Hypernuclear spectroscopy with electron beam at JLab Hall C

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For JLab E89-009, E01-011, E05-115 experiments

Collaborators before E01-011 experiment

JLab bird's eye view

Production reactions of Λ hypernucleus

- **Using meson beams**

	Elementary process	Lab. cross section at 0deg
(K^-,π^-) reaction @ BNL-AGS etc.	$nK^- \rightarrow \Lambda\pi^-$	5 mb/sr
(π^+,K^+) reaction @ KEK-PS	$n\pi^+ \rightarrow \Lambda K^+$	0.5 mb/sr

  - Relatively large elementary cross section
  - Use of secondary beams ~ Energy resolution is limited
    1.5 MeV (FWHM) with SKS at KEK

- **Using electron beam**

$(e,e'K^+)$ reaction	$\gamma^* p \rightarrow \Lambda K^+$	2 μb/sr

  - Elementary cross section : 10^2 to 10^3 times smaller
    ~ Can be overcame by high intensity (order of 10^{14}/s) e^- beam
  - Both e' and K^+ should be measured near 0 degree
    ~ Requires sophisticated experimental setup
  - Use of high quality primary beam ~ allows sub-MeV resolution

Characteristics of (e,e'K^+) reaction

- **Converts proton into Λ** cf. (π^+,K^+) (K^-,π^-) n→Λ
  - Neutron rich Λ hypernuclei (e.g. $^{7}_{\Lambda}$He)
    Mirror-symmetry Λ hypernuclei (for T=0 target)

- **Large momentum transfer** ~ production of { deeply bound states / stretched states

- **Large spin-flip amplitude** ~ Both Natural and Unnatural parity states

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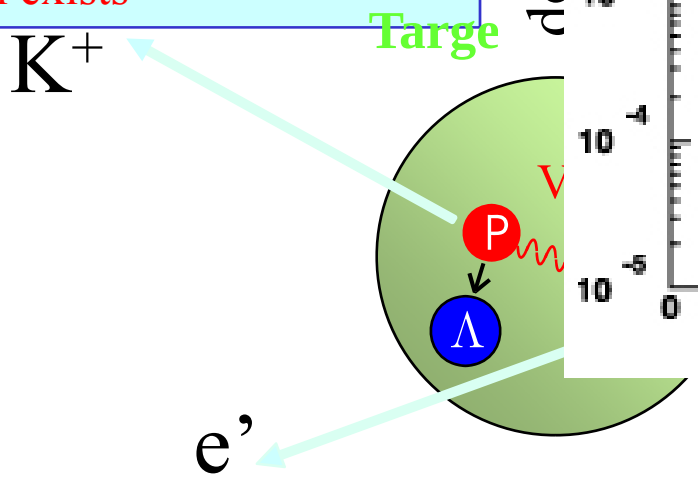
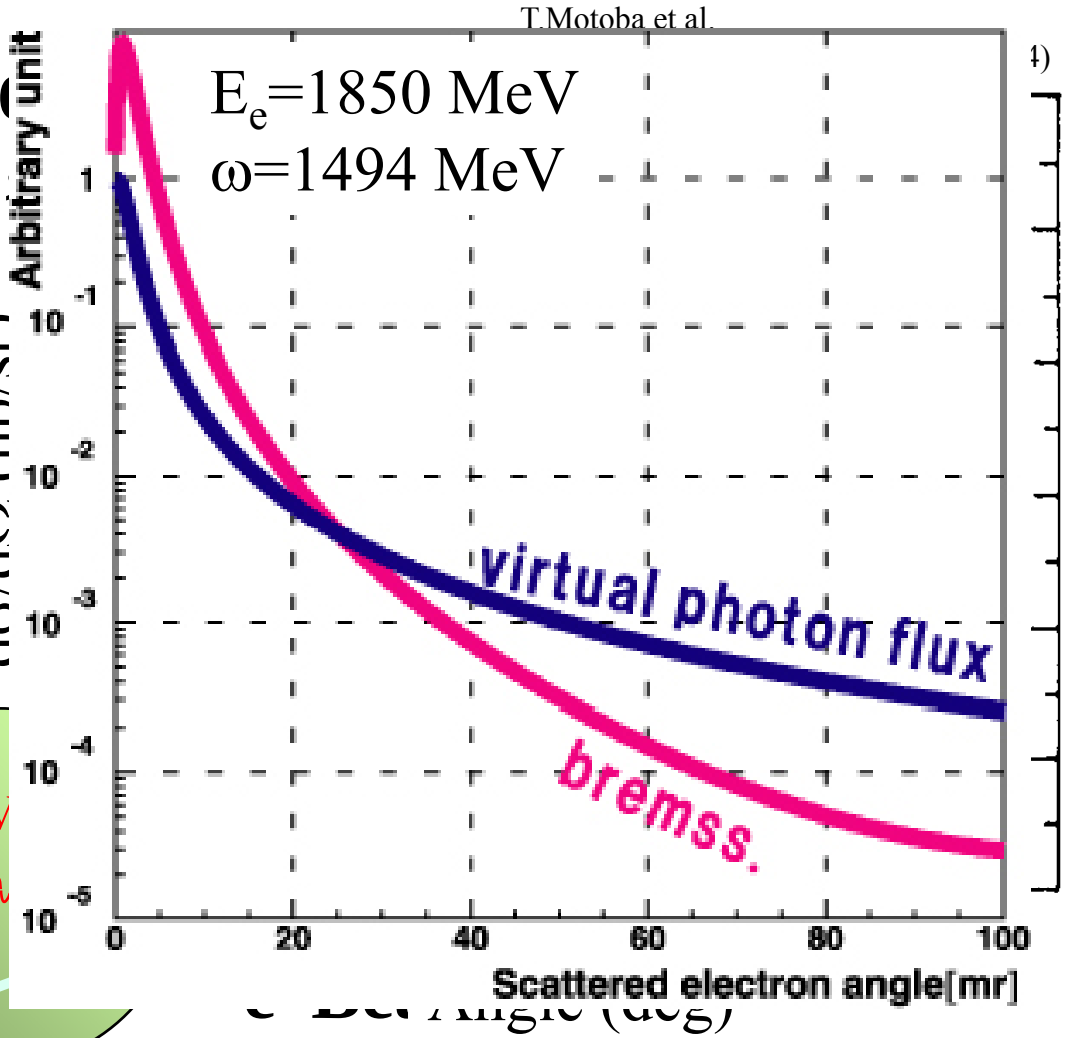
- **High resolution can be achieved**
  Use of high-intensity high-quality electron beam
  - sub MeV cf. (π^+,K^+) 1.5~2MeV(FWHM)

Kinematics of hyp
by the (e,e

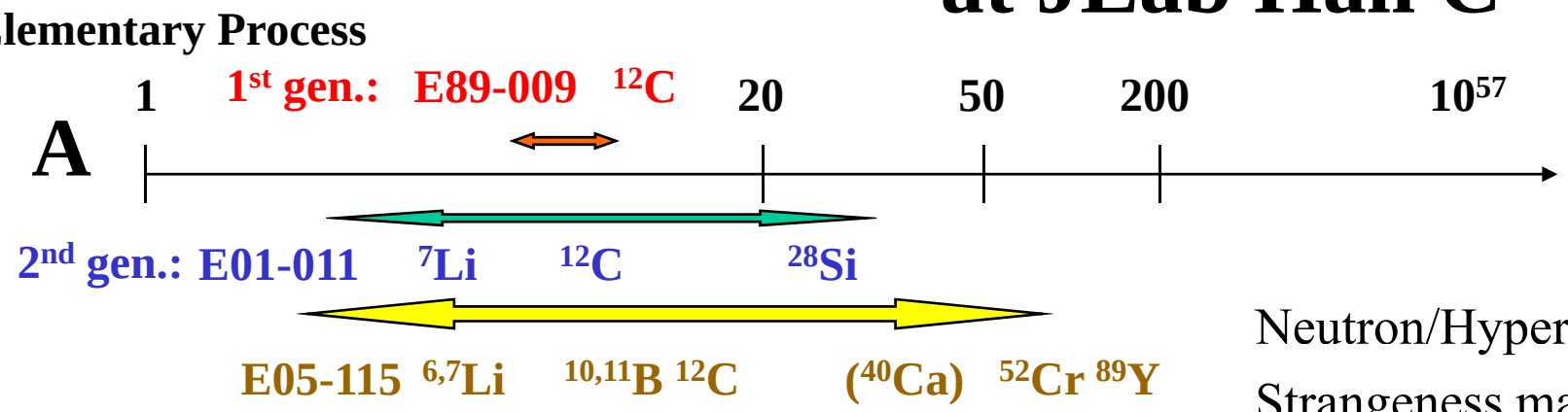
K^+ detection
At very forward angle (~ 0 deg.)
Maximum hypernuclear production cross section at 0deg.
NOTE : at 0deg. positrons from pair-creation exists





e' detection
Should be at extremely forward angles
NOTE: at 0deg. electrons from bremsstrahlung,
at certain forward angle (e.g. 3deg.), electrons from Møller scattering exists

Hypernuclear investigation in wide mass range at JLab Hall C



Neutron/Hyperon star,
Strangeness matter

Light Hypernuclei (s,p shell)

Baryon-baryon interaction in SU(3)
ΛΣ coupling in large isospin hypernuclei
Cluster structure, Fine structure
Neutron rich hypernuclei

Medium - Heavy hypernuclei

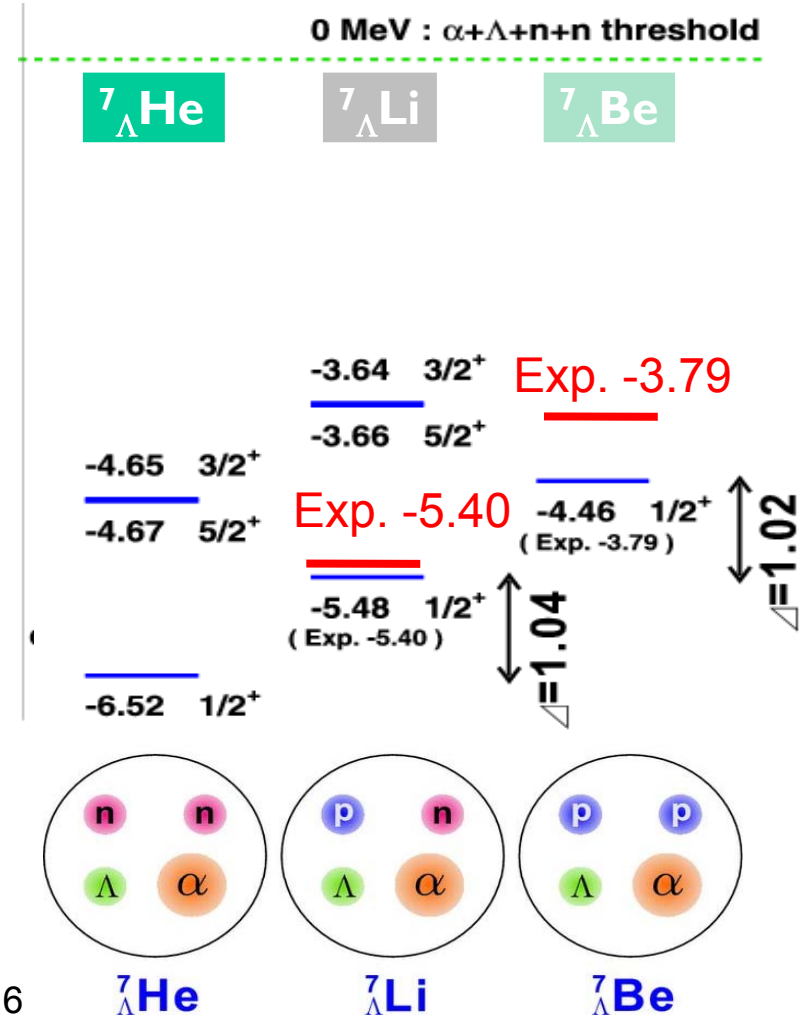
Single-particle potential
Distinguishability of a Λ hyperon
$U_0(r)$, $m_\Lambda^*(r)$, $V_{\Lambda NN}$, ...

→ 3rd Generation Experiment

Theoretical calculation of A=7 iso-triplet & emulsion data

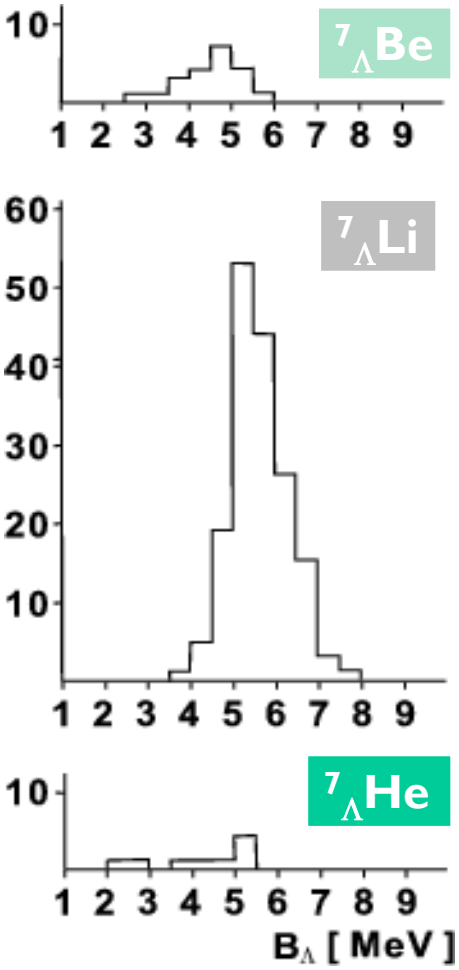
Cluster model calculation

(E. Hiyama Private Communication)



Emulsion data

Nucl. Phys. B52 (1973) 1



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First generation experiment
JLab E89-009

- Experiment performed in 2000

T. Miyoshi *et.al.* PRL **90** 232502 (2003)
L. Yuan *et.al.* PRC **73** 044607 (2006)

Jlab E89-009 experiment

~ First hypernuclear spectroscopy using electron beam

Kinematics: detect both K^+, e' around 0 degree

$\theta_{e'}$=0 deg ~ Maximize virtual photon tagging efficiency
θ_K=0~7deg ~ Maximize K^+ yield

E_{beam}=1.721, 1.864 GeV
$p_{e'}$=0.2~0.32GeV/c
p_K=1.2GeV/c±20%
} E_γ=1.4~1.6GeV → Maximum elementary c.s

Disadvantage of 0-degree tagging :
Background electrons from Bremsstrahlung (>100 MHz)
limited beam current and gave high accidental rate

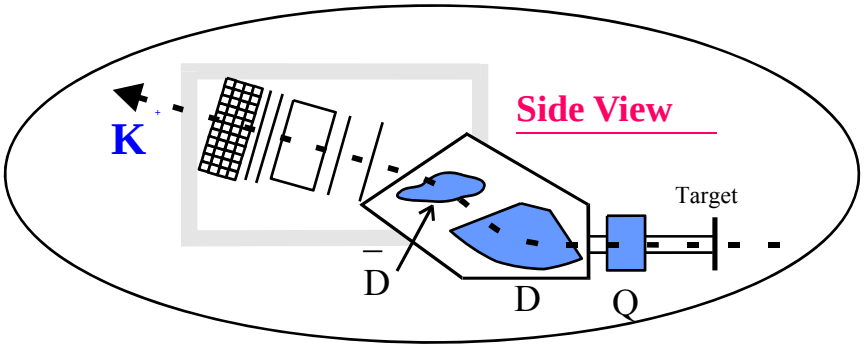
I_{beam}< 0.6 μA (for ^{12}C 22 mg/cm^2)

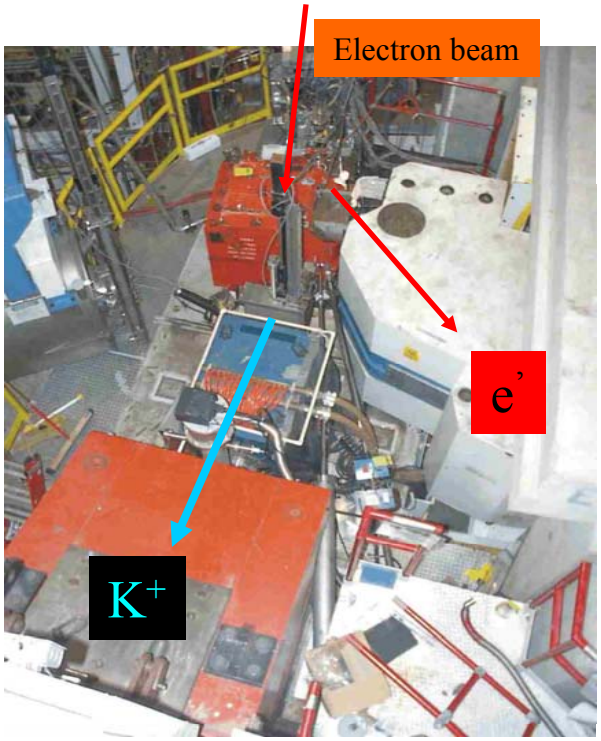
Experimental setup of E89-009

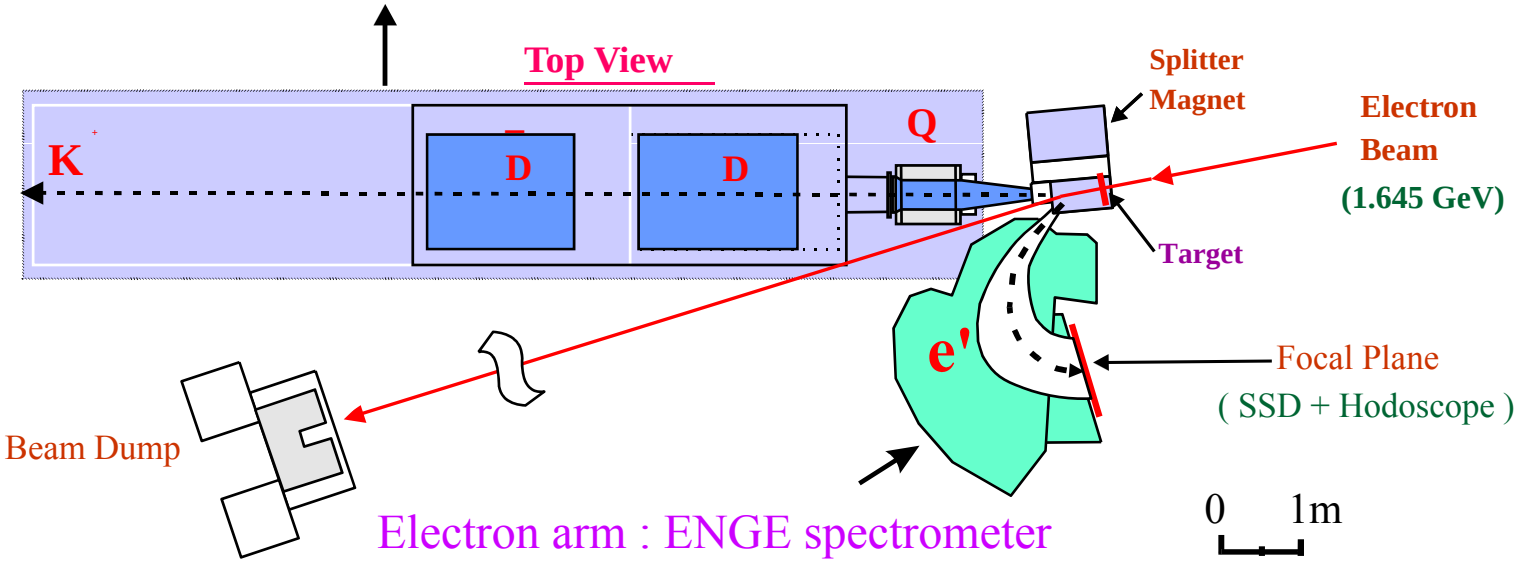
Kaon arm : SOS spectrometer

Momentum resolution : 5×10^{-4}

Solid angle : 6msr







Electron arm : ENGE spectrometer

Momentum resolution : 5×10^{-4}

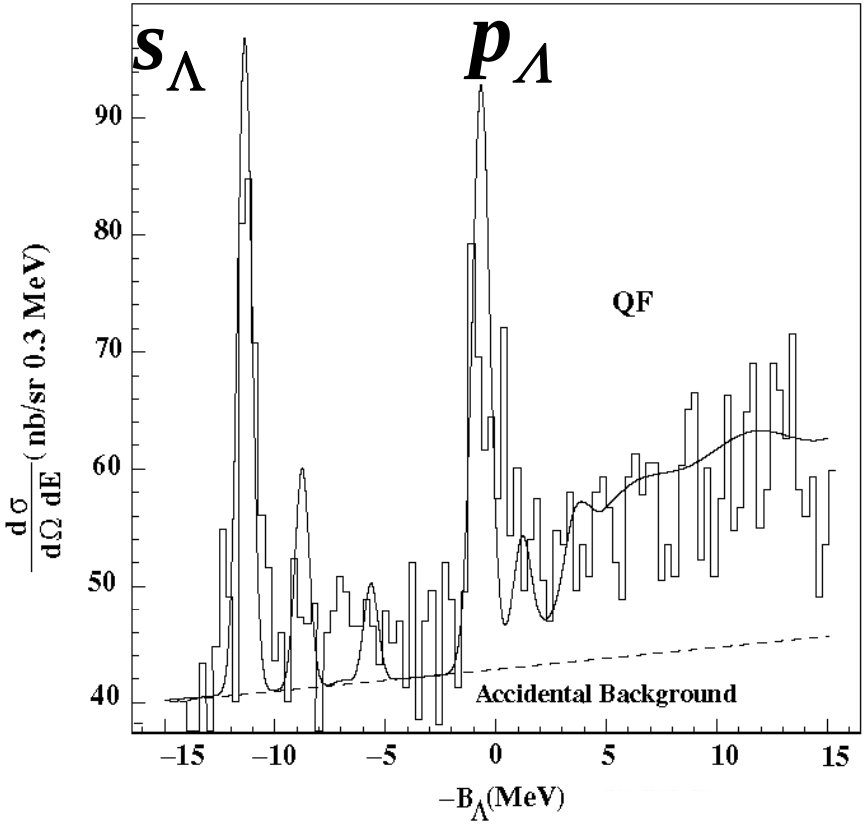
Solid angle : 1.6msr

Result of the first (e,e'K$^+$) experiment (E89-009, HNSS) at JLab

- Demonstrated that the **(e,e'K$^+$)** hypernuclear spectroscopy is **possible**!
- Good energy resolution **~750 keV (FWHM)**

Best energy resolution by the reaction spectroscopy at that time

^{12}C(e,e'K$^+$) $^{12}_{\Lambda}$B



PRC **73** 044607 (2006)

Second generation experiment
JLab E01-011

- Experiment performed from June to October 2005

Please see posters of L.Yuan and A.Matsumura for details of data analysis.

Characteristics of experimental setup of JLab E01-011

Based on E89-009 setup,

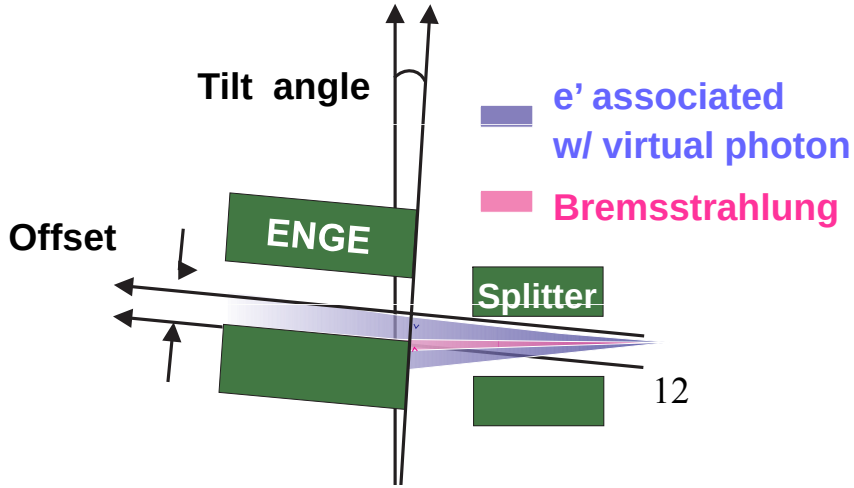
1. Kaon arm replaced by the HKS (High resolution Kaon Spectrometer)

- Better momentum resolution and large solid angle
  ($\Delta p/p=2\times10^{-4}$ FWHM, $\Delta\Omega$=16msr, cf. 5×10^{-4} FWHM, 4msr for SOS)

2. Electron arm vertically tilted (so-called "Tilt" Method)

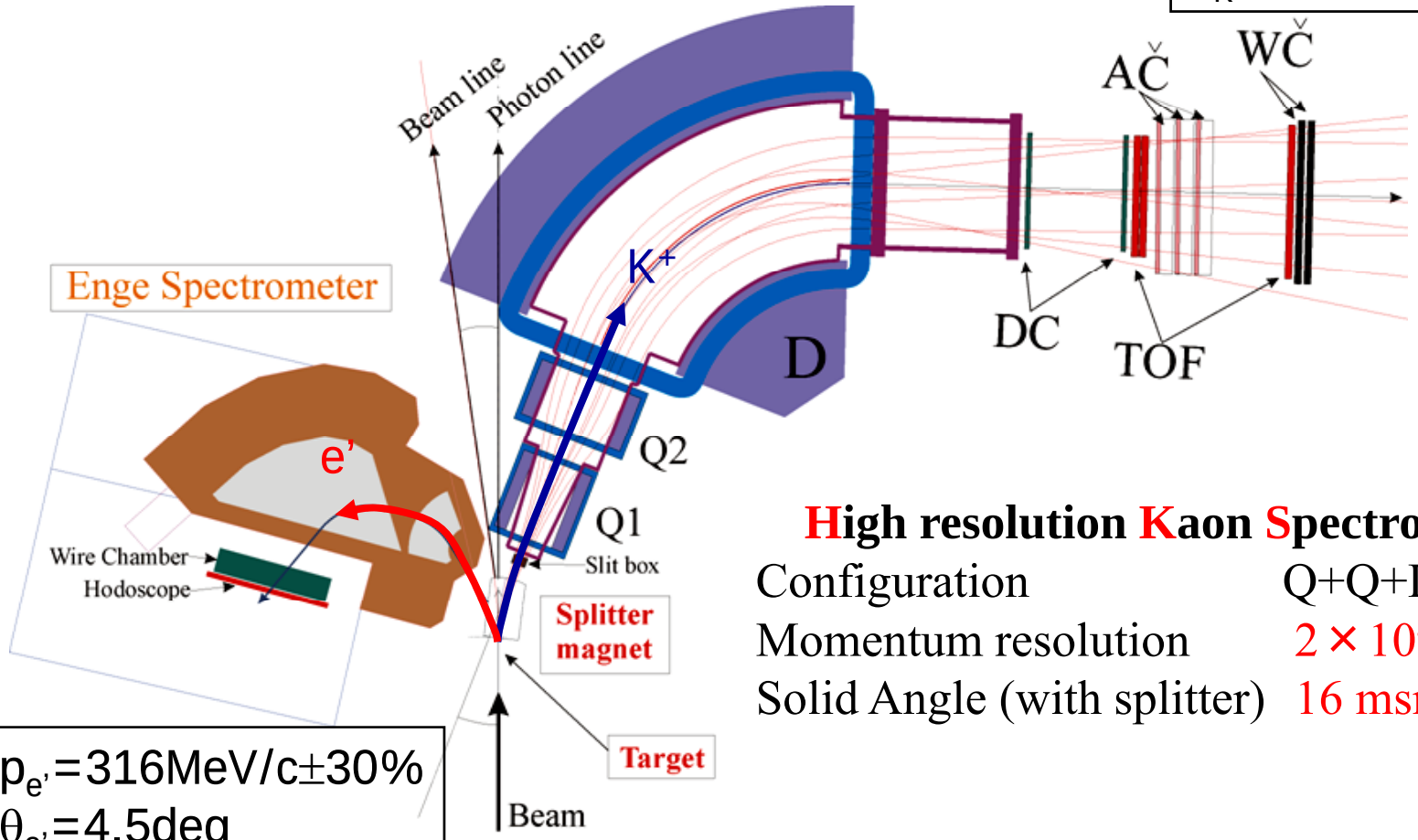
~ To avoid electrons from bremsstrahlung and Møller scattering

- Much better yield (10/h for $^{12}_{\Lambda}$B g.s. cf. 0.9/h for E89-009)
- Better Signal to accidental ratio (for $^{12}_{\Lambda}$B g.s. 4:1; cf. E89-009 1:1)
- Up to medium-heavy hypernuclei can be studied



Experimental setup of Jlab E01-011

p_K=1.2GeV/c±12.5%
θ_K=2 to 13deg



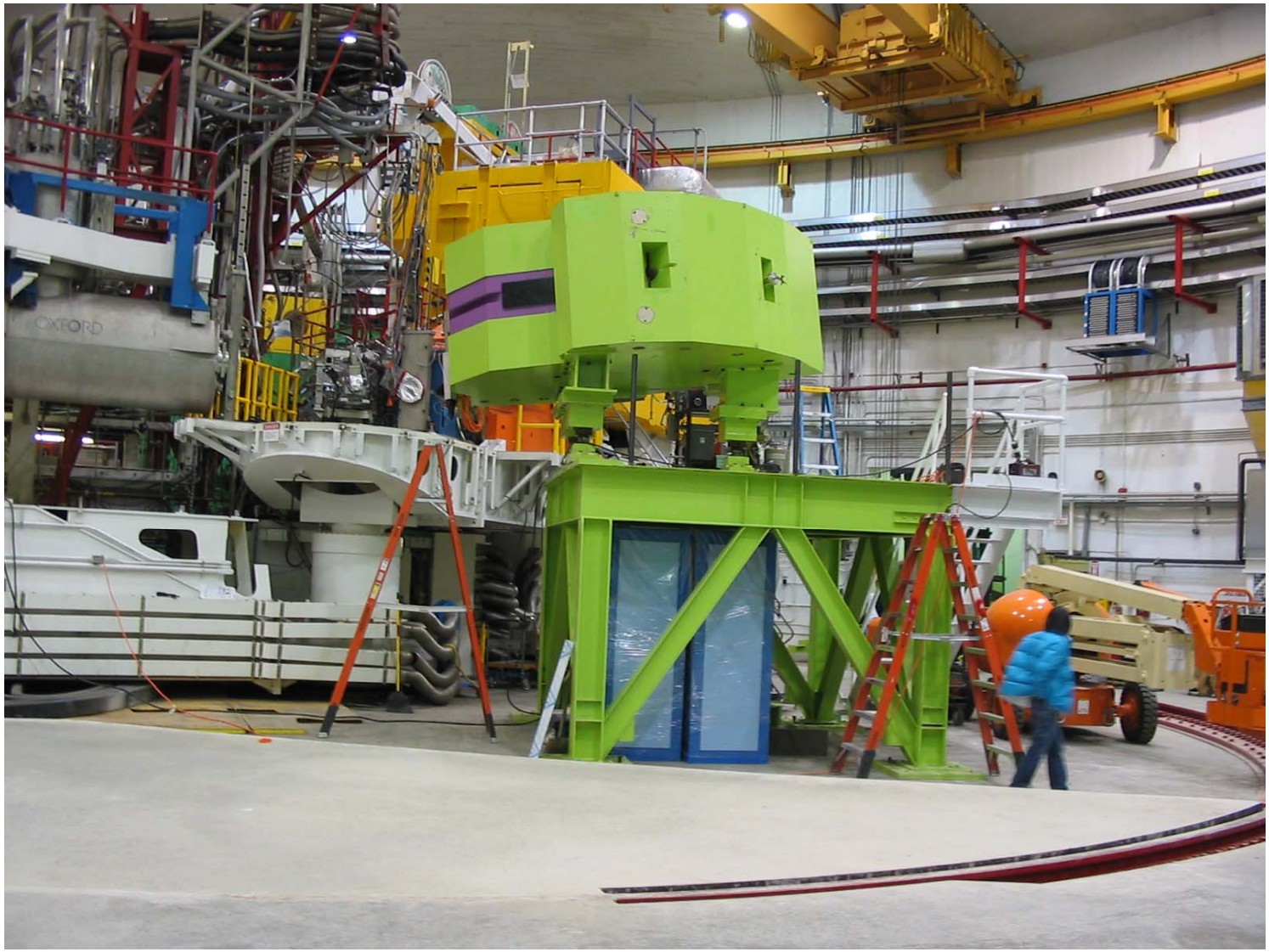
High resolution Kaon Spectrometer

Configuration	Q+Q+D
Momentum resolution	2×10^{-4} (FWHM)
Solid Angle (with splitter)	16 msr

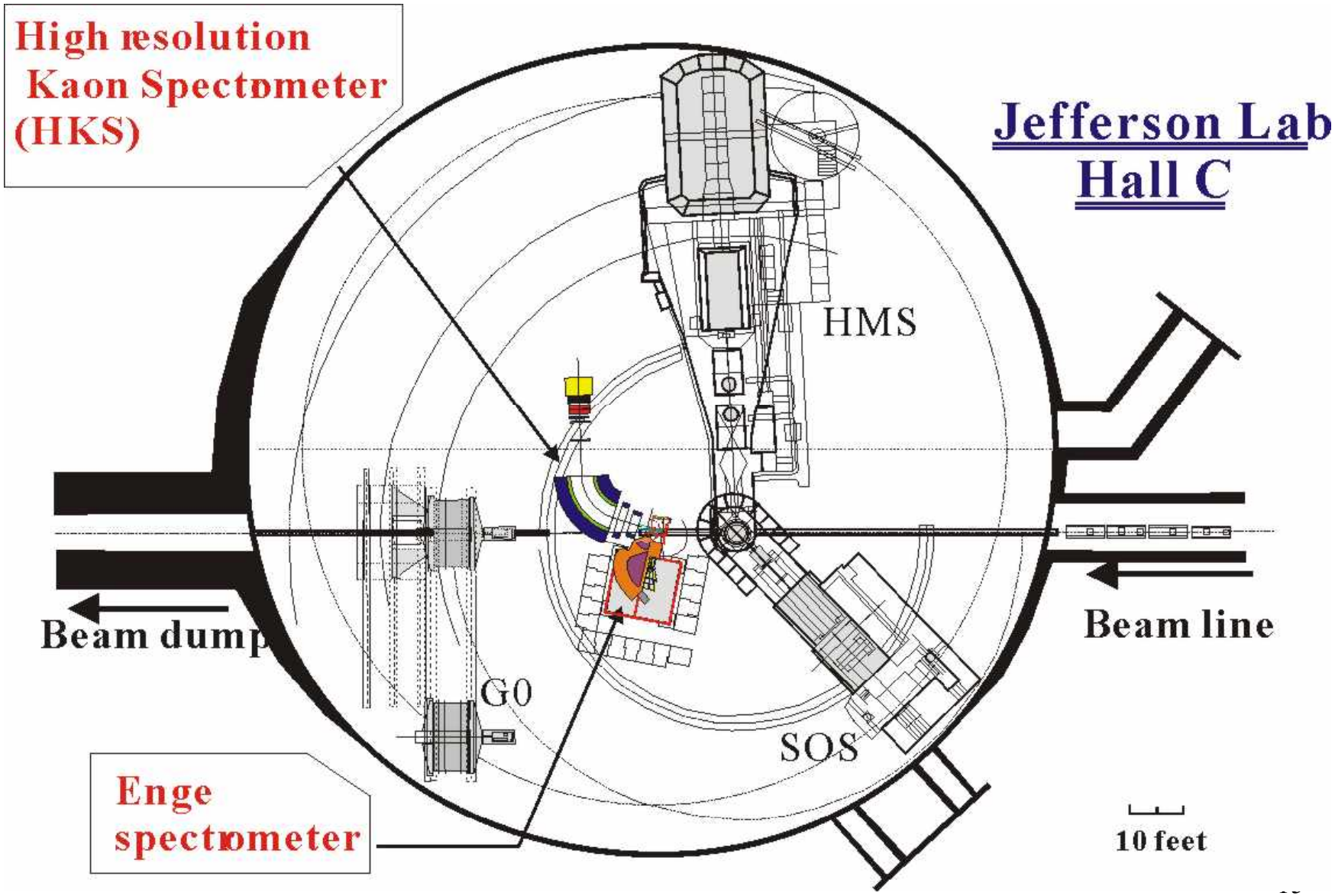
$p_{e'}$=316MeV/c±30%
$\theta_{e'}$=4.5deg

e 1.85 GeV
30μA

Electron arm (ENGE), tilted by 7.5 degrees



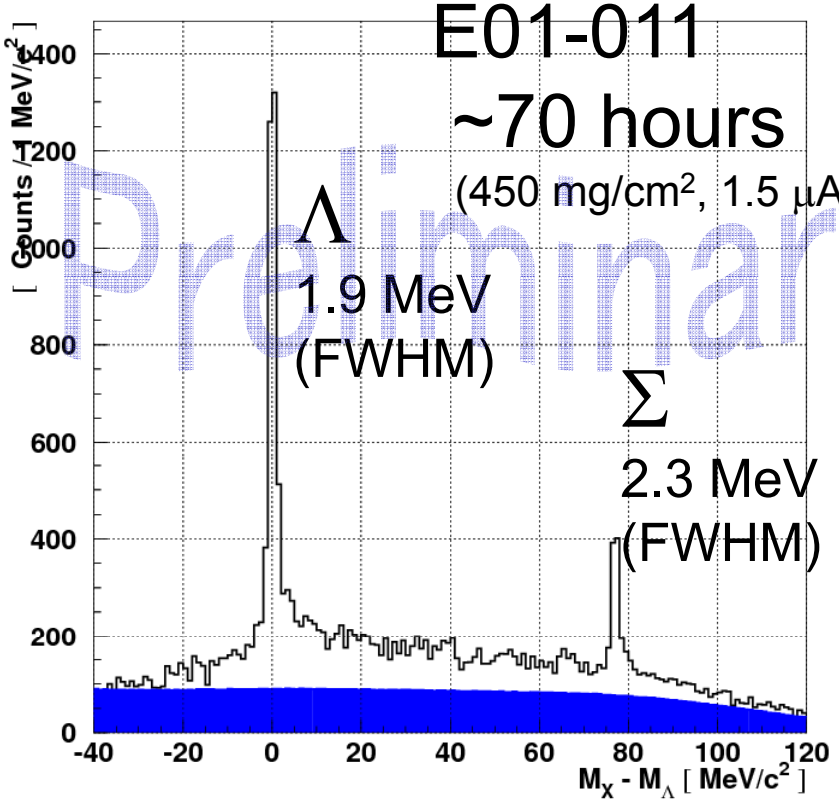
Experimental setup of JLab E01-011



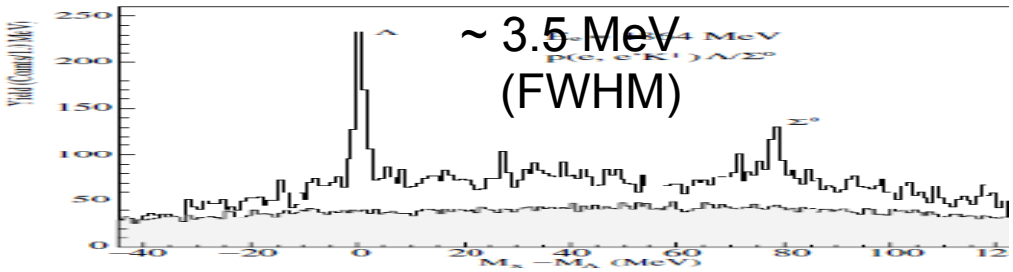
Looking downstream from upstream

Calibration data : $CH_2(e,e'K^+)\Lambda,\Sigma$

Absolute mass scale can be determined by Λ and Σ mass



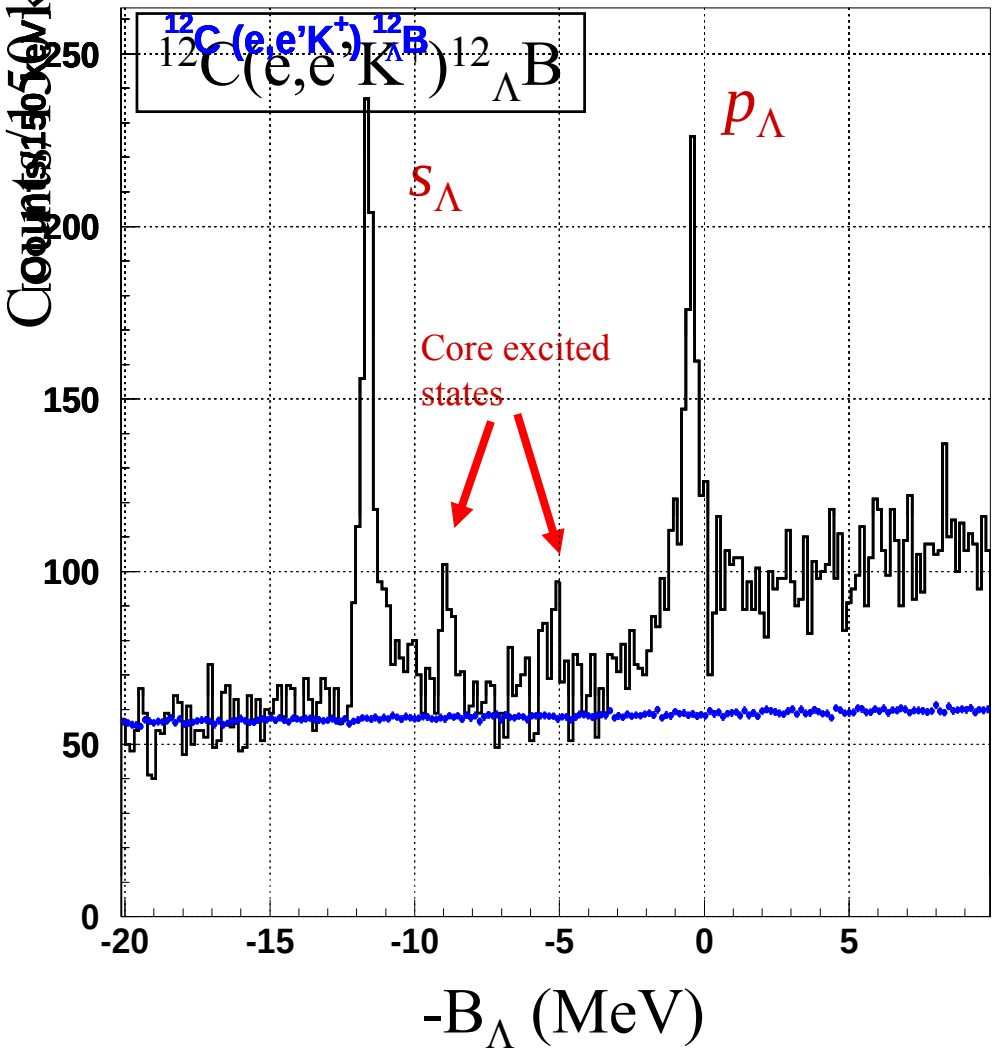
c.f. E89-009, 183 hours
(8.8 mg/cm², 0.5 or 1.0 μA)
T. Miyoshi *et al.*,
Phy. Rev. Lett. **90**, 232502(2003)



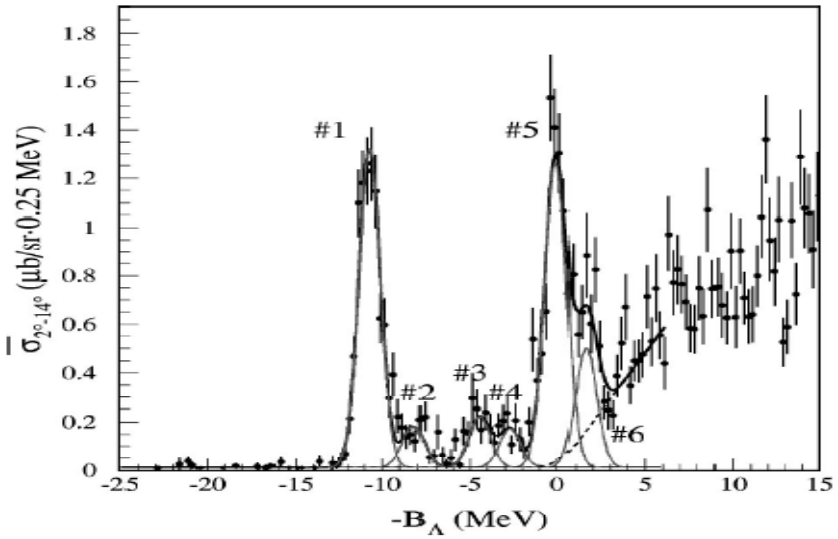
Better resolution and statistics

$^{12}C(e,e'K^+)^{12}_{\Lambda}B$ (preliminary)

Data taking : ~90 hours w/ 30 μA
Ground State : ΔE ~ 470 keV (FWHM)



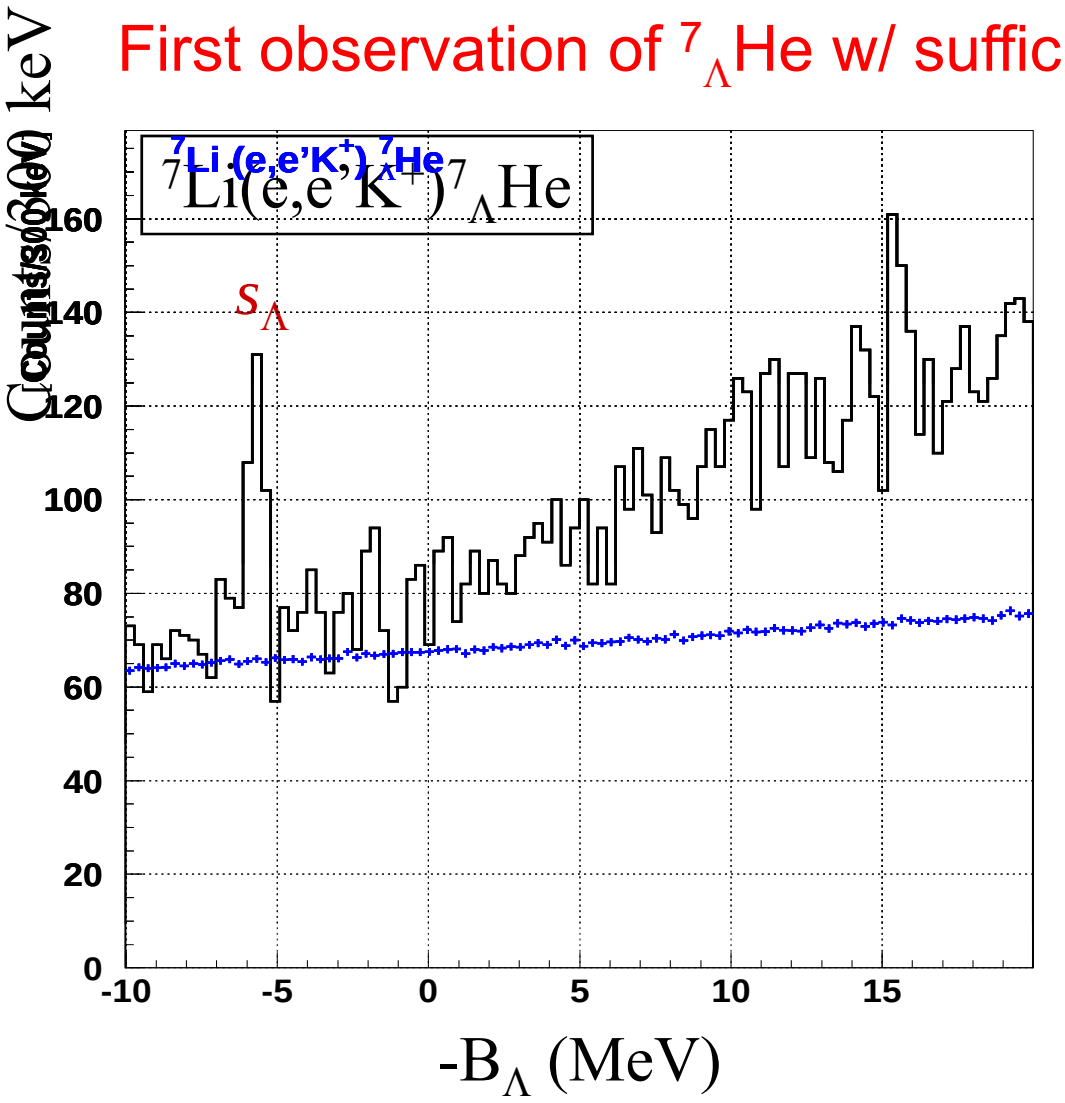
Mirror-symmetric $^{12}_{\Lambda}C$ @ (π^+,K^+)
T. Hotchi *et al.*,
Phys. Rev. C 64(2001) 044302



^{7}Li(e,e'K^{+})$^{7}_{\Lambda}$He (preliminary)

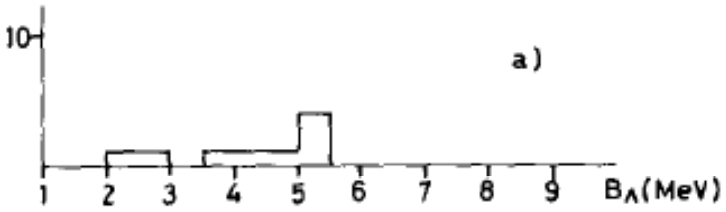
Data taking : ~30 hours w/ 30 μA

First observation of $^{7}_{\Lambda}$He w/ sufficient statistics



E. Hiyama (Preliminary)
B_{Λ}=5.83 MeV by 4-body calc.

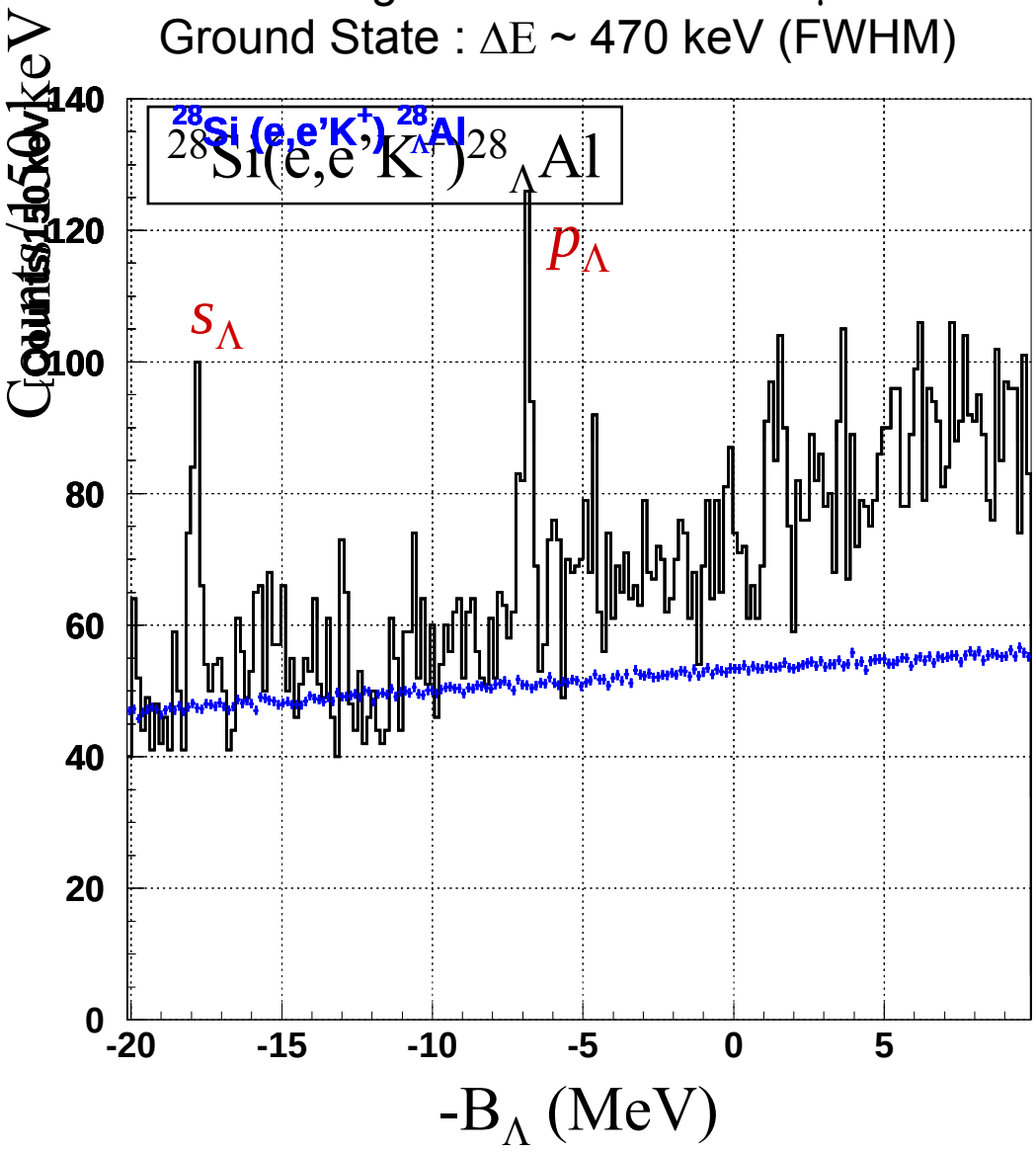
Emulsion data of $^{7}_{\Lambda}$He
M.Jurič et al.,
Nucl. Phs. B52(1973) 1



^{28}Si(e,e'K$^+$)$^{28}_{\Lambda}$Al (preliminary)

Data taking : ~140 hours w/ 30 μA

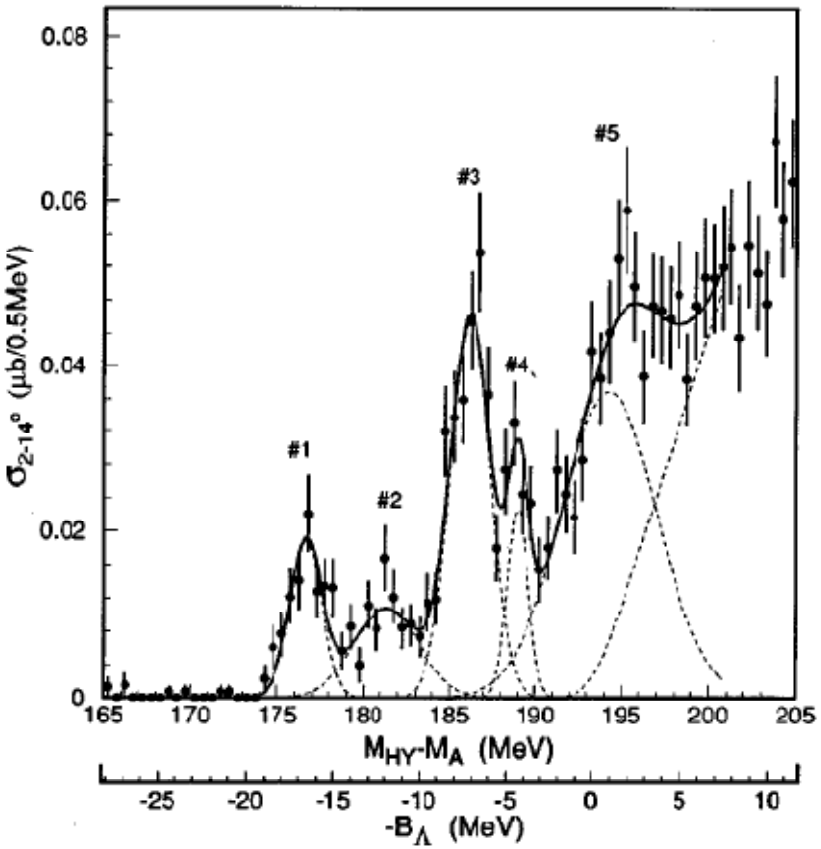
Ground State : ΔE ~ 470 keV (FWHM)



Mirror-symmetric $^{28}_{\Lambda}$Si @ (π^+,K$^+$)

T. Hasegawa et al.,

Phys. Rev. C 53(1996) 1210



Ground state : ΔE ~ 2200 keV (FWHM)

Third generation experiment
JLab E05-115

- Experiment scheduled in summer 2009

Please see posters of T.Maruta and D.Kawama for details of experimental setup and current status.

3rd Generation hypernuclear experiment

JLab E05-115

- ^{52}Cr(e,e'K$^+$)$^{52}_{\Lambda}$V reaction
  - Λ binding energies for *s*,*p*,*d*,*f* orbits
  - Λ hypernuclear structure
  - *ls* splitting in *l*=2,3 orbits if the splitting is sizable
    or information about the configuration mixing of core nucleus

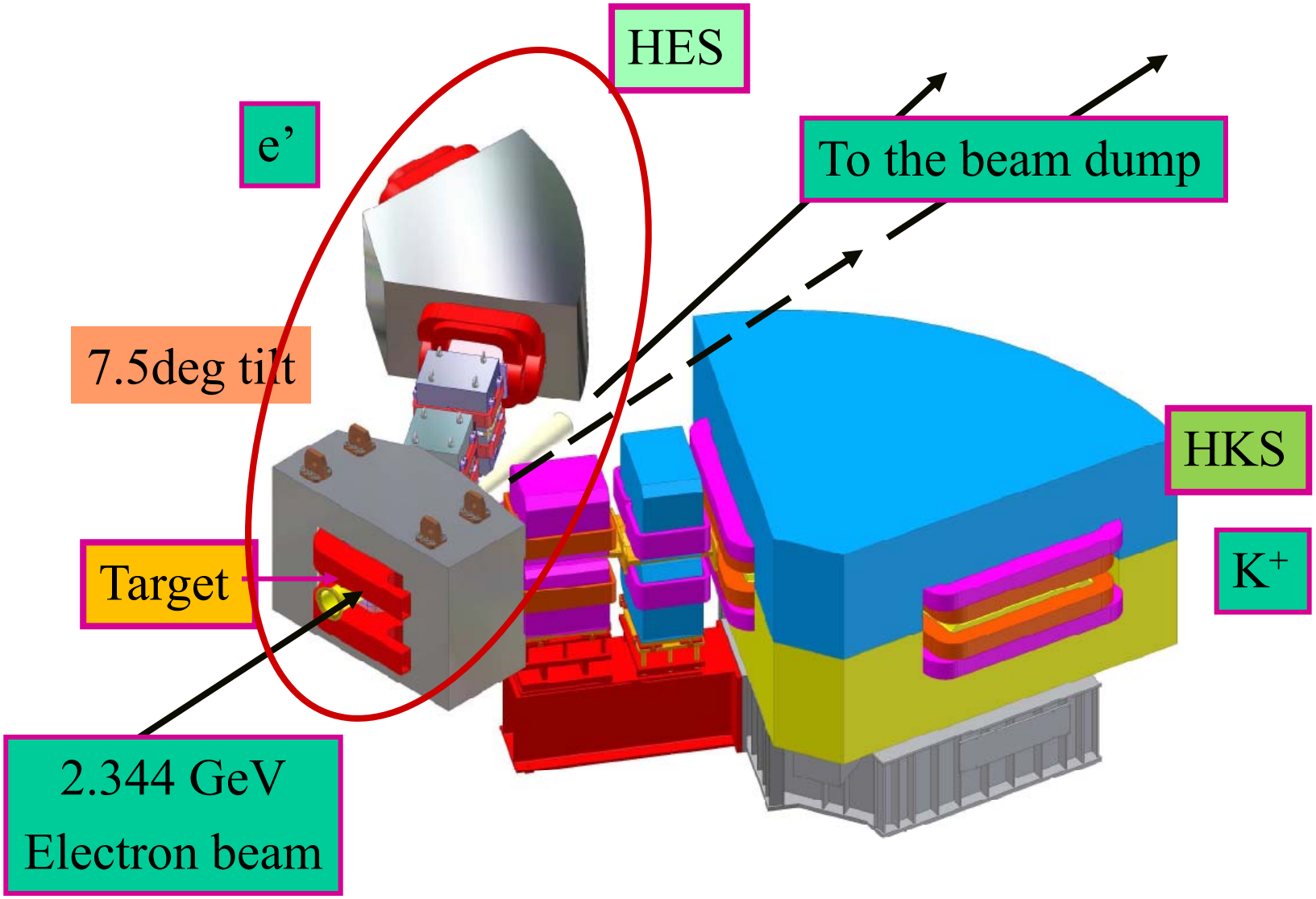
- ^{89}Y(e,e'K$^+$)$^{89}_{\Lambda}$Sr reaction
  - feasibility of (e,e'K$^+$) spectroscopy in heavier hypernuclei

- ^{6,7}Li(e,e'K$^+$)$^{6,7}_{\Lambda}$He and ^{10,11}B(e,e'K$^+$)$^{10,11}_{\Lambda}$Be
  - Precision hypernuclear structure in neutron-rich Λ hypernuclei
  - $\Lambda\Sigma$ coupling effect changing isospin with neutron number

Introduction of a new electron spectrometer (HES)
and a new charge separation magnet (Splitter)

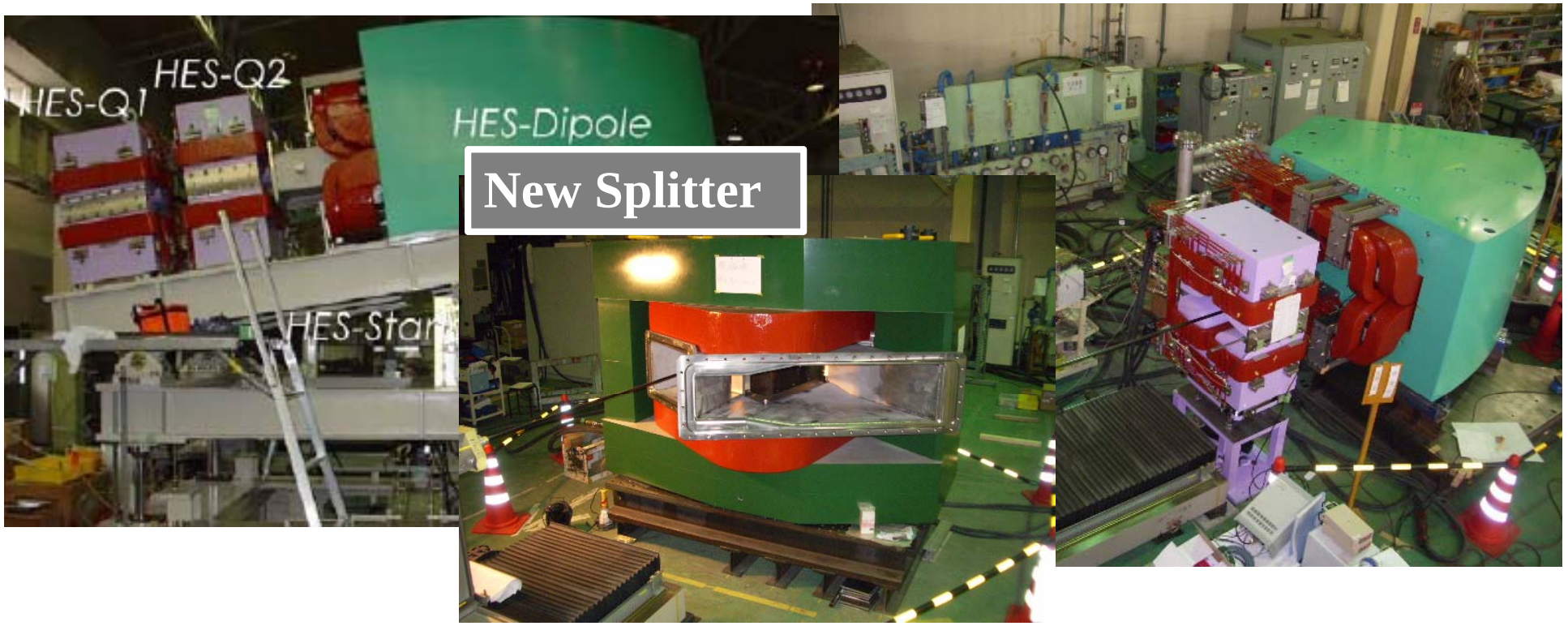
HKS + HES + New Splitter

Fully optimized for (e,e'K^+) hypernuclear spectroscopy



HES from Tohoku Univ.

E05-115 with HKS/HES



Spectrometer magnets were constructed at TOKIN, SENADAI and shipped to JLab

Evolution of $^{12}_{\Lambda}$B spectra

E89-009

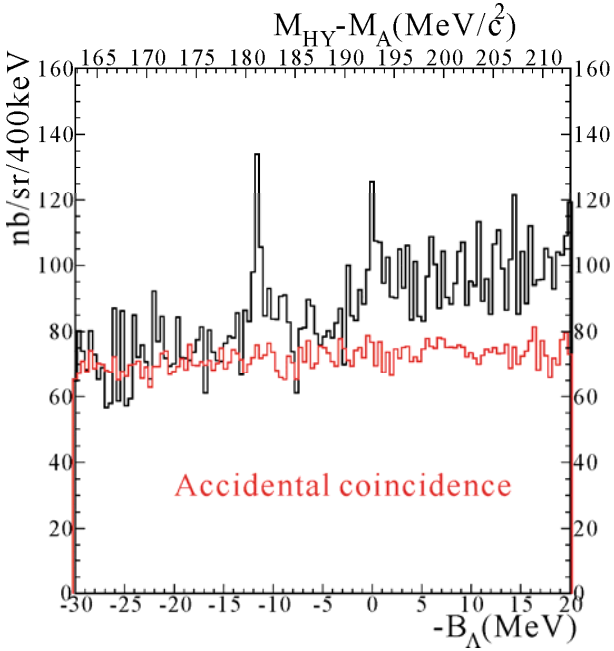
~300h x 0.6μA

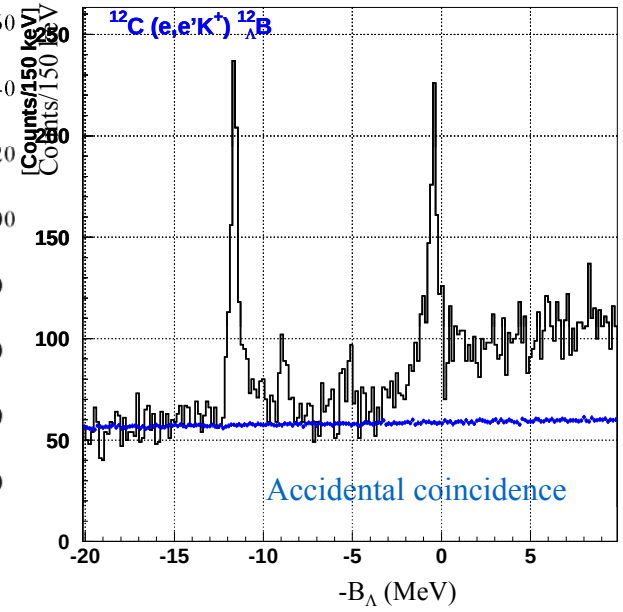
E01-011

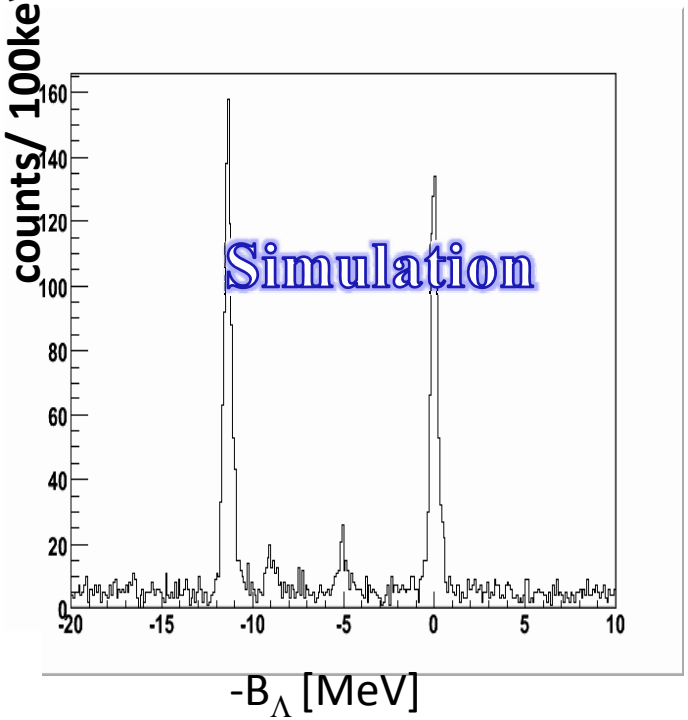
~120h x 30μA

E05-115

~24h x 30μA







Evolution of (e,e'K$^+$) hypernuclear spectroscopy at JLab Hall C

	2000	2005	(2009)
	E89-009	**E01-011**	**E05-115**
Configuration	SOS+ENGE +Splitter	HKS+ENGE +Splitter	HKS+HES +New splitter
Beam intensity (μA) on ^{12}C	0.66 ×40	24 ×5	30-100
thickness (mg/cm^2)	22 ×5	100	100
Hypernuclear yield ($^{12}_{\Lambda}B_{gr.}$ /hr)	**0.9** ×10	**10** ×10	**[> 40-100]**
Resolution (keV)	**750**	**400~500**	**[300-400]**
Beam energy (GeV)	1.7-1.8	1.850	2.344
p_K (central : GeV)	1.2	1.2	1.2
p_e (central: GeV)	0.3	0.3	0.7 – 1.0
θ_K (degree)	0-7	1-13	1-13
θ_e (degree)	0	4.5	6.5

[ ] expected

HKS+Tilt HKS+Tilt+HES

Summary

JLab Hall C hypernuclear spectroscopy collaboration has been performed a series of experiments using (e,e'K^+) reaction :

-E89-009 at 2000 : The proof of principle; SOS+ENGE+Spl.

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

-E01-011 at 2005 : Technique established; **HKS**+**tilted** ENGE+Spl.

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

We have good data on $^{7}_{\Lambda}$He, $^{12}_{\Lambda}$B, $^{28}_{\Lambda}$Al, to be finalized shortly

-E05-115 (2009) : Precision spectroscopy in the wide mass region

HKS+HES(tilted)+New Spl.

$^{6,7}_{\Lambda}$He, $^{10,11}_{\Lambda}$Be, $^{12}_{\Lambda}$B, $^{28}_{\Lambda}$Al, ($^{40}_{\Lambda}$K), $^{52}_{\Lambda}$V, $^{89}_{\Lambda}$Sr

We will have wide variety of hypernuclei data in 2009

After 12GeV upgrade of JLab, hypernuclear program of Hall A and Hall C are going to merge → Very strong collaboration