HYPERNUCLEAR PHYSICS USING CEBAF BEAM

PAST AND FUTURE

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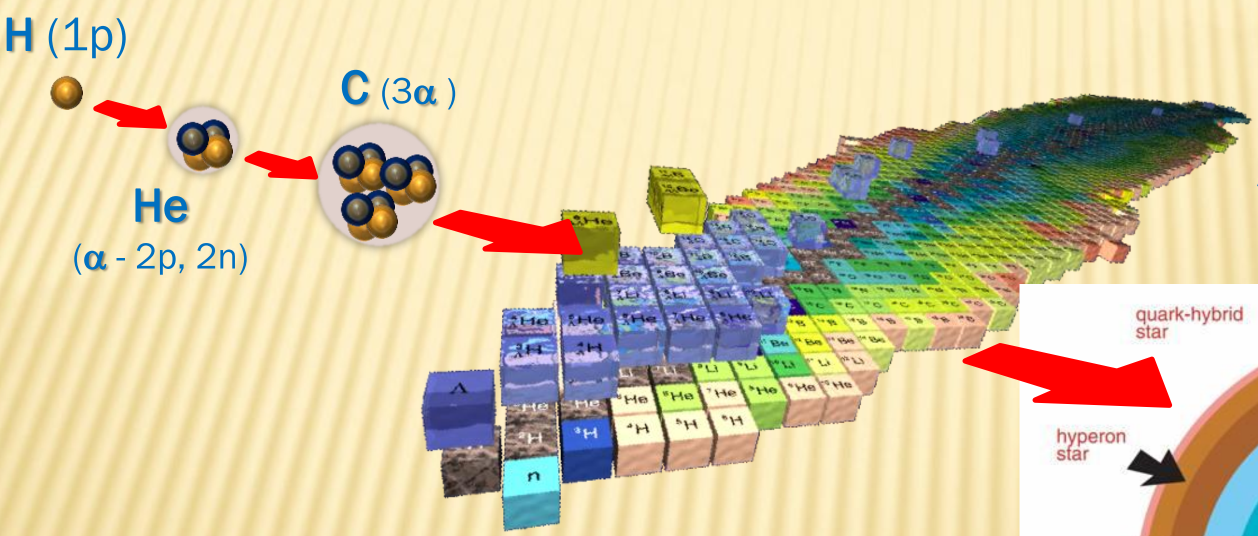
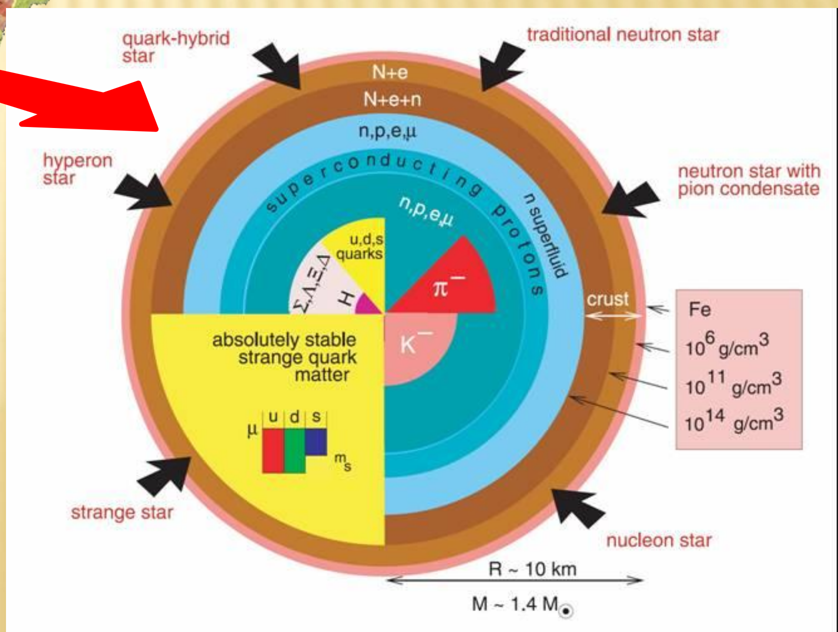
INTRODUCTION – BARYONIC INTERACTIONS

Baryonic interaction (*B-B)* is an important part of nuclear force that builds the "world"



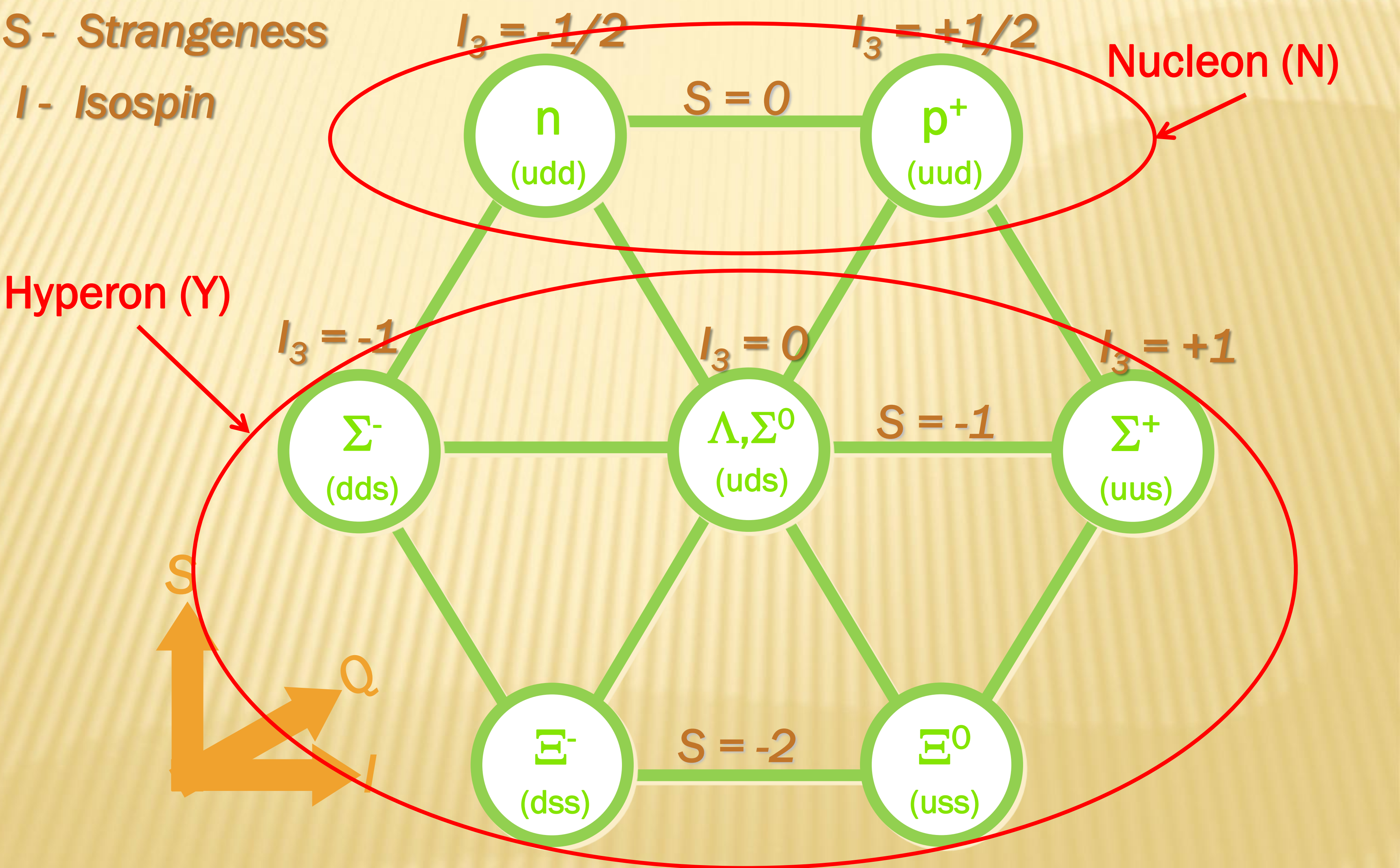
Astronomical Scale -

Neutron Stars -



Understand *B-B* interactions is one of the essential tasks in Nuclear Physics

INTRODUCTION – $J^P=1/2^+$ BARYON FAMILY

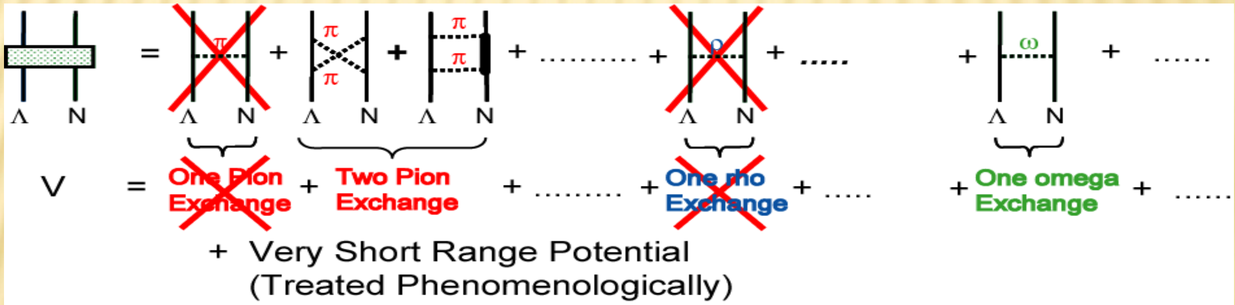


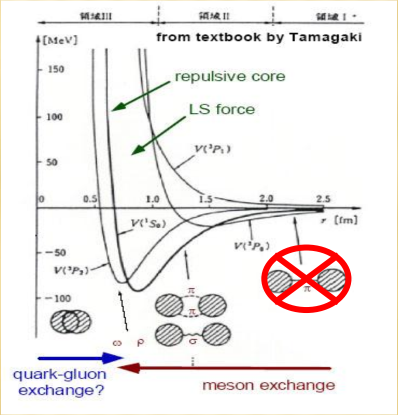
INTRODUCTION – HYPERNUCLEAR PHYSICS

- To understand YN and YY interactions
  - Producing Y inside of the nucleus
  - Extract YN and YY interactions by studying the many body system

> ΛN and $\Lambda\Lambda$ are the most fundamental interactions. Since Λ decays only weakly ($\Lambda \rightarrow \pi$N or ΛN$\rightarrow$NN) thus long lifetime, mass spectroscopy Λ-hypernuclei becomes possible analog to the nuclear mass spectroscopy

- To study short range interactions in baryonic interactions (OPE is absent in ΛN interaction)





- To better explore nuclear structure using Λ as a probe (not Pauli blocked by nucleons) and to explore new degree of freedom
  - Model the baryonic many body system
  - Study the role and the single particle nature of Λ in various nuclear medium and density

THEORETICAL DESCRIPTION: 2B POTENTIAL

- Shell Model with 2-B ΛN Effective Potential ($p_N s_\Lambda$)

$$V_{\Lambda N} = V_0(r) + V_\sigma(r)\, \boldsymbol{s}_N \cdot \boldsymbol{s}_\Lambda + V_\Lambda(r)\, \boldsymbol{L}_{N\Lambda} \cdot \boldsymbol{s}_\Lambda + V_N(r)\, \boldsymbol{L}_{N\Lambda} \cdot \boldsymbol{s}_N + V_T(r)\, S_{12}$$

$$\bar{V} \qquad \Delta \qquad S_\Lambda \qquad S_N \qquad T$$

5 Radial Integrals: Coefficients of operators

- Additional Contribution: Λ-Σ coupling
  + $\Lambda N \leftrightarrow \Sigma N$
  + Contribute to the repulsive core
  + Introduce an additional term: $\Lambda\Sigma$
- Observables:
  + Ground state single Λ binding energy
  + Excitation spectroscopy (levels and level spacing)
  + Production and production cross sections
  + Decays

BASIC PRODUCTION MECHANISMS

CERN → BNL → KEK & DAΦNE → J-PARC (Near Future)

Disadvantage: Lack absolute energy calibration and resolution

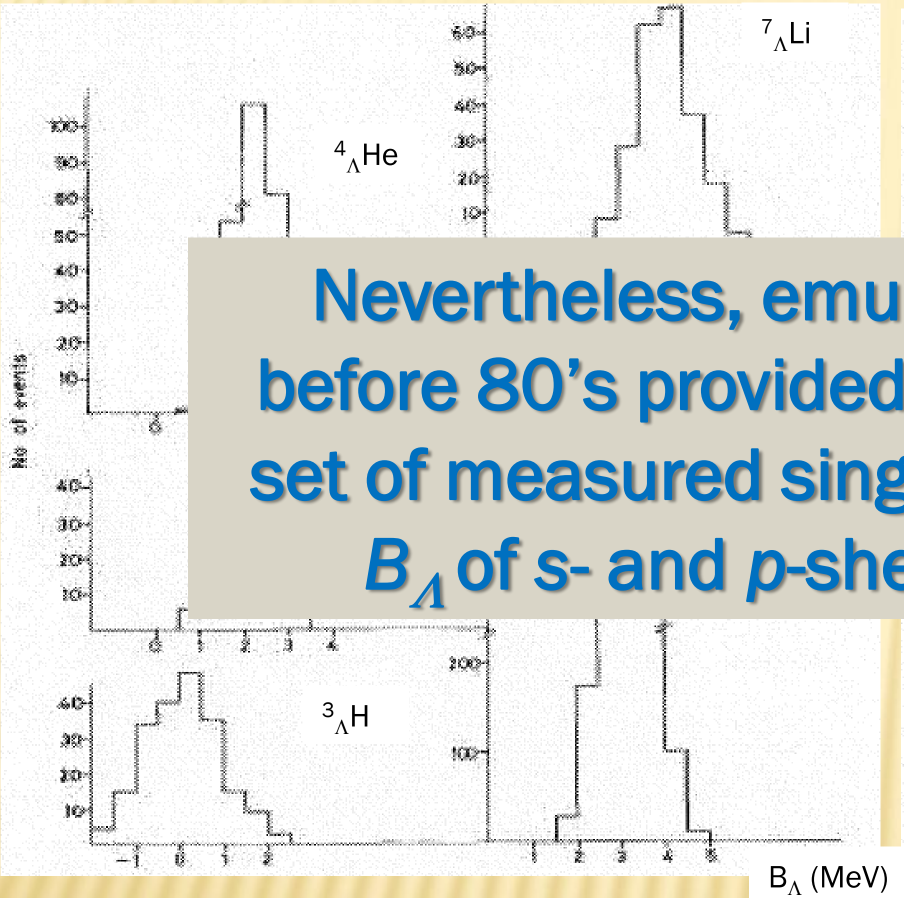
(e, e'K) Reaction

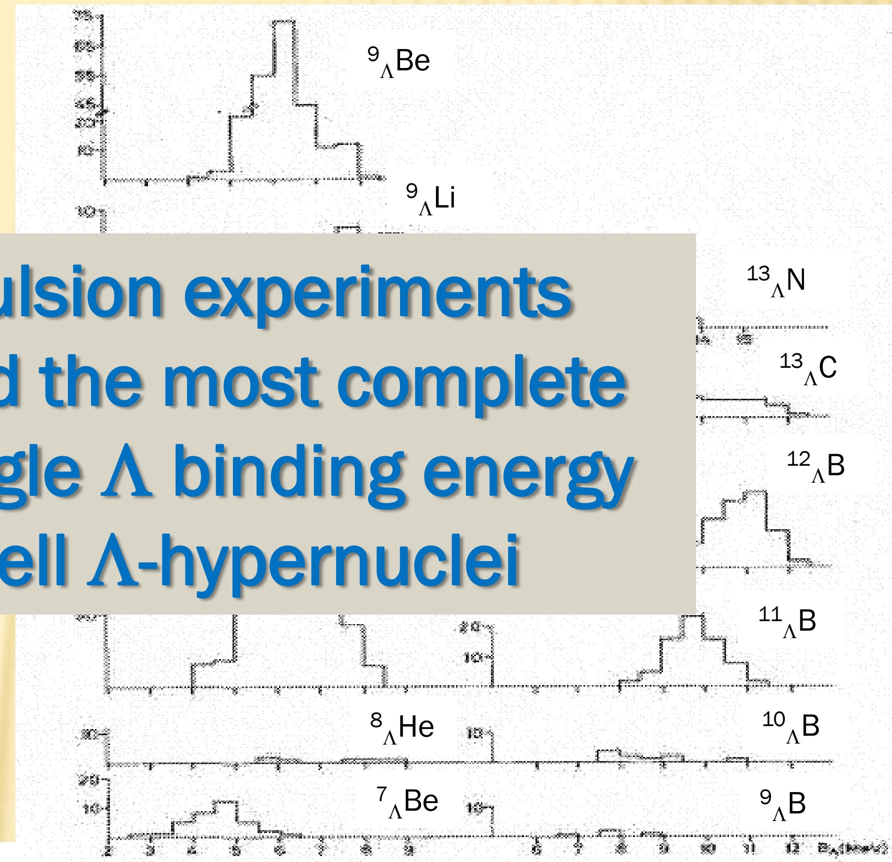
CEBAF at JLAB (MAMI-C Near Future)

Advantage: Absolute energy calibration & high resolution

- Neutron rich hypernuclei

RELIABILITY OF EMULSION RESULTS
USING (K^-_{STOP}, π^-) REACTION





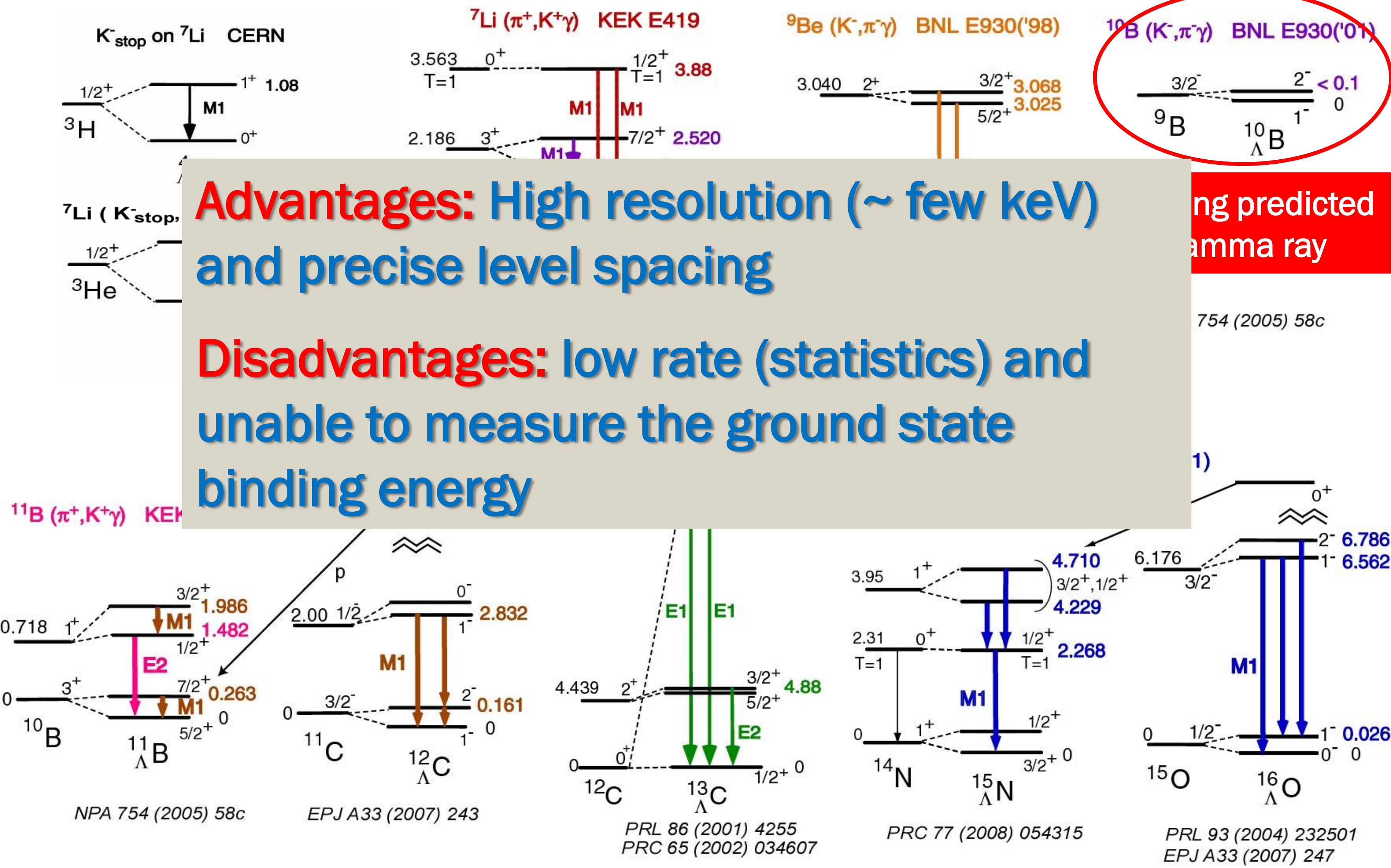
Nevertheless, emulsion experiments before 80's provided the most complete set of measured single Λ binding energy B_{Λ} of *s*- and *p*-shell Λ-hypernuclei

Important source of data
but lack statistics and resolution

Reliability: Questionable

ACHIEVEMENT OF GAMMA SPECTROSCOPY

22 GAMMA TRANSITIONS WERE SO FAR OBSERVED



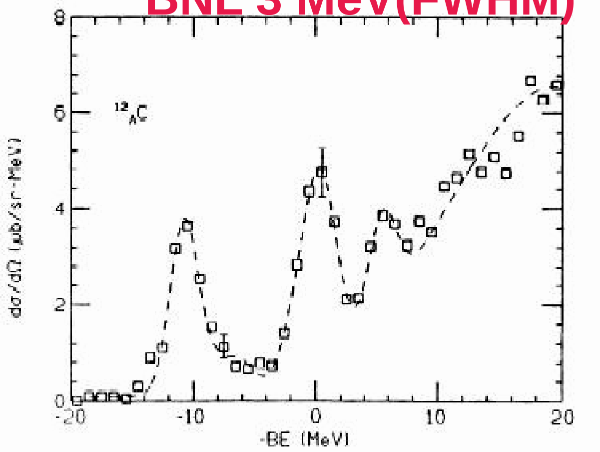
Advantages: High resolution (~ few keV) and precise level spacing

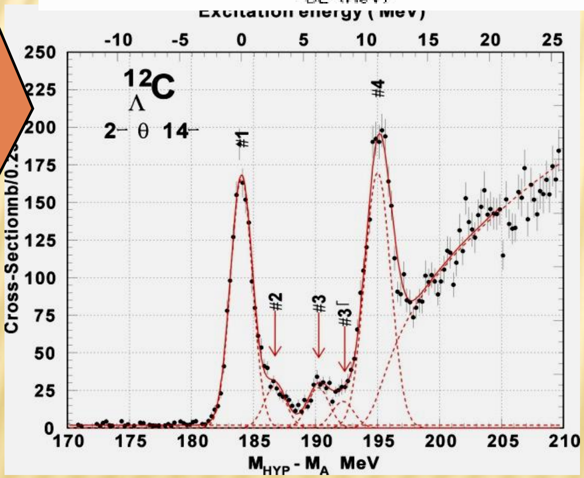
Disadvantages: low rate (statistics) and unable to measure the ground state binding energy

IMPORTANCE OF RESOLUTION AND MASS CALIBRATION

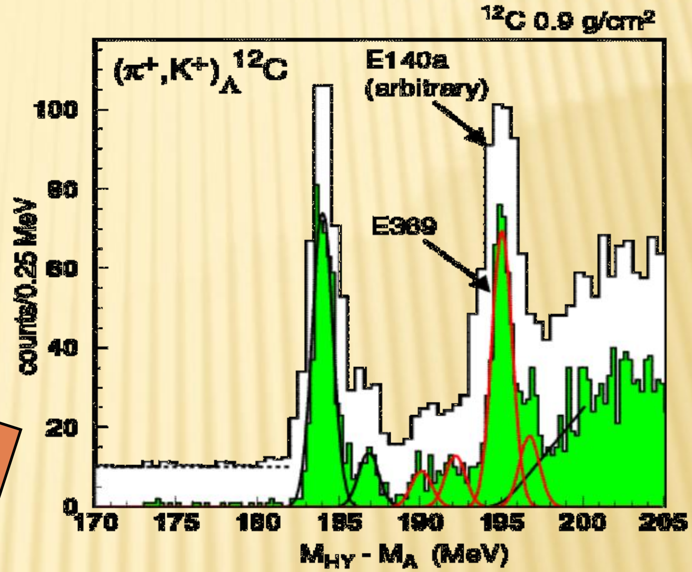
EXAMPLE: $^{12}C(\pi^+,K^+)^{12}{}_{\Lambda}C$ MASS SPECTRA WITH MESON BEAM

BNL 3 MeV(FWHM)





KEK336 2 MeV(FWHM)



KEK E369 1.5 MeV(FWHM)

High resolution, high yield, and systematic study is essential and is the key to unlock the "gate"

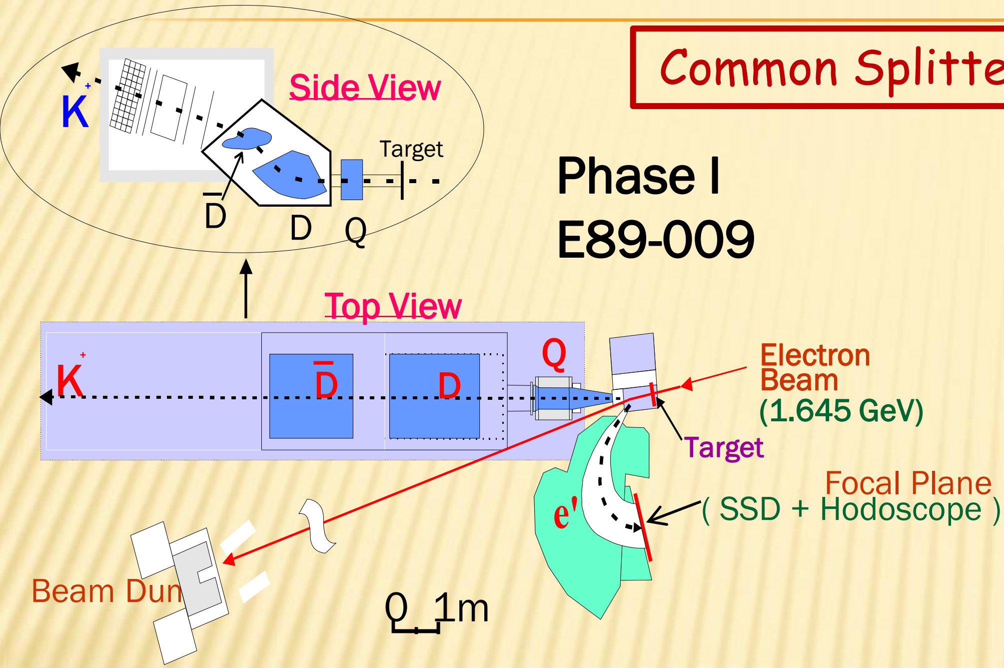
Meson beam lacks absolute mass calibration (no free neutron target)

ELECTRO-PRODUCTION USING CEBAF BEAM

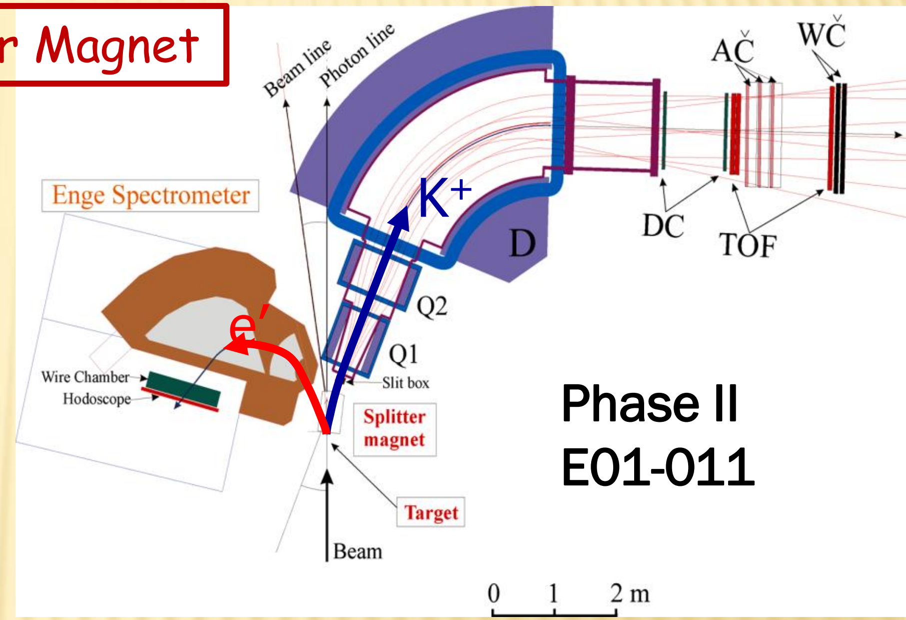
- High quality primary beam allows high precision mass spectroscopy on Λ-hypernuclei
- Producing Λ and Σ^0 from proton simultaneously allows absolute mass calibration – precise binding energy
- Mirror and neutron rich hypernuclei comparing those from (π^+,K^+) reaction
- Spectroscopy dominated by high spin-stretched spin-flip states
- Results are important in determining $\Lambda\Sigma$, S_N and V_0 terms from Λ_s states and S_Λ term from states with Λ at higher orbits

HALL C TECHNIQUE IN 6GEV PROGRAM

Common Splitter Magnet



Phase I
E89-009

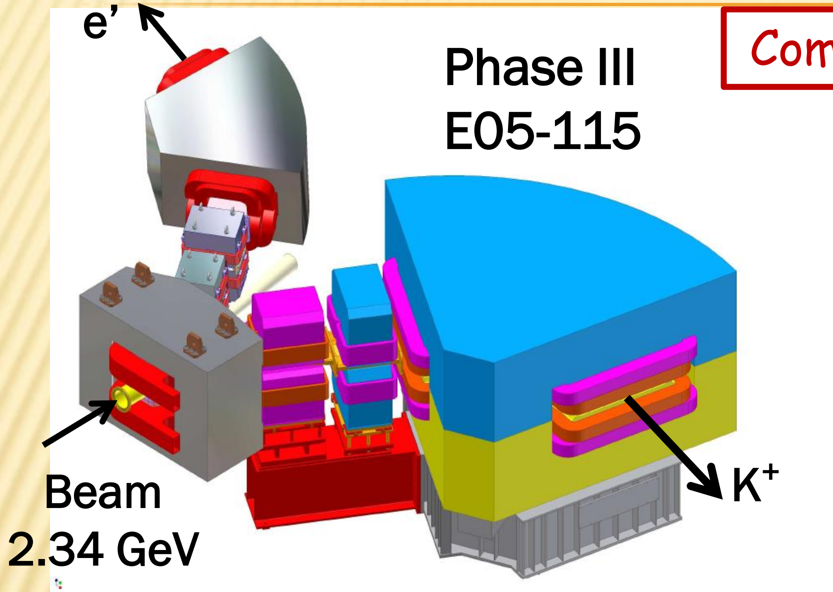


Phase II
E01-011

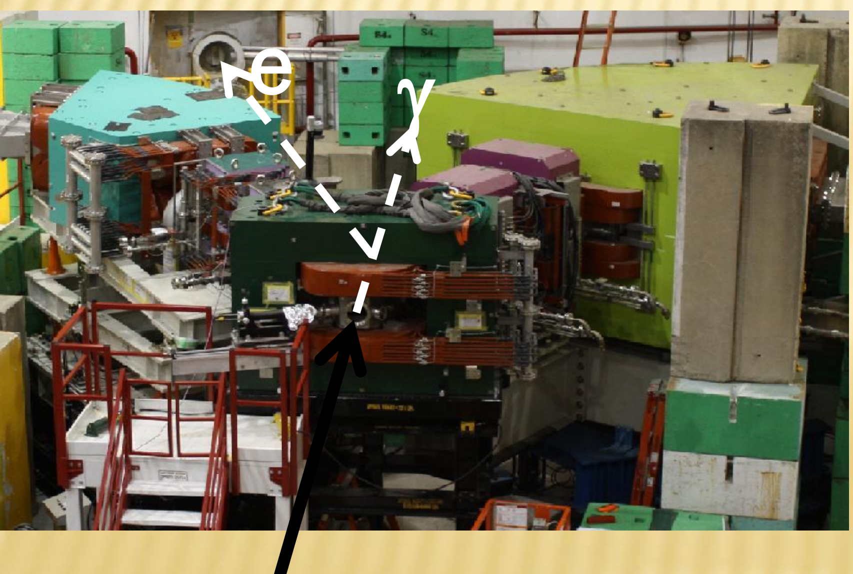
- ❖ Zero degree e' tagging
- ❖ High e' single rate
- ❖ Low beam luminosity
- ❖ High accidental rate
- ❖ Low yield rate
- ❖ A first important milestone for hypernuclear physics with electro-production

- ❖ New HKS spectrometer → large $\Delta\Omega$
- ❖ Tilted Enge spectrometer → Reduce e' single rate by a factor of 10^{-5}
- ❖ High beam luminosity
- ❖ Accidental rate improves 4 times
- ❖ High yield rate
- ❖ First possible study beyond p shell

HALL C TECHNIQUE IN 6GEV PROGRAM

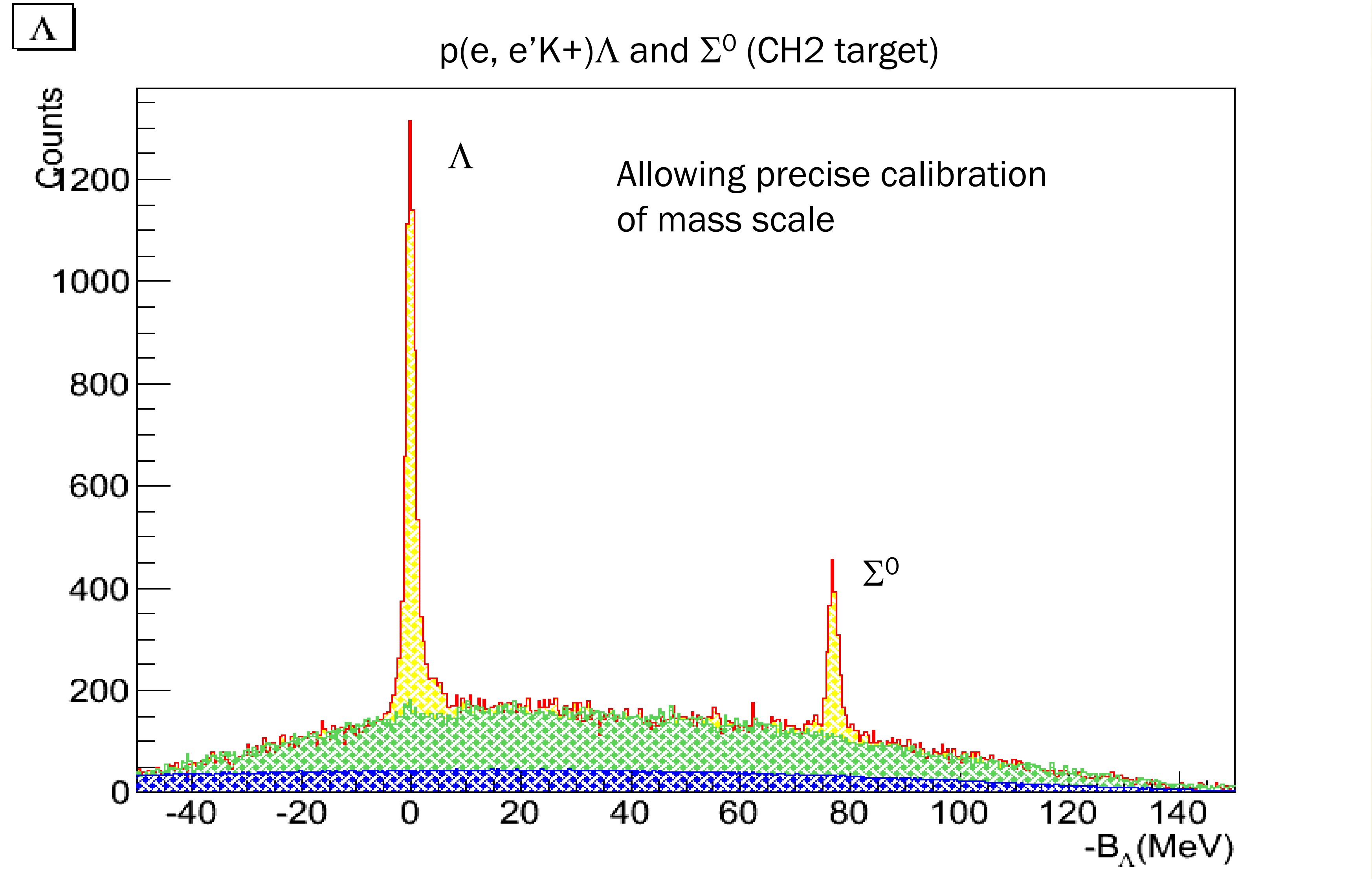


Common Splitter Magnet



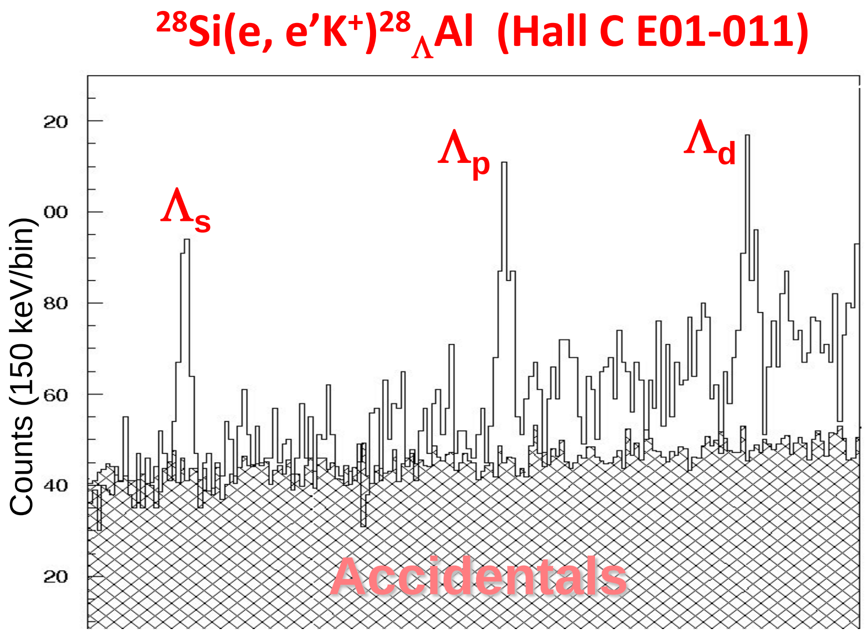
- New HES spectrometer → larger ΔΩ
- Same Tilt Method
- High beam luminosity
- Further improves accidental rate
- Further improves resolution and accuracy
- High yield rate
- First possible study for A > 50

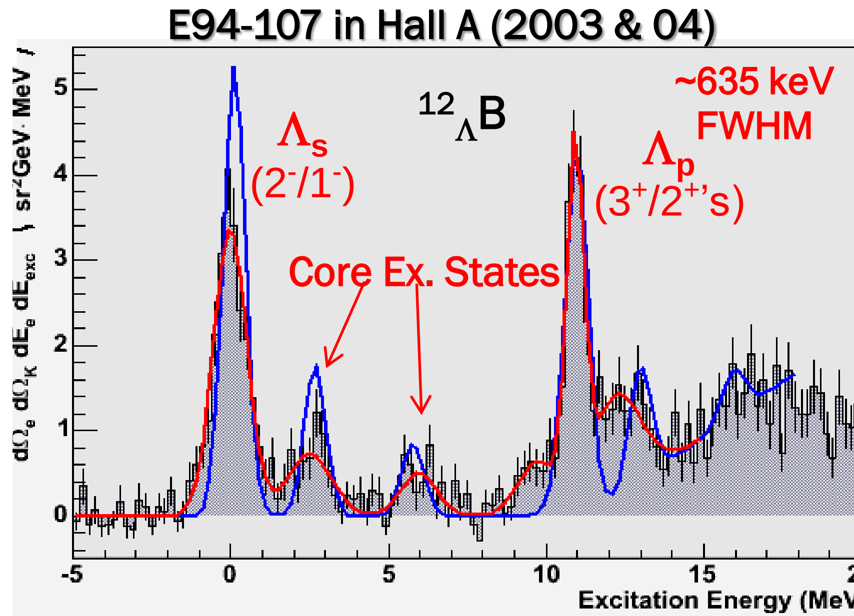
6GEV PROGRAM HIGHLIGHTS

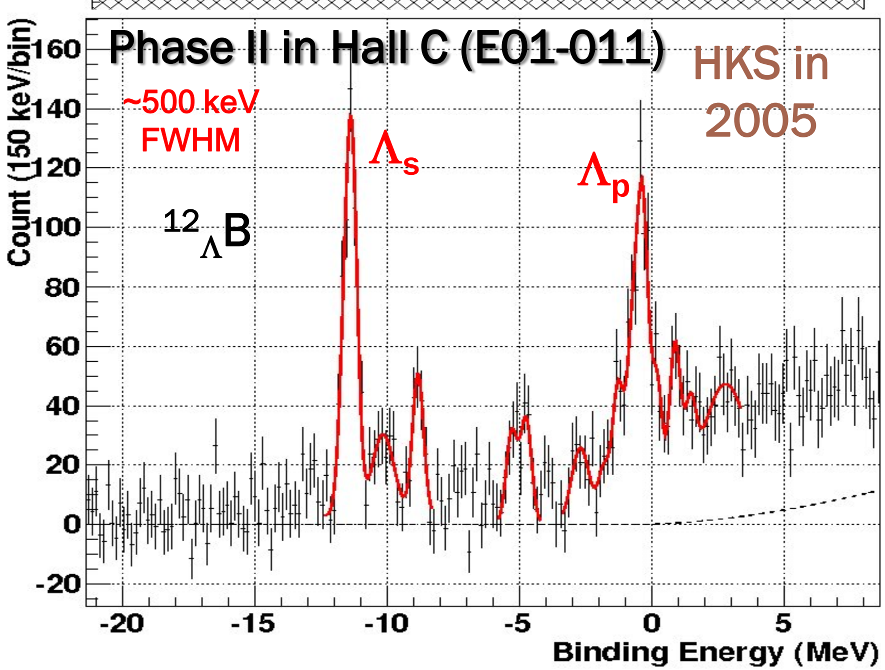


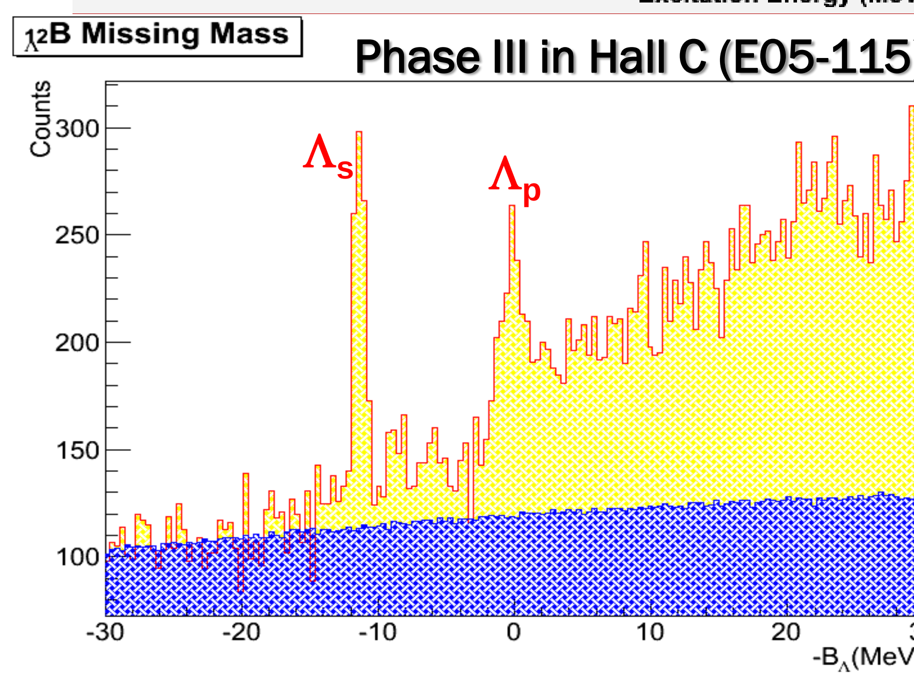
Allowing precise calibration of mass scale

6GEV PROGRAM HIGHLIGHTS– *CONT.*









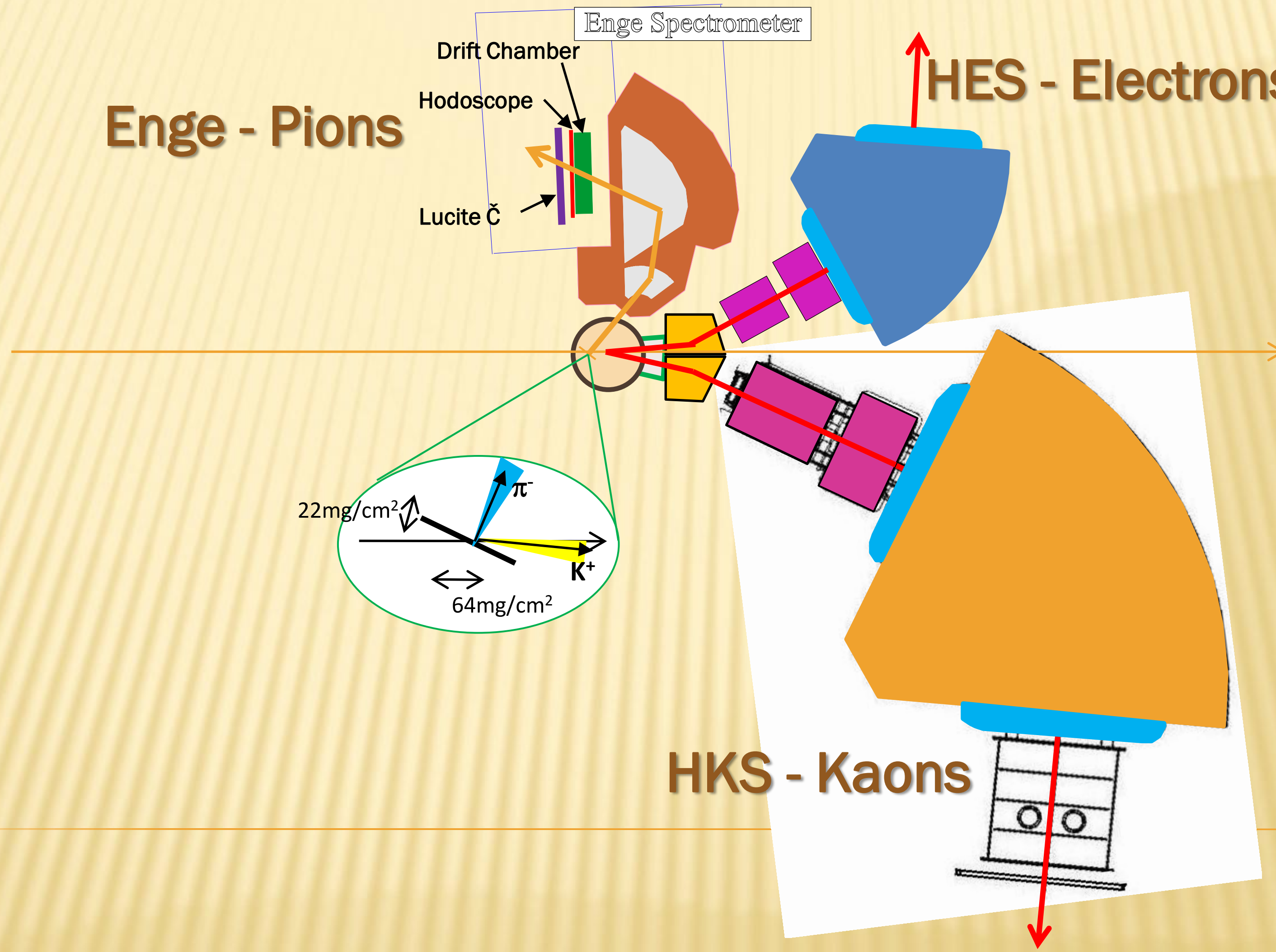
6GEV PROGRAM TECHNIQUE SUMMARY

- Hall A experiment (Pair of Septums + two HRS)
  - Advantage: Almost no accidental background and be able to study elementary process at low Q^2 at forward angle
  - Disadvantage: Low yield rate and cannot study heavier hypernuclei

- Hall C experiment (Common Splitter + HKS + HES/Enge)
  - Advantage: High yield rate and high precision in binding energy measurement
  - Disadvantage: High accidental background and solid targets only

Future program: Combination

EXPERIMENTAL LAYOUT IF IN HALL C



Trigger I: HKS(K) & Enge(π) for Decay Pion Spectroscopy Experiment
Trigger II: HKS(K) & HES(e') for Mass Spectroscopy Experiment

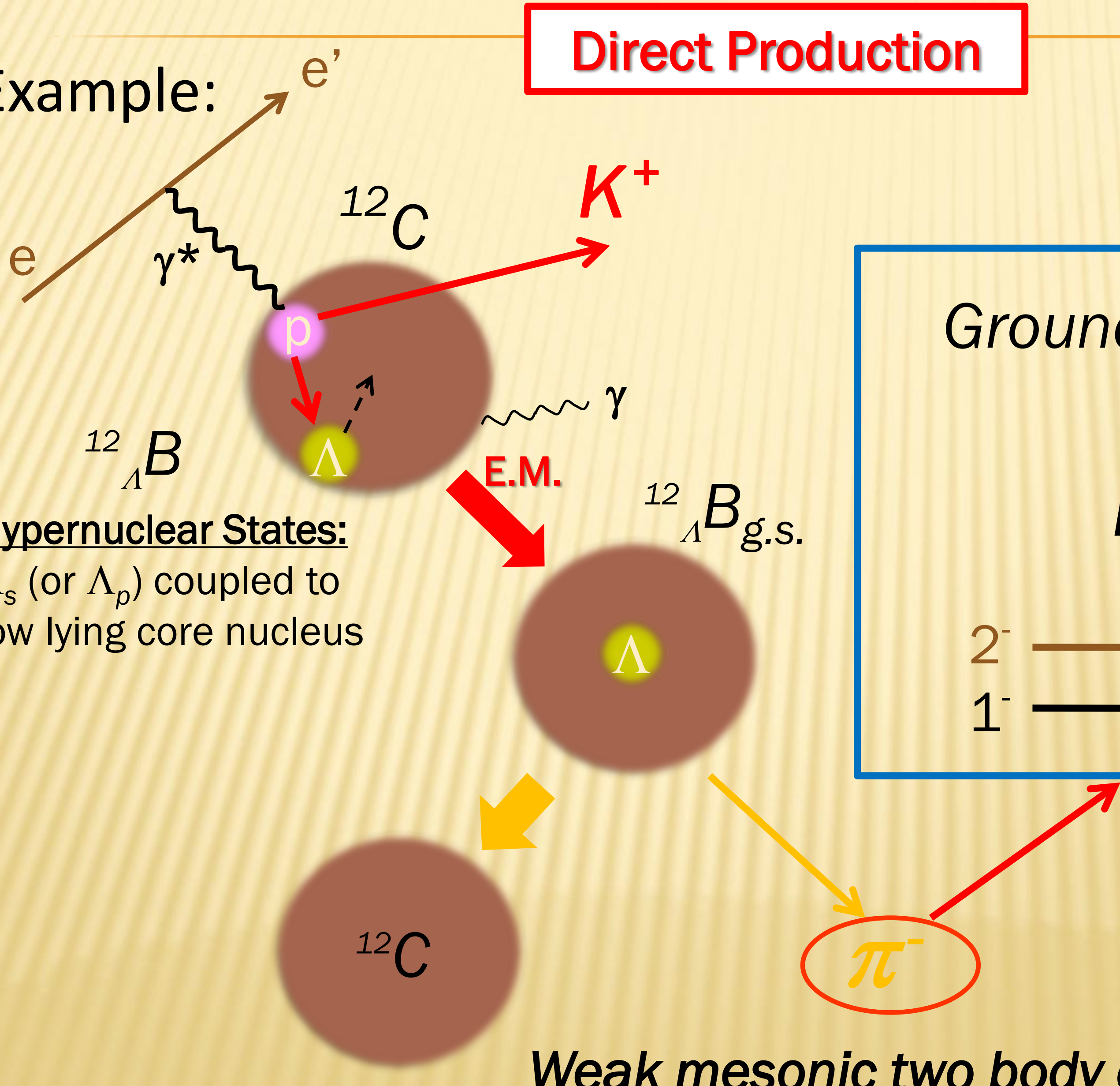
Technical Features of Future Program

- High quality with low background
- High precision on binding energy and high resolution
- High yield rate which leads to wide range of physics:
  - Elementary production at forward angle
  - Detailed and precise level structure of light and medium heavy hypernuclei (shell models)
  - Precise shell structure of heavy hypernuclei (single particle nature and field theory)
- High efficiency and productivity:

  one exp. ≈ Four 6GeV experiments
- New physics: Decay pion spectroscopy (Light Hypernuclei)
  - Precise ground state B_Λ
  - Determination of ground state J^p
  - Search for neutron rich limit (high Isospin states → $\Lambda\Sigma$)

DECAY PION SPECTROSCOPY TO STUDY Λ-HYPERNUCLEI

Example:



Hypernuclear States:
Λ_s (or Λ_p) coupled to low lying core nucleus

Ground state doublet of $^{12}_{\Lambda}B$

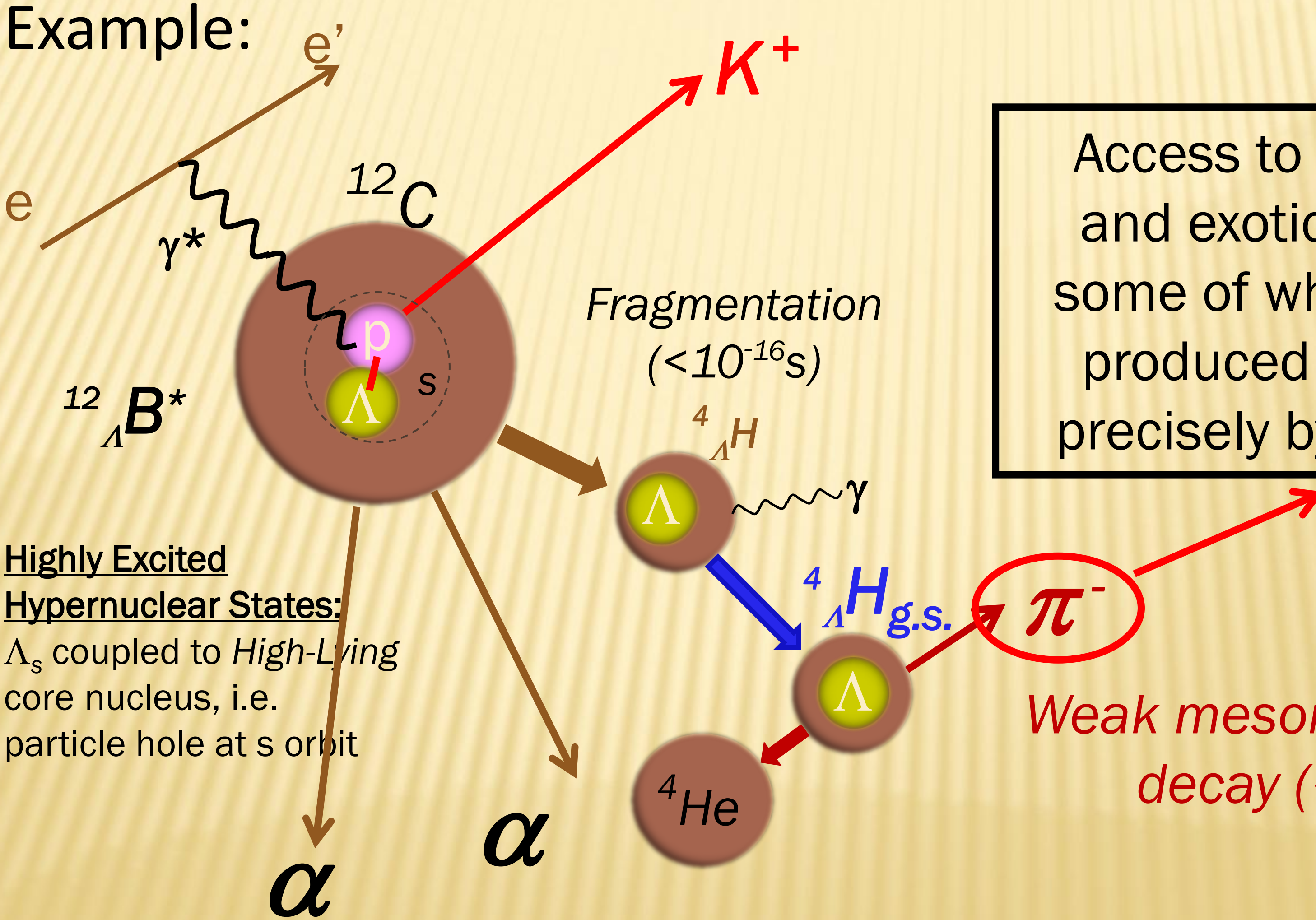
B_{Λ} and τ

2^-	———	~150 keV
1^-	———	0.0

DECAY PION SPECTROSCOPY FOR LIGHT AND EXOTIC Λ-HYPERNUCLEI

Fragmentation Process

Example:

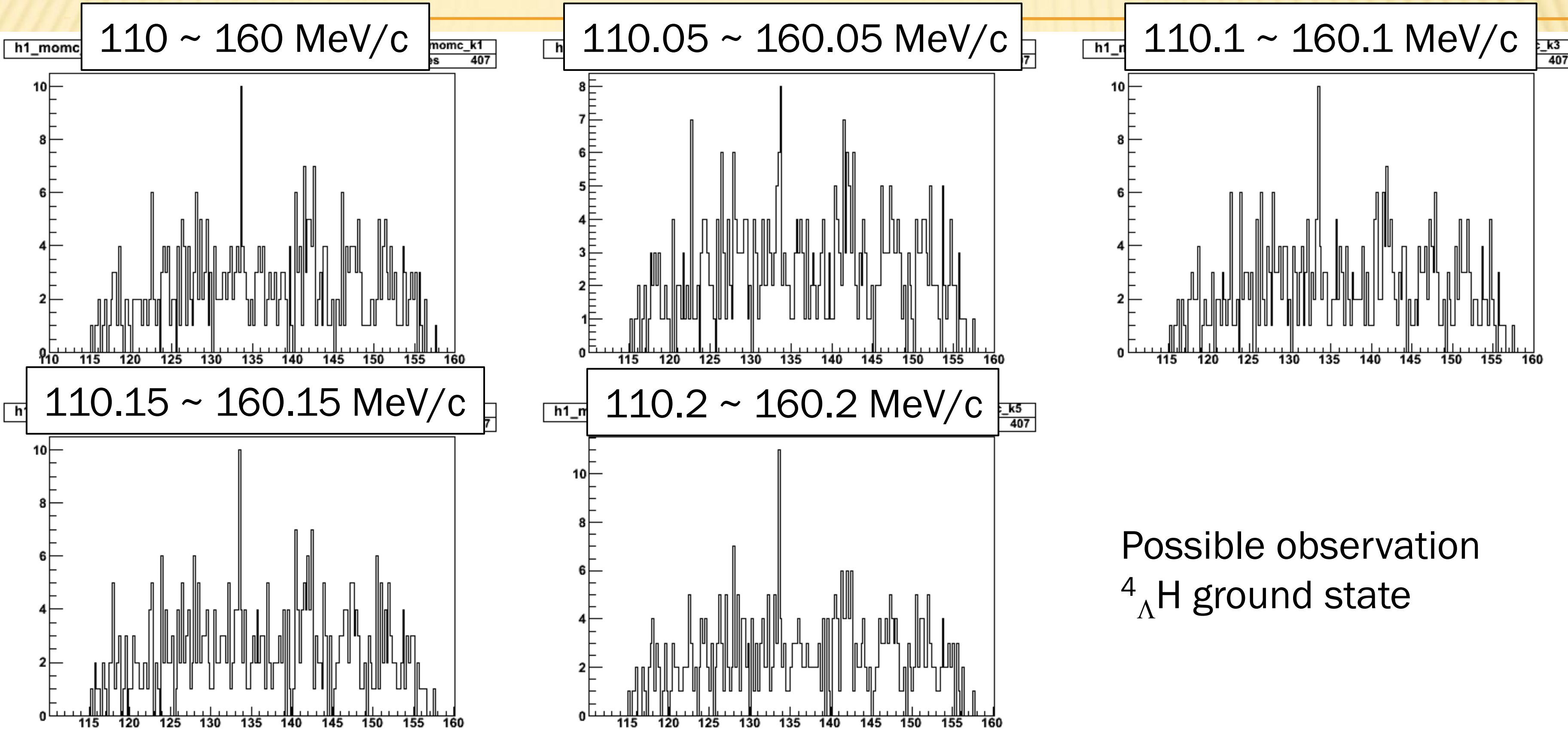


Access to variety of light and exotic hypernuclei, some of which cannot be produced or measured precisely by other means

__Highly Excited Hypernuclear States:__
Λ_s coupled to *High-Lying* core nucleus, i.e. particle hole at s orbit

Weak mesonic two body decay ($\sim 10^{-10}$s)

MAMI-C Short Test Run on Decay Pion Spectroscopy



Possible observation
$^{4}{}_{\Lambda}$H ground state

Central Mom. : 133.5 MeV/c $\rightarrow$ $B_{\Lambda}(^{4}{}_{\Lambda}H)$: ~ −1.60 MeV
Width : 97 keV/c FWHM
Target straggling loss was not corrected
Spec-C momentum calibration was not yet done

SUMMARY

- Hypernuclear Physics is an important part of nuclear physics
- Program with CEBAF beam is the only one that provides precise B_{Λ} and features as

  Precision mass spectroscopy program
- Future program will be highly productive