PR12-24-011

Study of triaxially deformed nucleus using a Lambda particle as a probe

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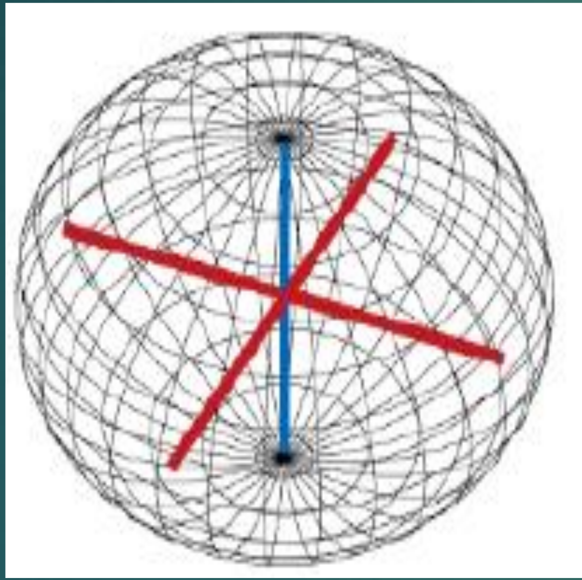
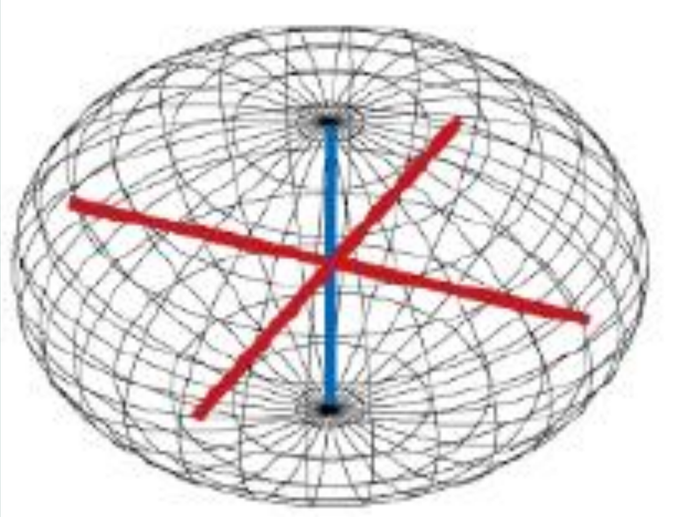
JLab Hypernuclear Collaboration

Nucleus

High density quantum many-body system



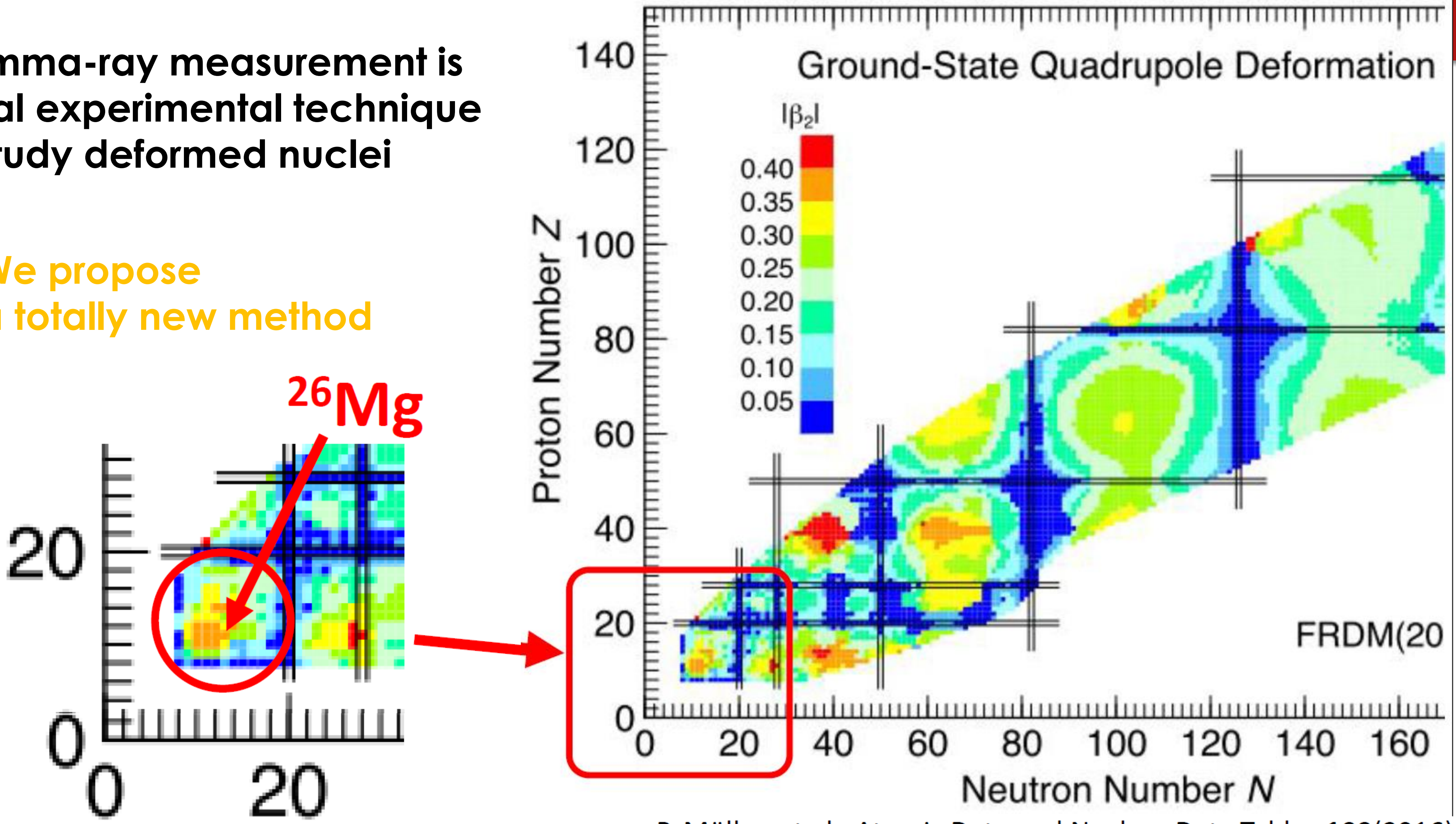


Extremely dense, but its shape can be changed with a relatively small energy.

Deformed nuclei are not special.

Gamma-ray measurement is usual experimental technique to study deformed nuclei

We propose a totally new method

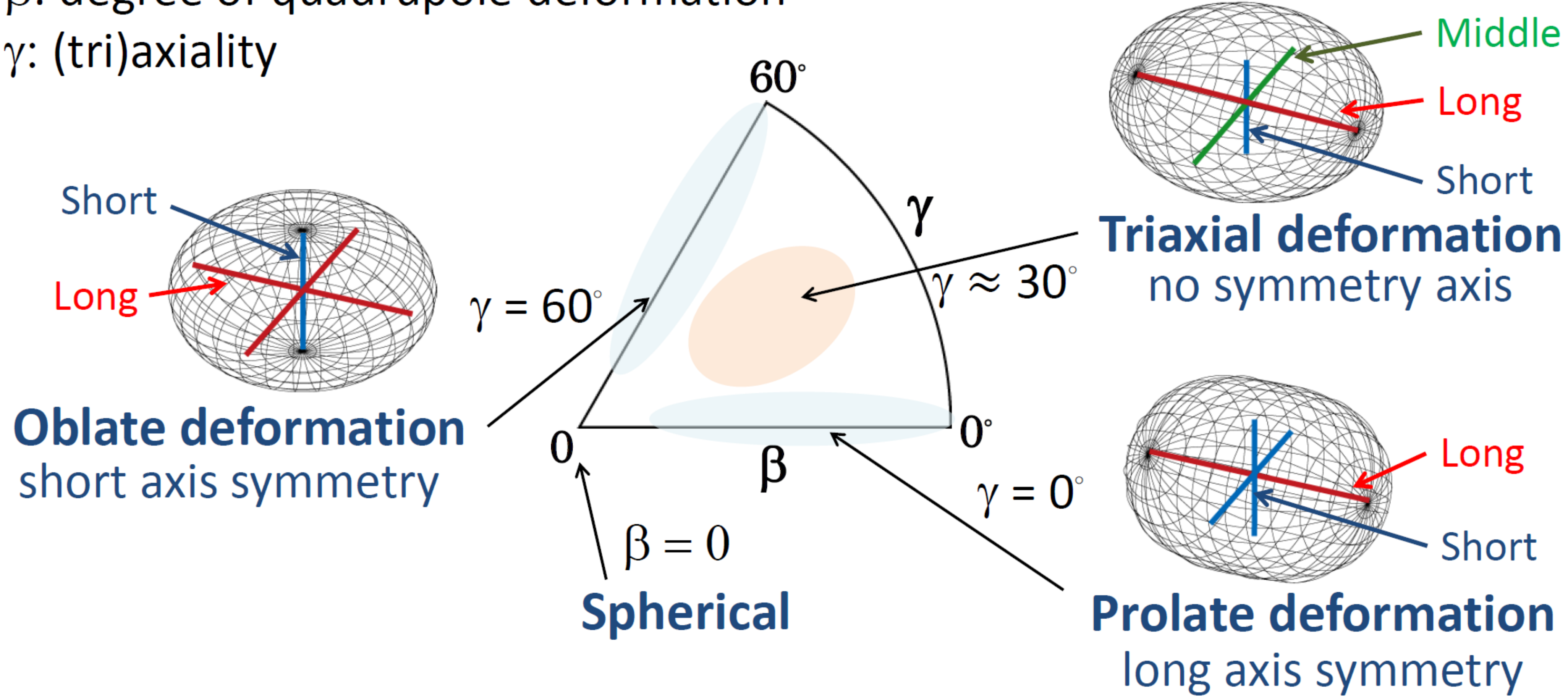


P. Möller, et al., Atomic Data and Nuclear Data Tables **109**(2016)

Parameters to describe deformation

Nuclear quadrupole deformation (β,γ)

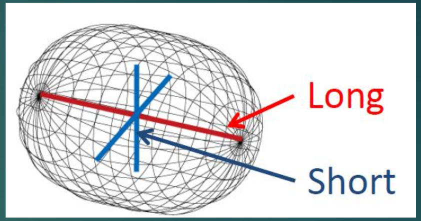
- β: degree of quadrupole deformation
- γ: (tri)axiality



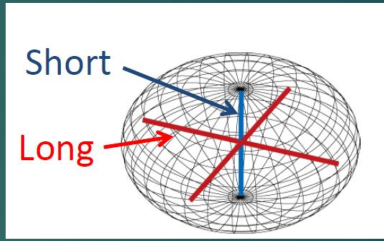
M.Isaka, Hypernuclear Physics Workshop 2023 at JLab

^{26}Mg is interesting candidate for triaxially deformed nucleus

Proton Z=12 Prolate



Neutron N=14 Oblate

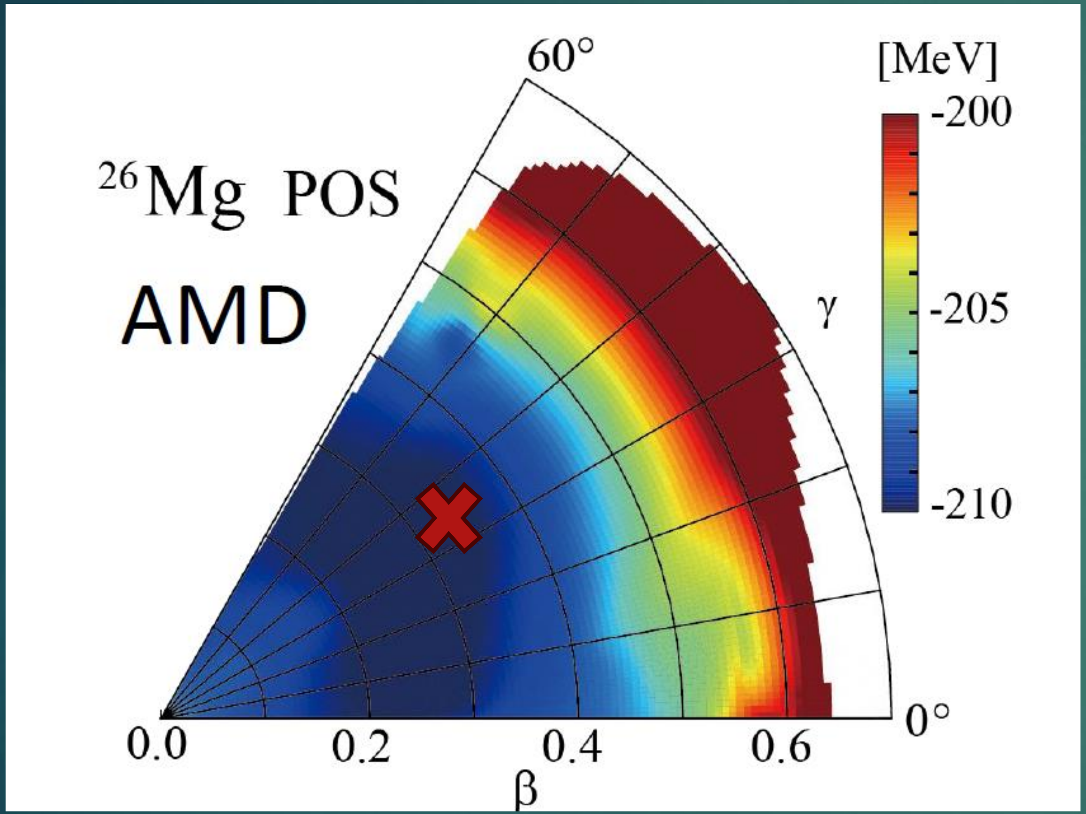


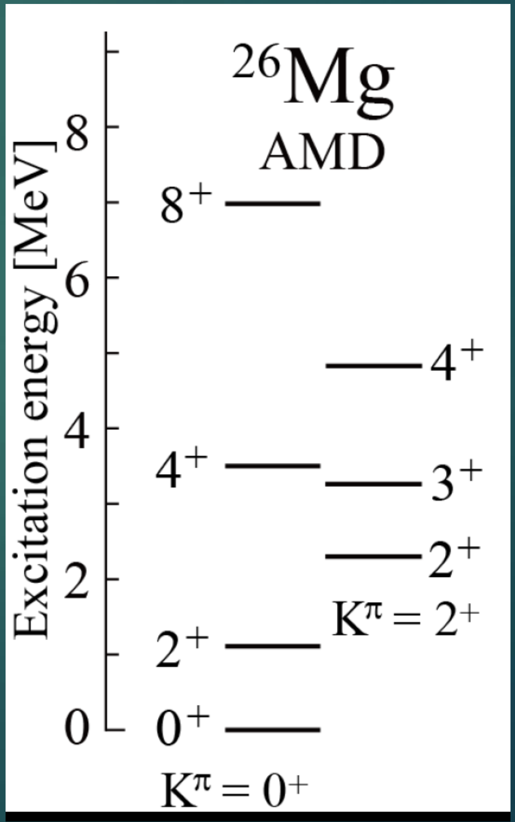
Co-existence of different deformations

Terasaki et al. NPA**621**(1997)
Rodrıguez-Guzman et al. NPA**709** (2002)
Peru et al PRC**77** (2008)
Hinohara, Kanada-En'yo PRC**83** (2011)

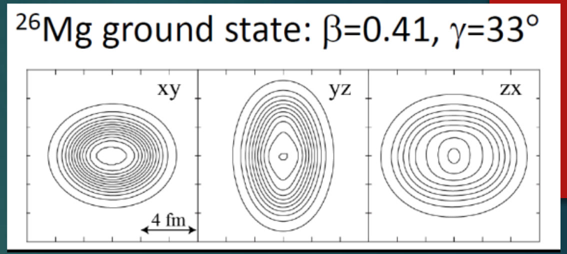
Recent theoretical calculation

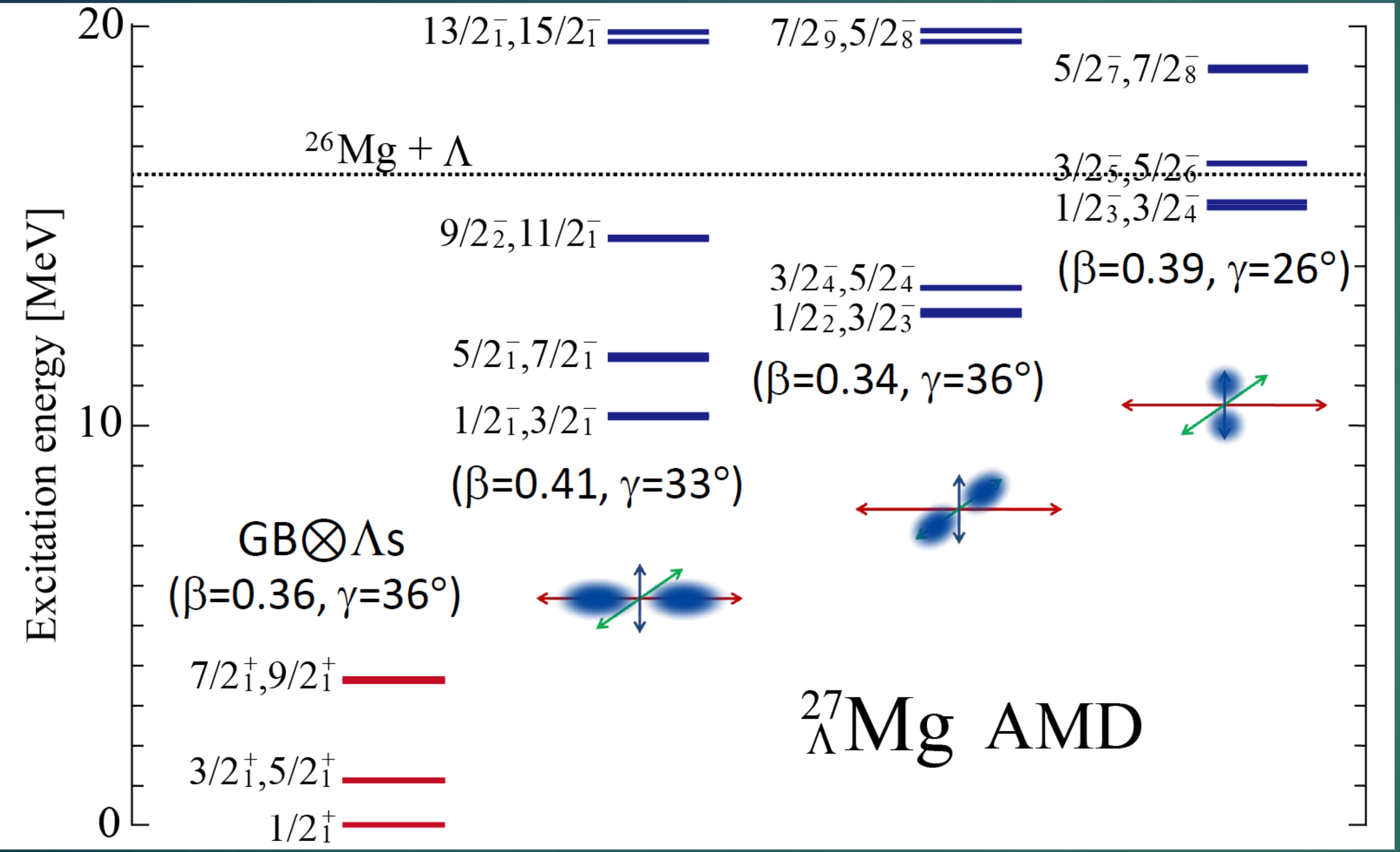
(Hyper)
Anti-symmetrized Molecular Dynamics
M. Isaka et al. PRC 83 (2011) 044323.
PRC 83 (2011) 054304.





Adding a Λ particle



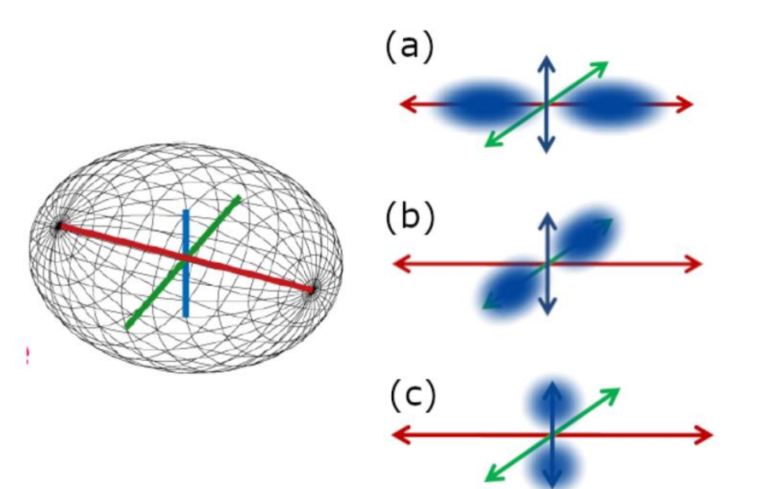


ΛN interaction is attractive

WF of Λ in p-orbit is straight

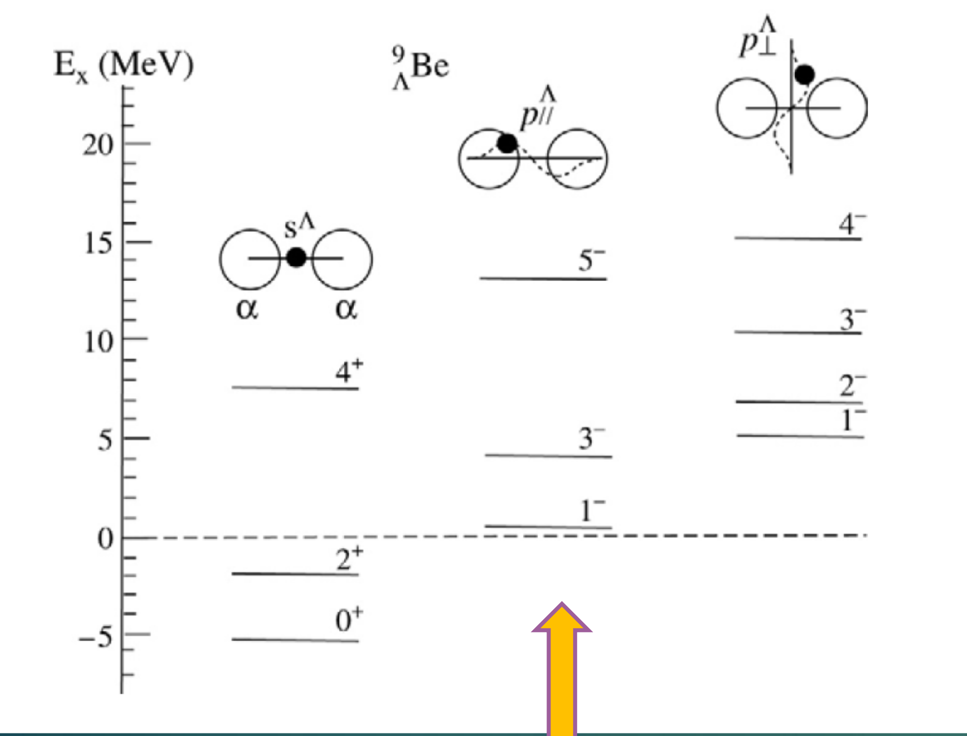
Overlap between Λ and ^{26}Mg core depends on axis direction

$^{26}\mathrm{Mg} \otimes \Lambda(p)$ splits in 3 states

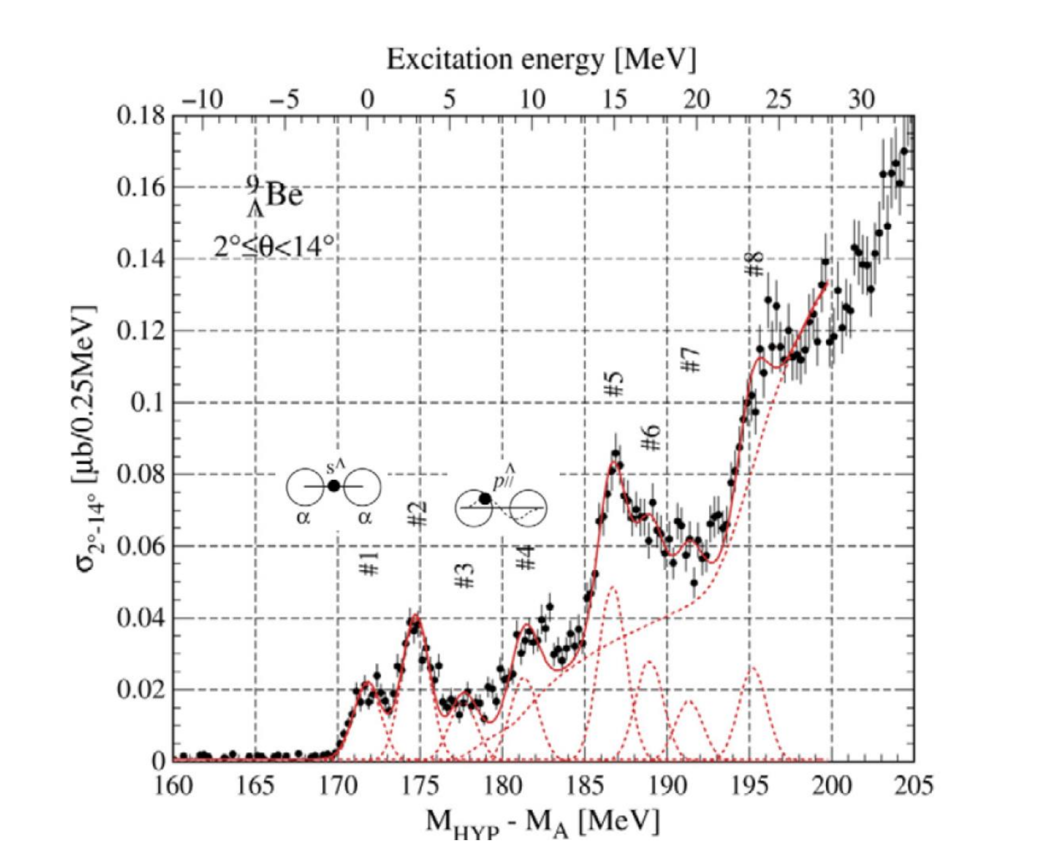


M.Isaka, Hypernuclear Physics Workshop 2023 at JLab

Genuine hypernuclear state : ${}^{9}_{\Lambda}\mathrm{Be}$



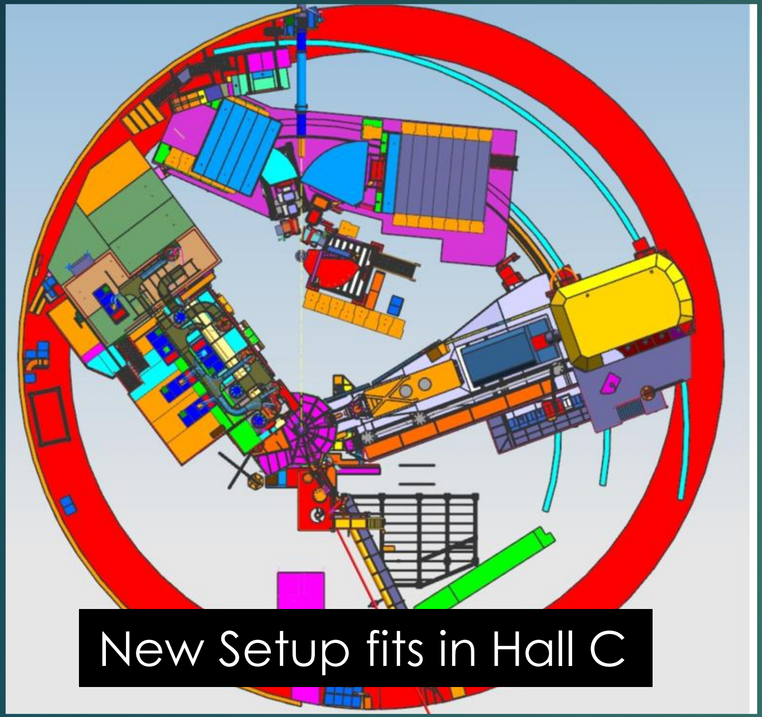
Impossible for normal nucleus due to Pauli blocking

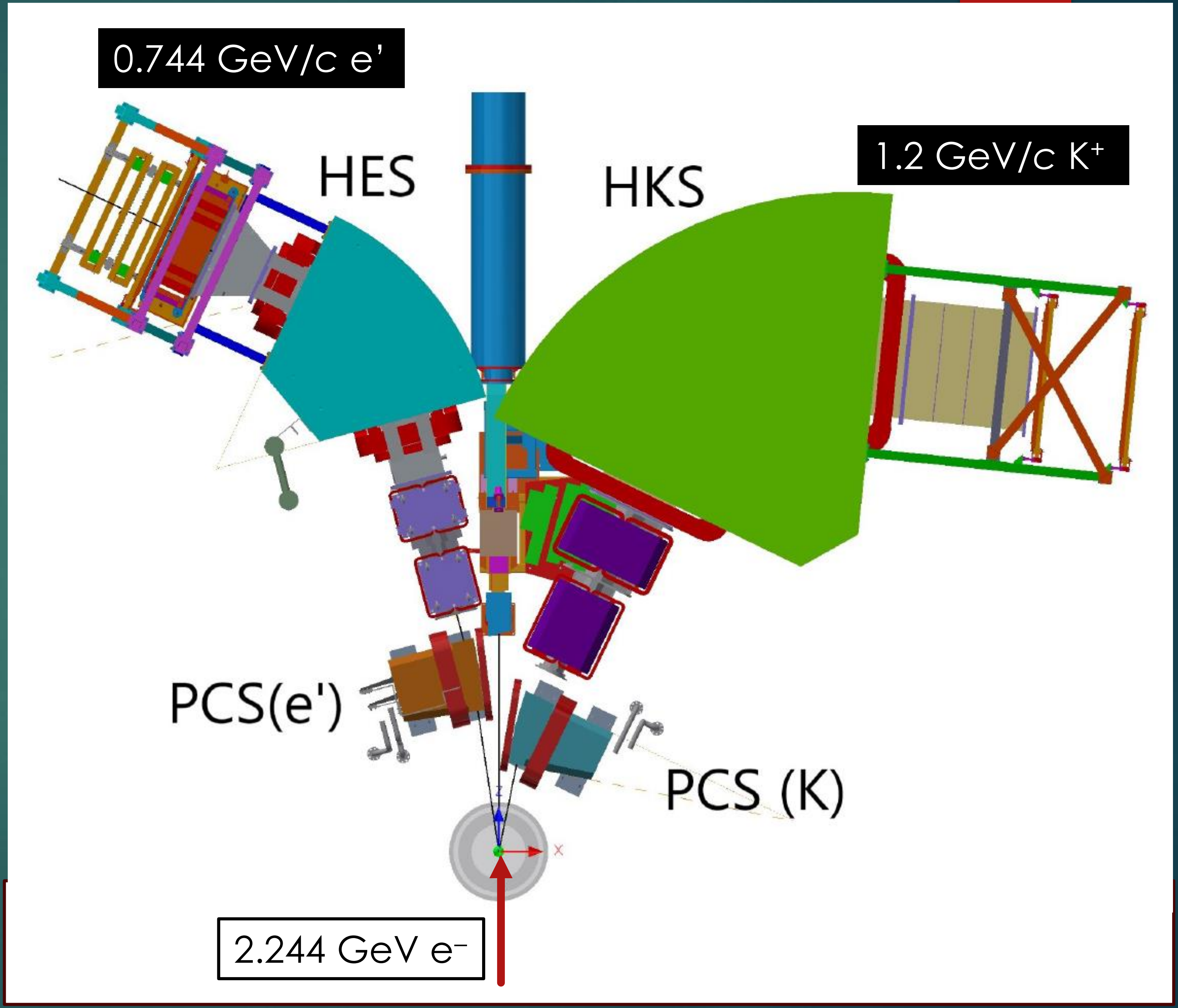


Energy spectrum obtained by the (π^+, K^+) reaction at KEK-PS

O. Hashimoto and H. Tamura, Prog. Part. and Nucl. Phys. **57** 564 (2006)

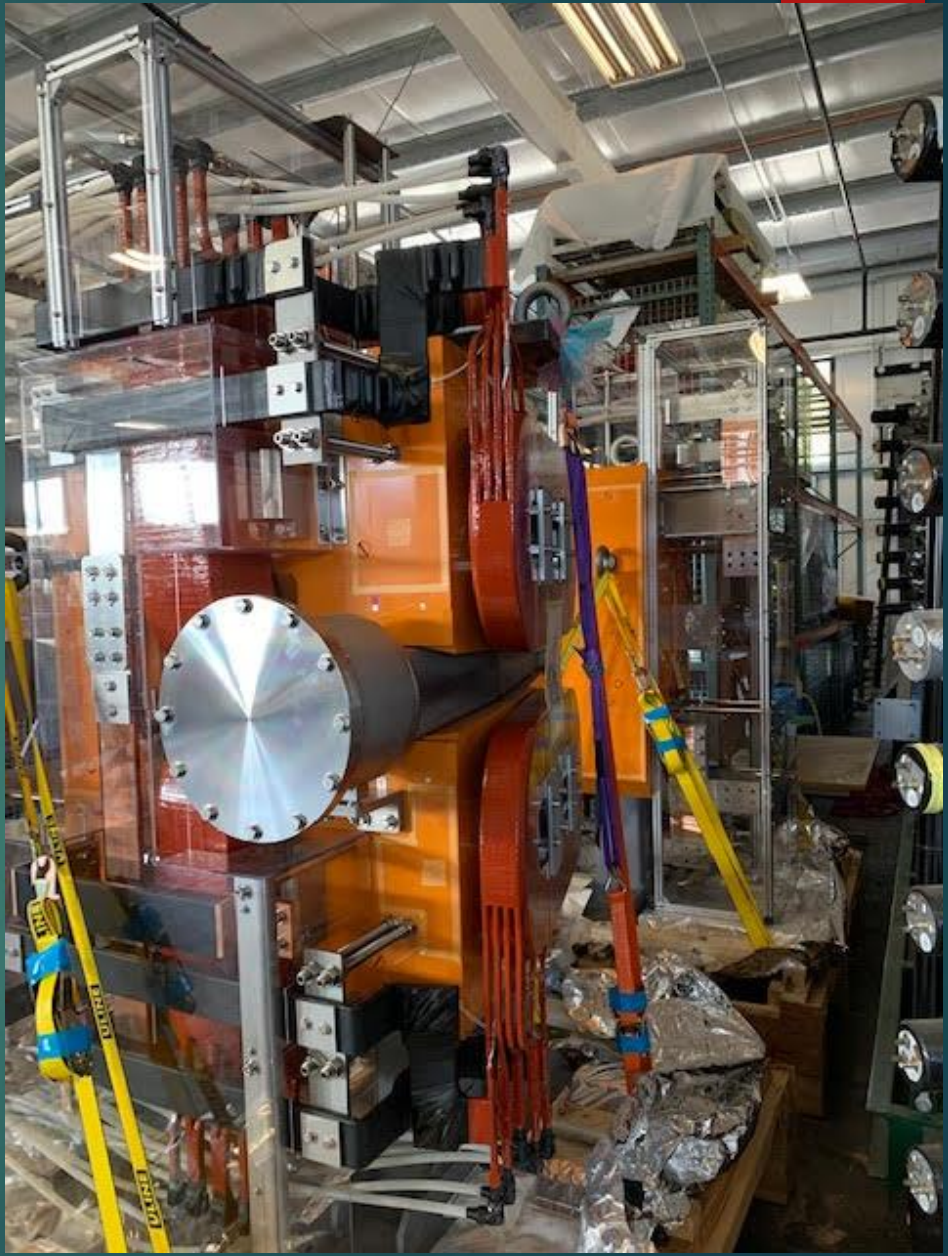
Setup in Hall-C



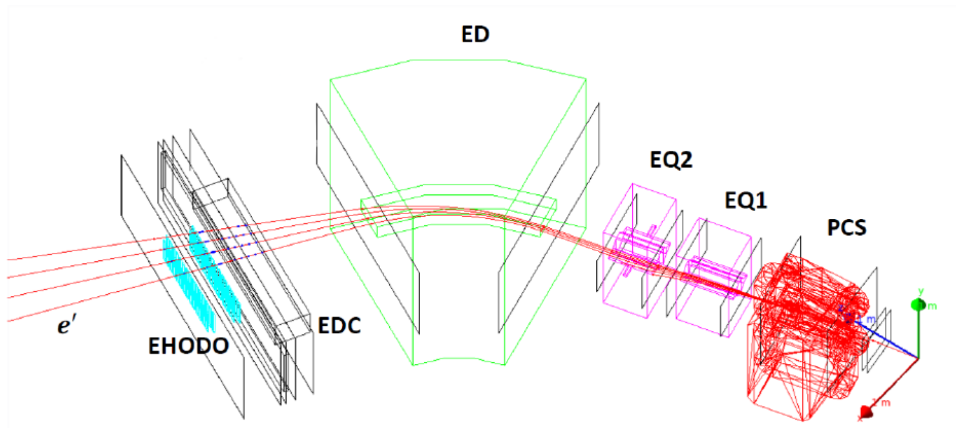


PCS magnets, newly developed major instrument, were already constructed and shipped to JLab

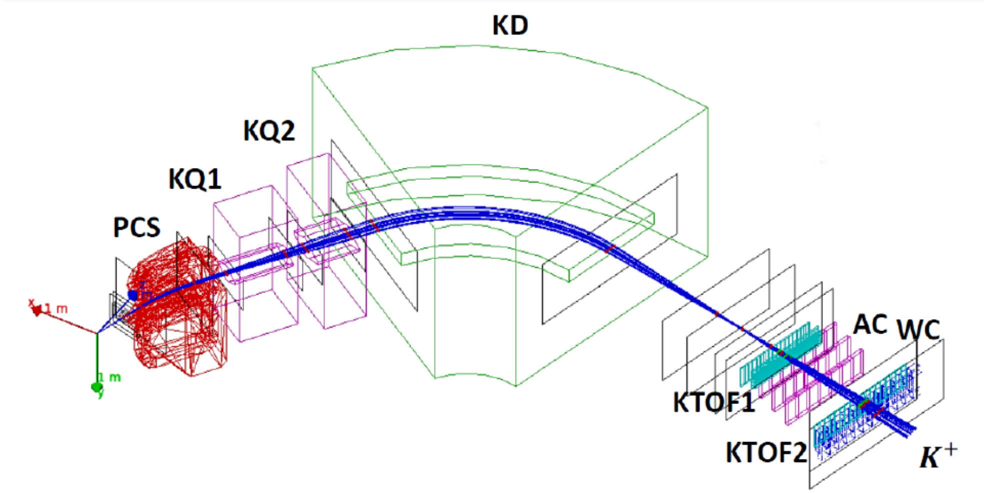
Newly constructed PCS magnets (TOKIN, 2020.3)



Delivered to JLab (2022.2 @ JLab)



(a) The model of HES implemented in GEANT4.



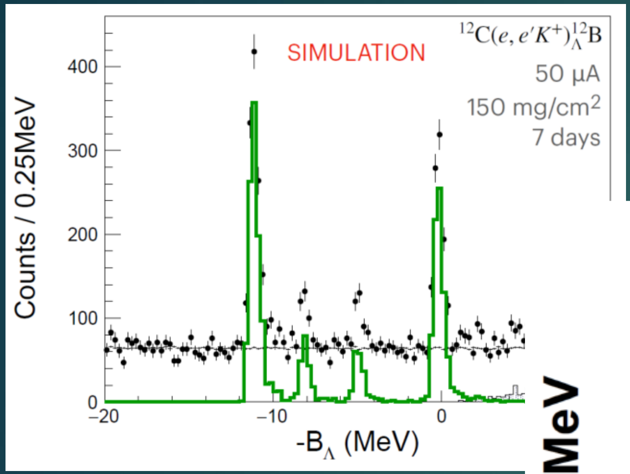
(b) The model of HKS implemented in GEANT4.

Beam	Energy E_e [/(GeV)]	2.240
	Energy stability $\Delta E_e/E_e$	$< 1 \times 10^{-4}$(FWHM)
PCS + HES	Central momentum P_e [/(GeV/c)]	0.744
	Central angle $\theta_{e,e'}$ [/(deg)]	8.5
	Solid angle $\Delta\Omega_{e'}$ [/(msr)]	3.4
	Momentum resolution $\Delta P_{e'}/P_{e'}$	4.3×10^{-4}(FWHM)
PCS + HKS	Central momentum P_K [/(GeV/c)]	1.200
	Central angle θ_K [/(deg)]	11.5
	Solid angle $\Delta\Omega_K$ [/(msr)]	7.0
	Momentum resolution $\Delta P_K/P_K$	2.9×10^{-4}(FWHM)
p $(e, e'K^+)$ Λ	W [/GeV]	1.912
	Q^2 [/(GeV/c)^2]	0.036
	$\theta_{\gamma^* K}$ (/deg)	7.35
	ϵ	0.59
	ϵ_L	0.0096

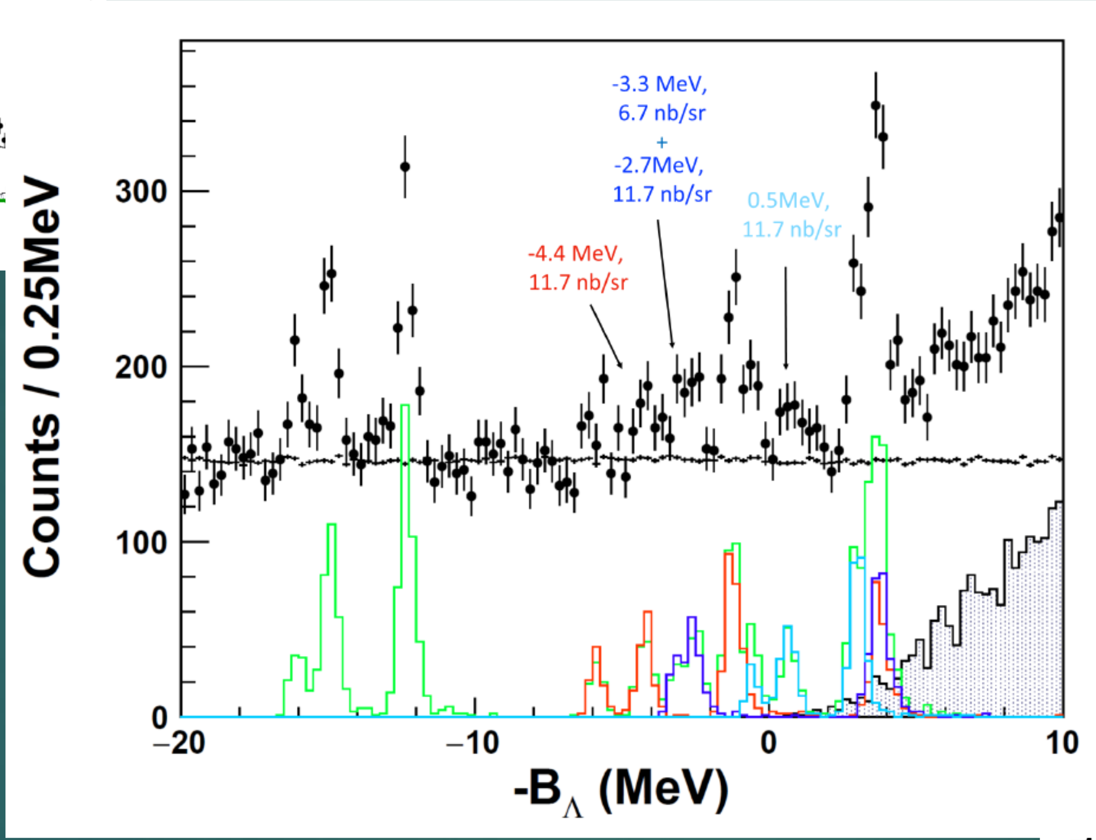
Detailed GEANT4 Simulation incl. PCS

Expected missing mass spectra for ${}^{12}_{\Lambda}\mathrm{B}$, ${}^{27}_{\Lambda}\mathrm{Mg}$

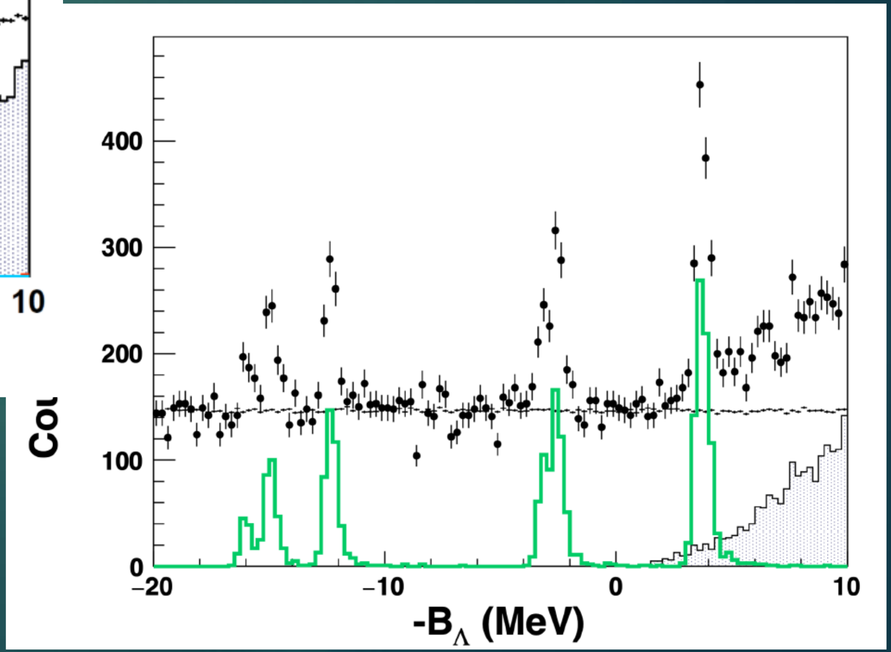
Expected resolution 0.6 MeV (FWHM)



Triaxially deformed ${}^{27}_{\Lambda}\mathrm{Mg}$



Energy level : Hyper-AMD (Isaka)
Cross Section: Shell model (Umeya)

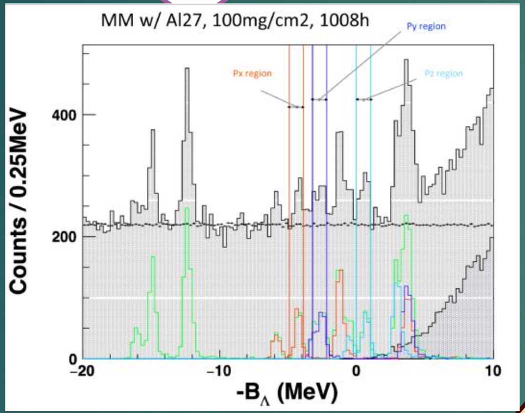


Sphere shape ${}^{27}_{\Lambda}\mathrm{Mg}$

Estimation of Necessary Beamtime

GEANT4 Simulation

Expected Spectra

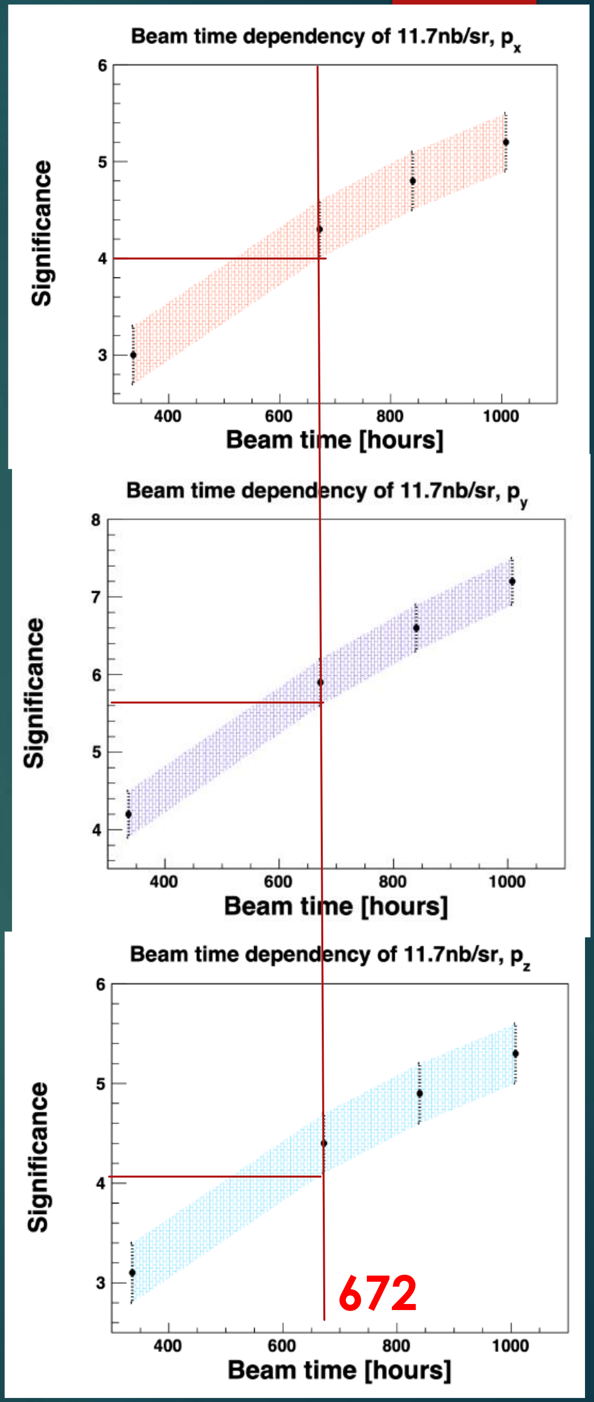


Mixed Event Analysis(BG subtraction)

X 1000

Peak Fit

Peak Significance $S/(S+N)^{1/2}$



Summary of request of beamtime

Target (Hyper Nucleus)	Beam current (μA)	Target thickness (mg/cm^2)	Assumed cross section (nb/sr)	Expected yield (/h)	Num. of events	Req. beamtime (hours)	B.G. rate (/MeV/h)	S/N	Comments
CH_2 (Λ, Σ^0)	2	450	1000	6.12	890	144	0.02	475	Calibration
^{12}C $(^{12}_{\Lambda}B)$	50	150	90	539	900	168	0.85	8.4	Calibration
Subtotal						—			Combined with E12-15-008
^{27}Al $(^{27}_{\Lambda}Mg)$	50	100	10 (p^{Λ})	0.18	120	672	0.55	0.4	Physics
Total						672			

Calibration beamtime can be shared
with E12-15-008/PR12-24-013 and other campaign exps.

Summary

- **Λ particle in p-orbit can be used as a probe to study triaxially deformed nucleus, ^{26}Mg.**
- This is a **totally new** experimental technique to study triaxially deformed nuclei. We **request 672 hours (28 days) beamtime, calibration beam time (CH_2 and ^{12}C) can be shared with other hypernuclear experiments and Al calibration beamtime (7days) of PR12-24-013 can be absorbed in this proposing experiment**.

This will open a possibility to use Lambda as a probe to study shape of various nuclei.

Answers to Reviewers

Q1. We understand from the TAC that the required high-level of beam stability is not routinely requested and run. Do you have an estimate on what level of instability can be tolerated for a successful measurement? Please provide clear guidance on the desired energy stability, as the TAC reports suggests.

A1. Answered to TAC and presentation of PR12-24-013.

Q2.

Answers to Reviewers

Q2. Similarly, do you have a minimum level of deformation for which the presence of the energy splitting can still be discerned? This is related to the fact that the 26Mg deformation parameters are a prediction by theory, with different models predicting different deformation parameters.

A2. Even if Mg26 is not deformed at all, Lambda particle in p orbit can be still observed. Any structure between the peaks between Λs and the expected peak of Λp in the undeformed case, can be considered evidence of deformation. If the observed structure is different from theoretical predictions, the core nucleus deformation parameters should be adjusted to reproduce the observed spectrum. Such kind of analysis requires significant involvement from theoreticians and we already start working with an AMD expert (Isaka) and shell model calculation (Umeya).

Sensitivity to deformation highly depends on statistics. Even if peaks cannot be separated clearly, we can fit the data to extract information with the help of theoretical calculations (this analysis is model-dependent). Though we have not yet performed a thorough study on sensitivity to various deformation parameters, a very naive estimation may be possible by assuming that the p-orbit energy separation is proportional to deformation.
With the current deformation (beta = 0.34, gamma = 36 degrees), a typical energy difference between different Lambda states in p-orbits is on the order of 1-2 MeV. Our expected resolution is 255 keV (sigma), and a two-sigma peak separation (510 keV) is necessary to see the difference. In this case, we can still observe peaks separately for the case of 50% of the expected deformation.

Answers to Reviewers

Q3. With 26Mg being deformed, is it possible that it is excited upon lambda capture as excitations out of the ground state are more probable than for semi(magic) systems? Would that matter?

A3. Such a reaction is possible and has been observed in other hypernuclei. We have already measured core-nucleus excited states plus Lambda in the s-orbit. Typically, the cross-section for such states is much smaller than that of the major hypernuclear peaks (ground state core plus Lambda in s, p, d... orbits). Though a detailed discussion with theoreticians is necessary, we believe that it is possible to separate these states from the Lambda in p-orbit.