National Nuclear Physics Summer School 2026
July 9th, 2026

Exploring Λ-Nucleon Interaction through Mass Spectroscopy of Hypernuclei at Jefferson Lab

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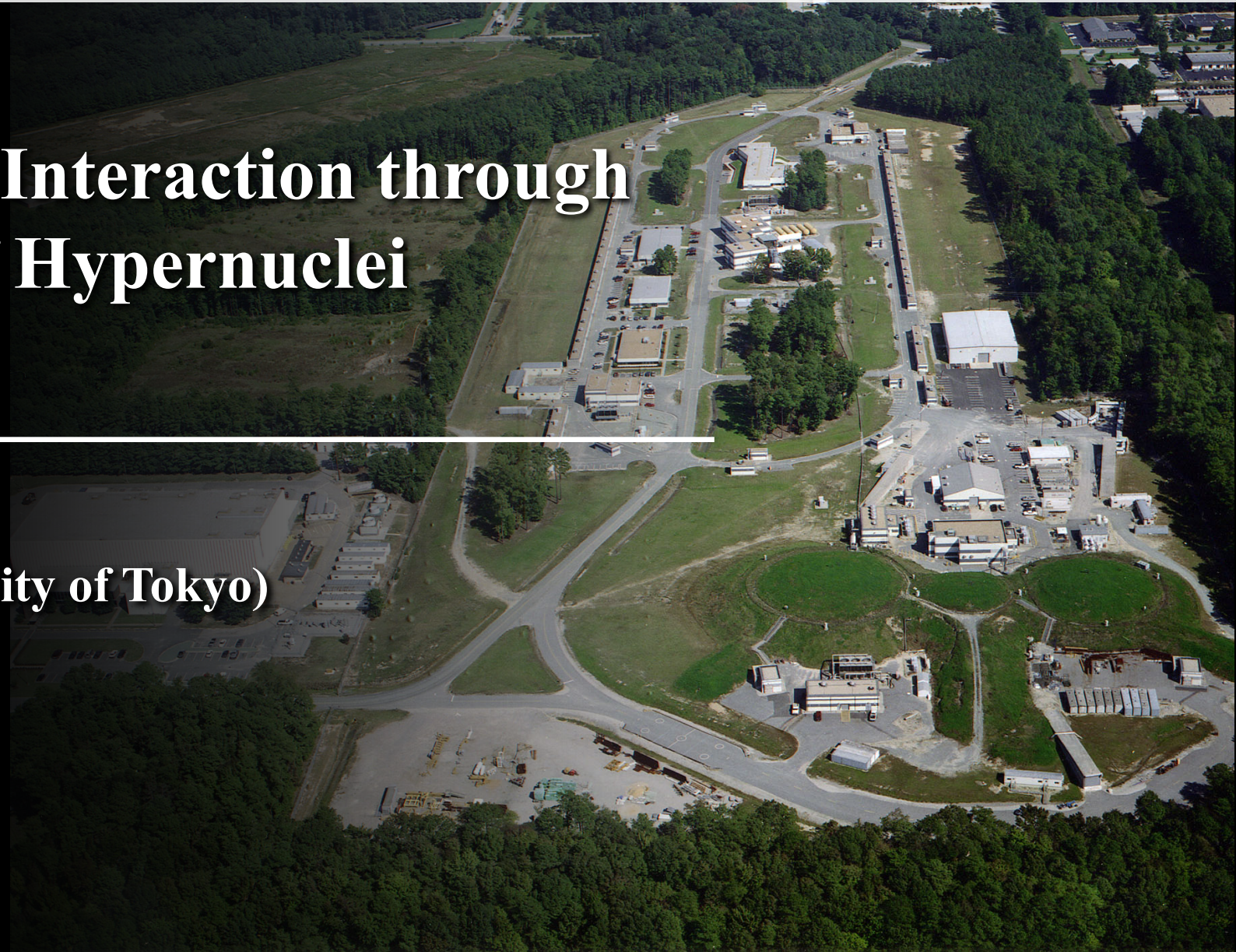
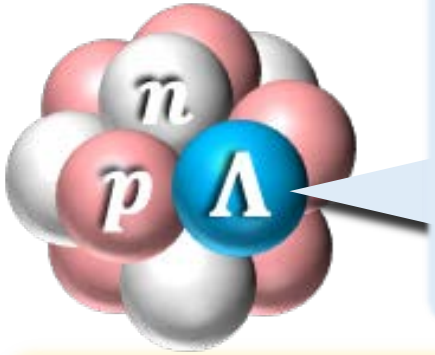
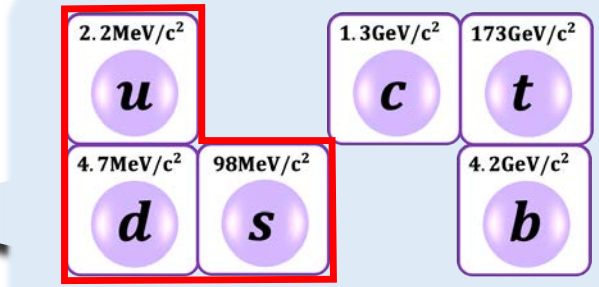
for the JLab Hypernuclear Collaboration



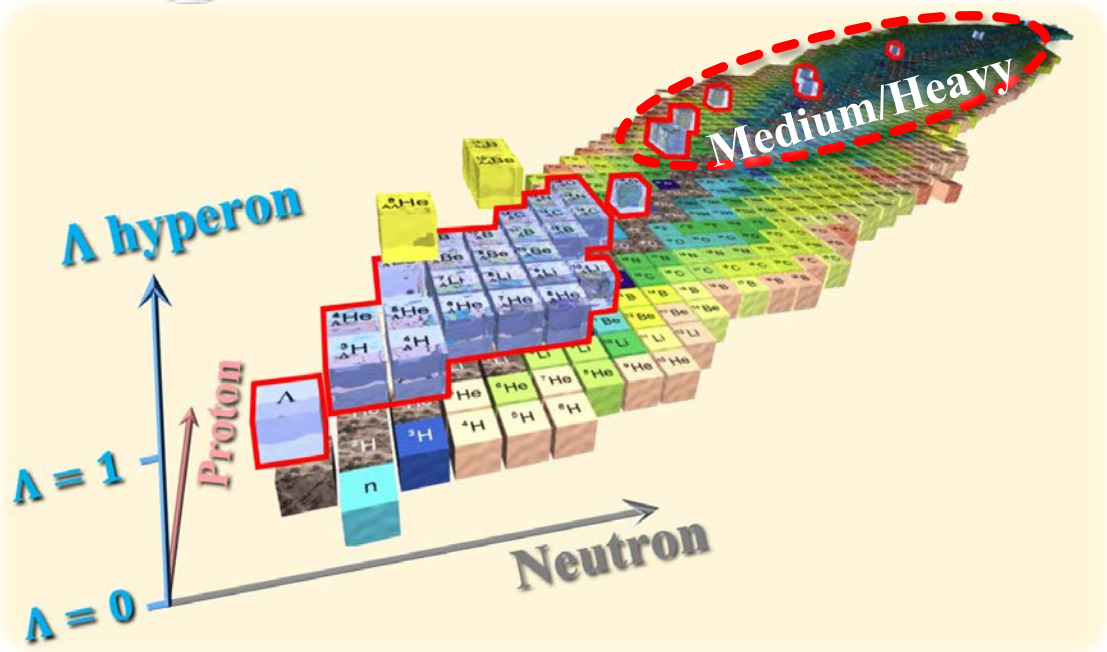
“Strange” nuclear system of Λ hypernuclei

Λ hypernucleus





flavor SU(3)



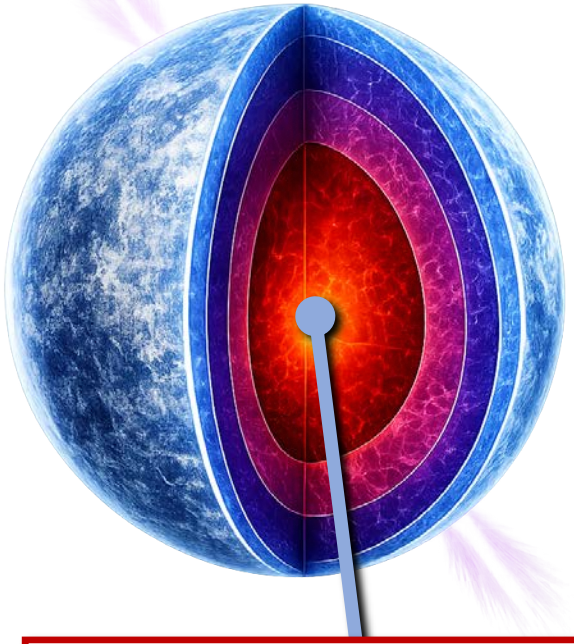
- What is Λ hypernucleus?
  - Nuclear system containing a Λ hyperon
- Why Λ hypernuclei?
  - Λ-Nucleon interaction beyond NN interaction
  - Hadronic scale: ΛN interaction in neutron star
  - Nuclear scale: Nuclear structure
- How can we study experimentally?
  - Measurement of Λ binding energy

$$B_\Lambda = M_{Core} + M_\Lambda - M_{Hypernuclei}$$

using mass spectroscopic techniques

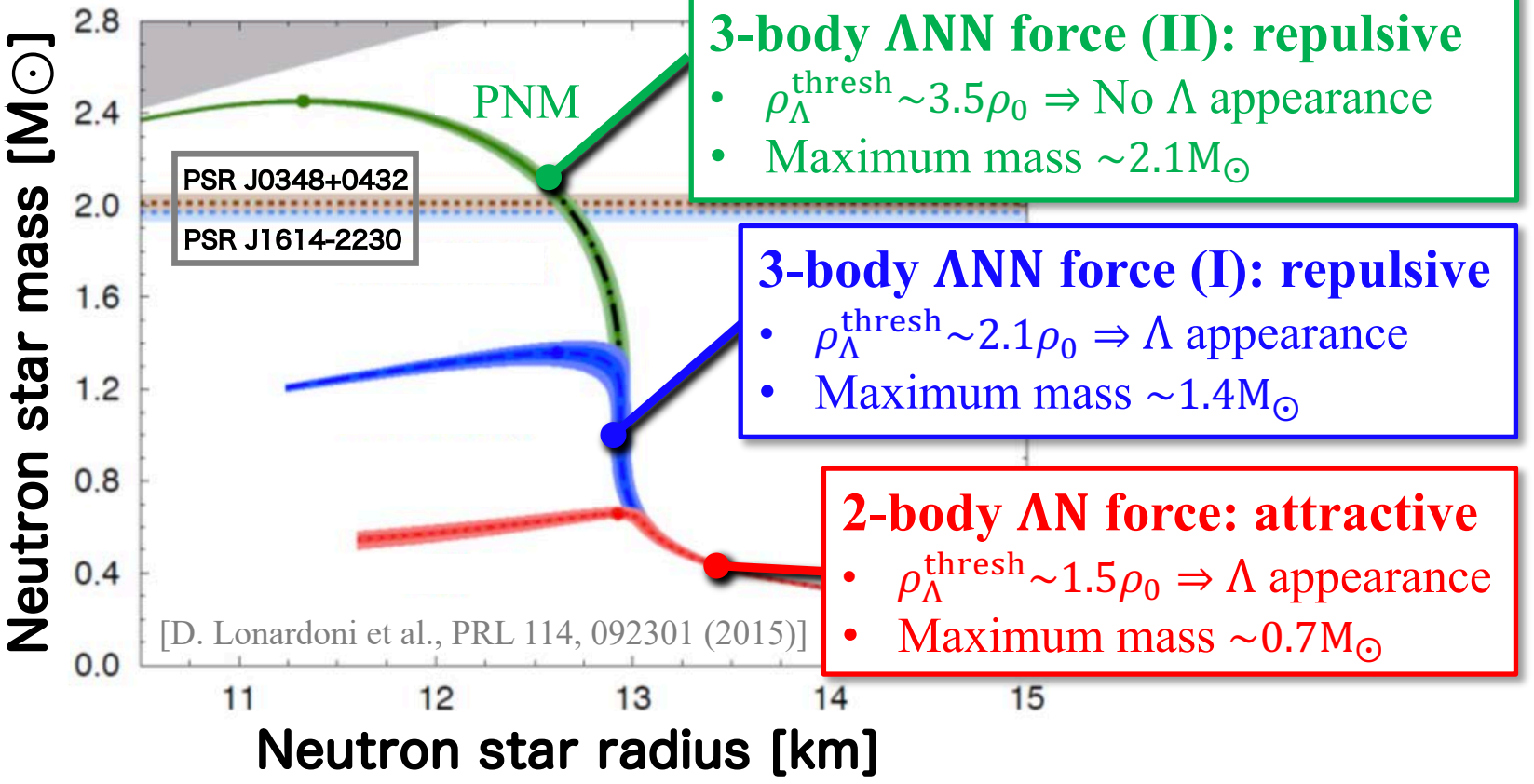
Physics1: Neutron Stars

Charles' fisrt lecture



Inner core of neutron star
- High density: $\sim 2\rho_0$
- Large isospin asymmetry
- Onset of Λ hyperons
  $n \rightleftarrows \Lambda + e^- + \bar{\nu}_e$
  softens the EOS

"Hyperon puzzle": discovery of $2M_\odot$ neutron stars
- Repulsive 3-body ΛNN force could hold up the heavy neutron star
  - In neutron-star-like environments?



3-body ΛNN force (II): repulsive
- $\rho_\Lambda^{\text{thresh}} \sim 3.5\rho_0 \Rightarrow$ No Λ appearance
- Maximum mass $\sim 2.1M_\odot$

3-body ΛNN force (I): repulsive
- $\rho_\Lambda^{\text{thresh}} \sim 2.1\rho_0 \Rightarrow$ Λ appearance
- Maximum mass $\sim 1.4M_\odot$

2-body ΛN force: attractive
- $\rho_\Lambda^{\text{thresh}} \sim 1.5\rho_0 \Rightarrow$ Λ appearance
- Maximum mass $\sim 0.7M_\odot$

Physics2: Nuclear Structure/Deformation

$^{27}_{\Lambda}$Mg hypernuclei

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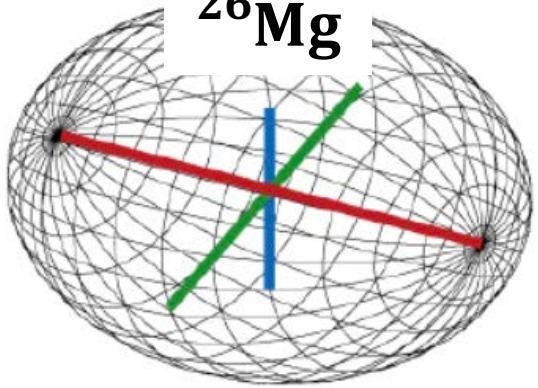
Triaxially deformed

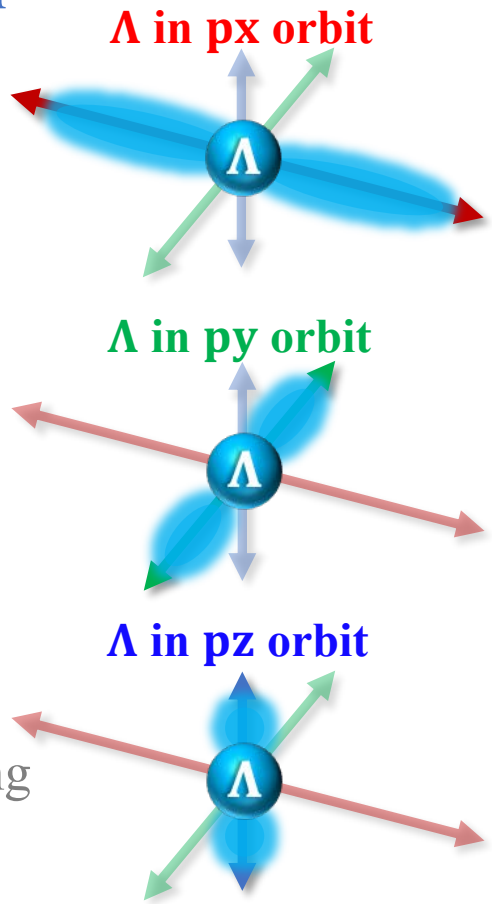
^{26}Mg



⊗

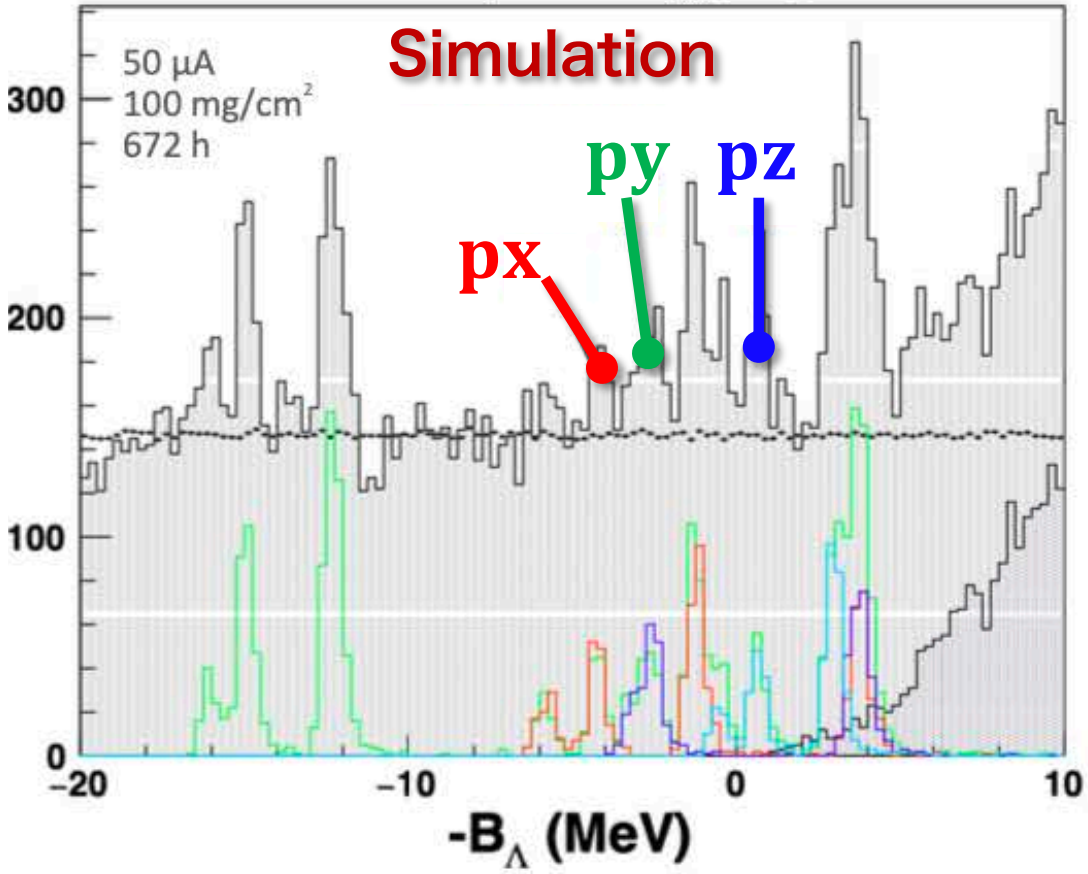
Λ in s-, p-orbits

⇒ free from Pauli blocking

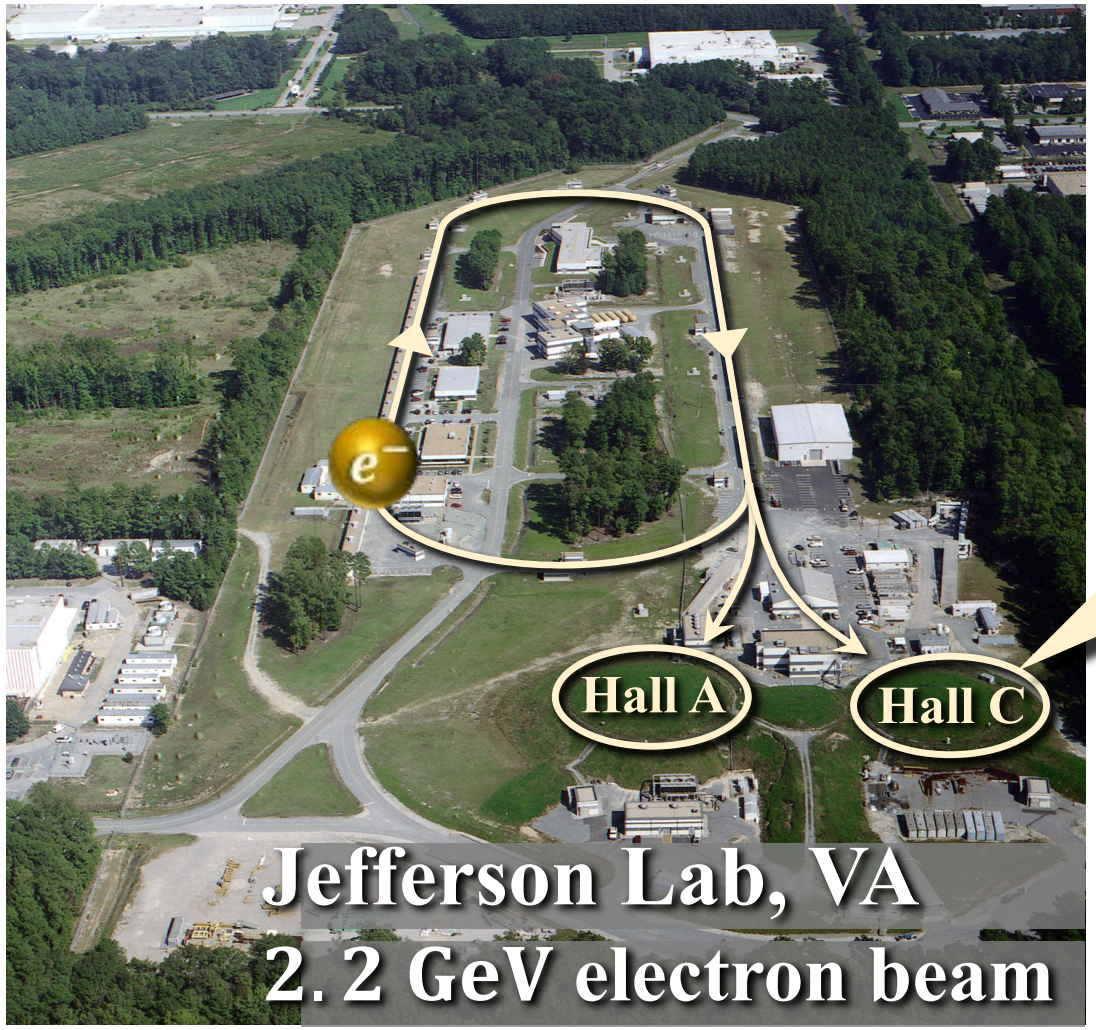


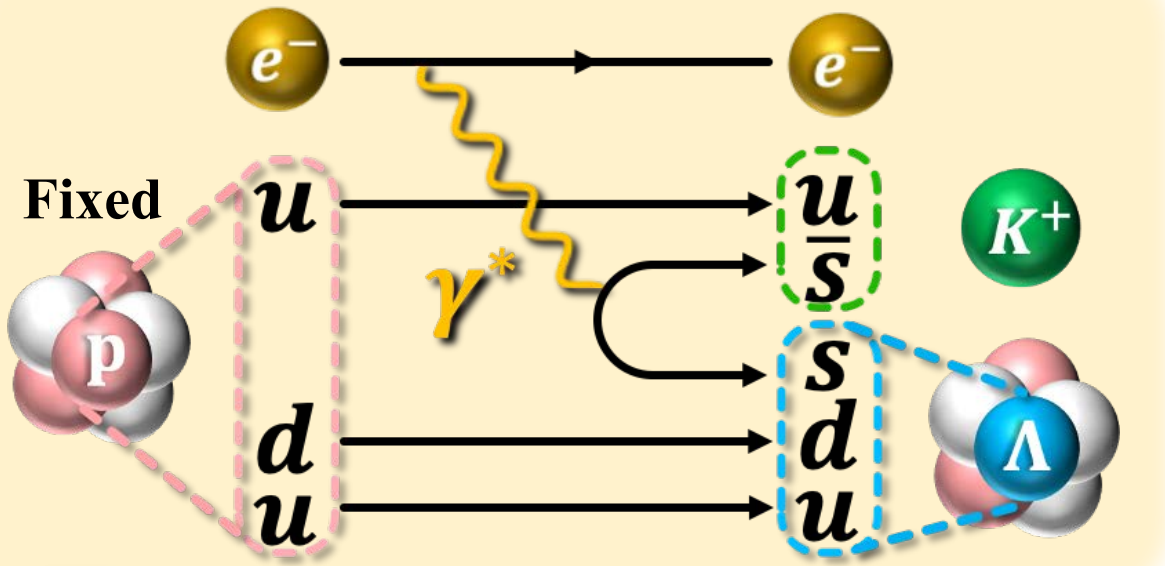
Nuclear deformation with Λ probe

- The energy splitting is observed with high resolution mass spectroscopy (ΔB_Λ~500keV)



Hypernuclear Experiment at Jefferson Lab





How to measure short-lifetime Λ hypernucleus??

Missing mass technique

$M_{Hypernucleus}$ ⇐ momentum of e' and K^+

$$\equiv \sqrt{(E_e - E_{e'} + m_{target} - E_K)^2 - |p_e - p_{e'} - p_K|^2}$$

Summary

Λ hypernuclear physics

- Nuclear system containing a Λ hyperon.
- Mass and binding energy are the experimental observables.

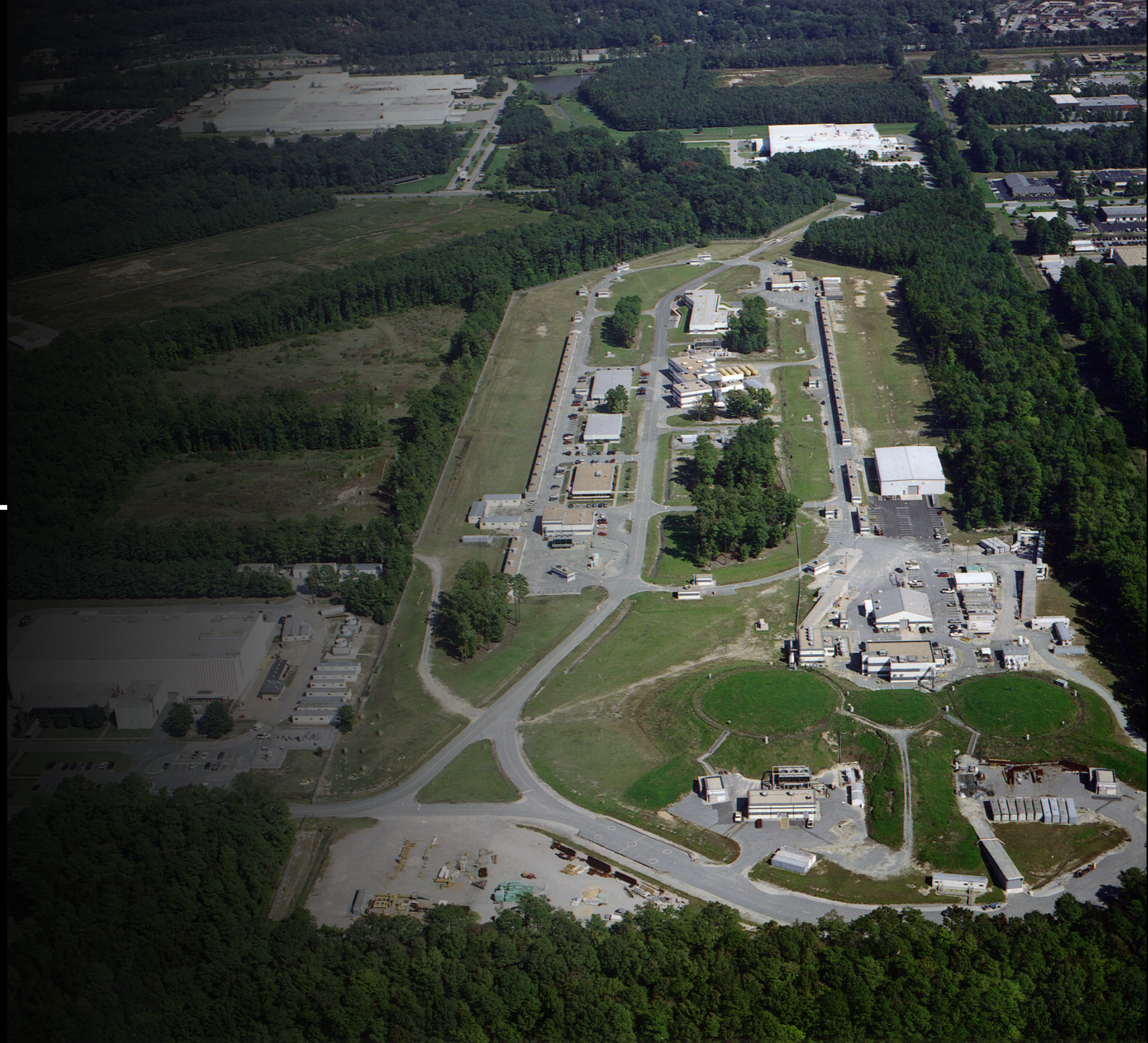
Major physics interests of Λ hypernuclei

- ΛN interaction inside neutron star to solve “hyperon puzzle”.
- Observation of nuclear structure/deformation using Λ probe.

Upcoming hypernuclear experiment at JLab Hall-C

- Electro-prodution of Λ hypernuclei over a wide mass range.
- High resolution & precision measurement via missing mass technique.
- Preration is on going at JLab for the beam time in 2029.

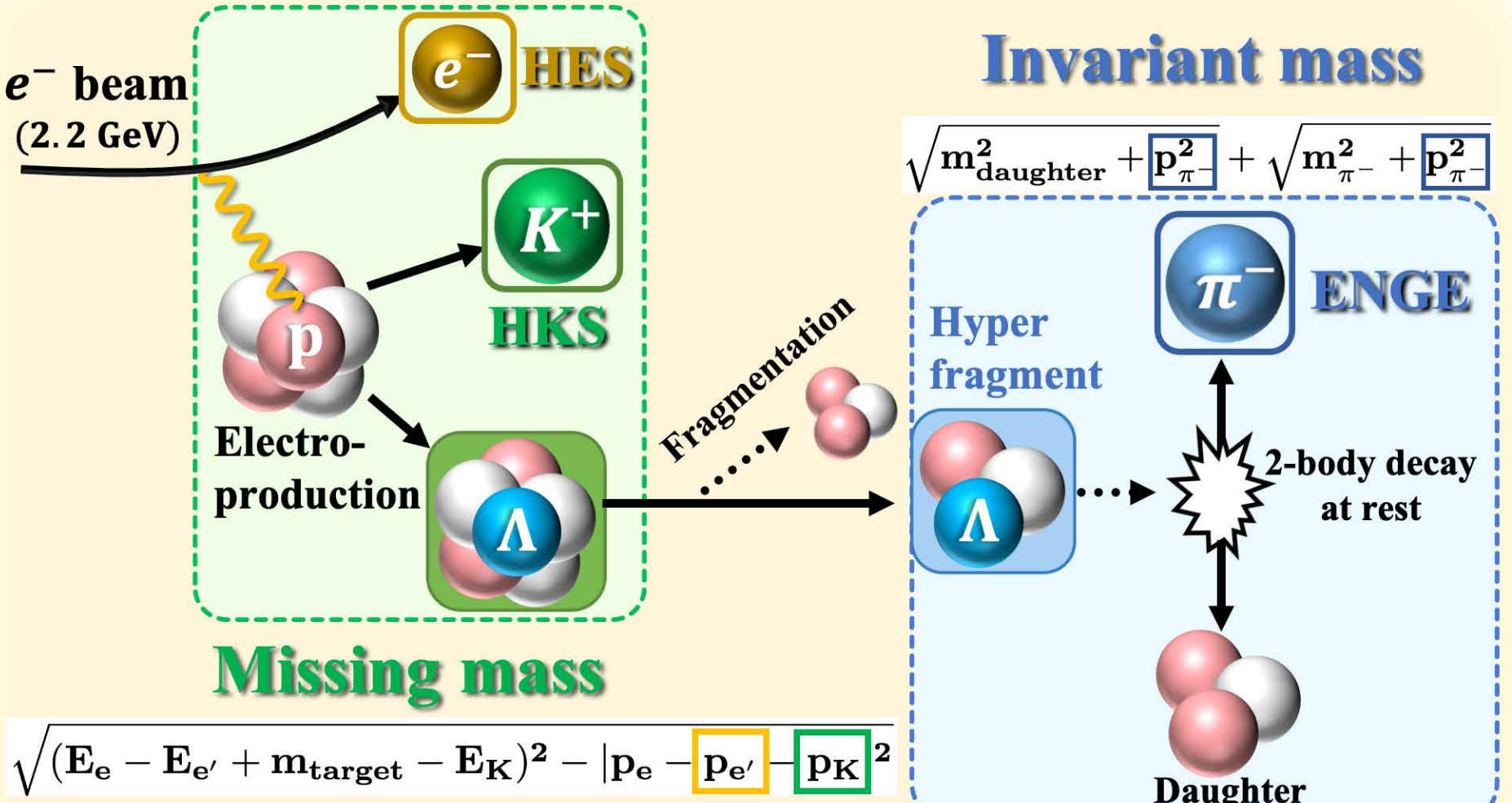
Backup Slides



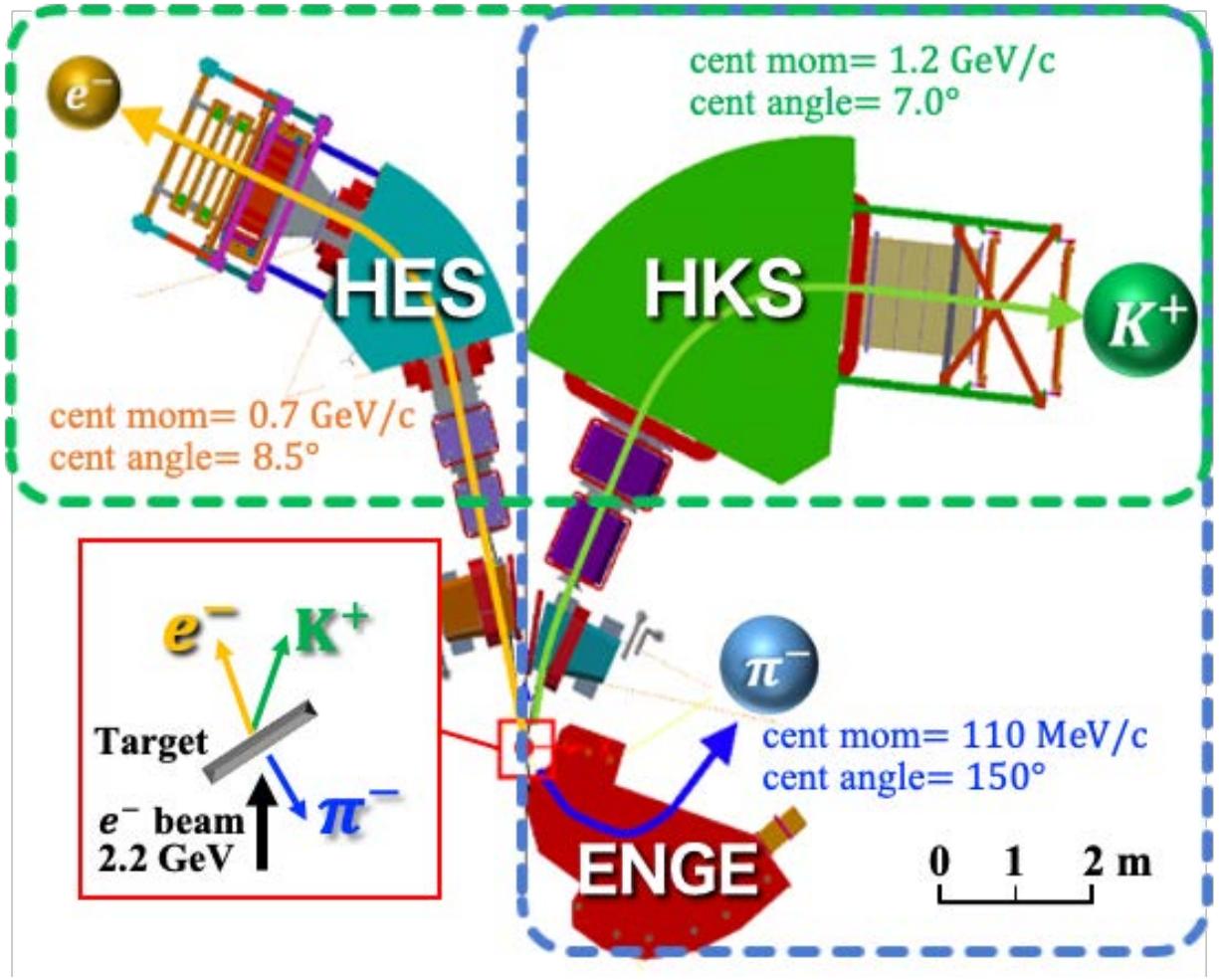
Various Targets over a Wide Mass Range

CSB in p-shell hypernuclei	^{6}Li ^{9}Be ^{11}B	→ → →	$^{6}_{\Lambda}$He $^{9}_{\Lambda}$Li $^{11}_{\Lambda}$Be	**Missing mass spectroscopy**
Triaxial deformation with a Λ probe	^{27}Al	→	$^{27}_{\Lambda}$Mg	
Isospin dependence of ΛN interaction	^{40}Ca ^{48}Ca	→ →	$^{40}_{\Lambda}$K $^{48}_{\Lambda}$K	
ΛN interaction in heavy hypernuclei	^{208}Pb	→	$^{208}_{\Lambda}$Tl	
Decay pion spectroscopy	All	→	light	**Decay pion spectroscopy**

Missing Mass & Invariant Mass Spectroscopy



Experimental Setup and Kinematics



- Three dedicated spectrometers for e^-, K^+, π^-
- Two spectroscopy techniques simultaneously
  - Missing mass spectroscopy with $K^+ \otimes e^-$
  - Invariant mass spectroscopy with $K^+ \otimes \pi^-$
- High resolution and precision
  - high resolution spectrometers ($\Delta p/p \sim 10^{-4}$)
  - small cross section (~ 10 nb/sr)
  - high intensity beam (~ 50 μA)
  - thin target (~ 100 mg/cm^2)
- Small $Q^2 (\sim 0.036$ GeV/c) → real photon like

High Resolution Spectrometers

HES spectrometer

- Configuraion: Q-Q-D
- Resolution: $\Delta p/p \sim 4.4\times10^{-4}$
- Acceptance: $\pm 17.5\%$
- Solid angle: 3.4 msr

HKS spectrometer

- Configuraion: Q-Q-D
- Resolution: $\Delta p/p \sim 2.9\times10^{-4}$
- Acceptance: $\pm 12.5\%$
- Solid angle: 7 msr

ENGE spectrometer

- Configuraion: D only
- Resolution: $\Delta p/p \sim 4.0\times10^{-4}$
- Acceptance: $\pm 40\%$
- Solid angle: 4 msr