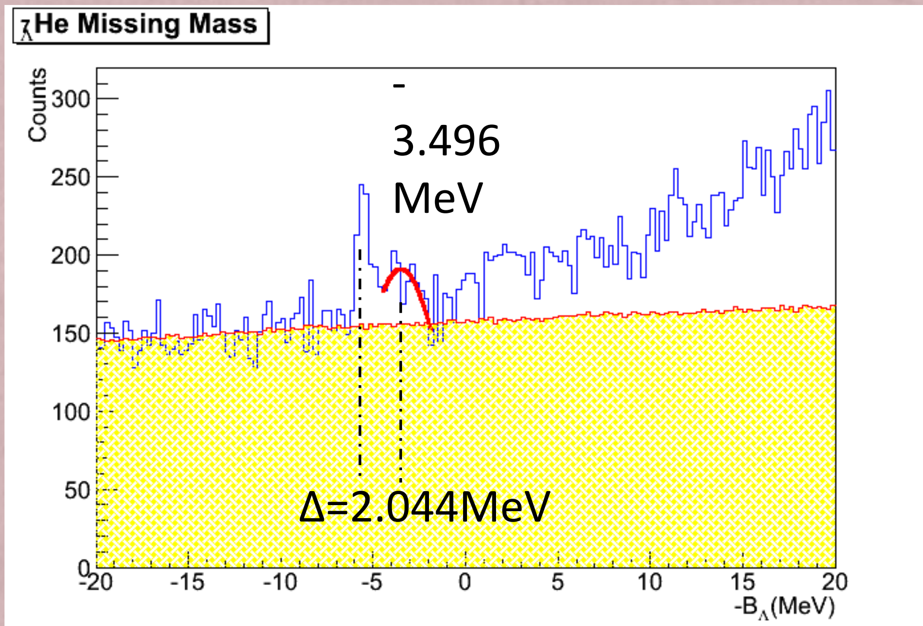
PRL 110, 012502 (2013)

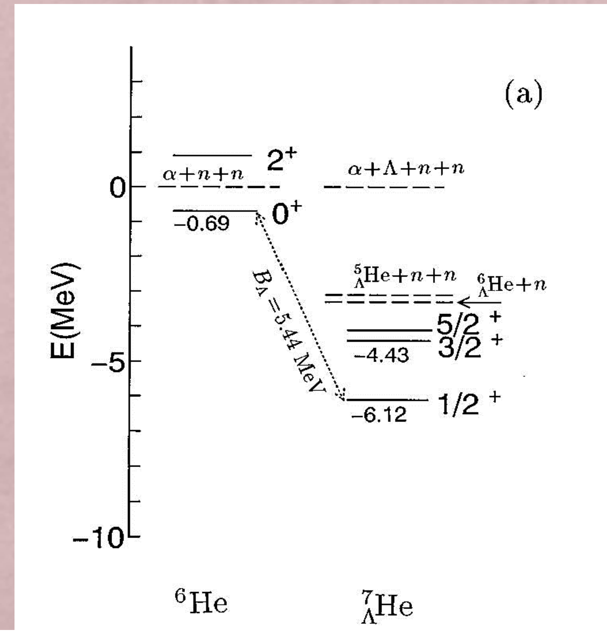
E01-011 reanalyzed

E05-115



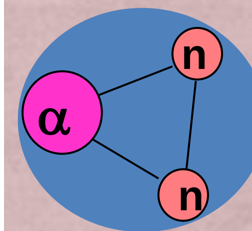
$^{7}_{\Lambda}He$

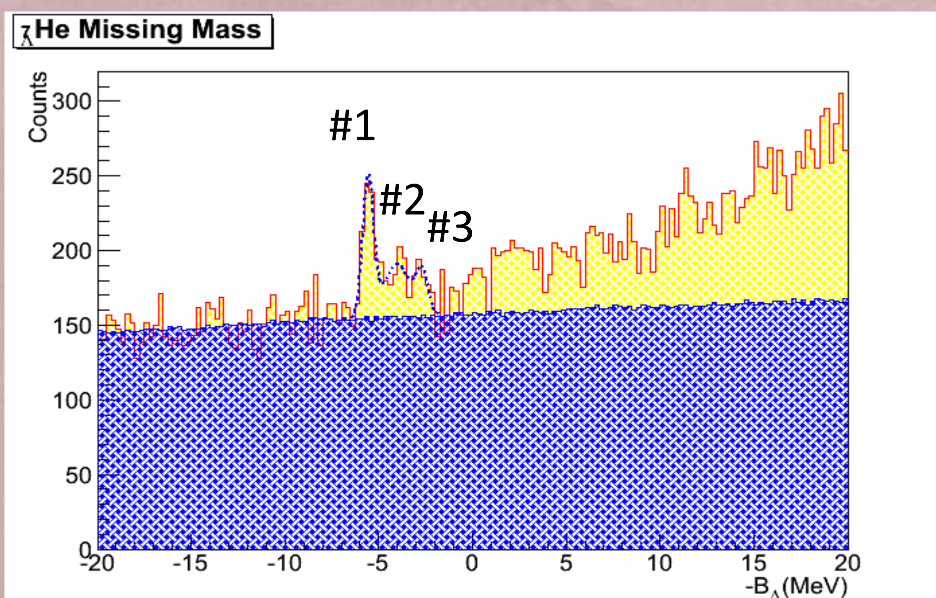




E. Hiyama, et al., PRC53 2078 (1996)

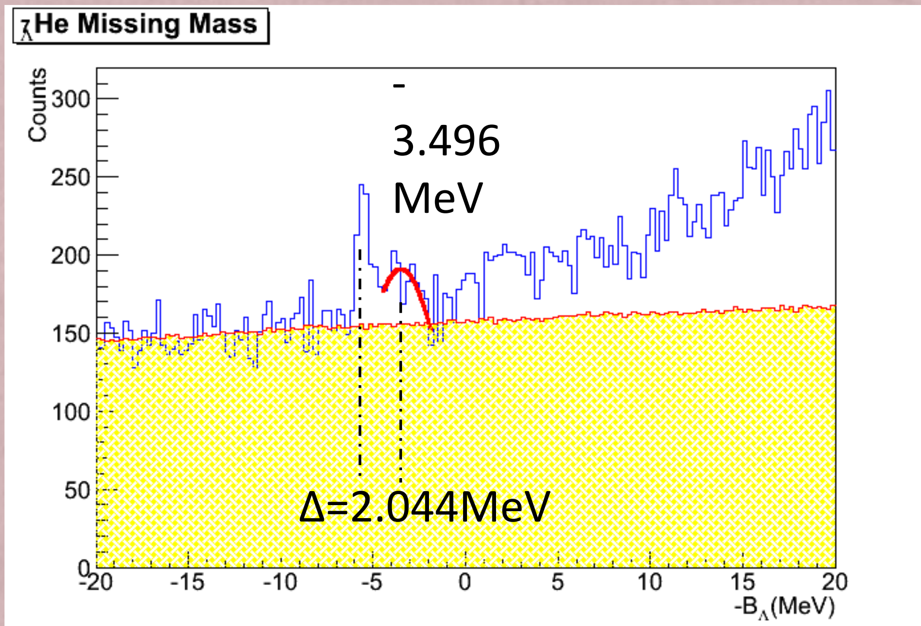
^{6}He core

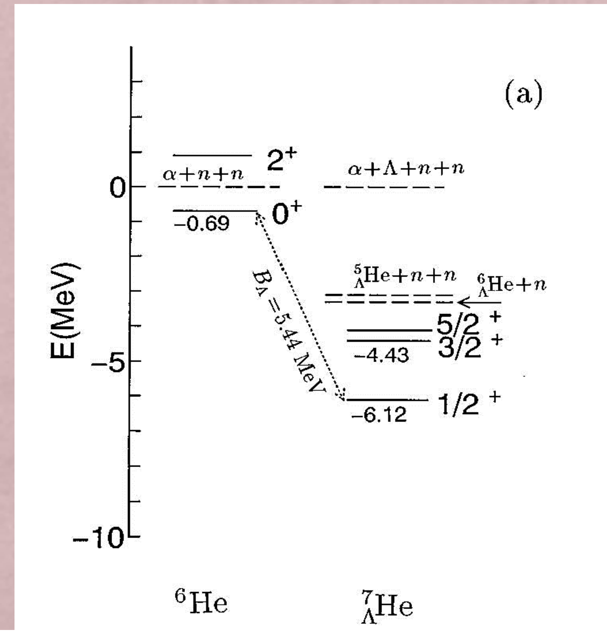




peak	Mean(MeV)	σ(KeV)
1	-5.54	253
2	-4.01	379
3	-2.97	375

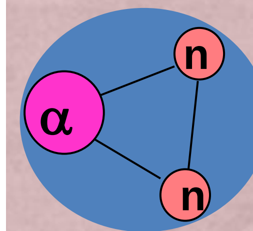
$^{7}_{\Lambda}He$

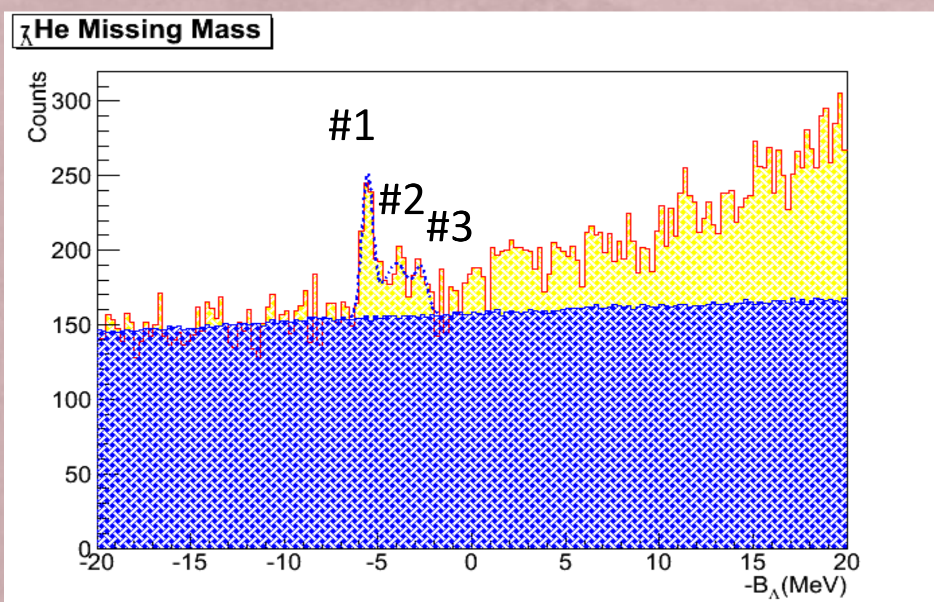




E. Hiyama, et al., PRC53 2078 (1996)

^{6}He core



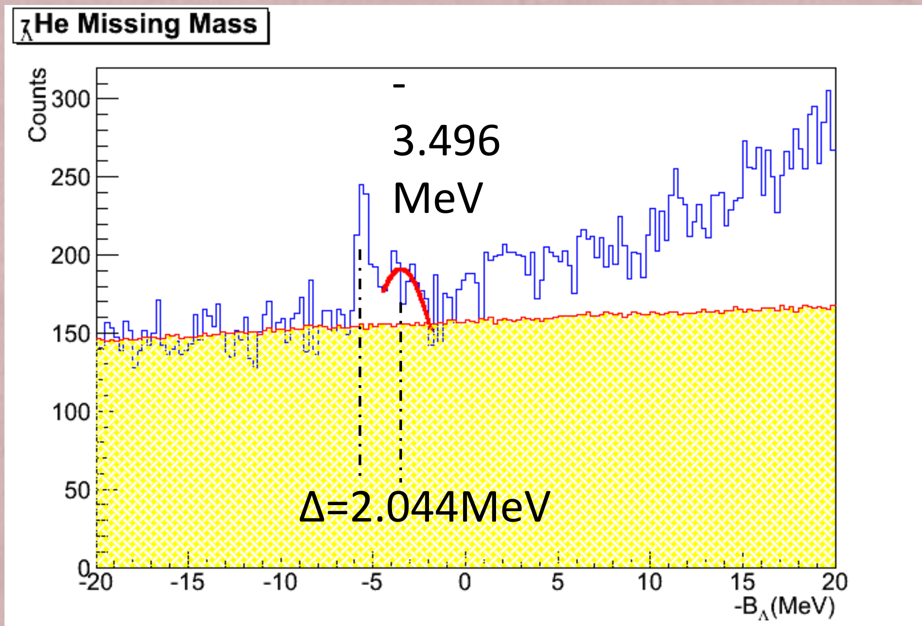


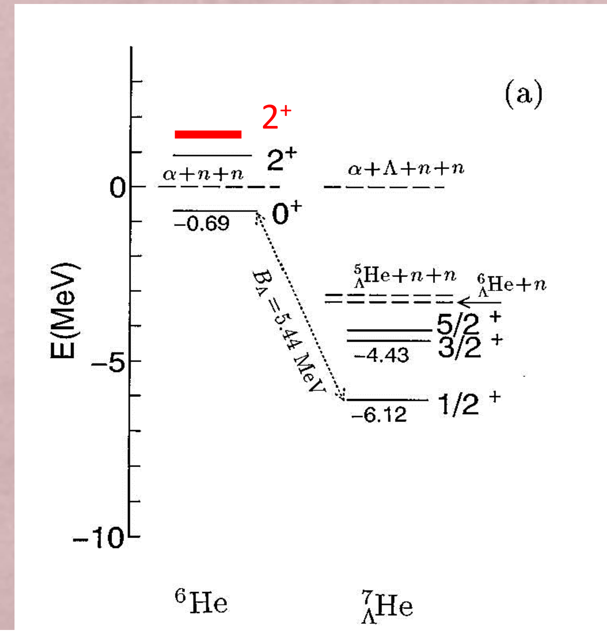
peak	Mean(MeV)	σ(KeV)
1	-5.54	253
2	-4.01	379
3	-2.97	375

ΔE_{Λ} ~ 130keV

$\frac{3^+}{2} / \frac{5^+}{2}$

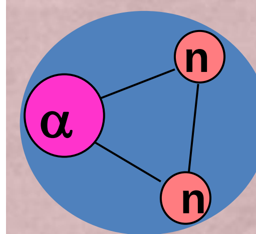
$^{7}_{\Lambda}$He

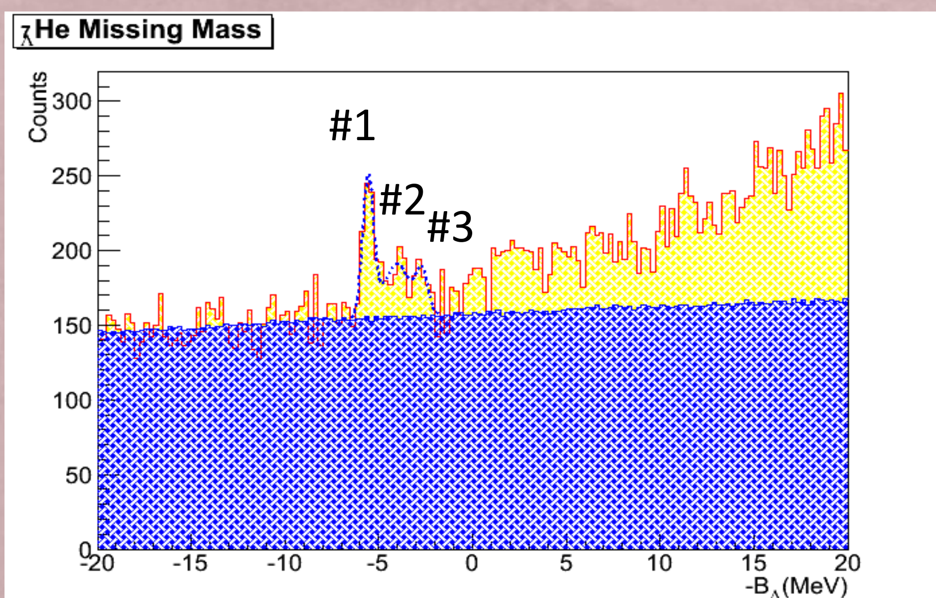




E. Hiyama, et al., PRC53 2078 (1996)

^{6}He core





peak	Mean(MeV)	σ(KeV)
1	-5.54	253
2	-4.01	379
3	-2.97	375

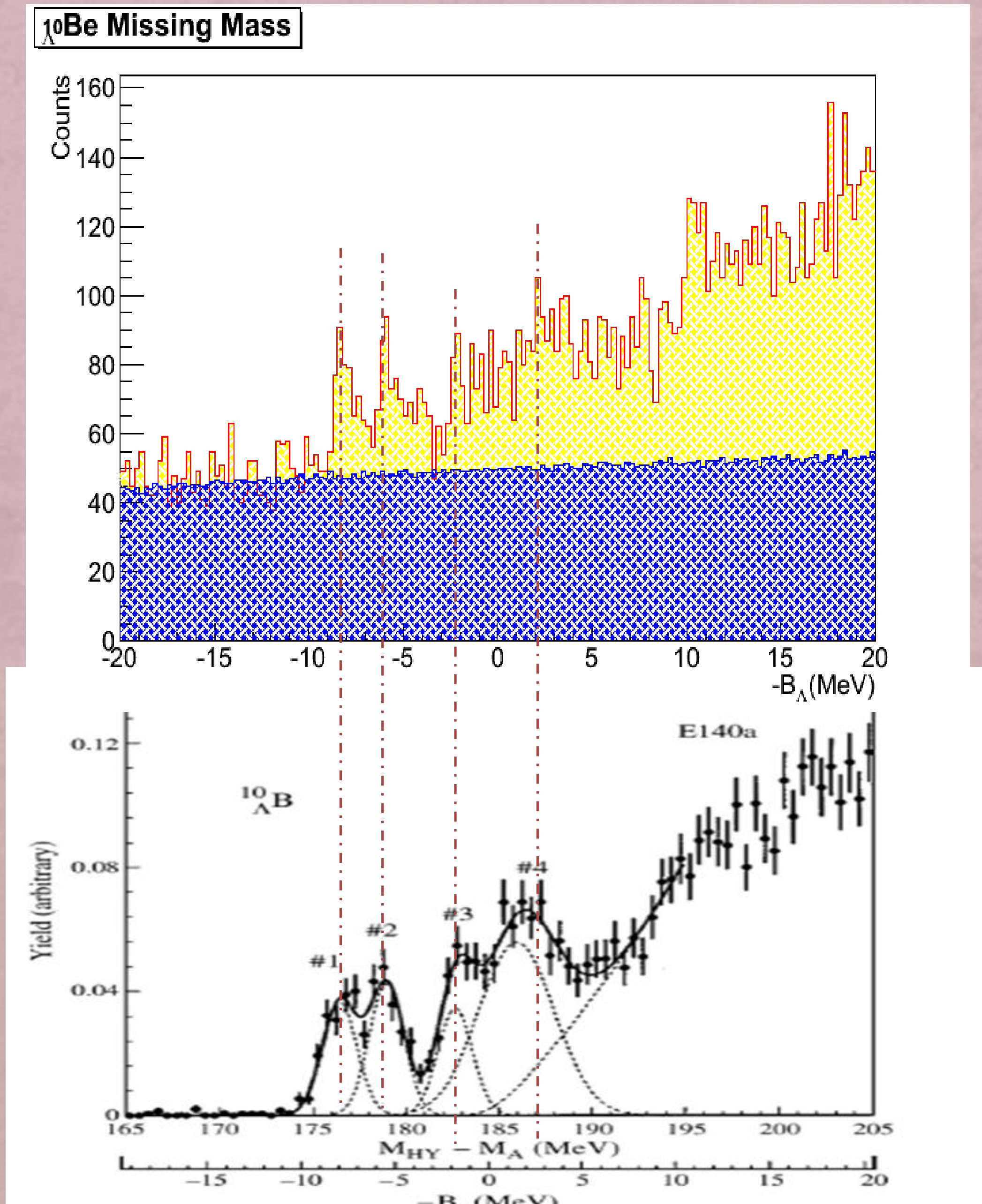
ΔE_{Λ} ~ 130keV

$\frac{3^+}{2} / \frac{5^+}{2}$

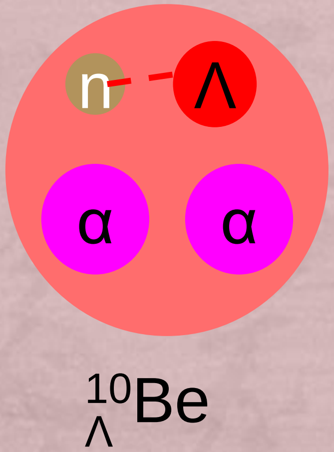
A resonance state

Possibility : Additional 2^+ core state

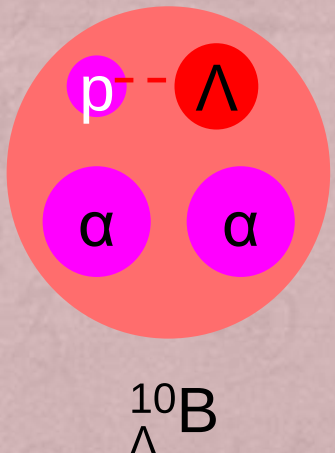
PRELIMINARY RESULT – $^{10}{}_{\Lambda}Be$



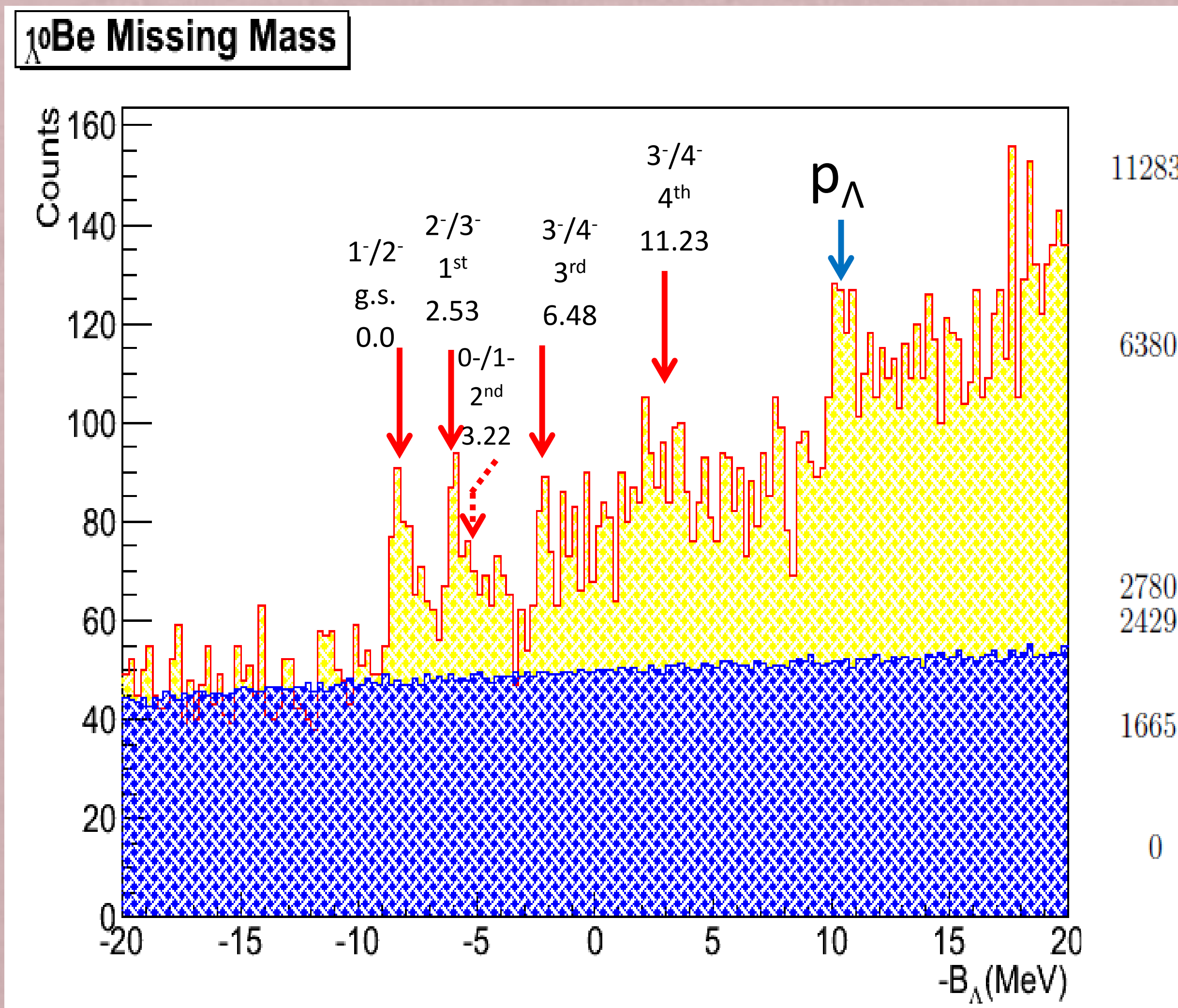
E05-115

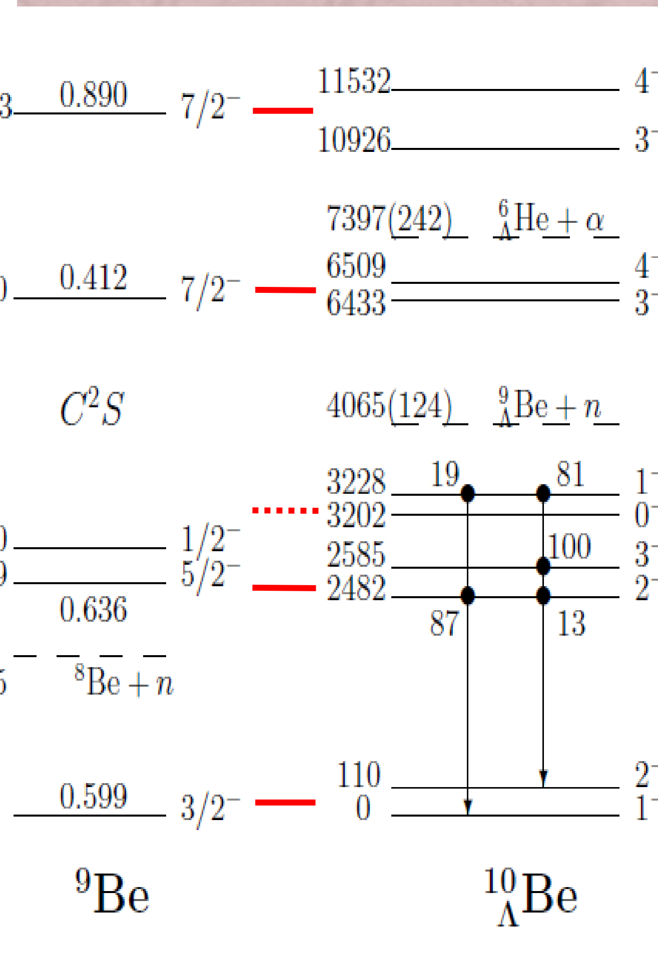


KEK-E140a
$^{10}{}_{\Lambda}B$



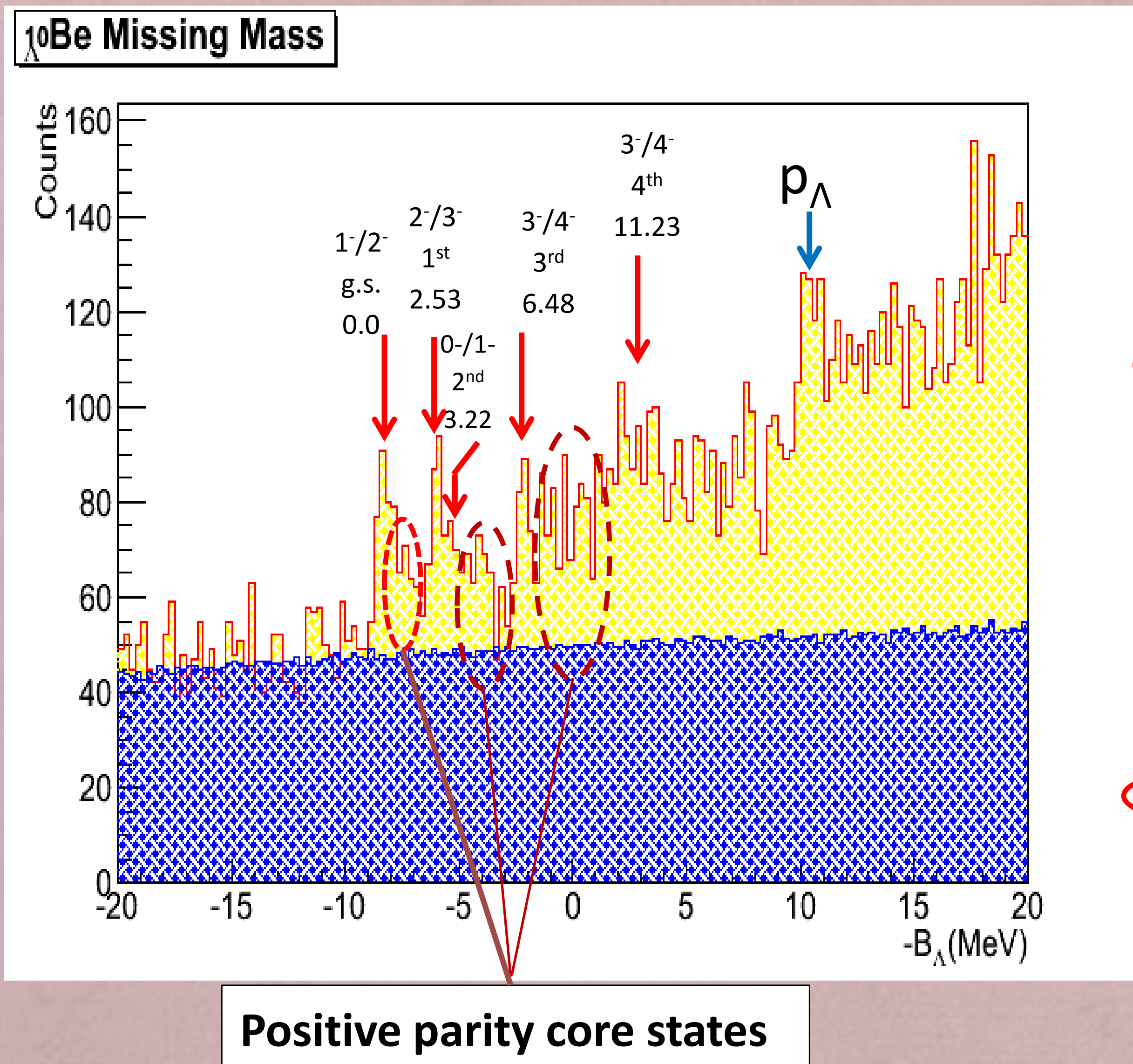
PRELIMINARY RESULT – $^{10}_{\Lambda}$Be





Calculated by D.J. Millener

PRELIMINARY RESULT – $^{10}_{\Lambda}$Be

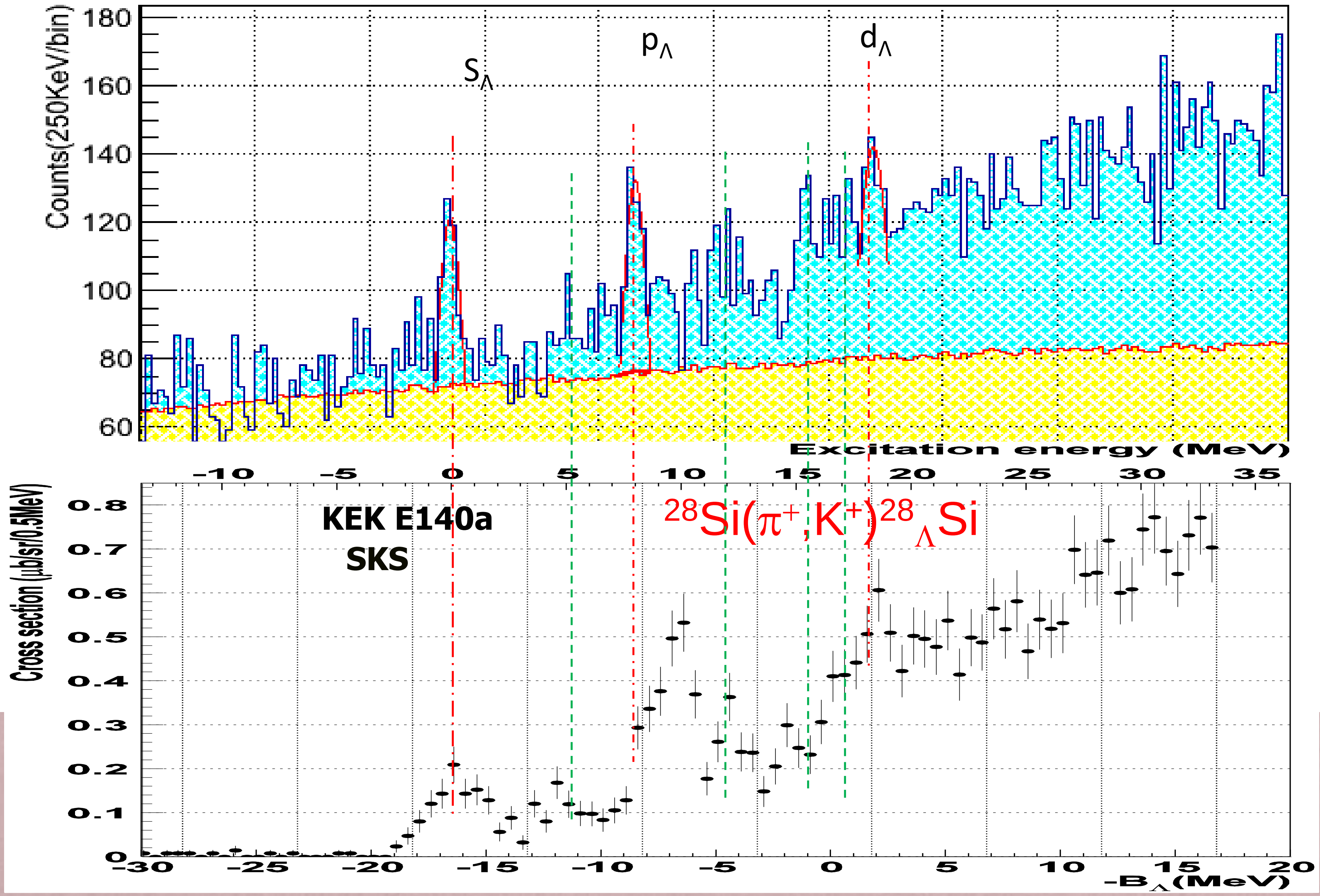


Mirror states ($T = \frac{1}{2}$) in $A = 9$ nuclei[a]

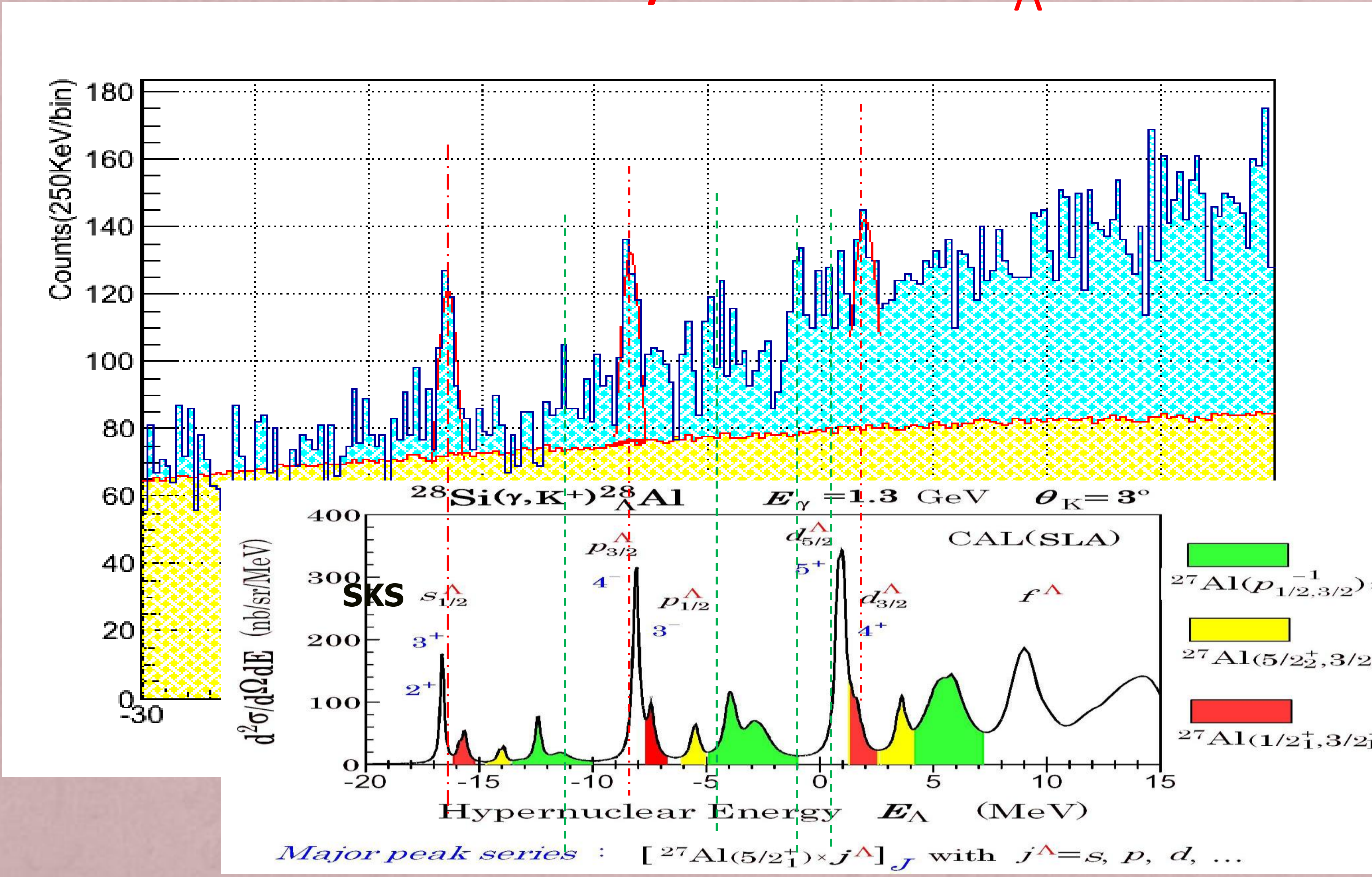
^{9}Be

E_x (MeV)	J^{π}
0	$\frac{3}{2}^-$
1.684	$\frac{1}{2}^+$
2.429	$\frac{5}{2}^-$
2.78	$\frac{1}{2}^-$
3.049	$\frac{5}{2}^+$
4.704	$(\frac{3}{2})^+$
5.59	$(\frac{3}{2}^-)$
6.38[d]	$\frac{7}{2}^-$
6.76	$\frac{9}{2}^+$
7.94	$(\frac{5}{2}^-)$
11.283	$(\frac{7}{2}^-)$
11.81	$\frac{5}{2}^-$

Preliminary Status – $^{28}{}_{\Lambda}Al$



Preliminary Status – $^{28}{}_{\Lambda}$Al



SUMMARY

- Our systematic calibration is almost completed;
- The precise level structure of p-shell Λ hypernuclei ($^{7}_{\Lambda}He$, $^{10}_{\Lambda}Be$, and $^{12}_{\Lambda}B$) are evidential and encouraging;
- There is stronger evidence for sd-shell nuclei from spectroscopy of $^{12}_{\Lambda}B$ and $^{28}_{\Lambda}Al$;
- $^{52}_{\Lambda}V$ spectroscopy is coming soon.

BACK UP

CALIBRATION PROCEDURE

$$MM = f(E_{beam}, P_k, xt'_k, yt'_k, P_{e'}, xt'_{e'}, yt'_{e'})$$
$$= f(Ebeam_0 + \Delta E_{beam0}, P_{k0} + \Delta P_{k0}, xt'_k, yt'_k, P_{e'0} + \Delta P_{e'0}, xt'_{e'}, yt'_{e'})$$

$$P = P0(1+\delta/100)$$

$$\begin{pmatrix} xt' \\ yt' \\ \delta \end{pmatrix} = (M) \begin{pmatrix} xf \\ xf' \\ yf \\ yf' \end{pmatrix} = \begin{pmatrix} M\_angle \\ M\_momentum \end{pmatrix} \begin{pmatrix} xf \\ xf' \\ yf \\ yf' \end{pmatrix}$$

- Field Map Correction → Real Optics
  - ✓ Agreement between Simulation data and Real SS data
  - ✓ Independence of invariant mass to reconstructed kinematical parameters. (Λ&Σ; P,xt',yt')

Initial Matrices

- Mathematical optimization by **Nonlinear Least Chi^2 fitting**

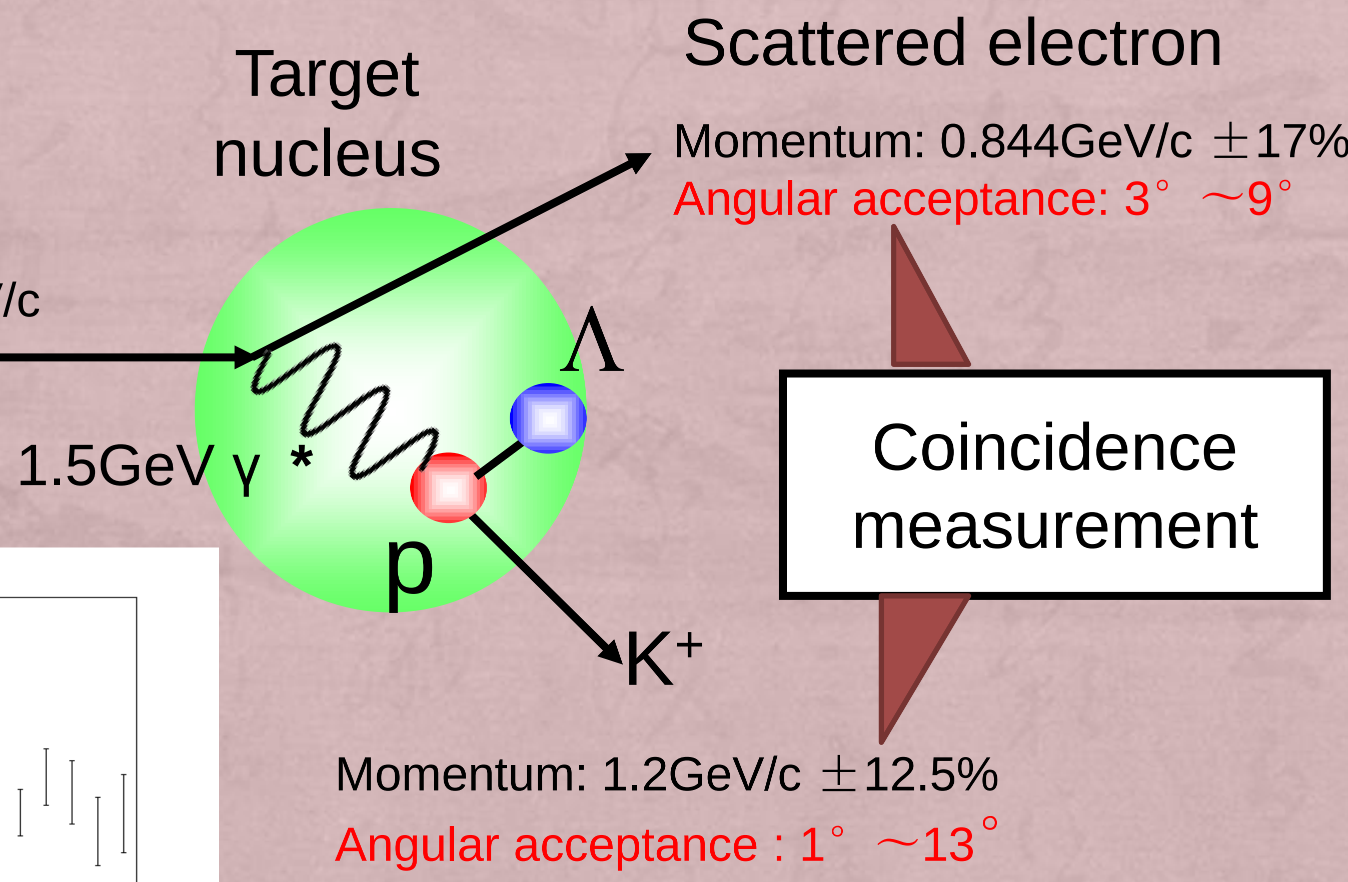
  a. Central kinematics scan (m_Λ,m_Σ,$\Delta m_{\Lambda\Sigma}$)

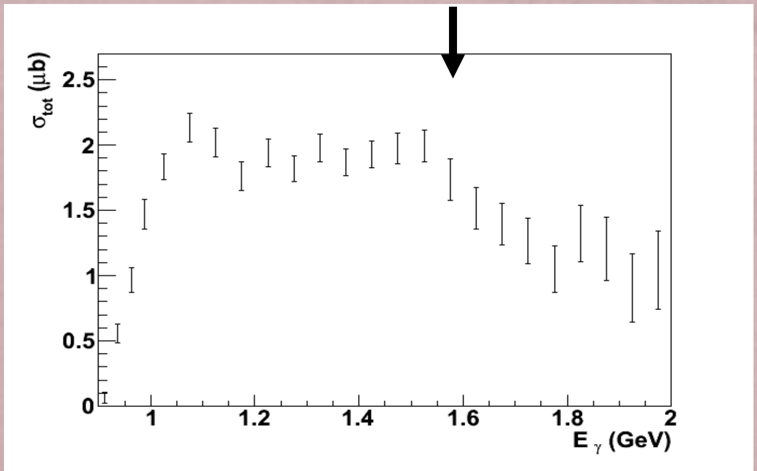
  b. Angular matrices (m_Λ,m_Σ,σ)

  c. Momentum matrices ($^{12}{}_\Lambda$Bgs)

  d. Iteration

Kinematics of the E05-115 Experiment





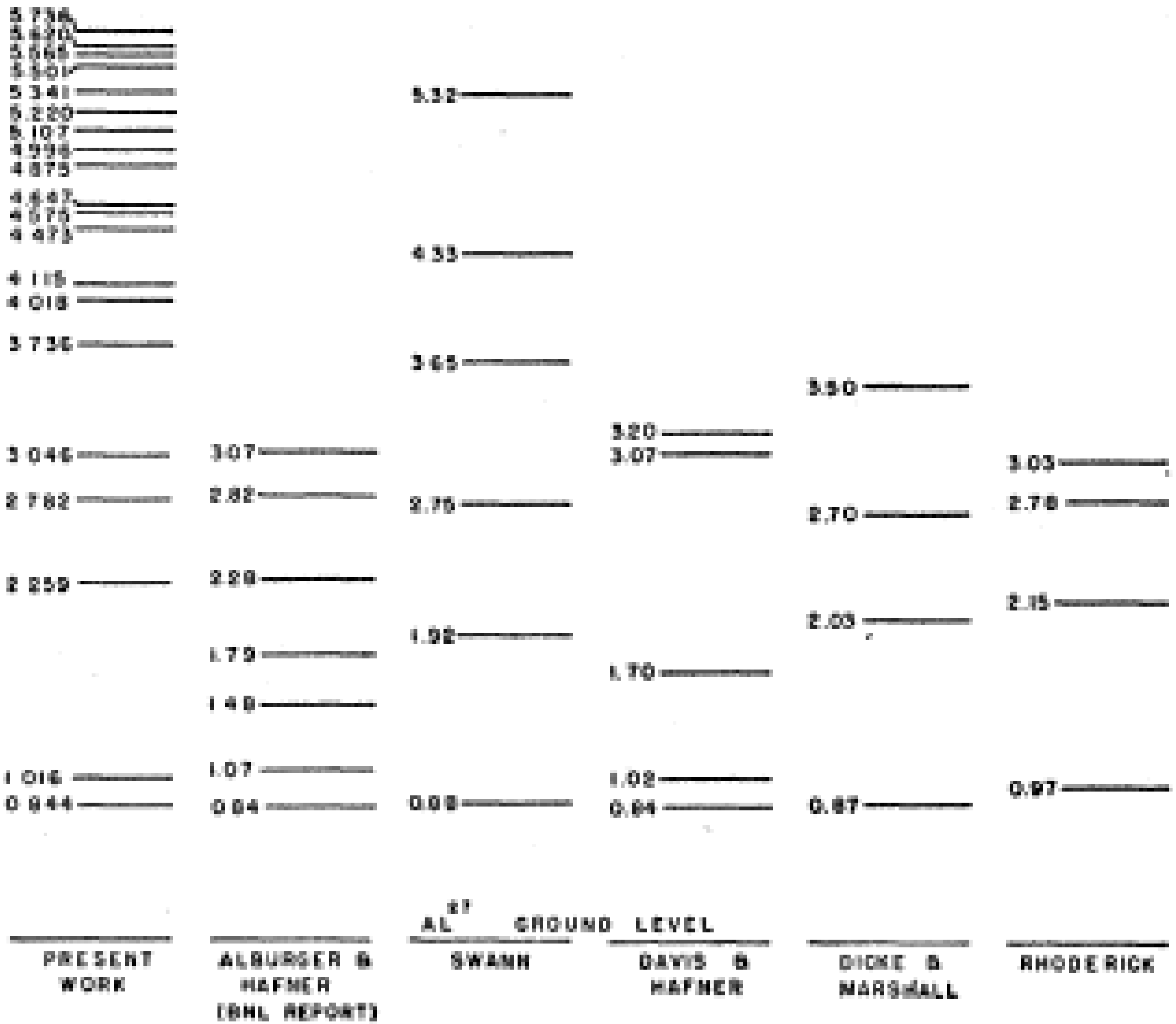
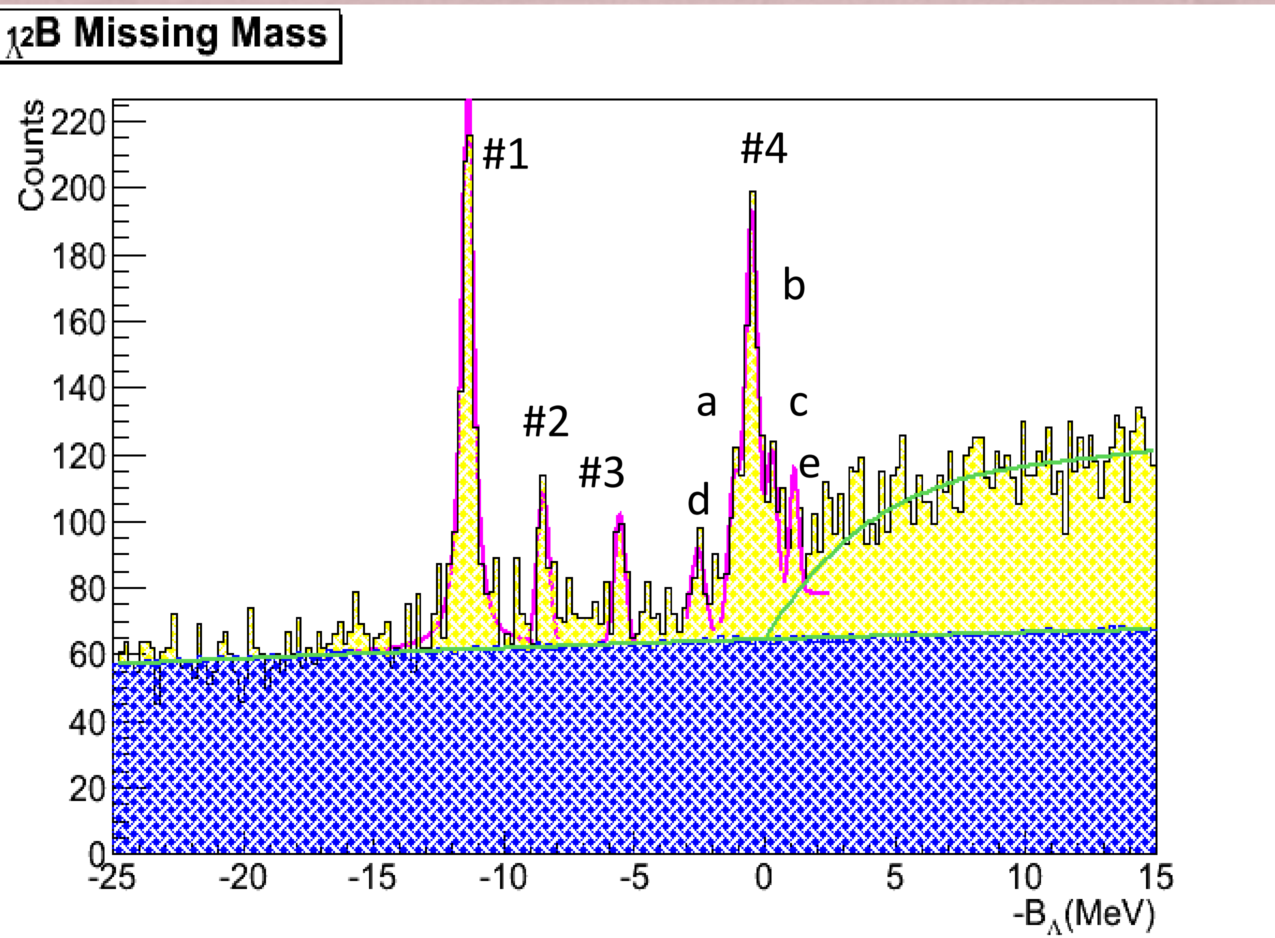
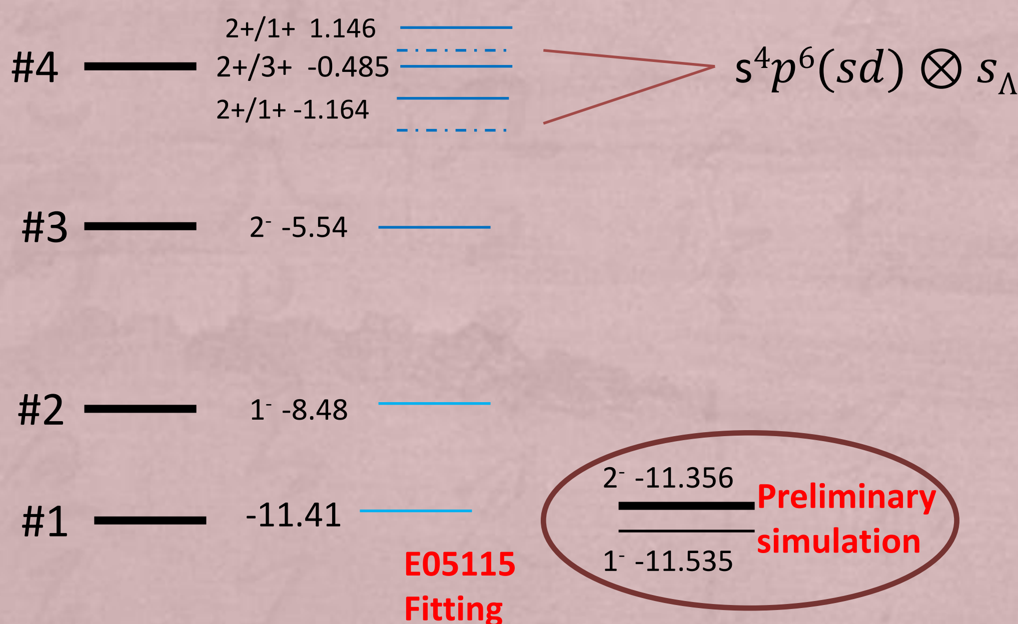


FIG. 2. Energy level scheme for Al^{27}.

$^{12}_{\Lambda}B$



peak		Mean(MeV)	σ(KeV)
1		-11.41	265
2		-8.48	231
3		-5.54	210
4	a	-1.164	240
	b	-0.485	
	c	0.295	
	d	-2.539	281
	e	1.146	172



peak		Mean(MeV)	σ(KeV)
1		-11.41	265
2		-8.48	231
3		-5.54	210
4	a	-1.164	240
	b	-0.485	
	c	0.295	
	d	-2.539	281
	e	1.146	234