Hypernuclear study from ^{27}Al (A=27)

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<u>Next hypernuclear experiments @JLab</u>

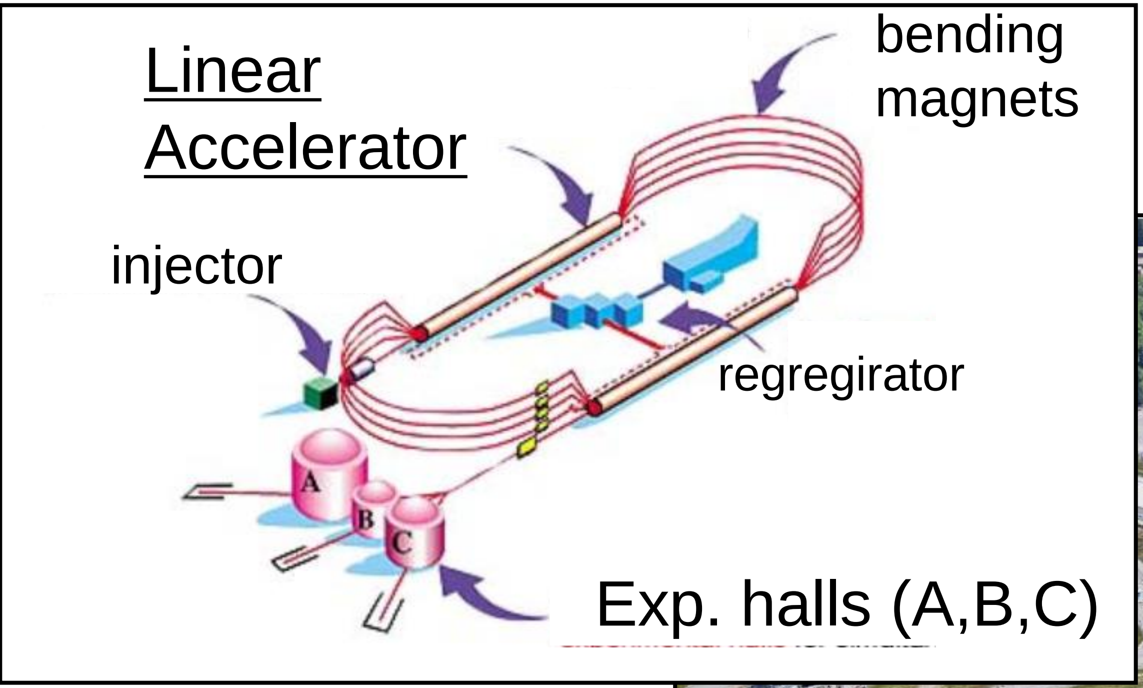
- A campaign of three experiments targeting light to heavy hypernuclei (E12-15-008, E12-20-013, E12-19-002)

- $^{27}Al(e,e'K^+)^{27}{}_{\Lambda}Mg$ reaction using ^{27}Al target (A=27) ←**this talk**!

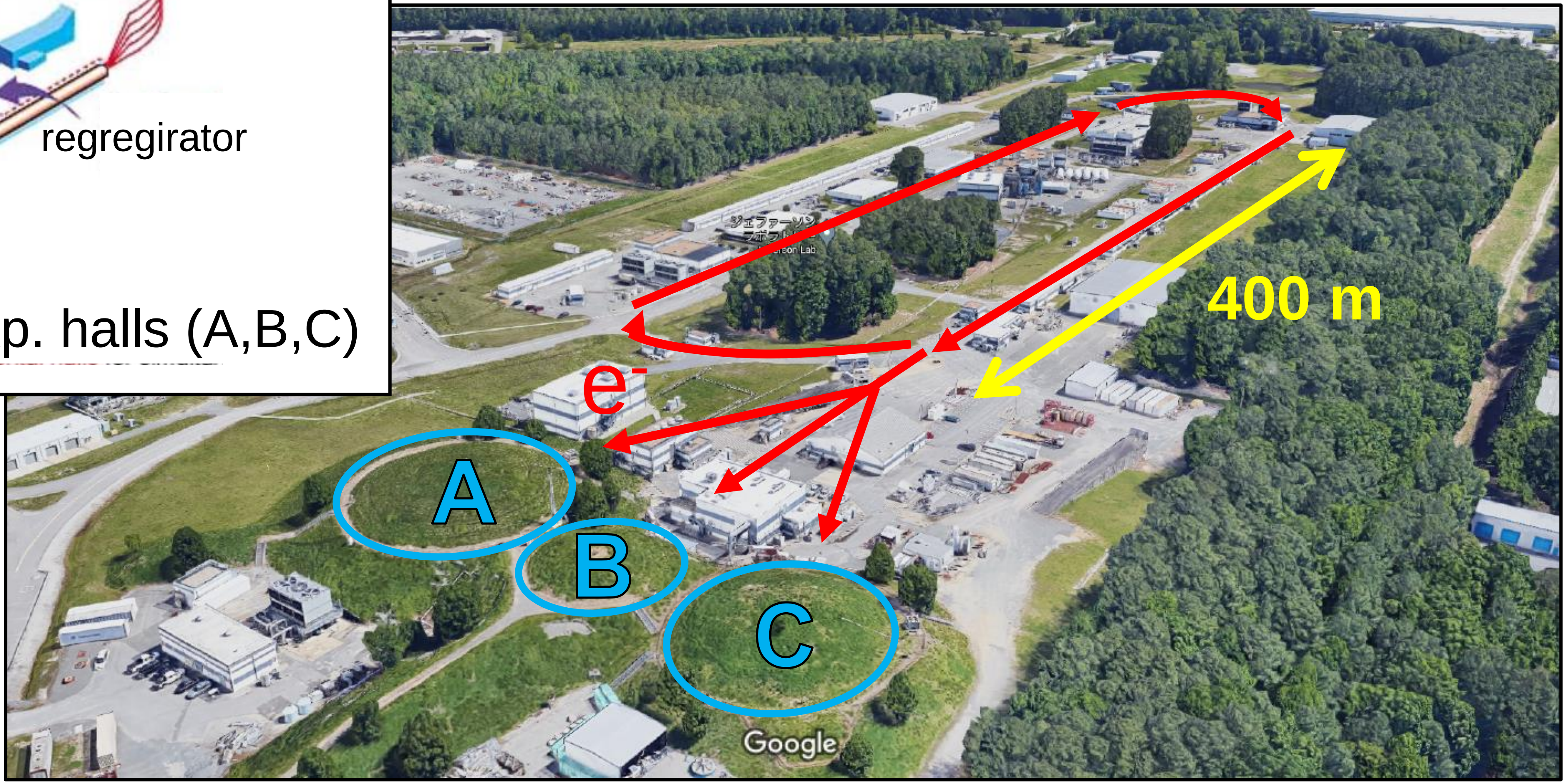
1. Brief Introduction of Our Experiments at JLab
2. Outline and Strategy of $^{27}{}_{\Lambda}Mg$ Mass Spectroscopy
3. Physics Motivation: Triaxial Deformation
4. Expectations (yield, spectrum)

Next Experiments at JLab

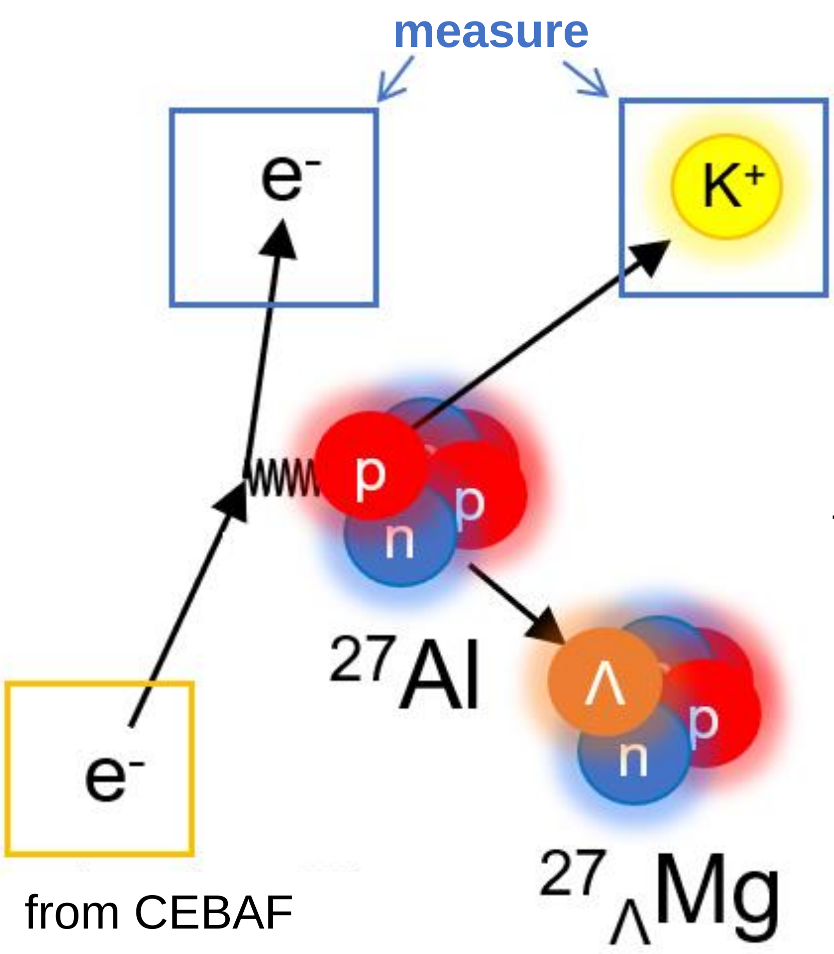
Jefferson Lab (JLab)



Continuous Electron Beam Accelerator Facility (CEBAF)



^{27}Al(e,e'K^{+})$^{27}{}_{\Lambda}$Mg reaction at JLab



spectrometers	Hall-A	Hall-C
for scattered electrons :	HRS	HES
for produced kaons :	HKS	HKS

⇨ K. Okuyama "*Experimental performance study by Geant4 for Hall C option*" (Dec. 8, 2021)

Missing Mass

$$M({}^{27}_{\Lambda}\mathrm{Mg}) = \sqrt{\{(E_{\mathrm{e}} - E_{\mathrm{e'}}) + M({}^{27}\mathrm{Al}) - E_{\mathrm{K}}\}^2 - \{(\boldsymbol{P}_{\mathrm{e}} - \boldsymbol{P}_{\mathrm{e'}}) - \boldsymbol{P}_{\mathrm{K}}\}^2}$$

$$-B_{\Lambda} = M({}^{27}_{\Lambda}\mathrm{Mg}) - M_{\Lambda} - M({}^{26}\mathrm{Mg})$$

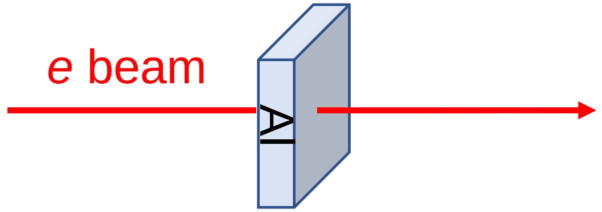
high-resolution
$^{27}{}_{\Lambda}$Mg mass spectroscopy

Outline and Strategy

1 PAC day = 2 days

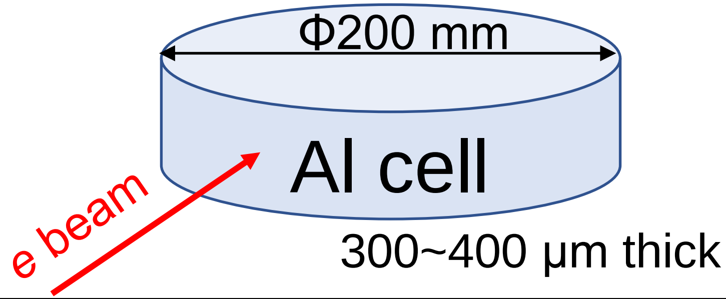
Exp. No.	Beamtime [PAC days]	Target
E12-15-008 *approved*	28	CH_2, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{12}C, **^{27}Al**, **^{40}Ca**, **^{48}Ca**
E12-20-013 *approved*	20	**^{208}Pb**
E12-19-002 *approved*	14.5	^{12}C, **H_2(gas)**, **$^{3,4}He$(gas)**, **^{27}Al(cell)**

There are two chances to take data using Aluminum target



1) E12-15-008 → ***high quality***
   *We plan to use Al target as a calibration source
   *Beamtime for the calibration is limited
   *Data taking with a suitable condition (thickness etc.)

2) E12-19-002 → ***high statistics***
   *Al cell will be used to seal the gas targets
   *The position of the Al cell deviates from the center of acceptance



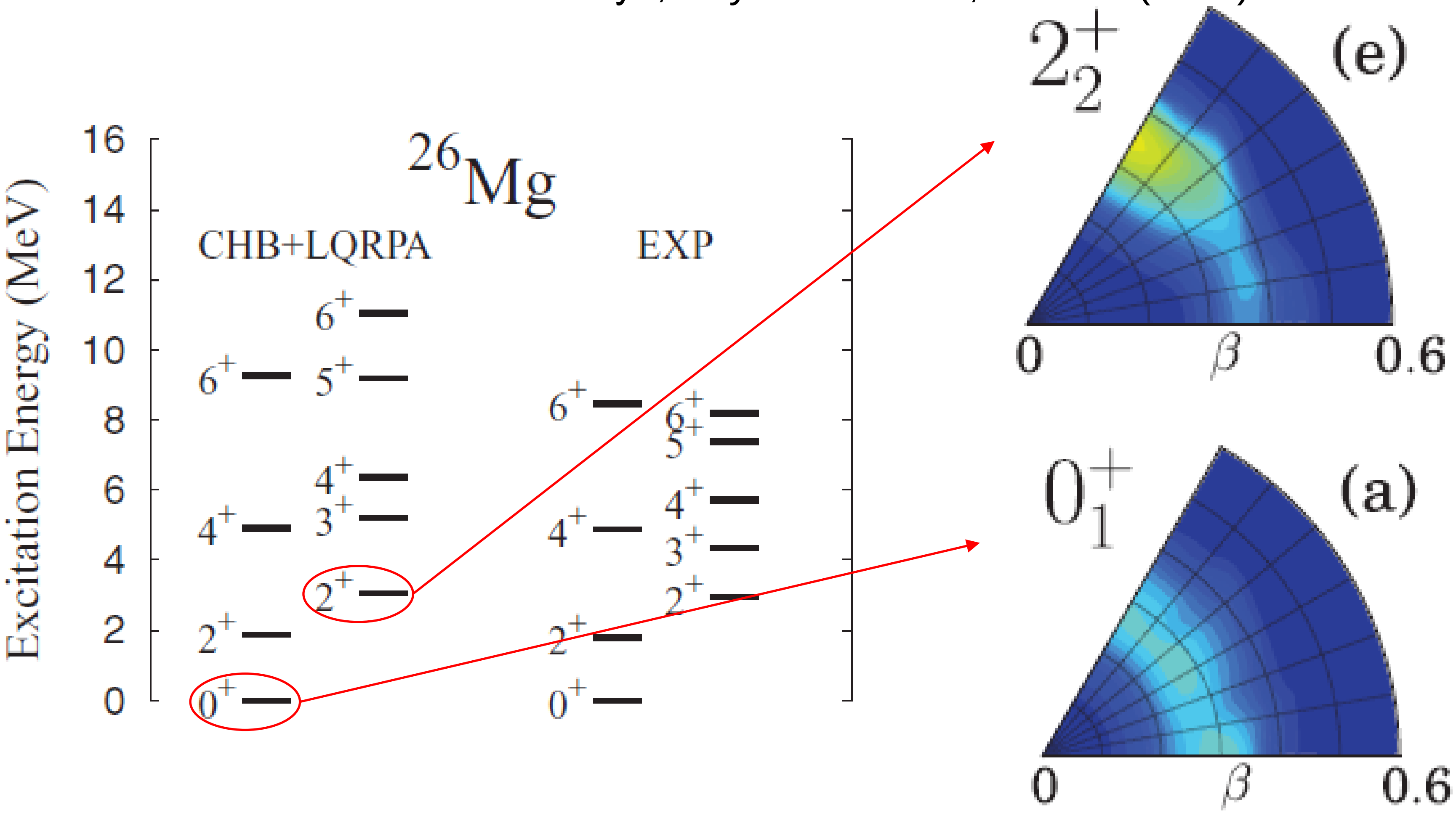
Motivation: triaxial deformation

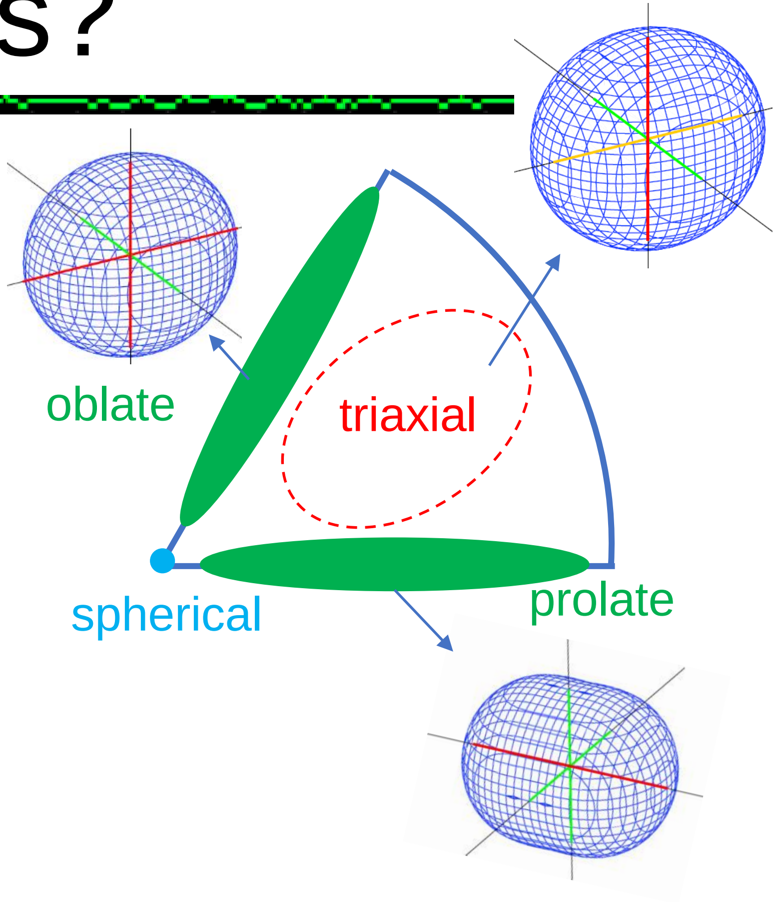
^{26}Mg is a candidate of triaxial deformed nucleus

What if a Λ couples to the deformed nucleus? → $^{27}_{\Lambda}$Mg

^{26}Mg: triaxial deformed nucleus?

N. Hinohara and Y. Kanada-En'yo, Phys. Rev. C **83**, 014321 (2011).



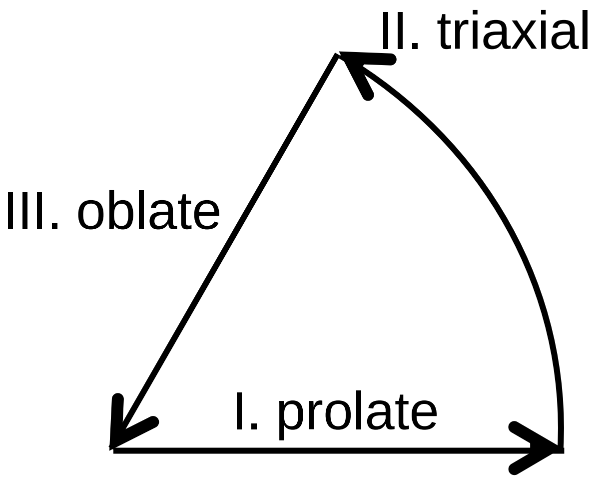


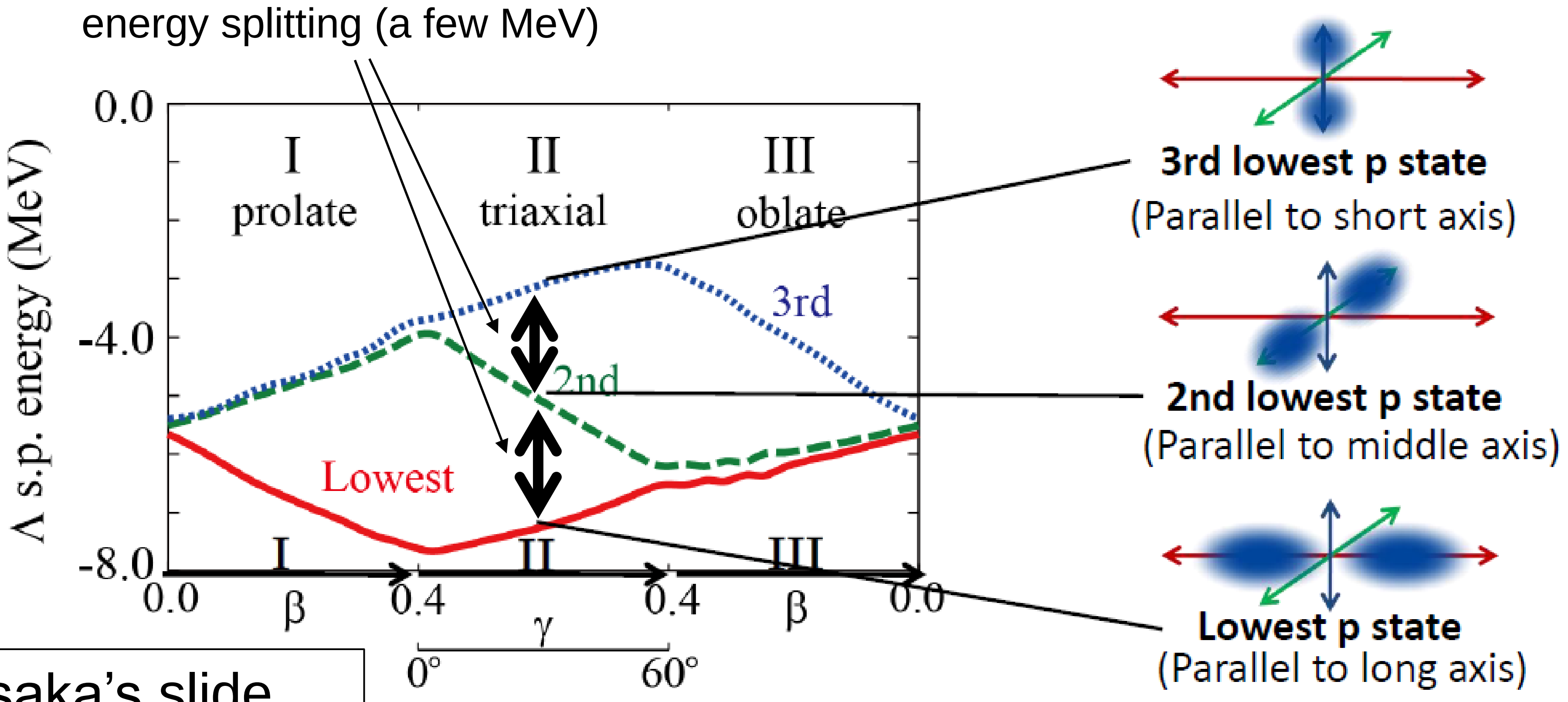
γ soft character
→triaxial deformation(?)

vibrational w.f. squared: $\beta^4|\Phi_{\alpha I}(\beta,\gamma)|^2$

^{26}Mg (triaxial deformed?) ⊗ Λ ⇒ $^{27}{}_{\Lambda}$Mg

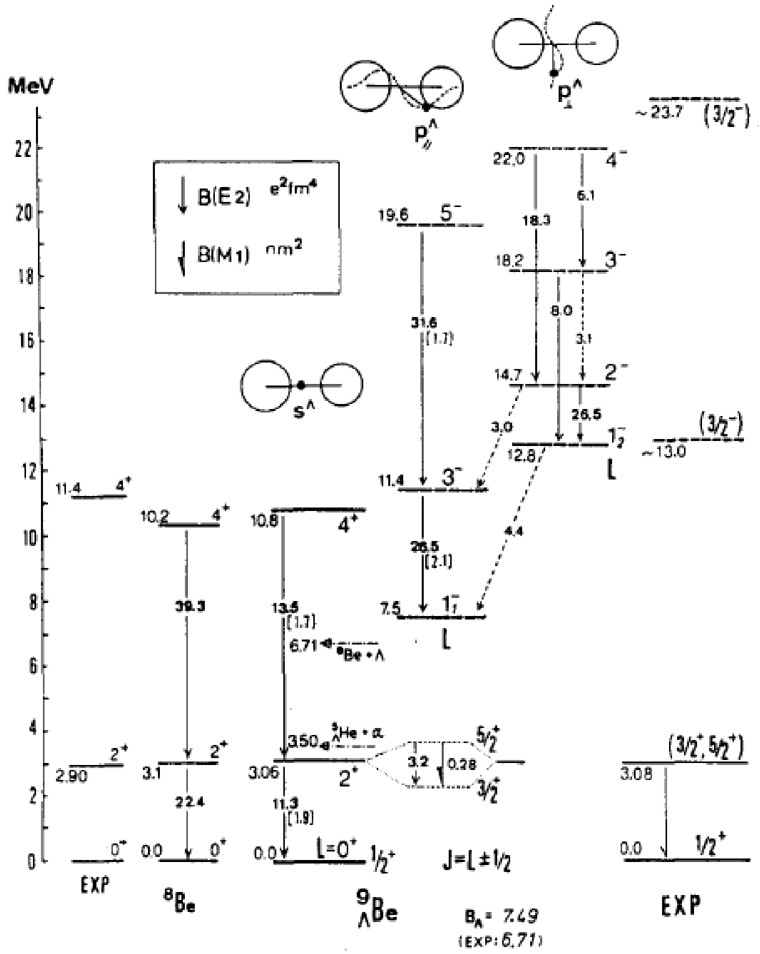
if Λ couples to a deformed nucleus
→**p-orbit splitting** can be an observable.



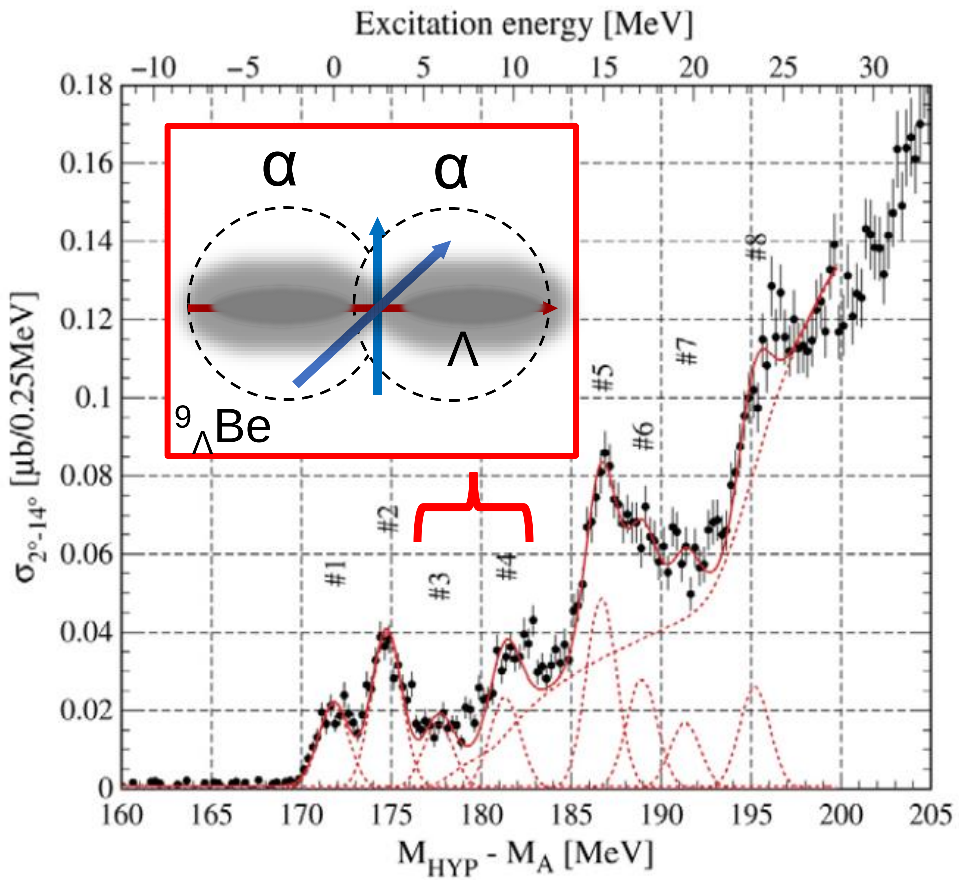


Quoted from Dr. M. Isaka's slide
M. Isaka *et al*. Phys. Rev. C **94**, 044310 (2016).

cf.) Precedent in p-shell hypernucleus

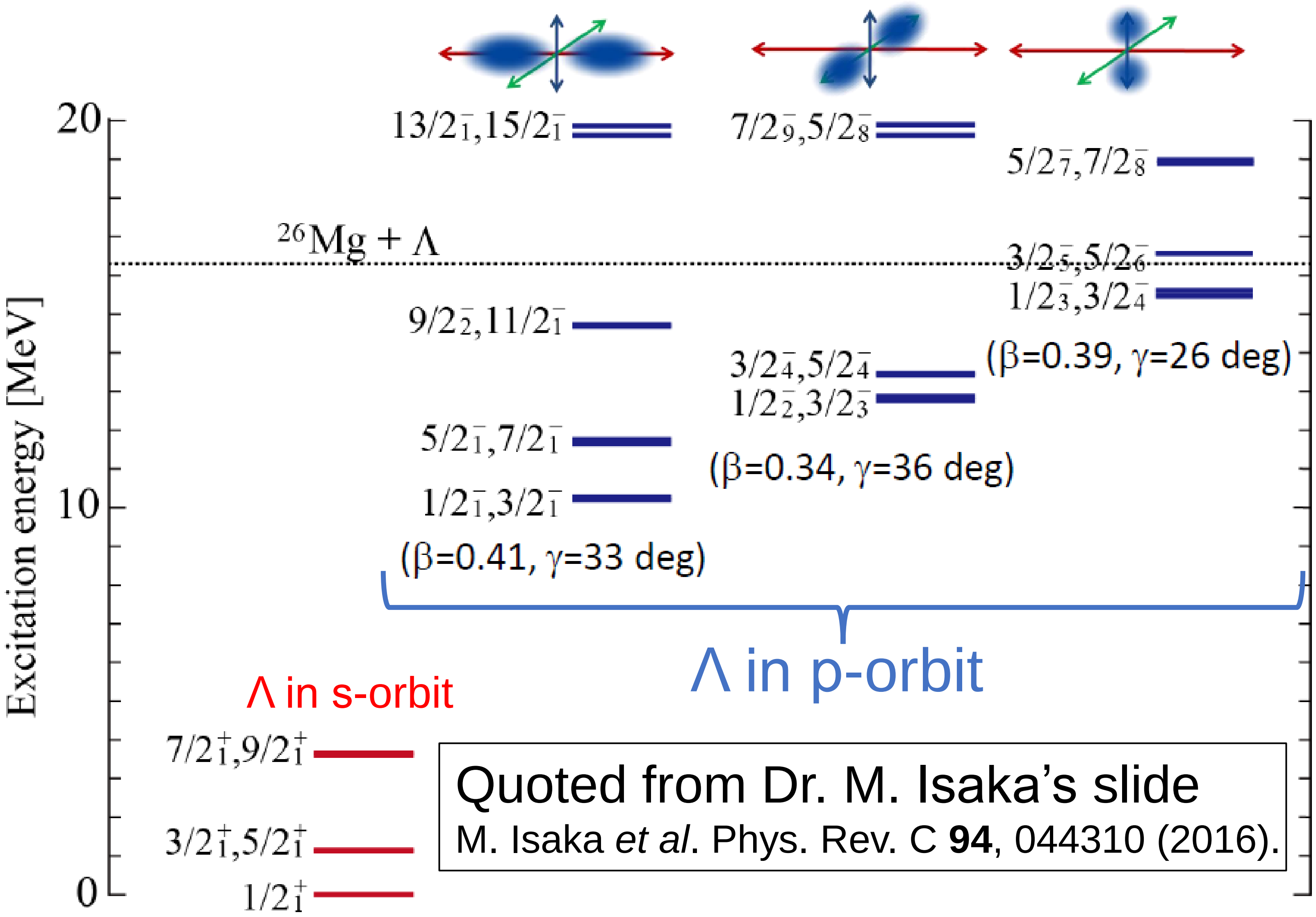


Λ doesn't suffer from Pauli blocking
→ accessible inside nucleus as a probe
(cf. $^{9}_{\Lambda}$Be: genuine hypernuclear states (H. Bando))



O. Hashimoto and H. Tamura, Prog. Part. Nucl. Phys. 57 (2006) 564–653.
H. Bando, Nucl. Phys. A450 (1986) 217c.
O. Hashimoto et al., Nucl. Phys. A639 (1998) 93c-102c.

$^{27}_{\Lambda}$Mg energy level by HyperAMD



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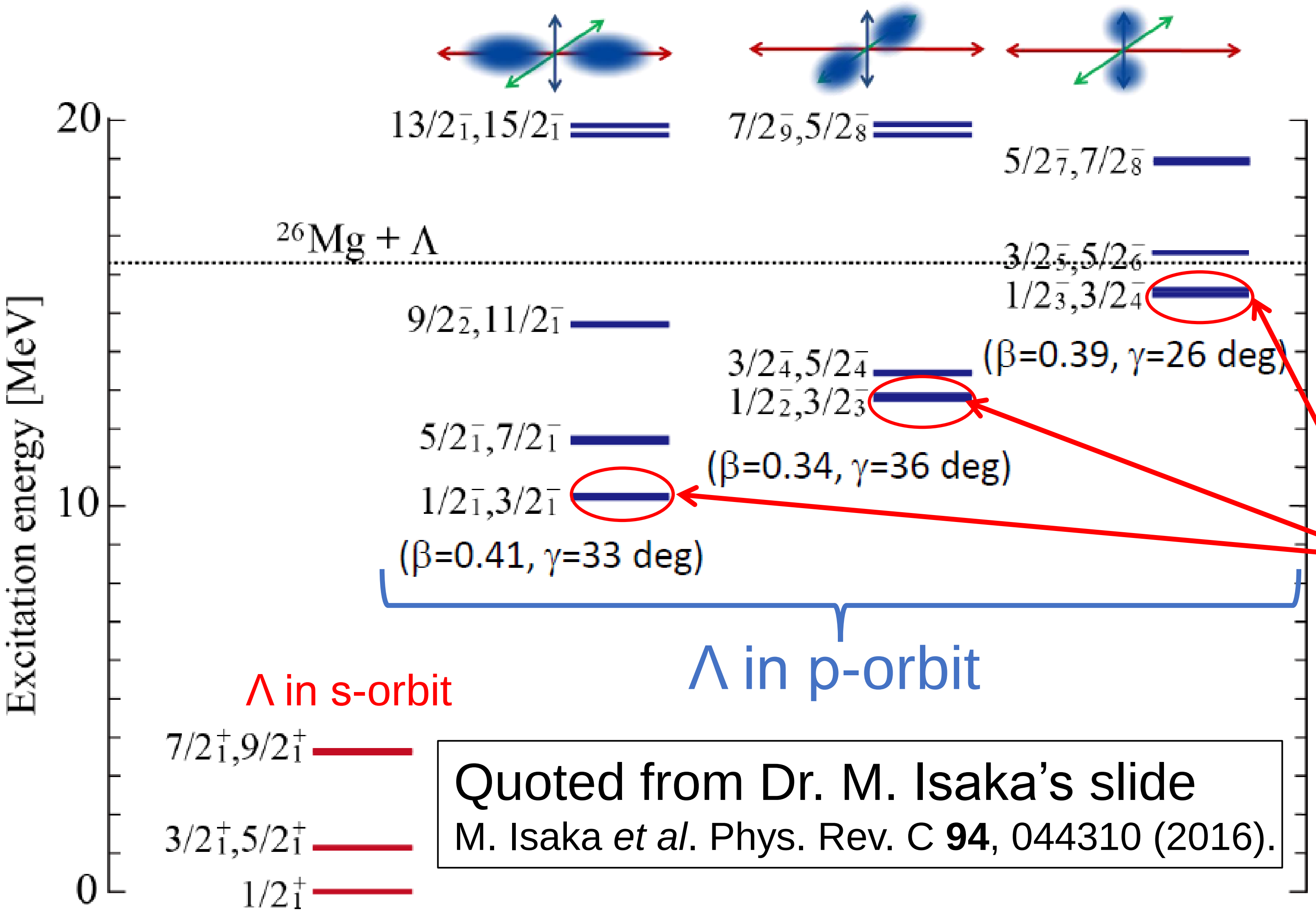
three different K^{π} bands appears because of the core deformation.

but, we don't know which states are enhanced.
(CS calc. will be done in future)

$^{27}{}_{\Lambda}$Mg energy level by HyperAMD



Quoted from Dr. M. Isaka's slide
M. Isaka *et al*. Phys. Rev. C **94**, 044310 (2016).

three different K^{π} bands appears because of the core deformation.

but, we don't know which states are enhanced.
(CS calc. will be done in future)

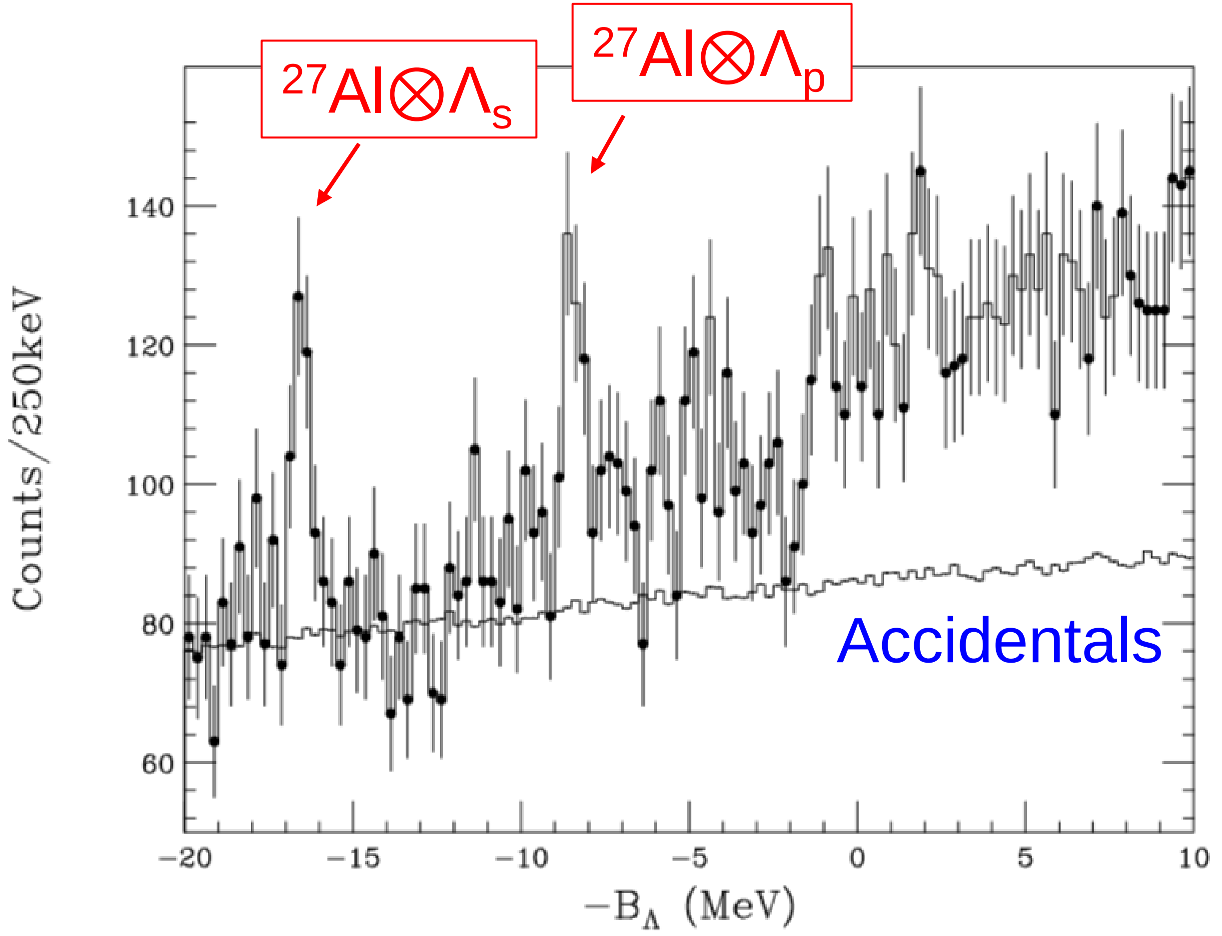
[assumption]
1. lowest states of bands are enhanced dominantly.
2. $d\sigma/d\Omega$ is similar to ^{28}Si(e,e'K$^+$)$^{28}{}_{\Lambda}$Al data taken at JLab in 2005.

Expectations

based on our past experiment: $^{28}Si(e,e'K^+)^{28}_{\Lambda}Al$ in E01-011 at JLab

E01-011 data at JLab in 2005

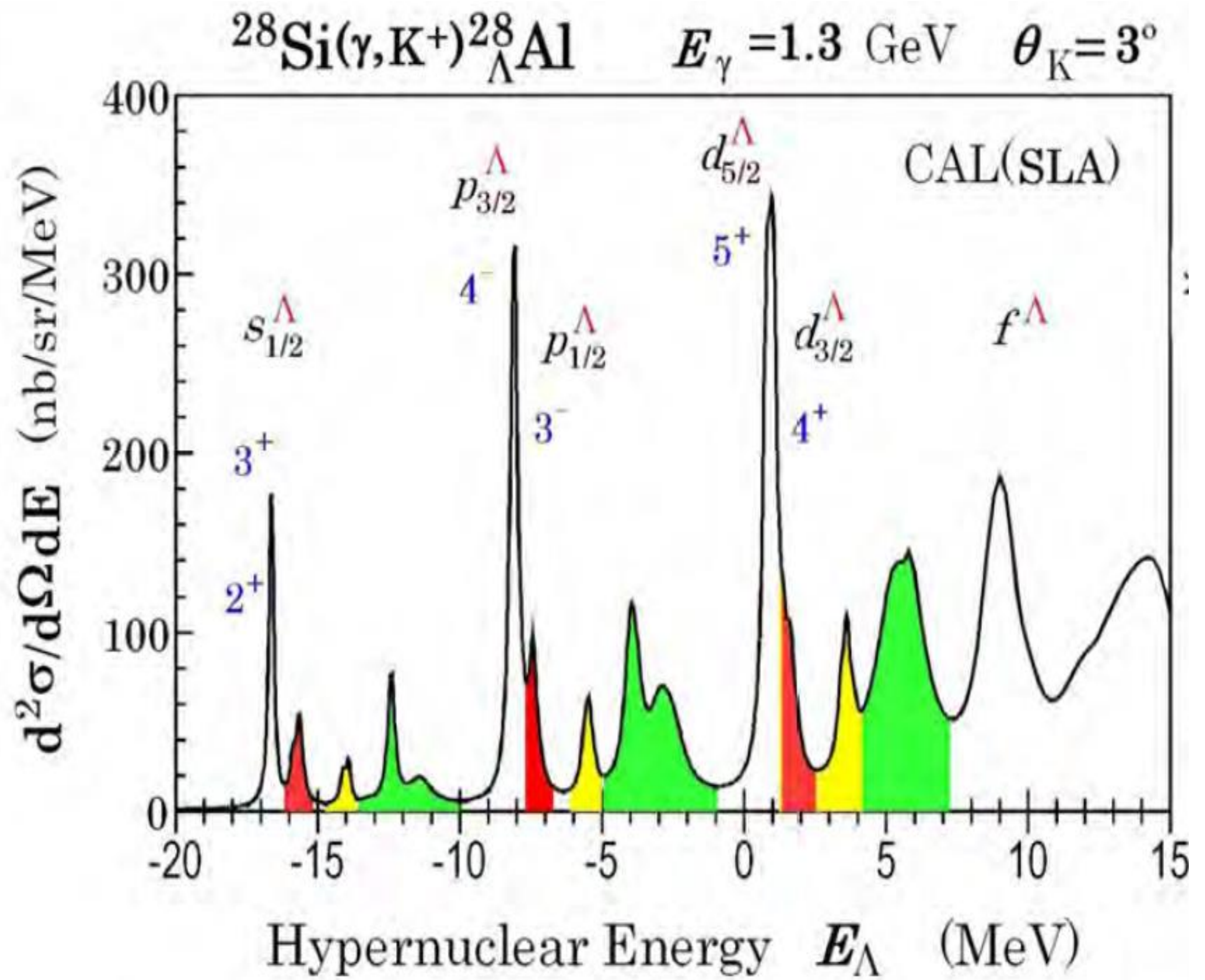
S.N. Nakamura *et al*., Proc. 12th Int. Conf. on Hypernuclear and Strange Particle Physics (HYP2015)

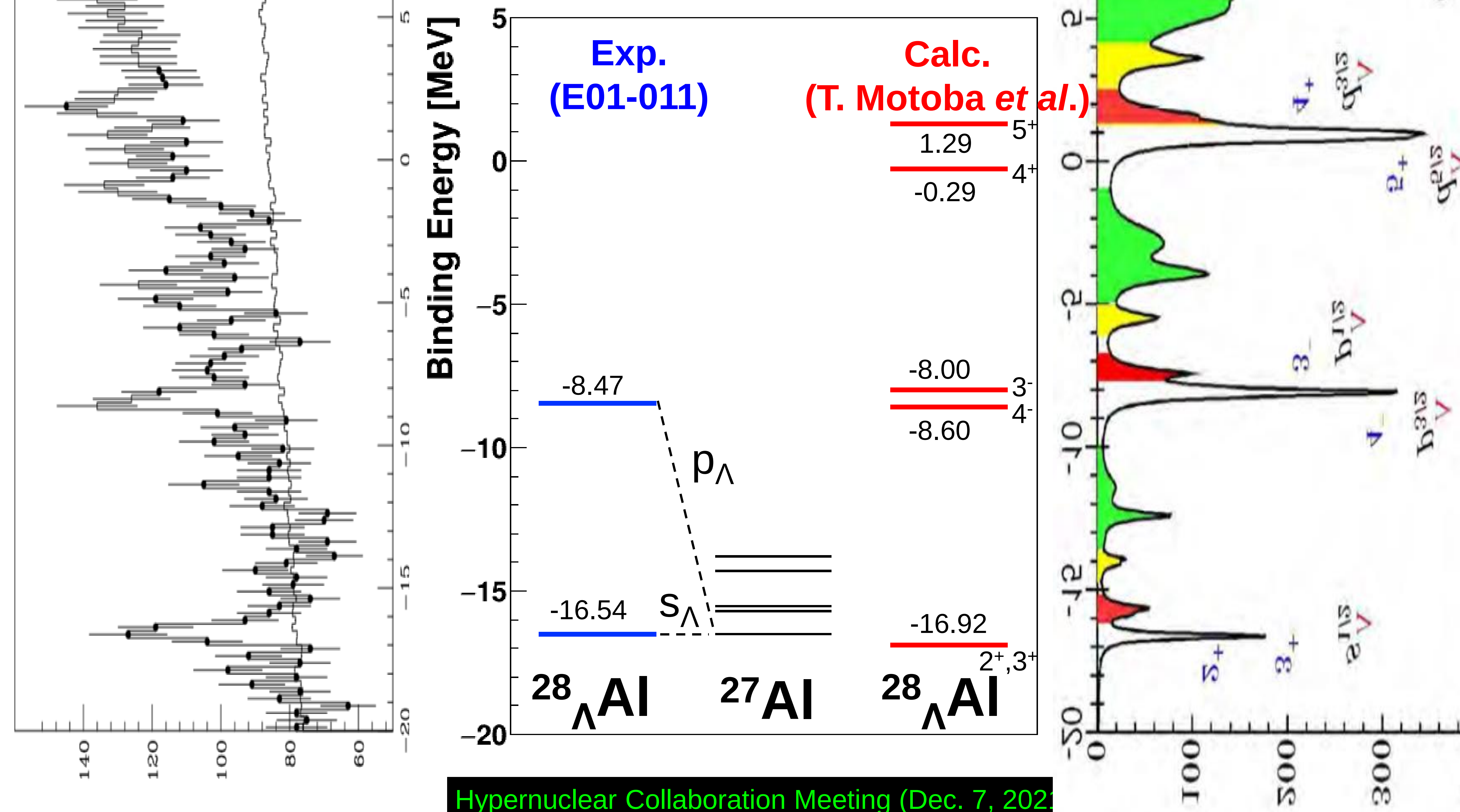


Ee=1.851 GeV, pe' = 0.351 GeV/*c*, pK = 1.2 GeV/*c*

Shell model calc. with DWIA

T. Motoba *et al*., Sendai2008,
Strangeness in nuclear and hadronic system, p178





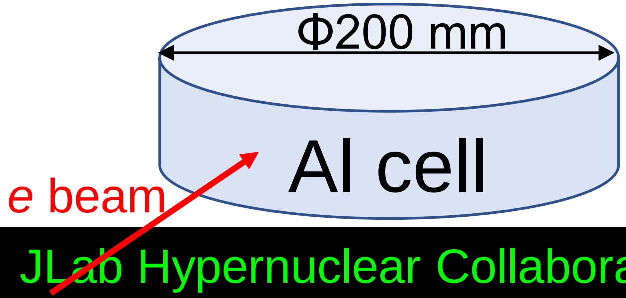
Exp.
(E01-011)
Calc.
(T. Motoba et al.)
Binding Energy [MeV]
-8.47
-16.54
p_Λ
s_Λ
5^+
1.29
4^+
-0.29
-8.00
3^-
4^-
-8.60
-16.92
$2^+,3^+$
$^{28}_{\Lambda}Al$
^{27}Al
$^{28}_{\Lambda}Al$

Yield Estimation (*Hall-A option*)

$$\text{Yield} = N_{\gamma^*} \times N_{\text{t}} \times \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega_{\text{K}}}\right) \times \Delta\Omega_{\text{K}} \times \varepsilon$$

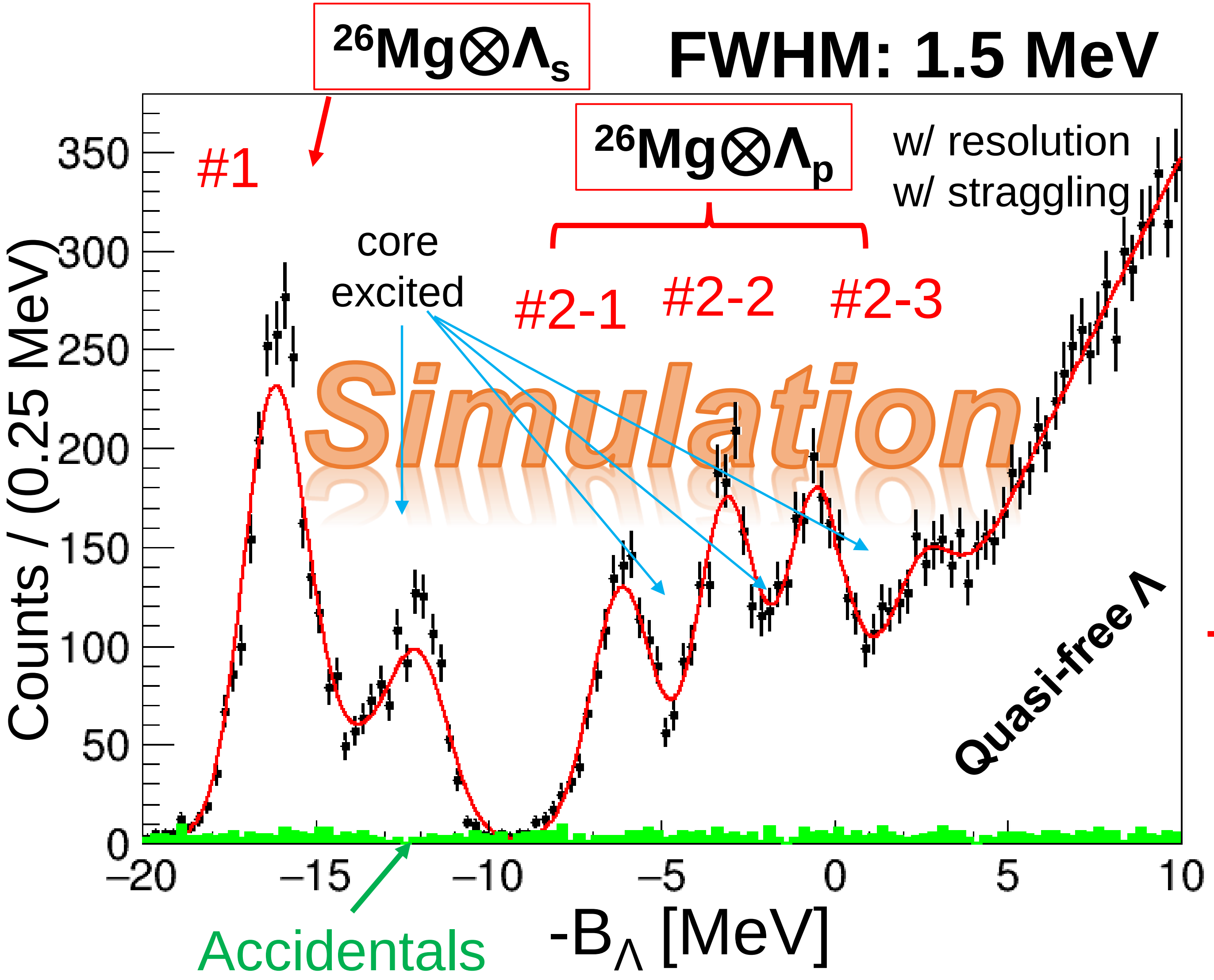
$\Delta\Omega_K$ = 4.94 [msr]
${}^{int}\Gamma = 2.40\times10^{-5}$ [/electron]
ε = 0.3×0.5 (decay & analysis cut)

Reaction	Beam Current [μA]	Target Thickness [mg/cm^2]	$\left(\frac{d\sigma}{d\Omega}\right)^{lab}_{expected}$ [nb/sr]	Yield [/day]
^{12}C→$^{12}_{\Lambda}$B (g.s.)	20	100	100	109
^{27}Al→^{26}Mg⊗Λ_s	20	100	66	32
^{27}Al→^{26}Mg⊗Λ_p		**Al → 370 μm**	104	51

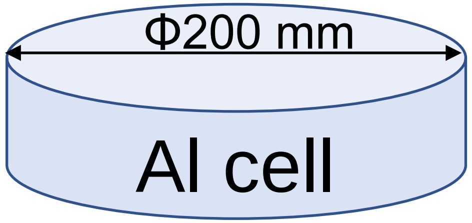


E01-011: ^{28}Si(e,e'K$^+$)$^{28}_{\Lambda}$Al
※Ratio of outermost proton: 5/6

$^{27}Al(e,e'K^+)^{27}_{\Lambda}Mg$: Expected Spectrum at Hall-A



- 12 PAC days for He+Al (E12-19-002)
- ^{27}Al cell: 0.37 mm thick



Simulation input from HyperAMD

#1 B_Λ = 16.3 MeV : $^{26}Mg\otimes\Lambda_s$

#2-1 B_Λ = 6.3 MeV : $^{26}Mg\otimes\Lambda_p^{1st}$

#2-2 B_Λ = 3.3 MeV : $^{26}Mg\otimes\Lambda_p^{2nd}$

#2-3 B_Λ = 0.8 MeV : $^{26}Mg\otimes\Lambda_p^{3rd}$

p-orbit splitting due to the triaxial deformation

ΔB_Λ (stat.) = 20 keV

Summary & Outlook

- $^{27}Al(e,e'K^{+})^{27}_{\Lambda}Mg$ spectroscopy in the next experiment at JLab
- ^{26}Mg is a candidate of triaxial deformed nucleus
- Λ as a probe which is accessible inside nucleus

→ $^{27}_{\Lambda}Mg$: p-orbit splitting depending on the deformation of the core nucleus

Unique approach to a triaxial deformed nucleus
from hypernuclear experiments!

- Our experiments will be performed at JLab
- Experimental performance at Hall-C will be shown tomorrow

K. Okuyama "*Experimental performance study by Geant4 for Hall C option*" (Dec. 8)

- Theoretical support is necessary, and it's now ongoing
  (core excited states, cross section of each state)