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

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

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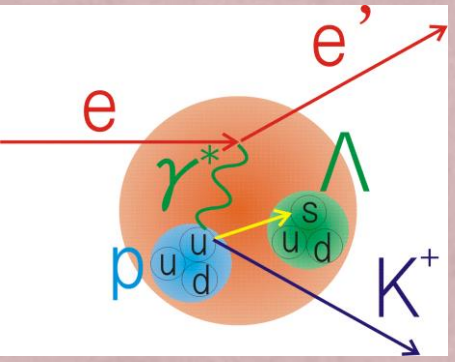
DNP Oct. 25, 2013

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

$p(e,e'K^+)\Lambda$ 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.

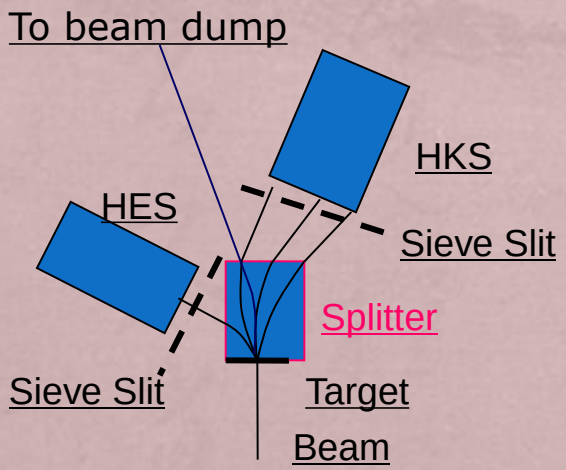
Spectrometer System Calibration

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

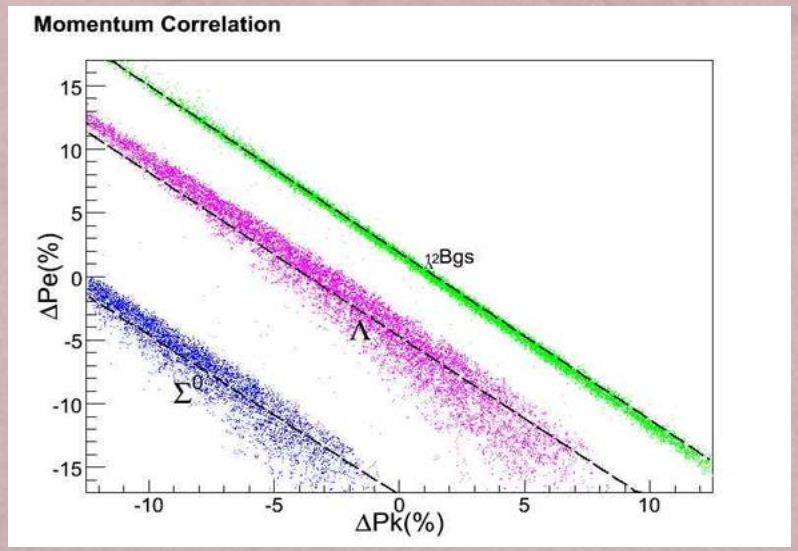
- Common splitter : Separated single arm calibration is impossible
- Technique: 2-arm coupled calibration for both kinematics and optics

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

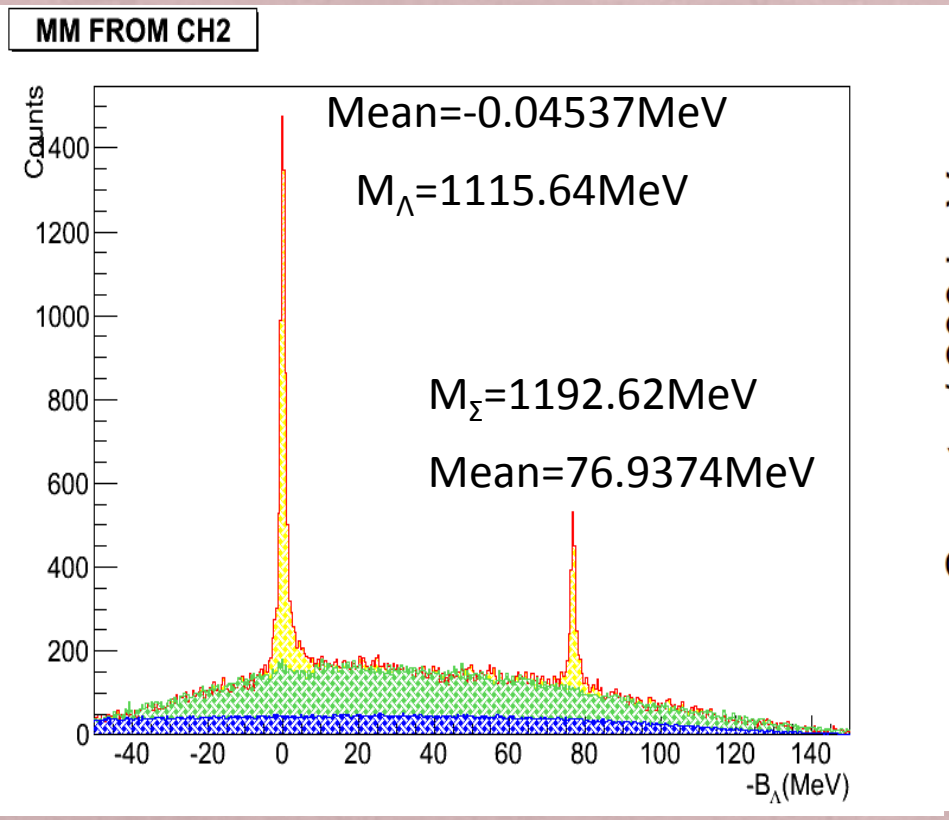
HES spectrometer system



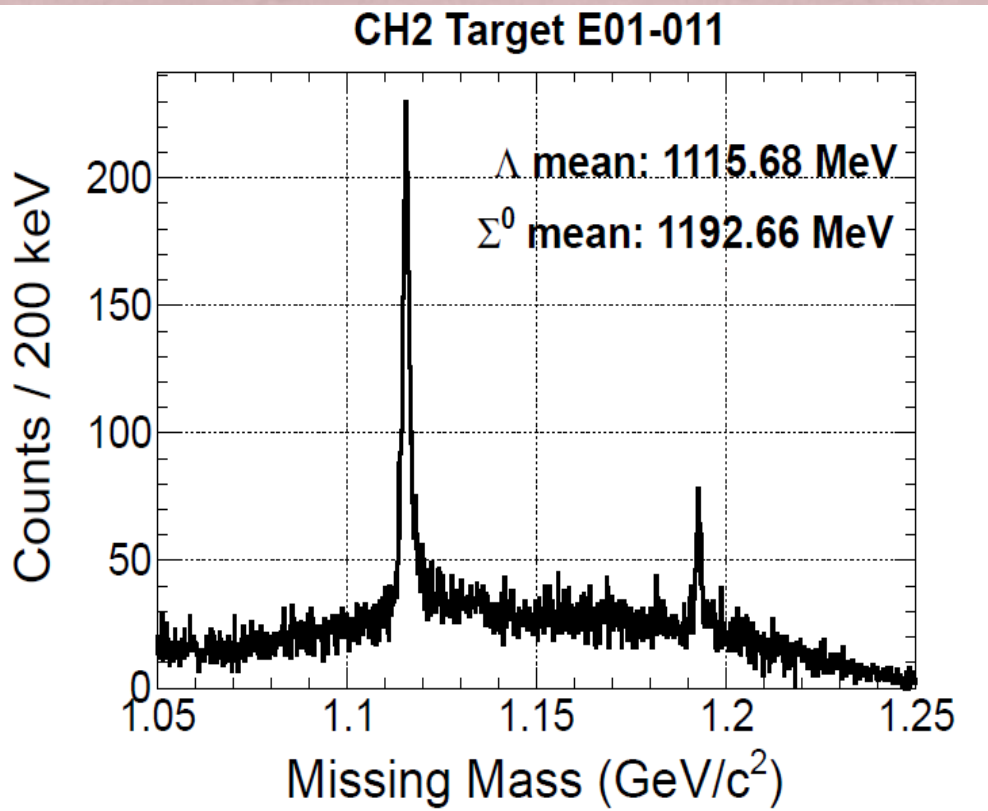
Kinematics coverage



CALIBRATION DATA RESULT



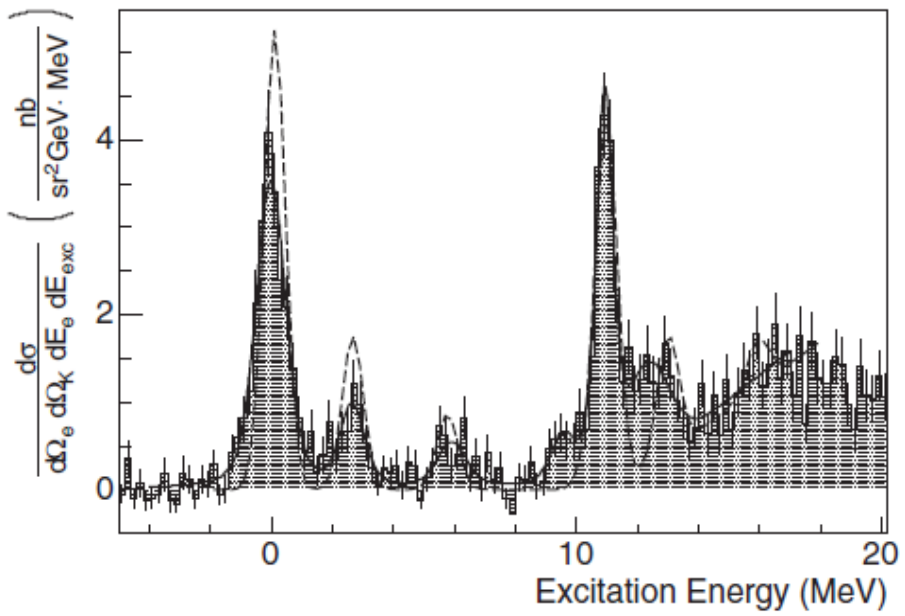
E05-115

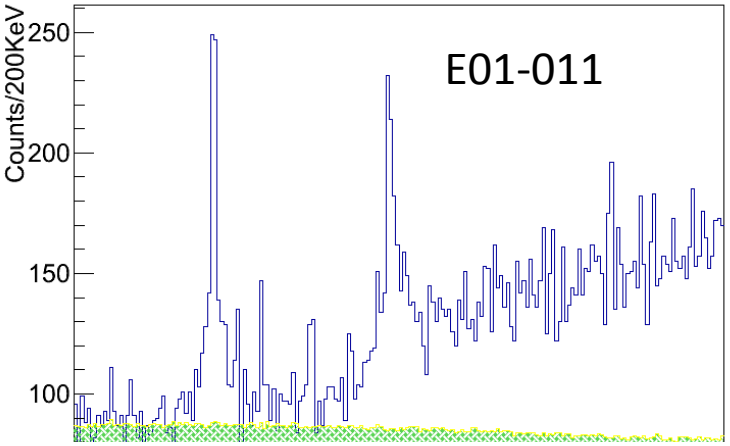


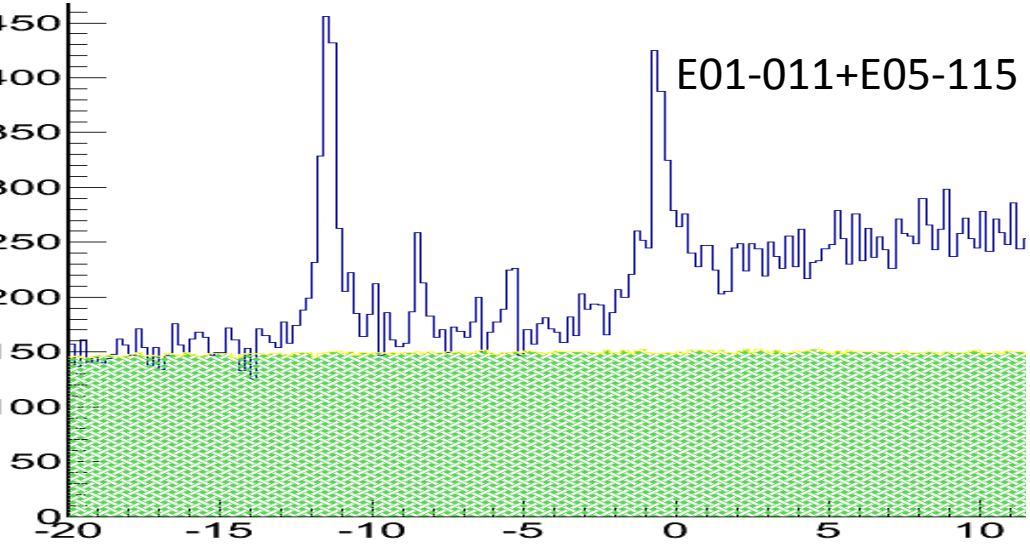
E01-011

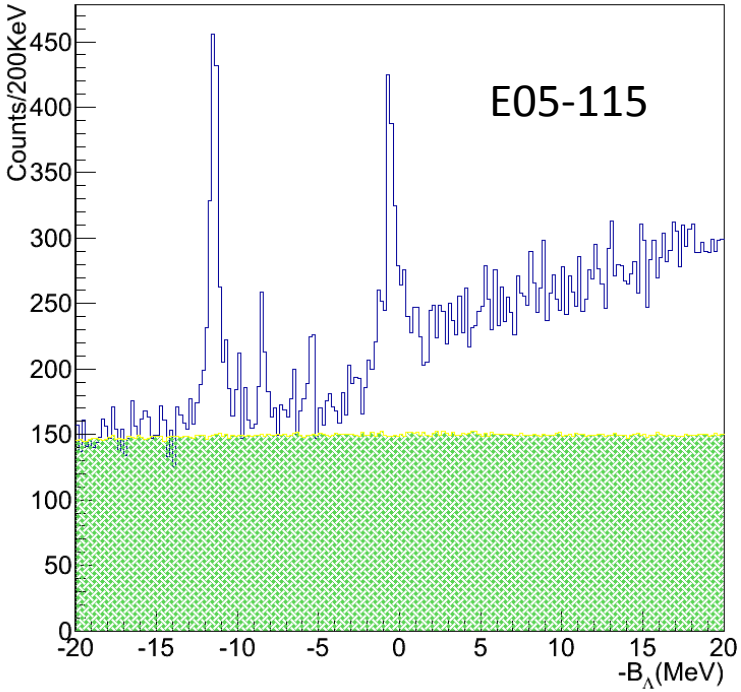
$^{12}_{\Lambda}B$

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









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

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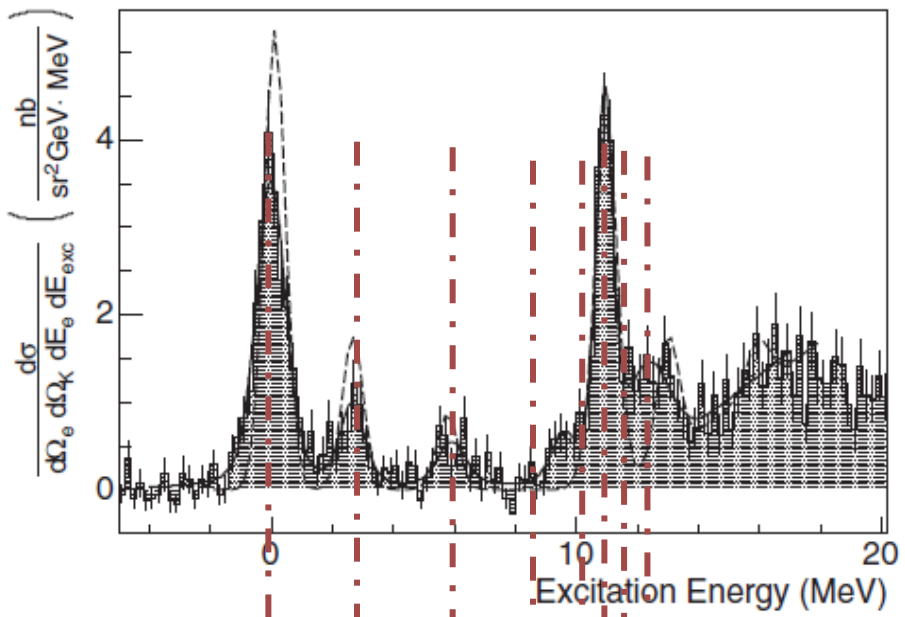
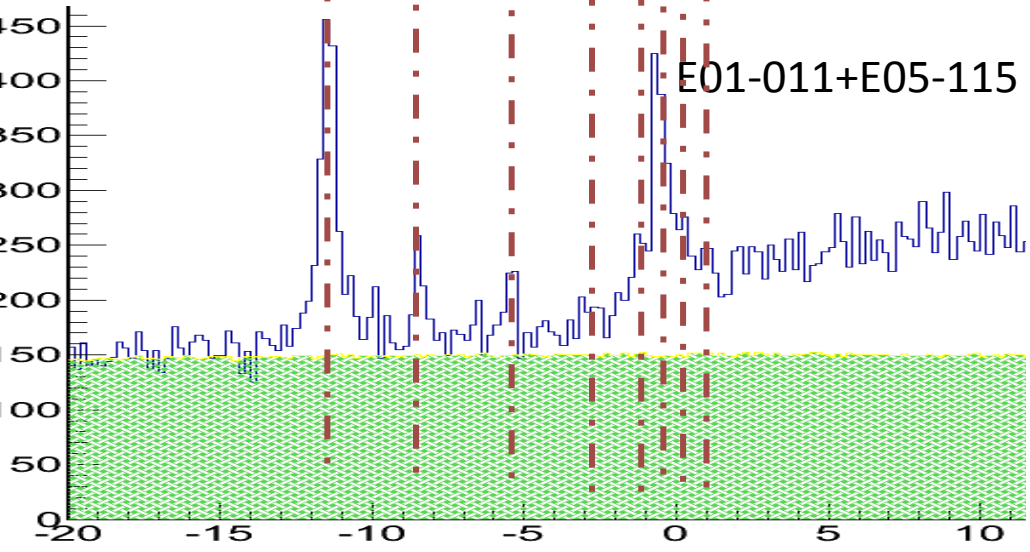
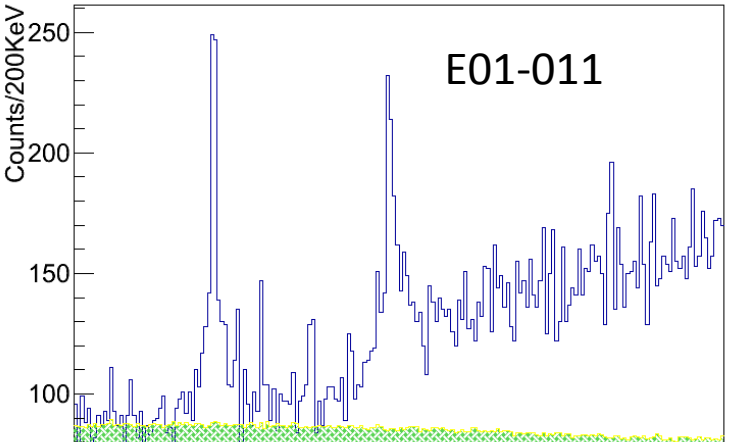
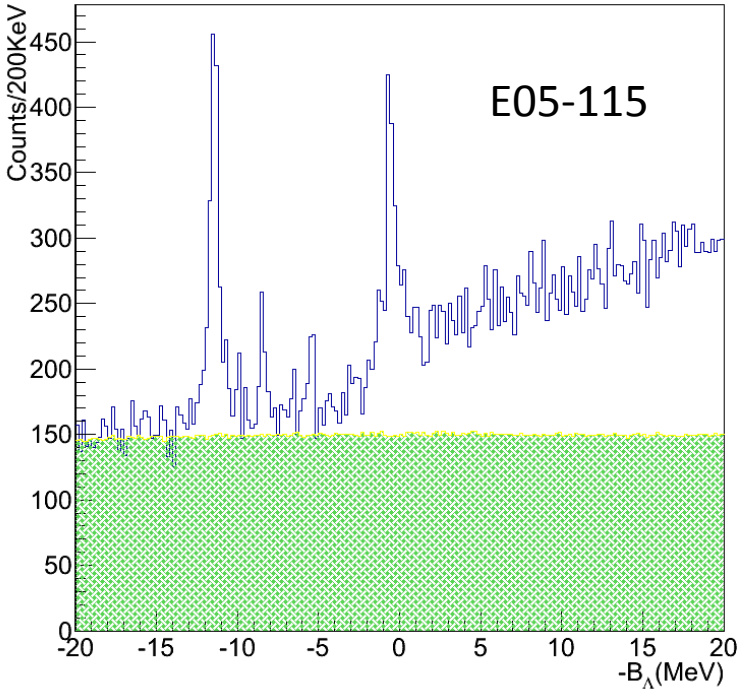
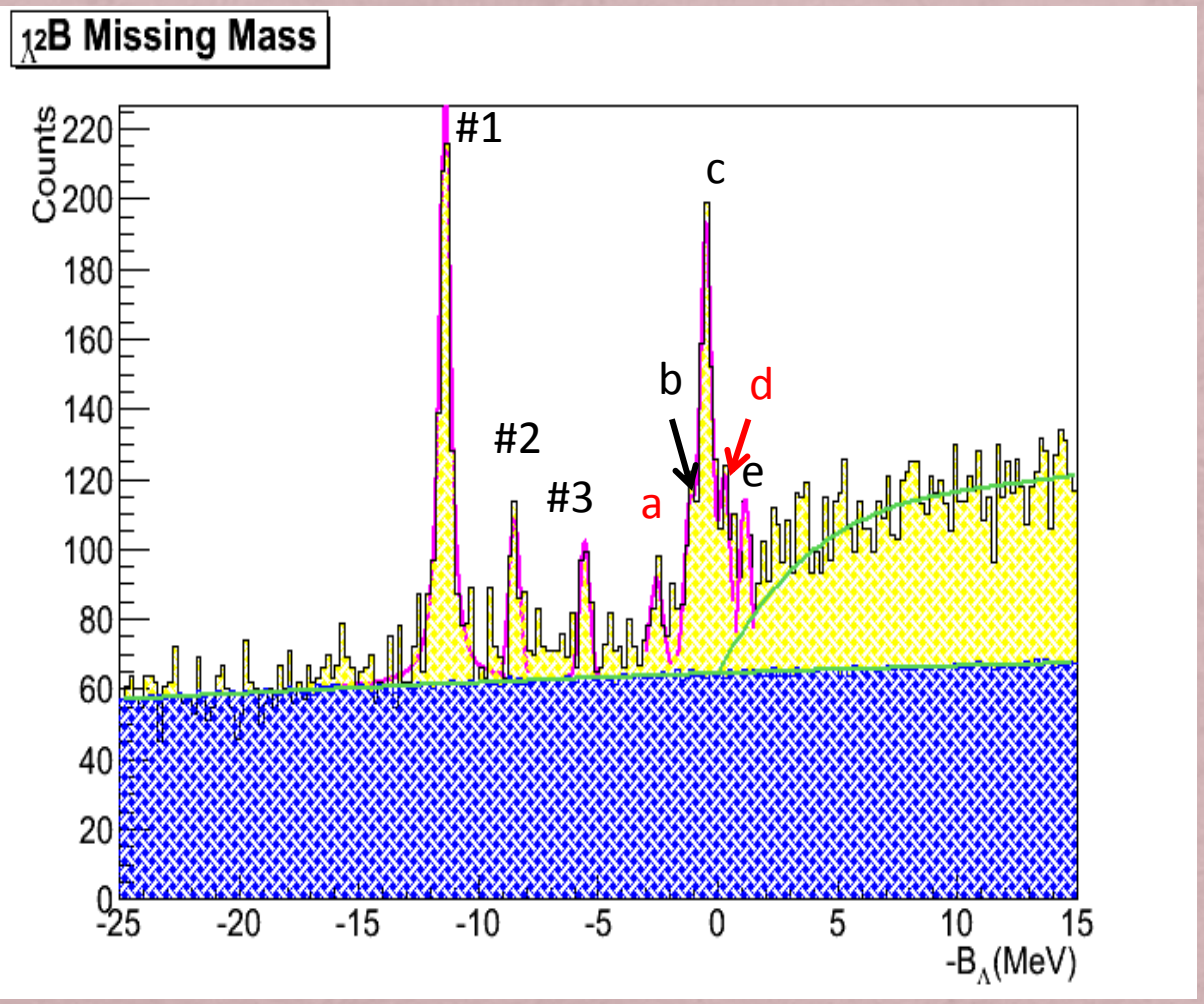








$^{12}_{\Lambda}B$

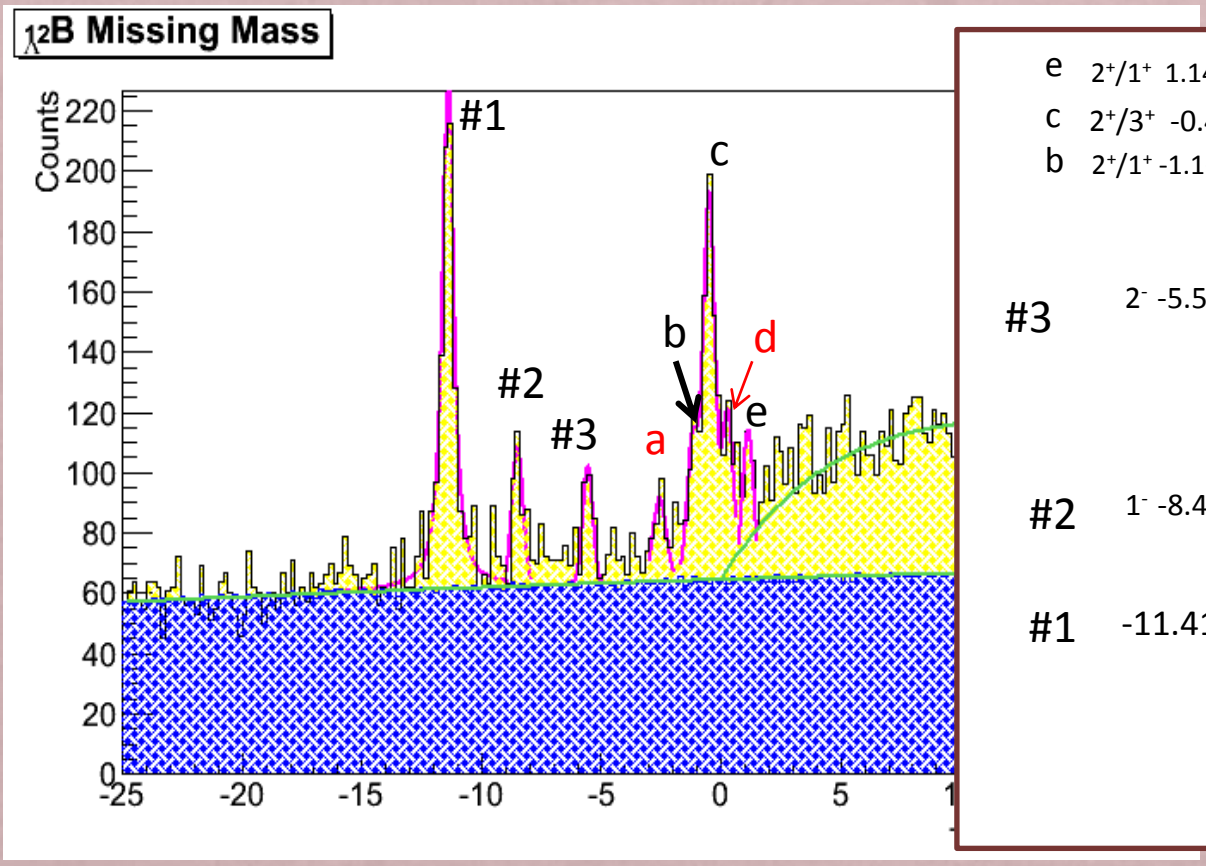


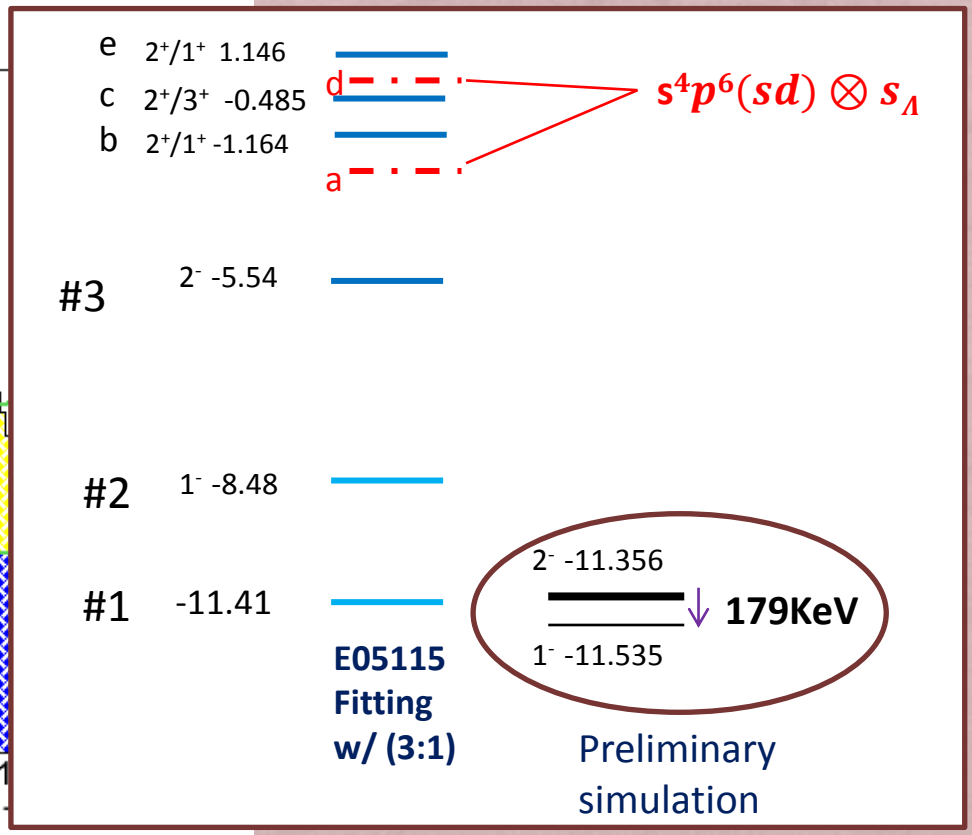
peak	Mean (MeV)	σ (KeV)
1	-11.41	265
2	-8.48	231
3	-5.54	210
a	**-2.539**	**281**
b	-1.164	240
c	-0.485	240
d	**0.295**	**240**
e	1.146	234

Resolution:

σ = ~240 keV or ~ 565 keV FWHM

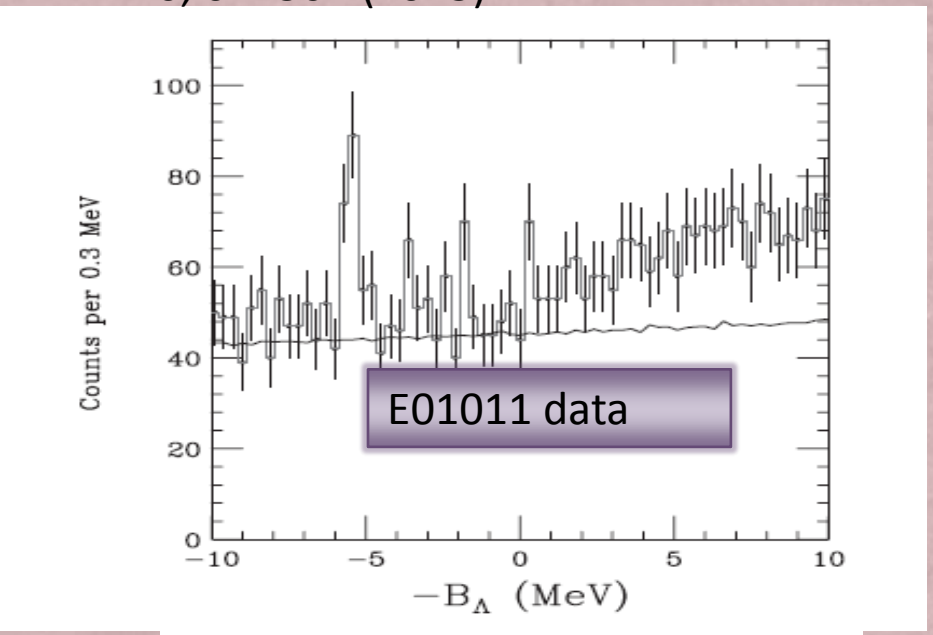
$^{12}_{\Lambda}B$

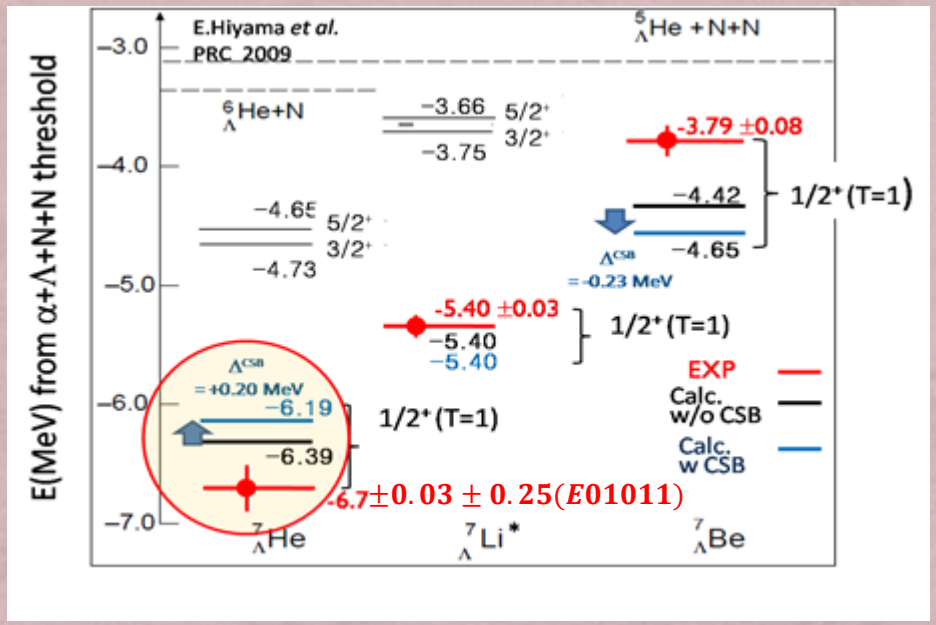

ΛB Missing Mass
Counts
#1
#2
#3
a
b
c
d
e

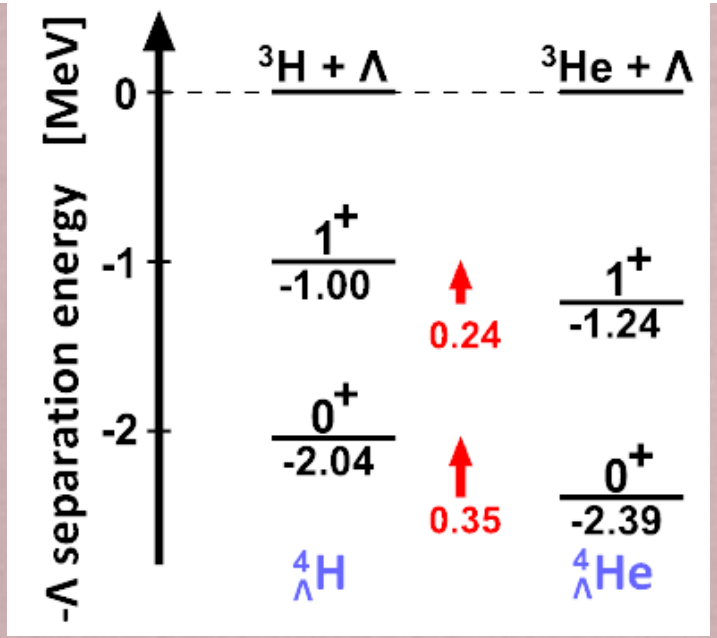

e 2+/1+ 1.146
c 2+/3+ -0.485
b 2+/1+ -1.164
d
a
$s^4p^6(sd) \otimes s_\Lambda$
#3 2- -5.54
#2 1- -8.48
#1 -11.41
E05115 Fitting w/ (3:1)
2- -11.356
179KeV
1- -11.535
Preliminary simulation

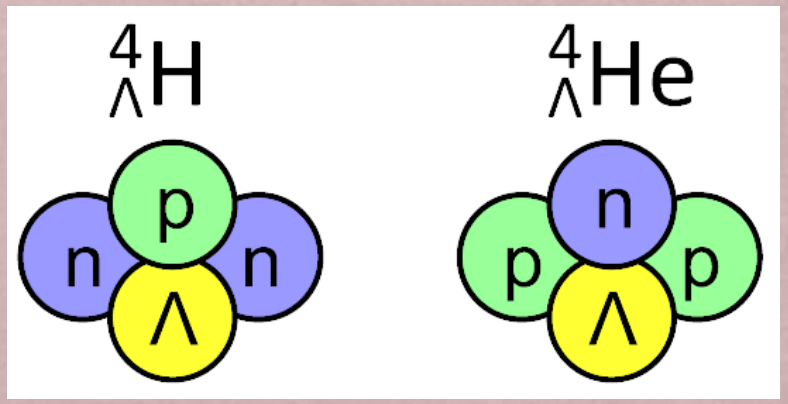
$^{7}_{\Lambda}$He

PRL 110, 012502 (2013)



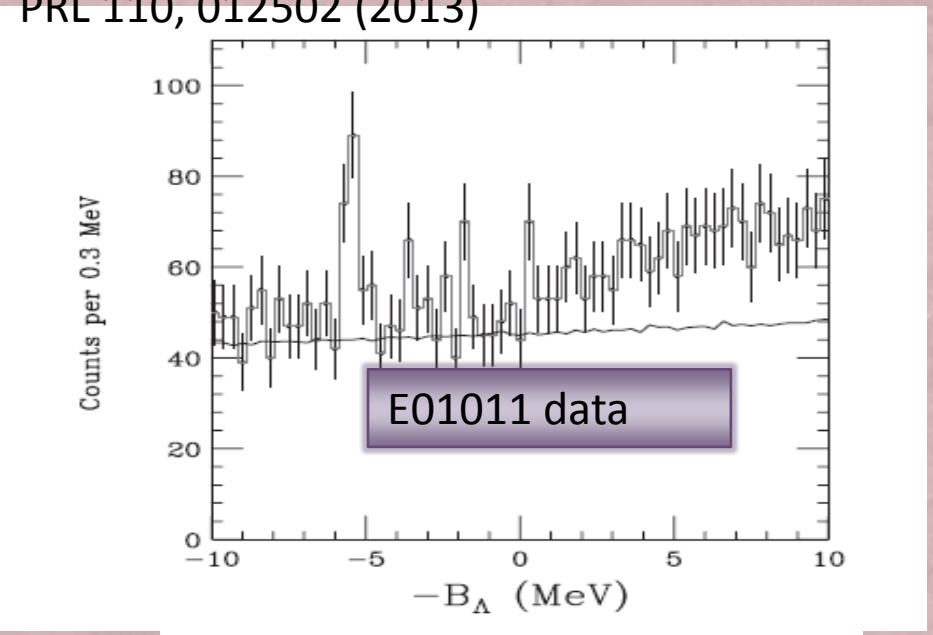


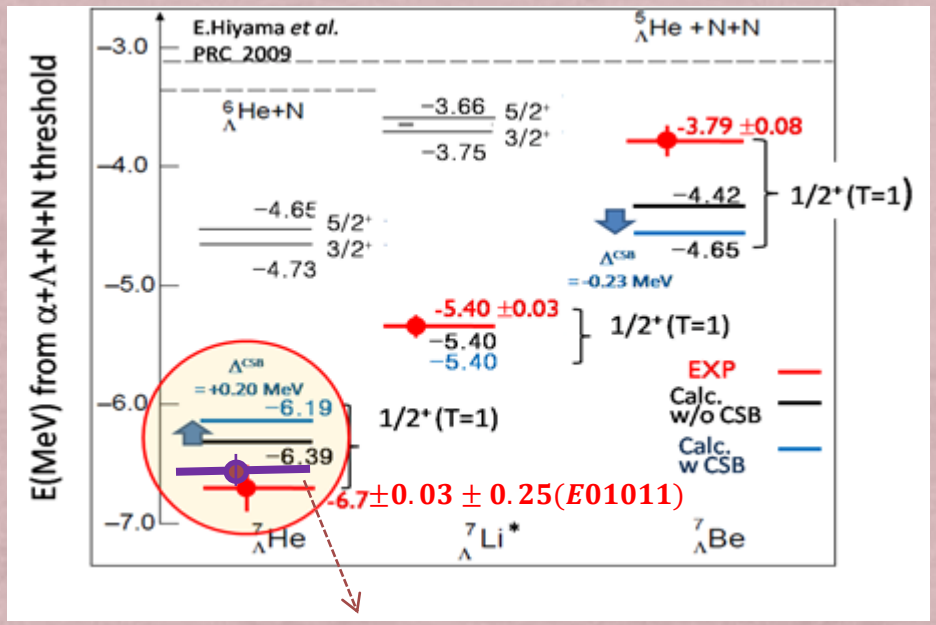




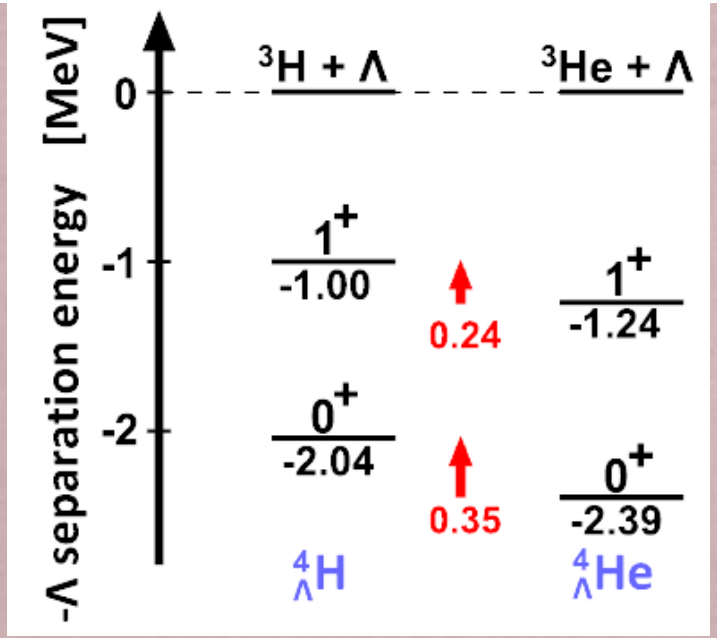
$^{7}_{\Lambda}$He

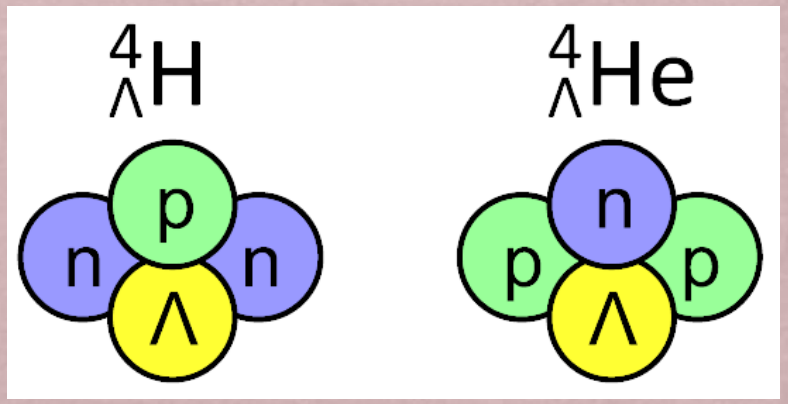
PRL 110, 012502 (2013)





E05-115 with 4 time more statistics and better precision





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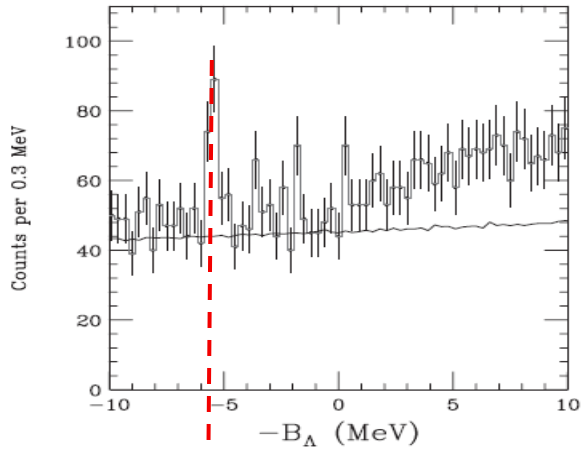
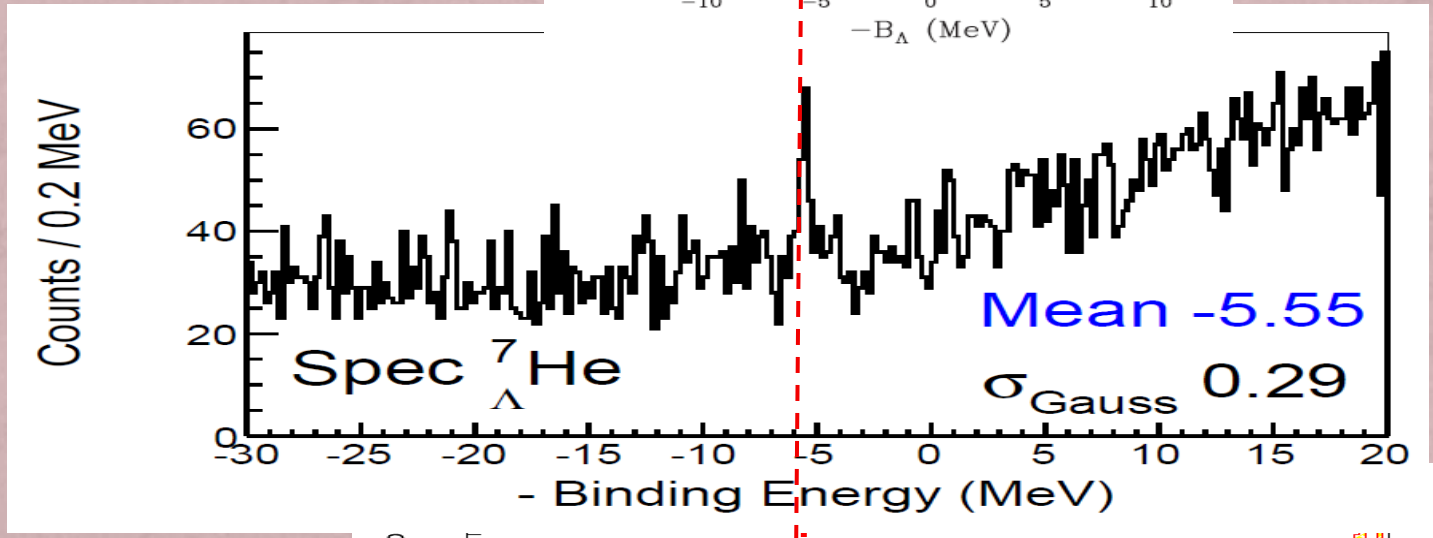


E01-011 reanalyzed



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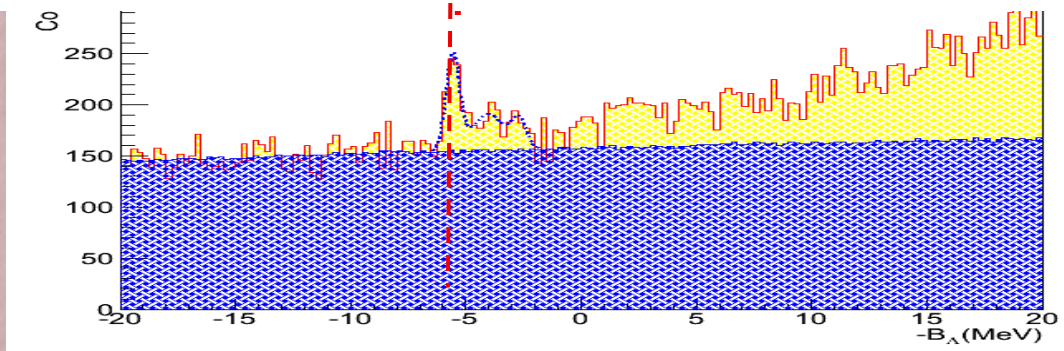

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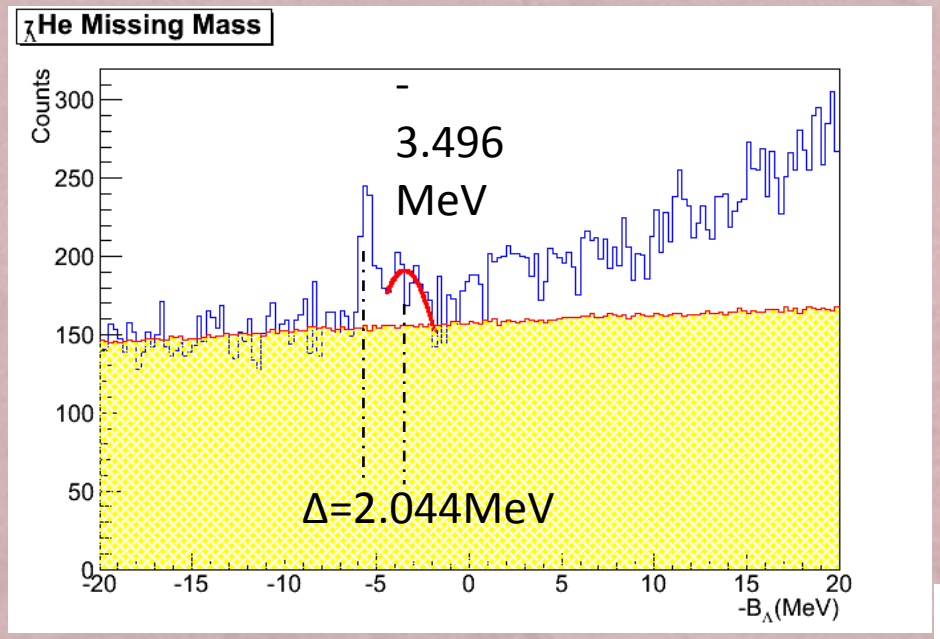
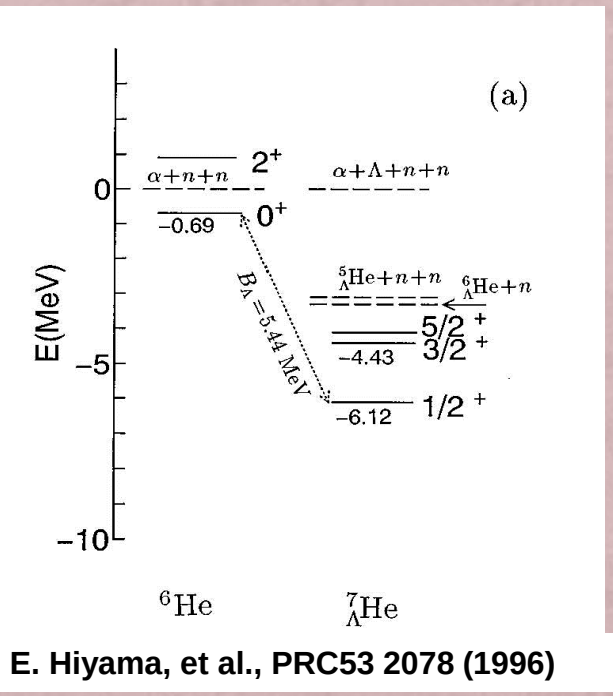
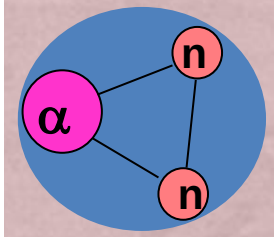
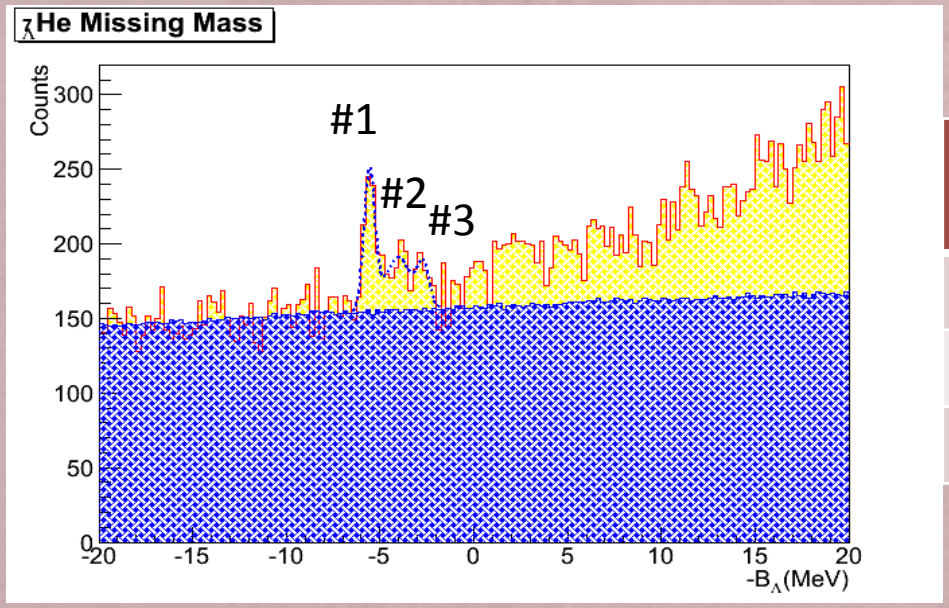




E. Hiyama, et al., PRC53 2078 (1996)

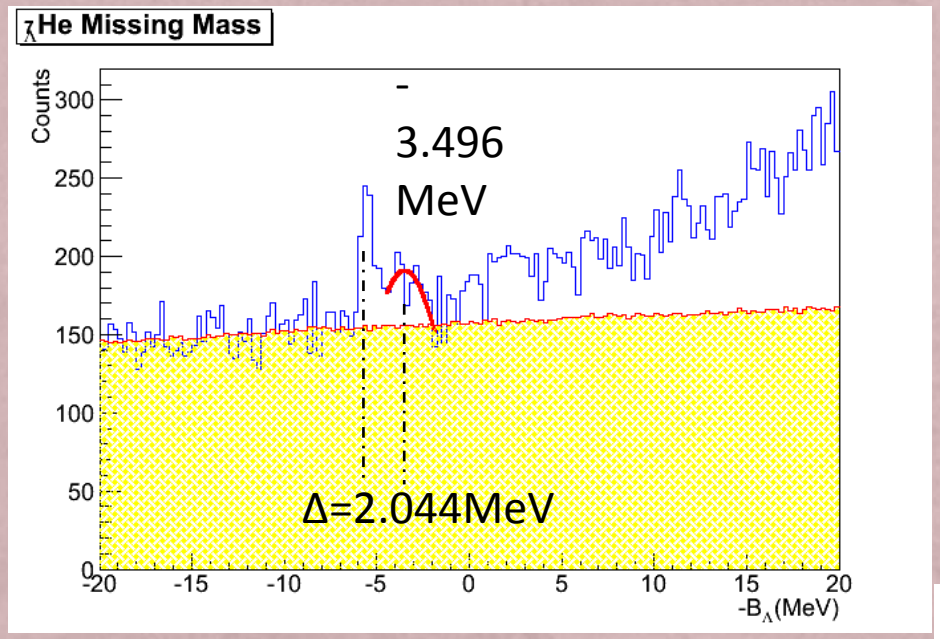
^{6}He core

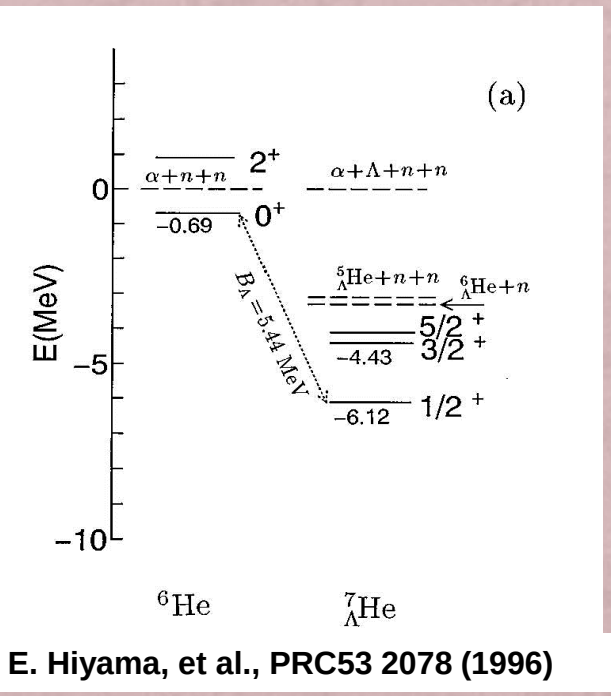




peak	Mean(MeV)	σ(KeV)
1	-5.54	253
2	-4.01	379
3	**-2.97**	**375**

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





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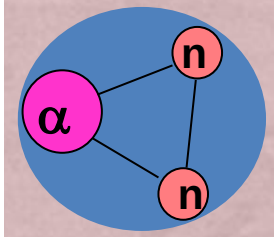

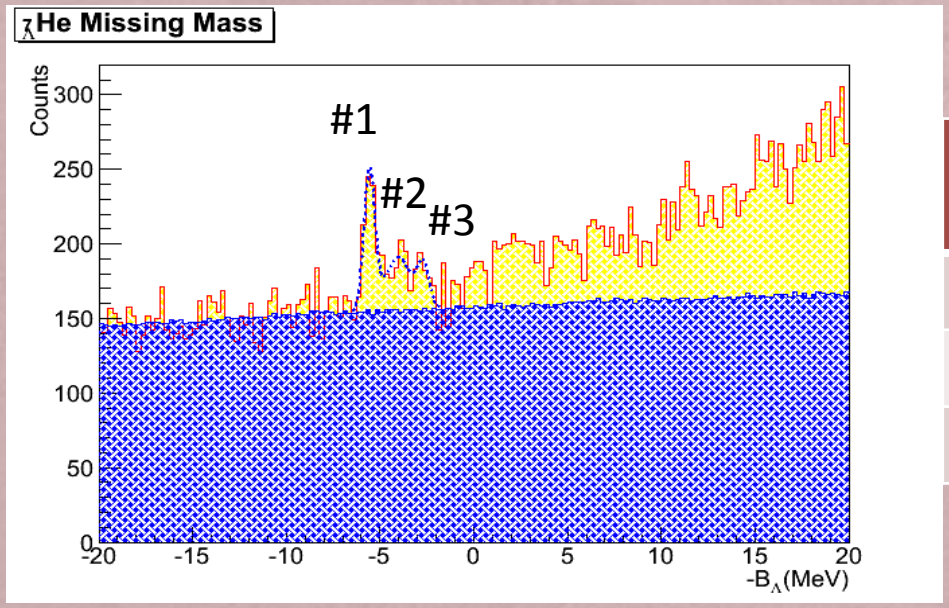

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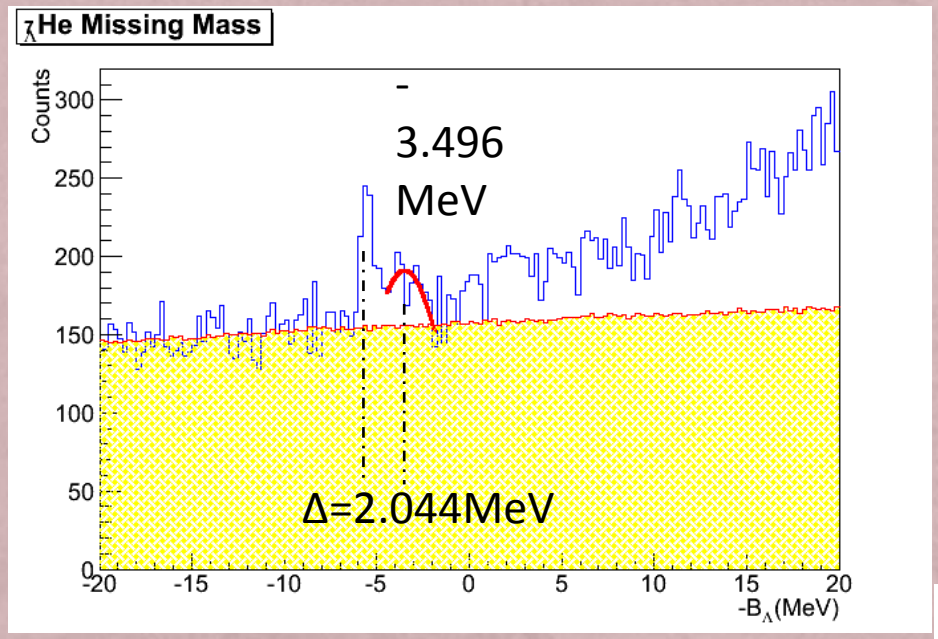
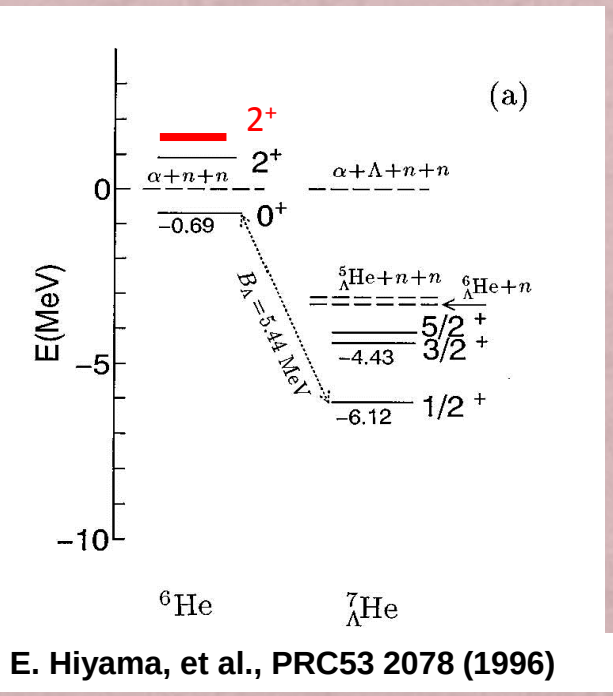
ΔE_{Λ} ~ 130keV

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

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





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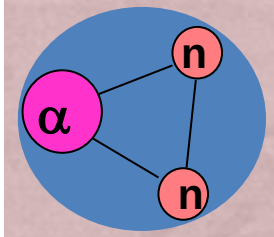
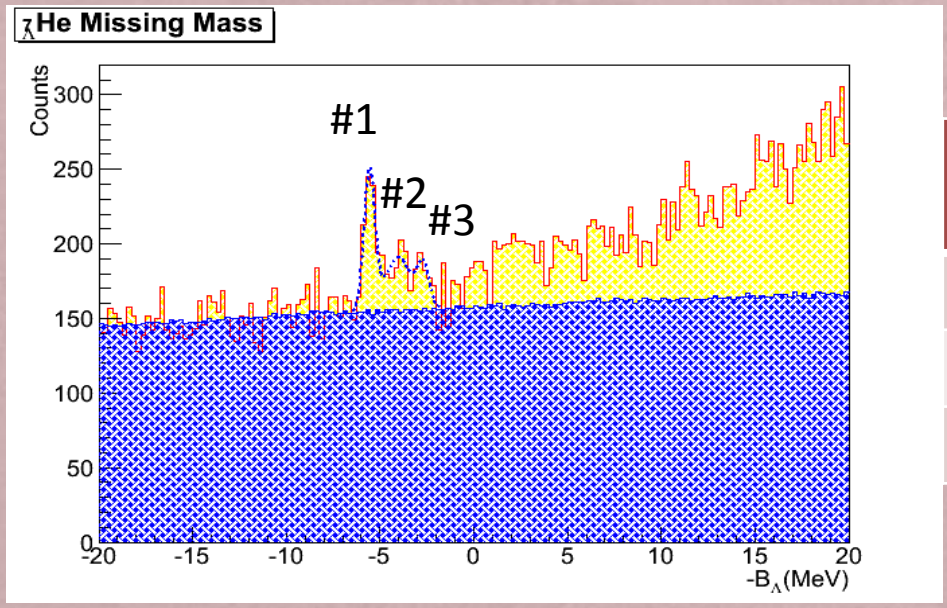
^{6}He core





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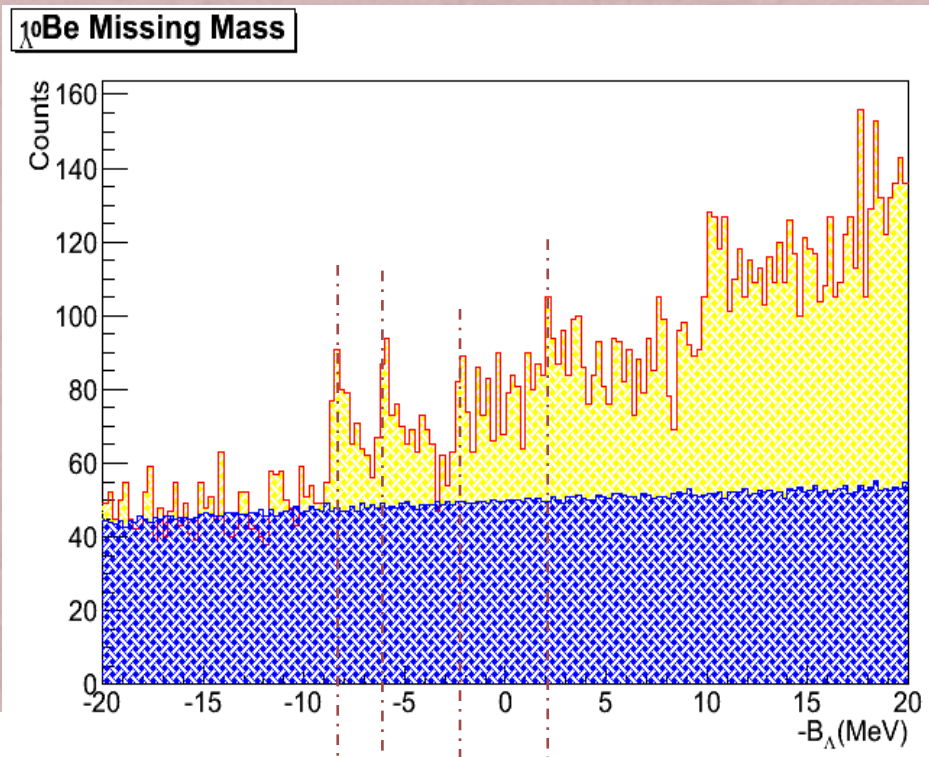
ΔE_{Λ} ~ 130keV

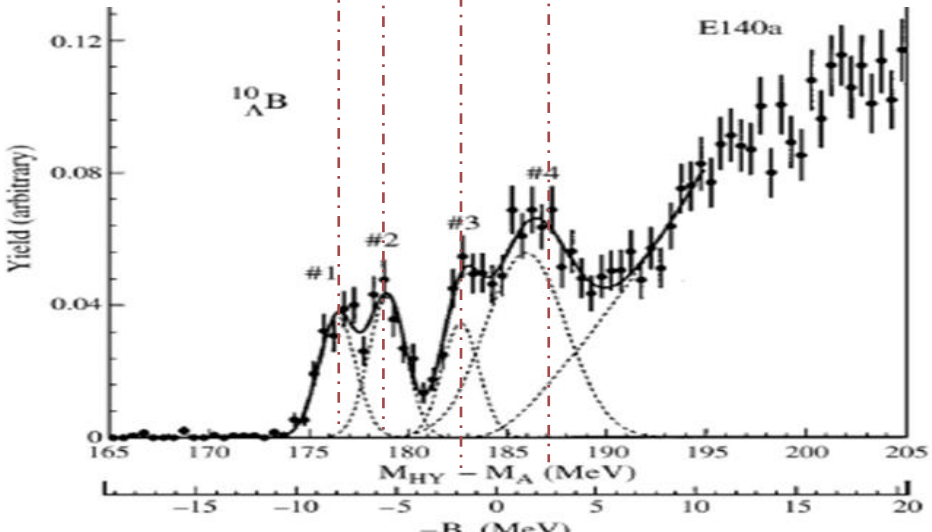
$\frac{3^+}{2} / \frac{5^+}{2}$

A resonance state

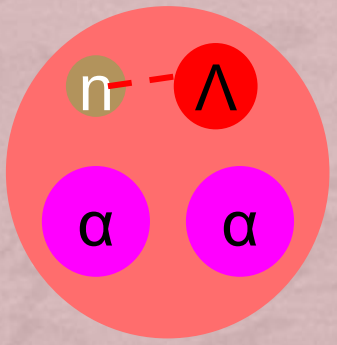
Possibility : Additional 2^+ core state

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



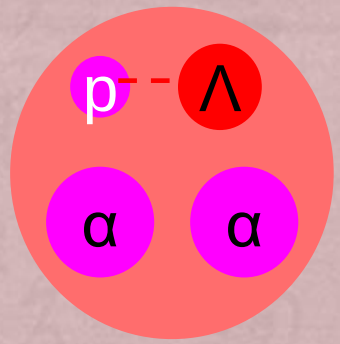


E05-115



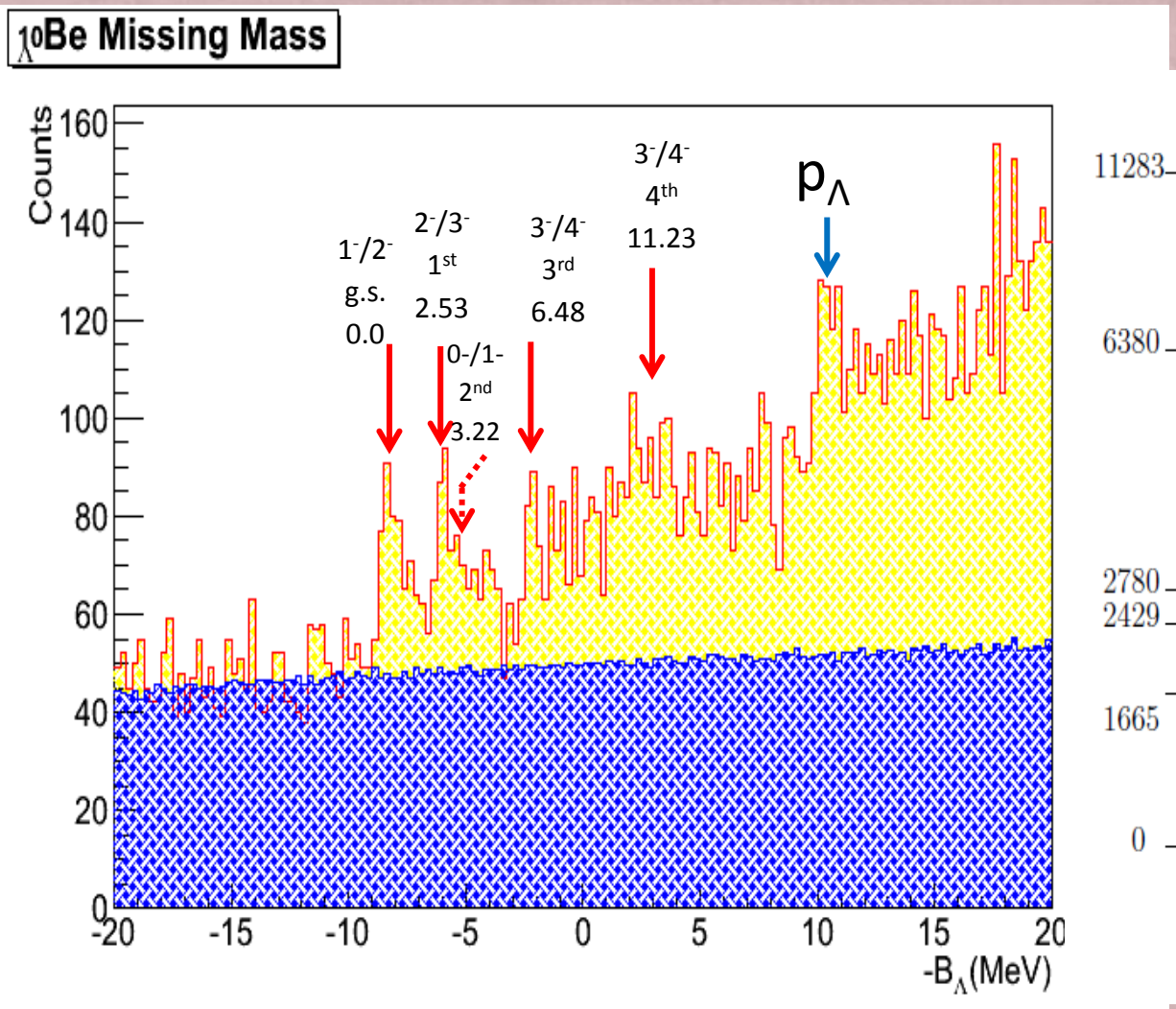
$^{10}_{\Lambda}$Be

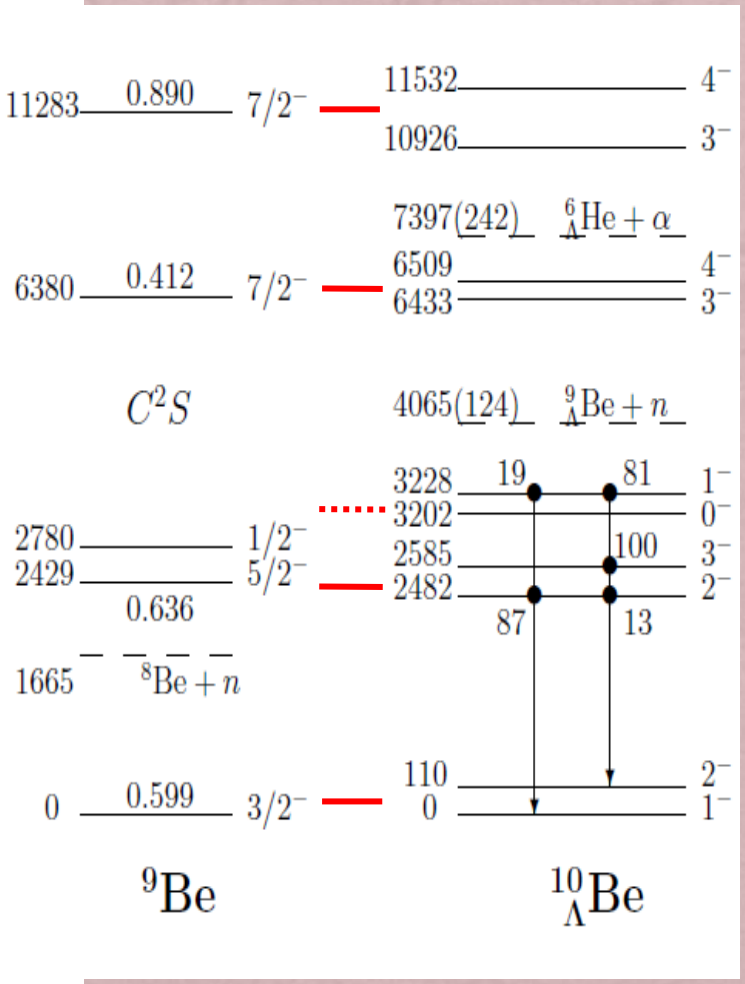
KEK-E140a
$^{10}_{\Lambda}$B



$^{10}_{\Lambda}$B

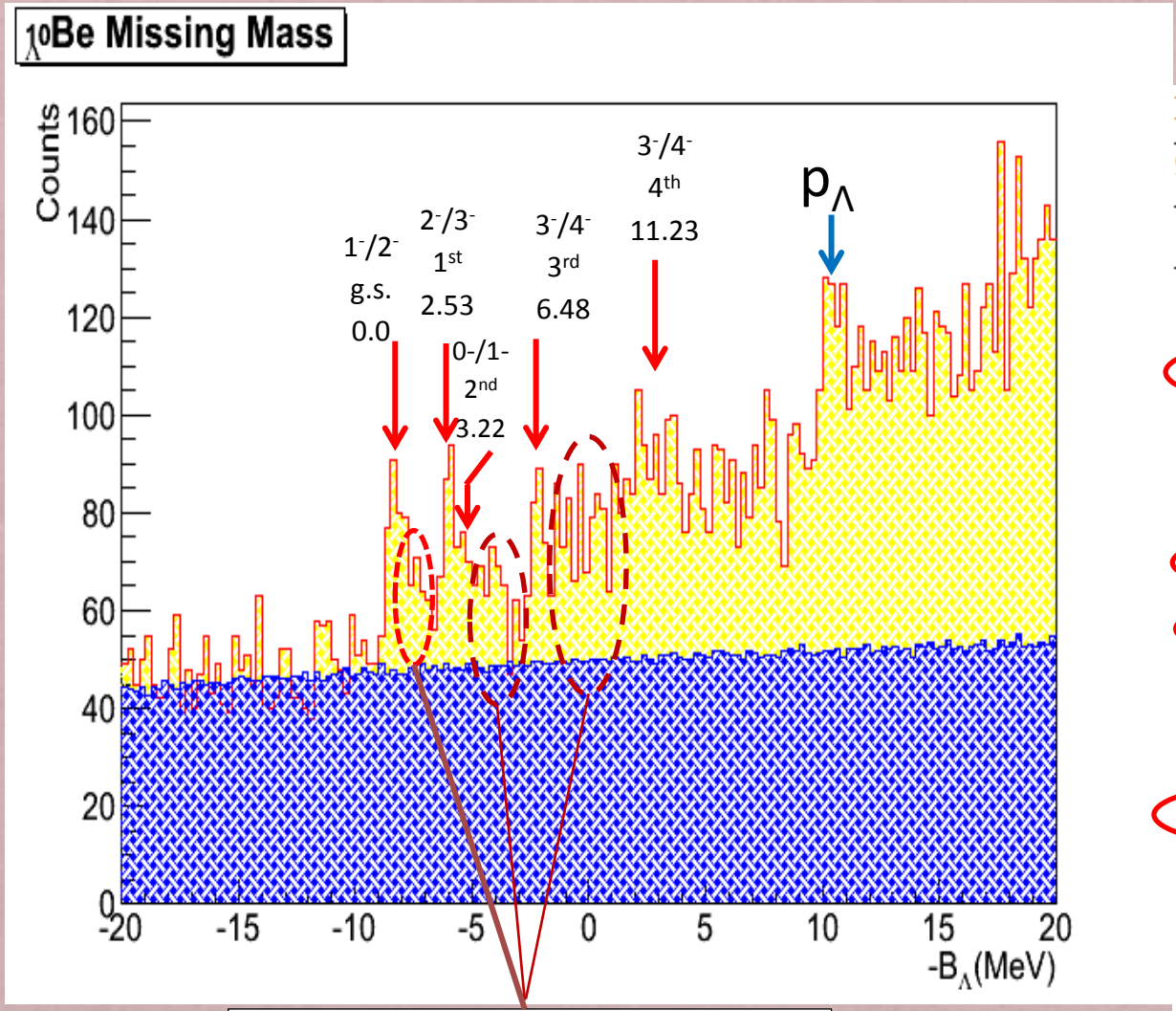
PRELIMINARY RESULT – $^{10}_{\Lambda}$Be





Calculated by D.J. Millener

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



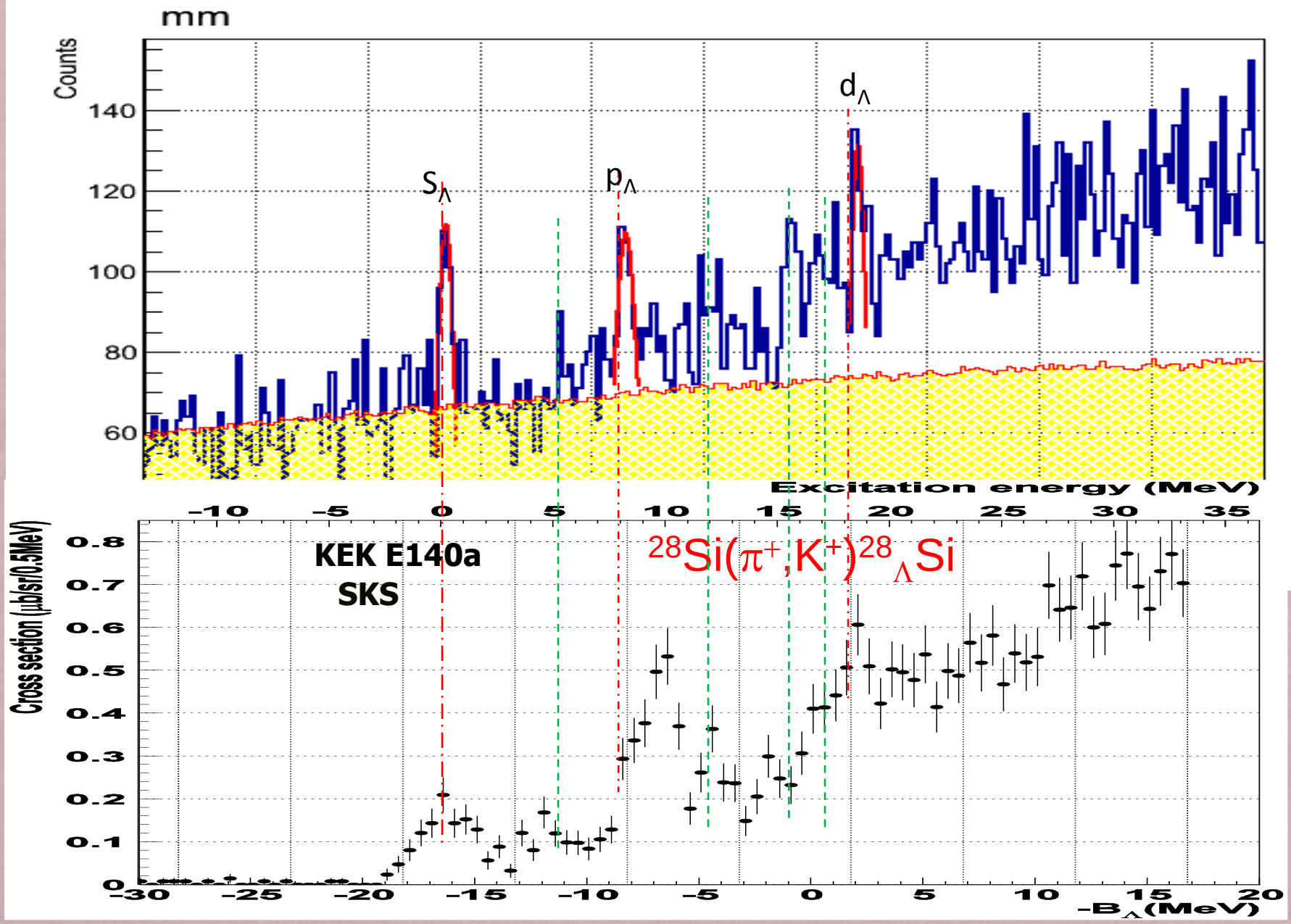
Positive parity core states

Energy levels of ^{9}B

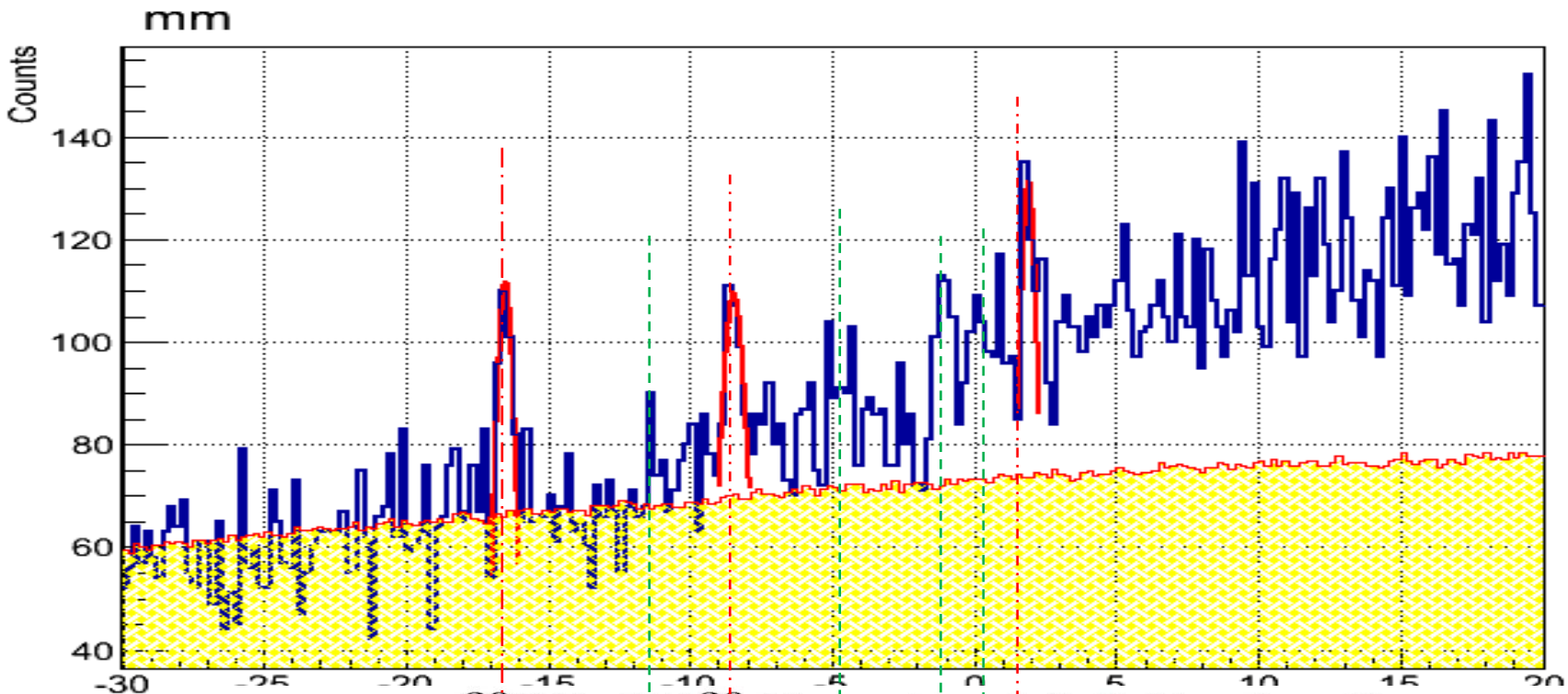
Mirror states ($T = \frac{1}{2}$) in $A = 9$ nuclei[a]

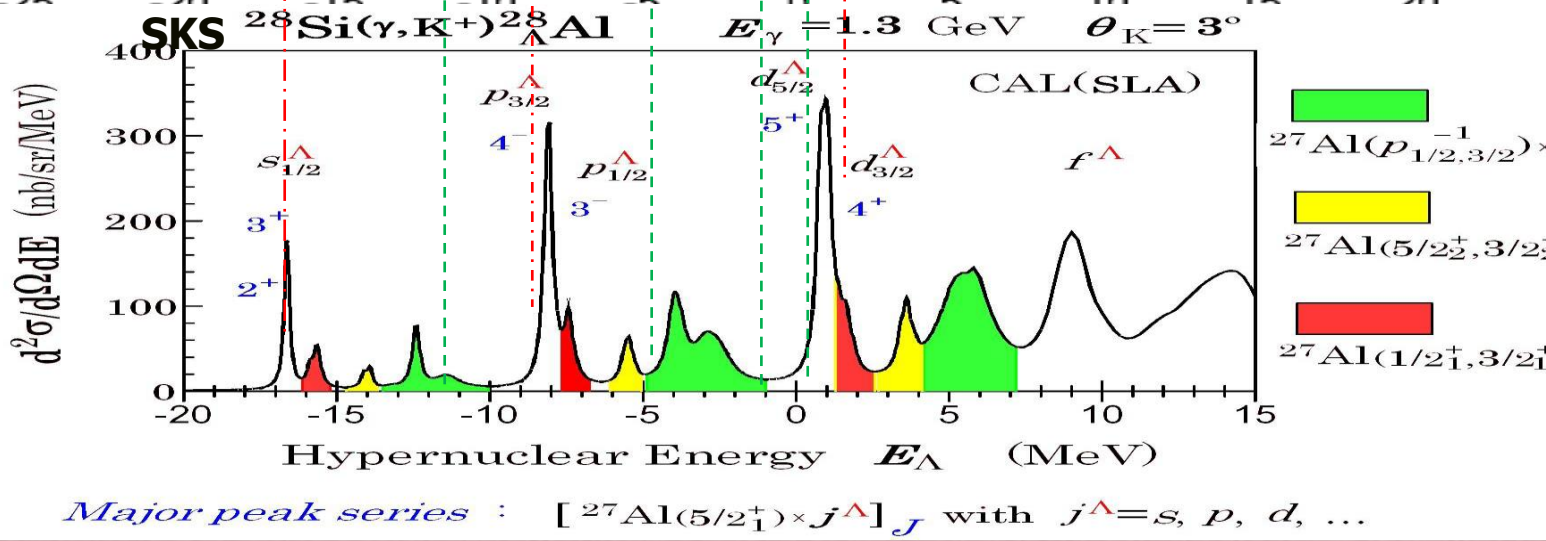
^{9}Be	
E_x (MeV)	J^π
0	$\frac{3}{2}^-$
1.684	$\frac{1}{2}^+$
2.429	$\frac{5}{2}^-$
2.78	$\frac{1}{2}^-$
3.049	$\frac{5}{2}^+$
4.704	$(\frac{3}{2})^+$
5.59	$(\frac{3}{2}^-)$
6.38[d]	$\frac{7}{2}^-$
6.76	$\frac{9}{2}^+$
7.94	$(\frac{5}{2}^-)$
11.283	$(\frac{7}{2}^-)$
11.81	$\frac{5}{2}^-$

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



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





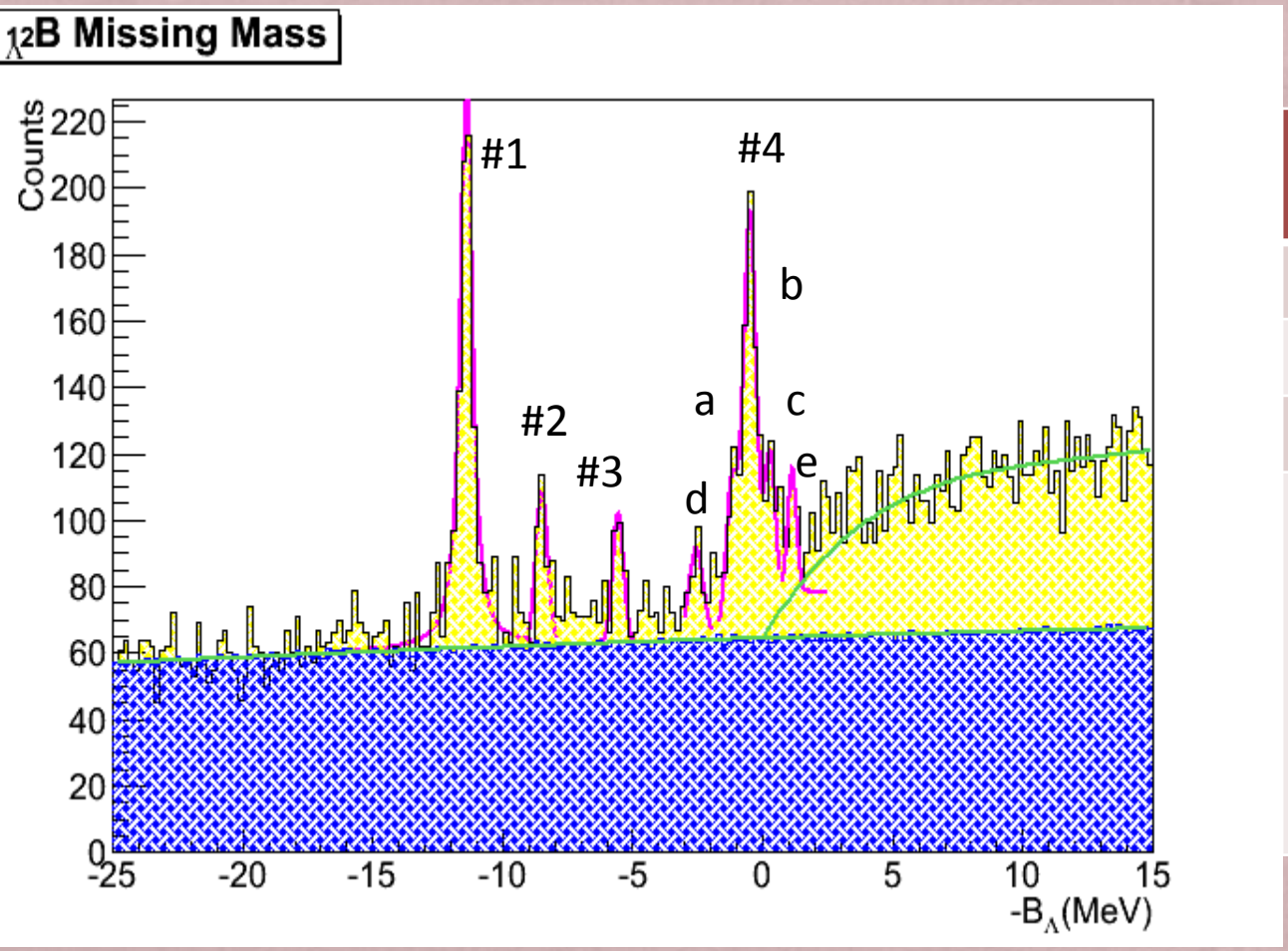
Major peak series : $[\,^{27}\mathrm{Al}(5/2^+_1)\times j^{\Lambda}]_J$ with $j^{\Lambda}=s,\ p,\ d,\ \ldots$

SUMMARY

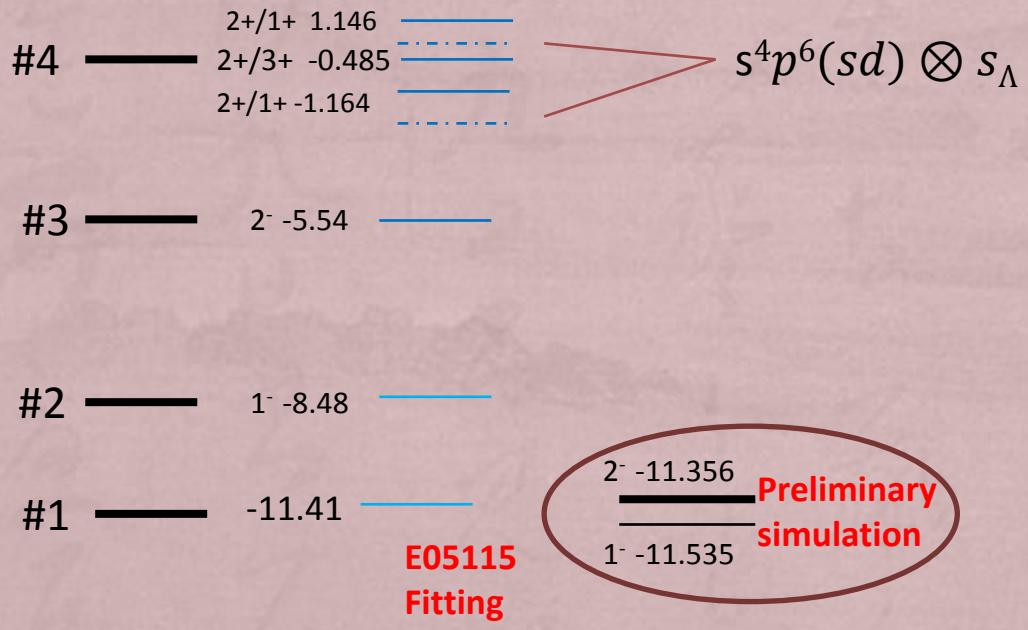
- Our systematic calibration is almost completed;
- The precise level structure of p-shell Λ hypernuclei ($^{7}_{\Lambda}$He, $^{10}_{\Lambda}$Be, and $^{12}_{\Lambda}$B) are evidential and encouraging;
- There is stronger evidence for sd-shell nuclei from spectroscopy of $^{12}_{\Lambda}$B and $^{28}_{\Lambda}$Al;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

BACK UP

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



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



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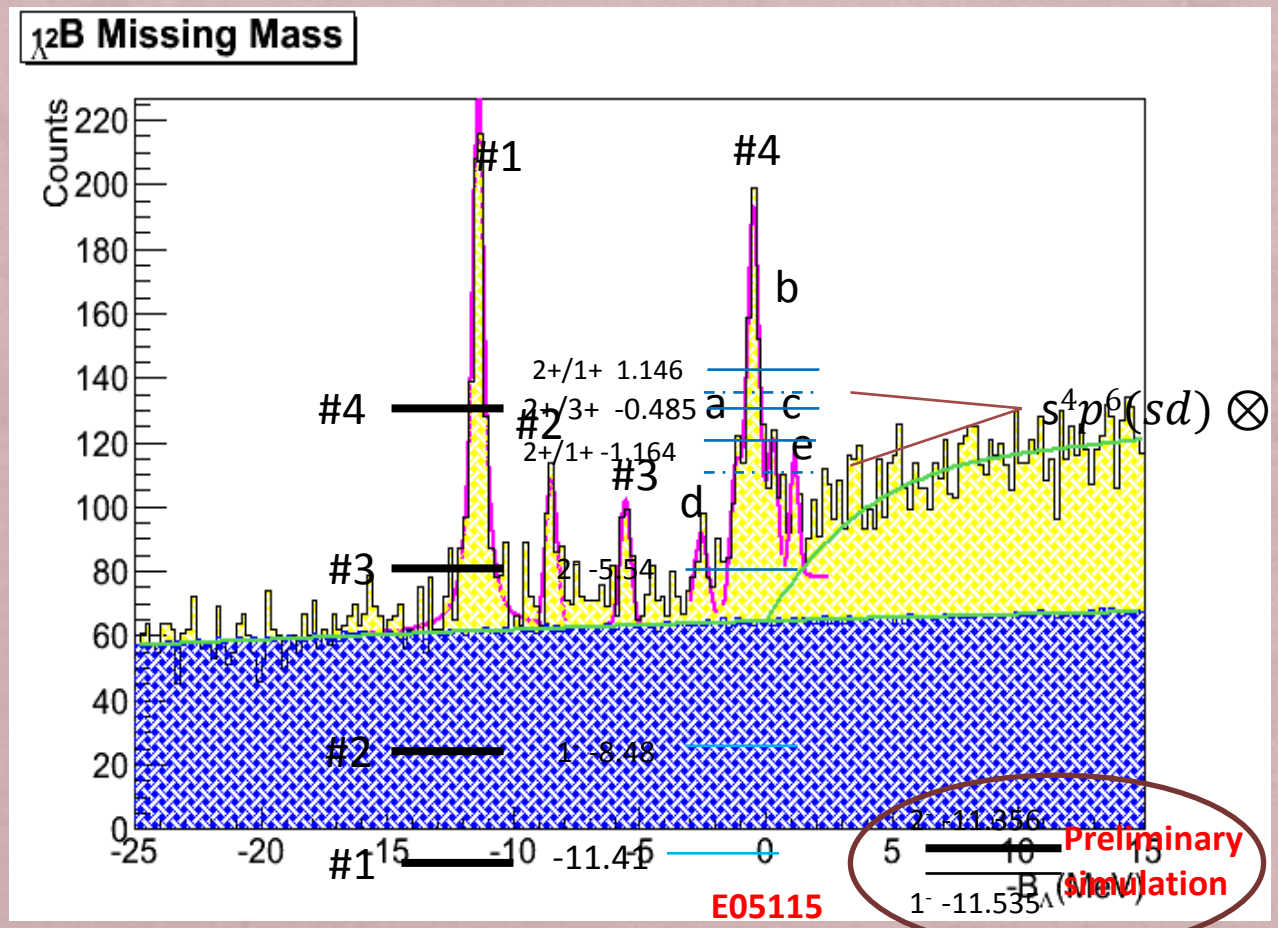
	c	0.295	
	d	-2.539	281
	e	1.146	234

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


$^{12}_{\Lambda}$B Missing Mass
Counts
#1
#4
b
2+/1+ 1.146
#4
2+/3+ -0.485
a
c
#2
2+/1+ -1.164
e
#3
d
#3
2- -5.54
#2
1- -8.48
#1
-11.41
2- -11.356
1- -11.535
Preliminary
Simulation
E05115
Fitting
$s^4p^6(sd) \otimes s_\Lambda$