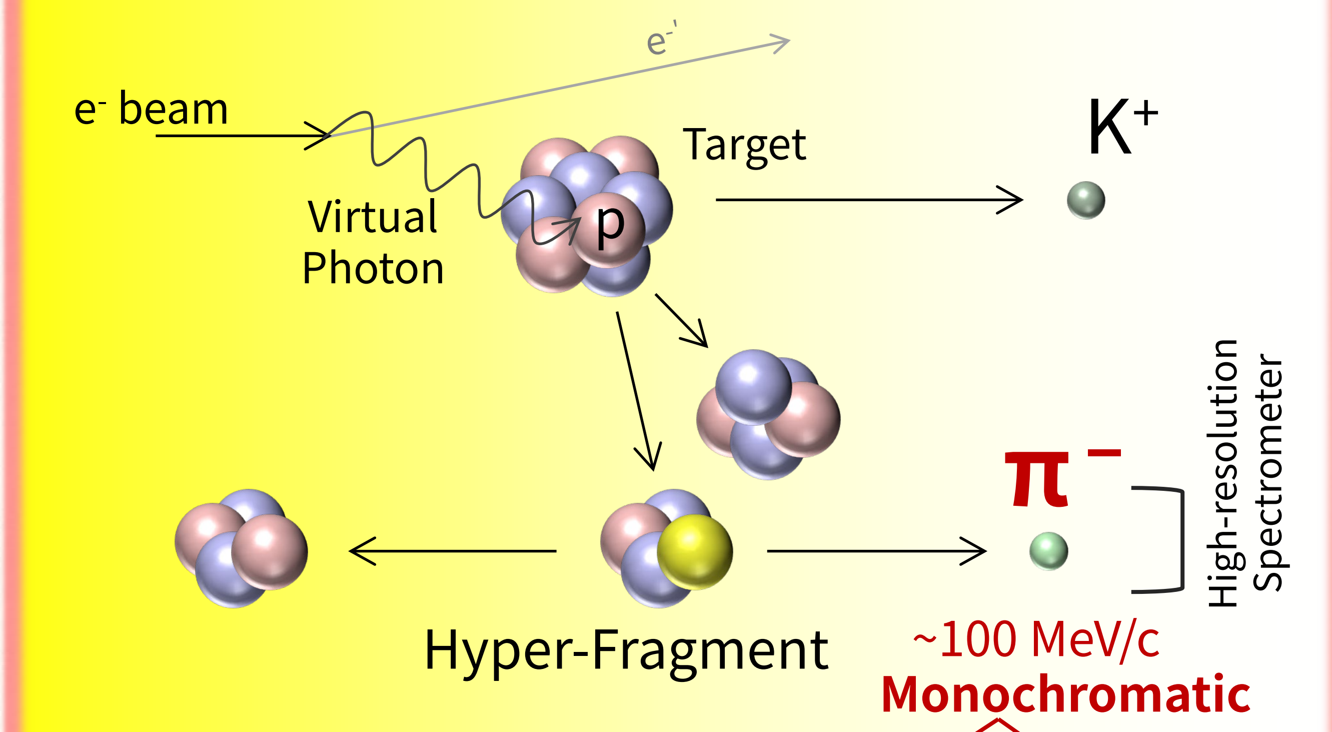
Enge for Decay Pion Spectroscopy

University of Tokyo
Sho Nagao

March 22, 2024

Decay Pion Spectroscopy

High-resolution, High-precision mass spectroscopy

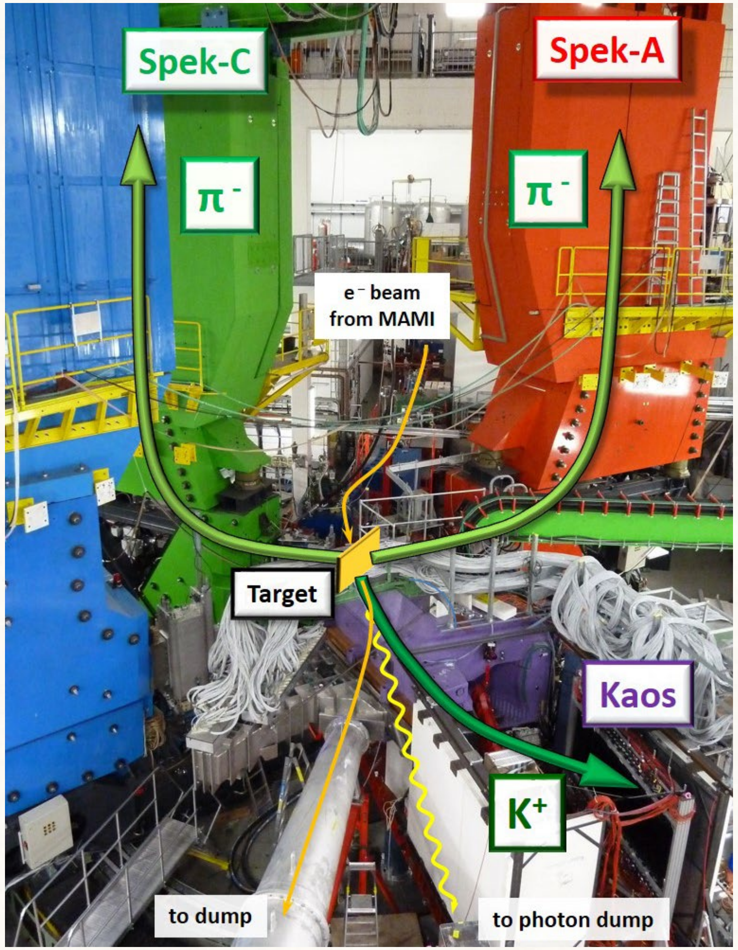


$$M({}^{A}_{\Lambda}Z) = \sqrt{M({}^{A}(Z+1))^2 + p_\pi^2} + \sqrt{M_\pi^2 + p_\pi^2}$$

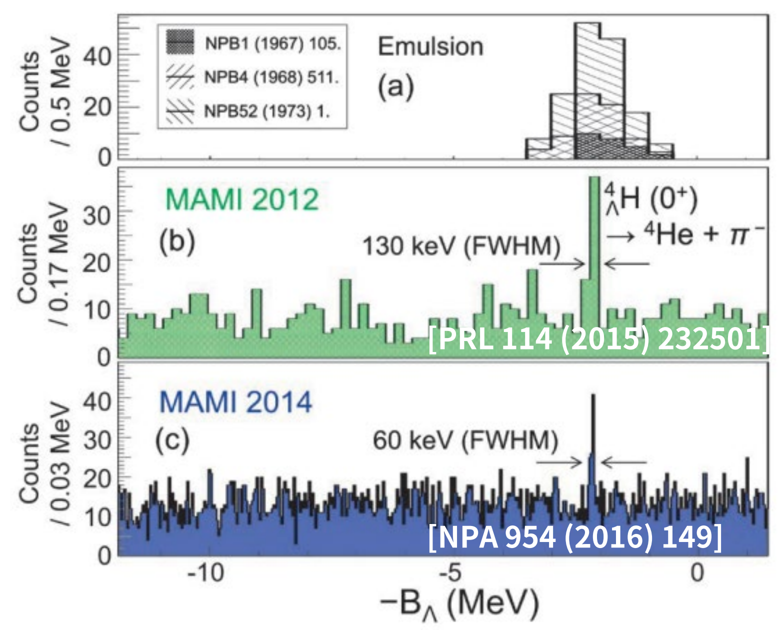
- Measurement of two-body decay pions
- Kaon Tagging
- Thin Target
  → High-Resolution
- Precise Momentum Calibration
  → Accurate mass
- More precise measurement than (e,eK+)
- Spectroscopy for the hyp. ground state

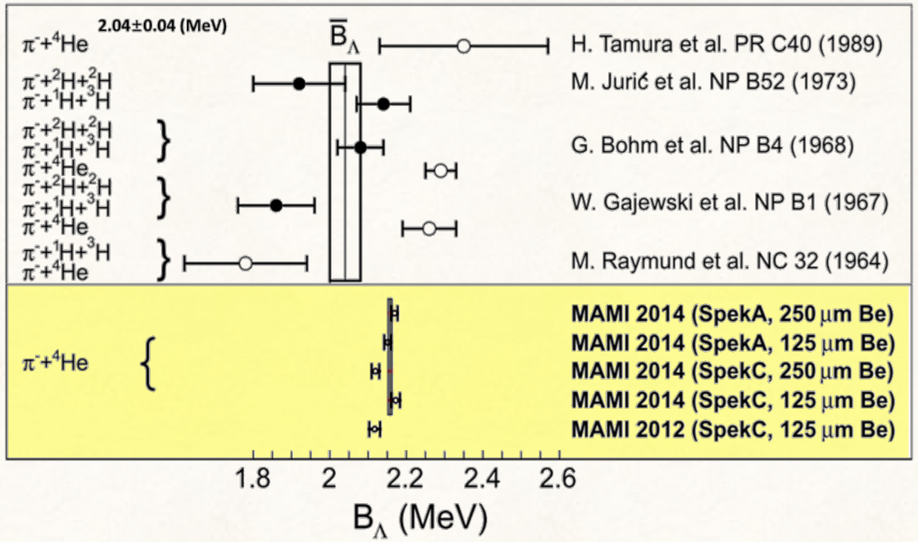
Previous Experiment at MAMI

Proof of Principle at MAMI



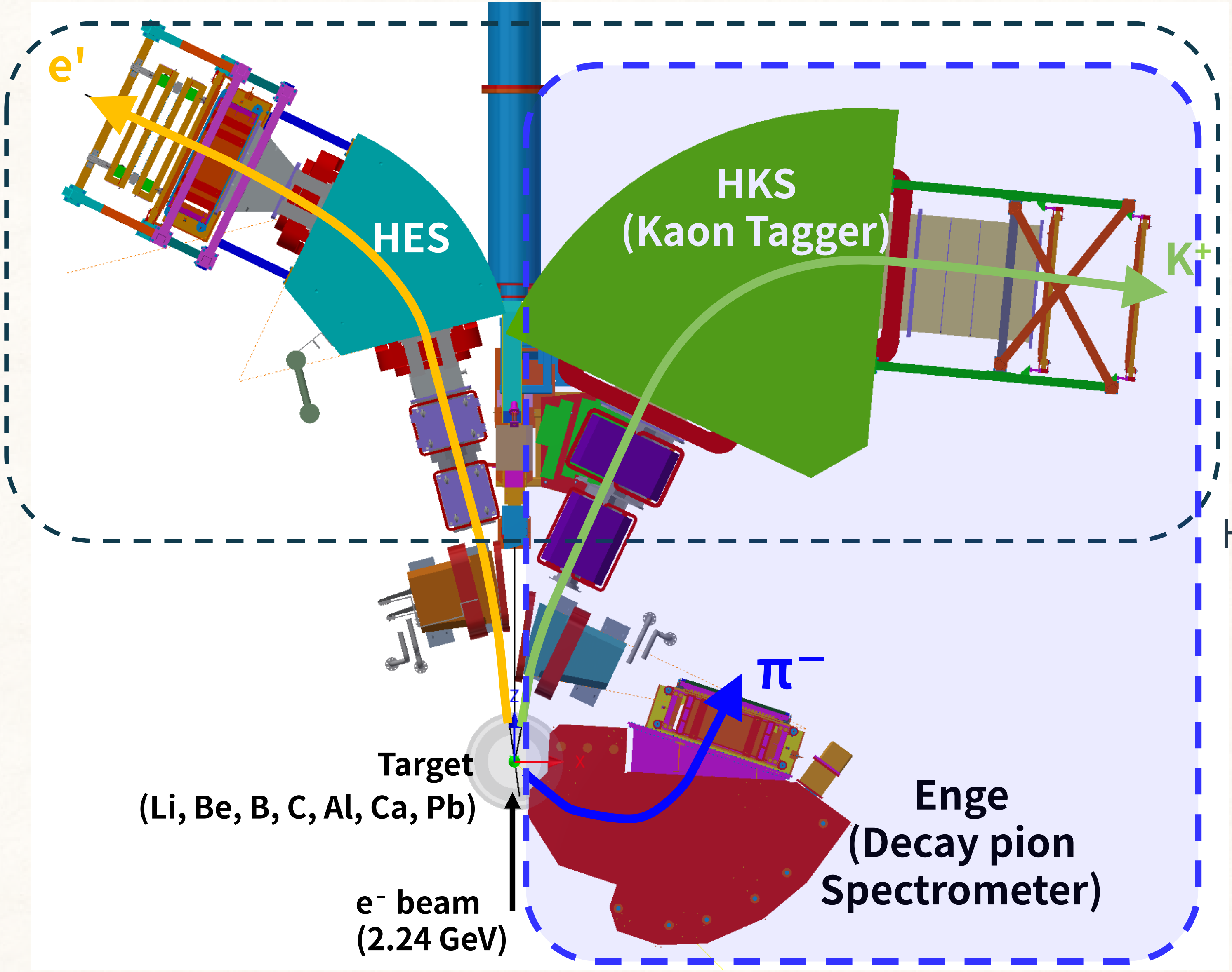
- Pion measurement with spectrometers at the backward angles
- First observation of ${}^{4}_{\Lambda}H \rightarrow {}^{4}He + \pi^{-}$
- N ~ 40, Resolution ~ 100 keV, Precision ~ 5 keV
- Large CSB between Λp - Λn





$$M({}^{A}_{\Lambda}Z) = \sqrt{M({}^{A}(Z+1))^2 + p_{\pi}^2} + \sqrt{M_{\pi}^2 + p_{\pi}^2}$$

Proposed DPS at JLab (LOI12-23-011)



Approved

- Medium-heavy $_{\Lambda}$K isotopes (E12-15-008)
- Super-heavy $^{208}{}_{\Lambda}$Tl (E12-20-013)

To be proposed

- CSB in p-shell (LOI12-23-013)
- Triaxial Deformation (LOI12-23-016)

High-resolution spectroscopy with HKS⊗HES

Another Spectrometer "Enge" for decay pion measurement

DPS with HKS⊗Enge

Parallel exp. with (e,e'K$^+$)

Advantage of DPS with CEBAF + HKS + Enge

- Higher Beam Energy (1.5 GeV → 2.3 GeV)
- Better K^+ ID (2-layers AC → 3-layers AC & 2-layers WC)
- Better Detector & DAQ Performance (several 100 Hz → several kHz)

  Higher beam current (20 → 50 μA) & Thicker target (40 → 150 mg/cm^2)

- Better yield per unit time (30 times)

$$N_{HYP} = \boxed{N_\Lambda} R_{F.P} \boxed{R_{stop}} \Gamma_{\pi^-} \Delta\Omega_{\pi^-} \boxed{\varepsilon_{\pi^-}^{decay}} \boxed{\varepsilon_{\pi^-}^{det}}$$

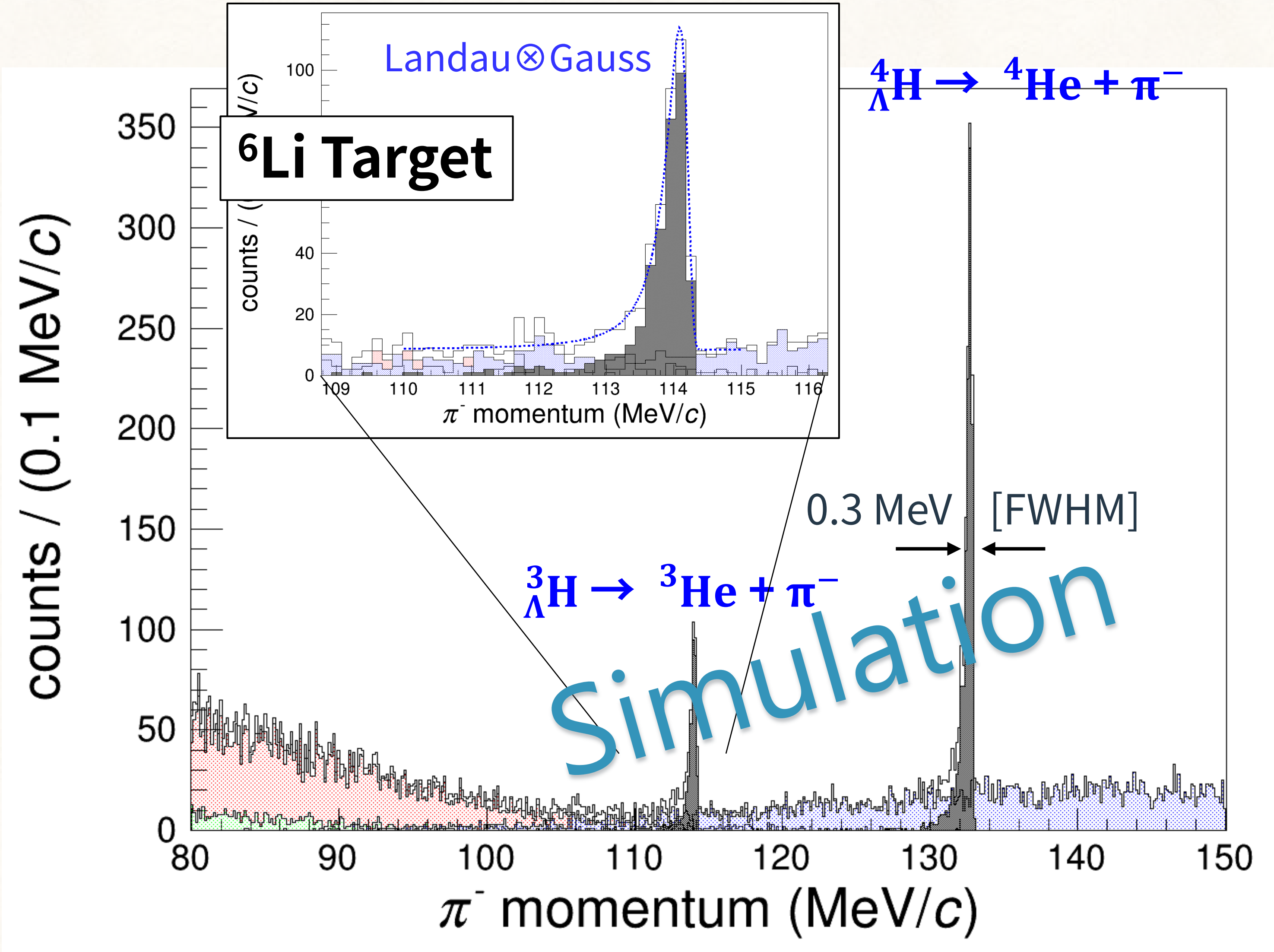
N_Λ: ↑ ×25; R_{stop}: ↑ ×2; $\varepsilon_{\pi^-}^{decay}$: ↓ ×1.6; $\varepsilon_{\pi^-}^{det}$: ↓ ×1.6

N_Λ	:	The number of Λ hyperons with K^+ tagging,
$R_{F.P}$	:	Hyperfragment formation probability,
R_{stop}	:	Hyperfragment stopping probability in target,
Γ_{π^-}	:	$\frac{\Gamma(X+\pi^-)}{\Gamma_{all}}$, Branching ratio of ${}^A_\Lambda Z \to \pi^- + {}^A(Z+1)$,
$\Delta\Omega_{\pi^-}$	:	Solid angle of π^- spectrometer,
$\varepsilon_{\pi^-}^{decay}$	:	Survival ratio of π^-,
$\varepsilon_{\pi^-}^{det}$	:	Detection efficiency of π^-.

- Less Background
- Many kinds of targets (Li, Be, B, C, Ca, Pb.....)

  Hypernuclear ID

Demonstration



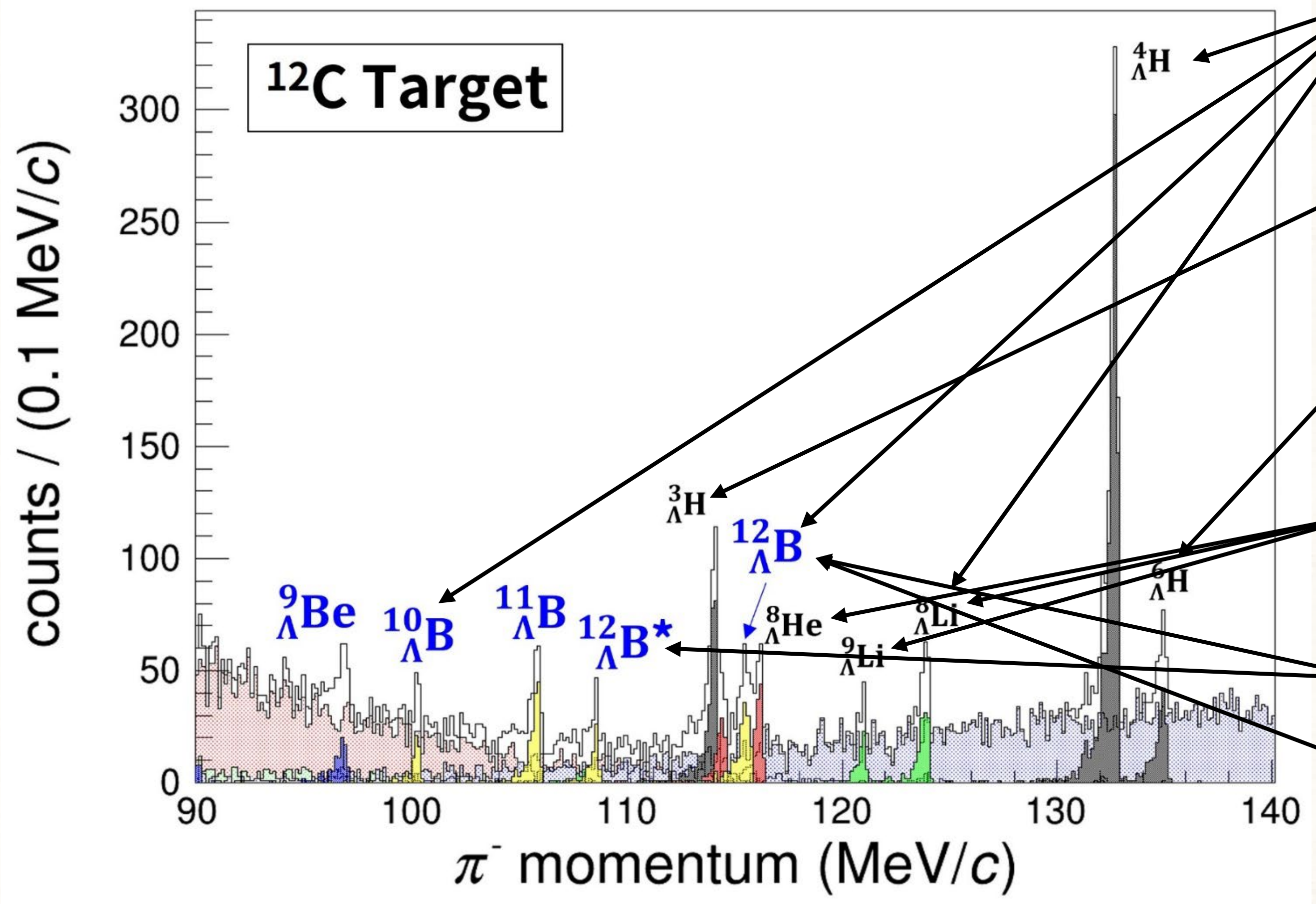
- Possible Hypernuclei

  $^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$
- >1000 $^{4}_{\Lambda}H$ per week
- Evaluation of peak position with the response function
- Peak position (M.P.V)
- Stat. error of peak M.P. V. < 1 keV

Physics Impact

New determination of hypernuclear masses with excellent accuracy (< 10 keV)

Note: These are several tens -- a few hundred keV currently



Charge Symmetry

Λp & Λn interaction is the same ?

Hypertriton Puzzle

Deeply Bound ?

Super neutron-rich hyper-hydrogen

Bound or not ?

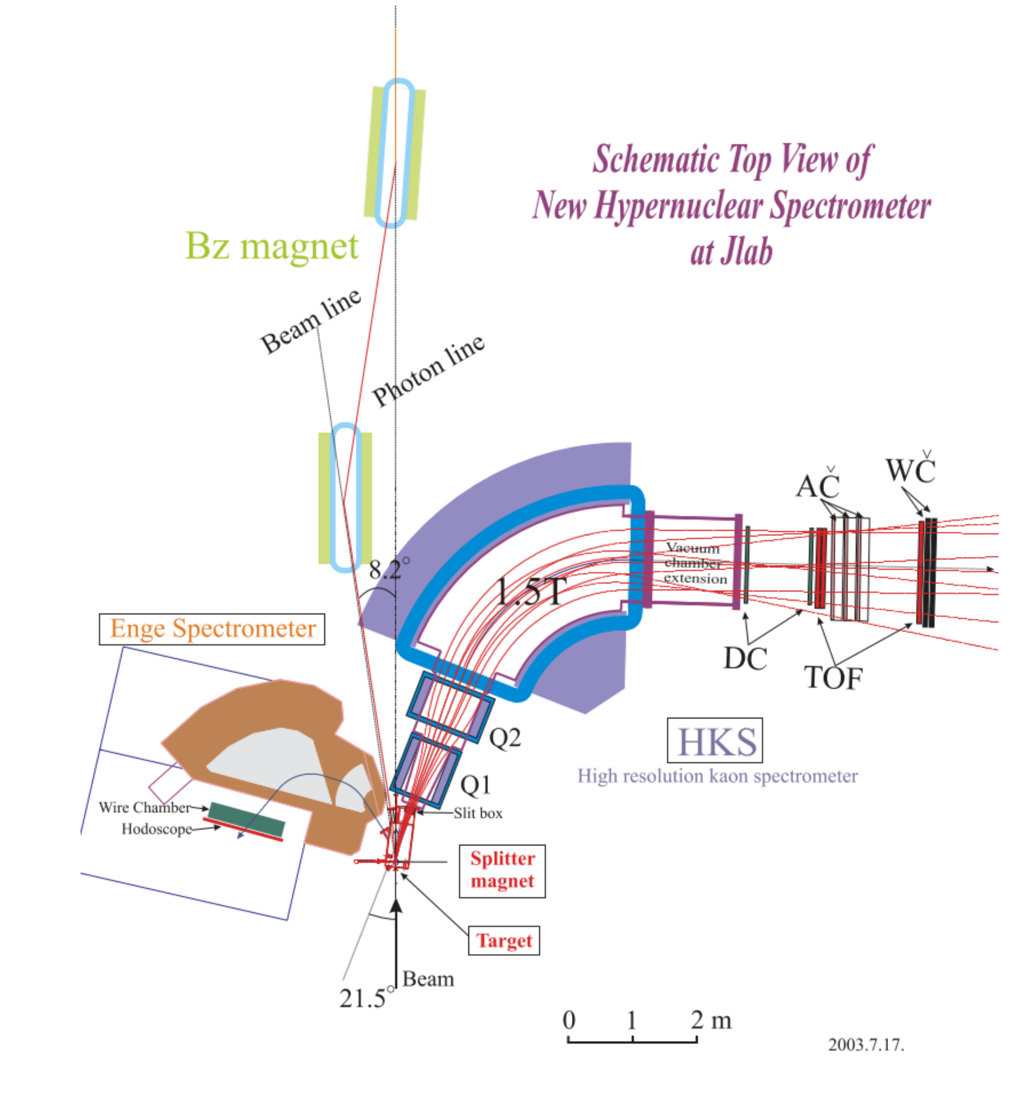
Σ coupling effect

3-body interaction nuclear medium

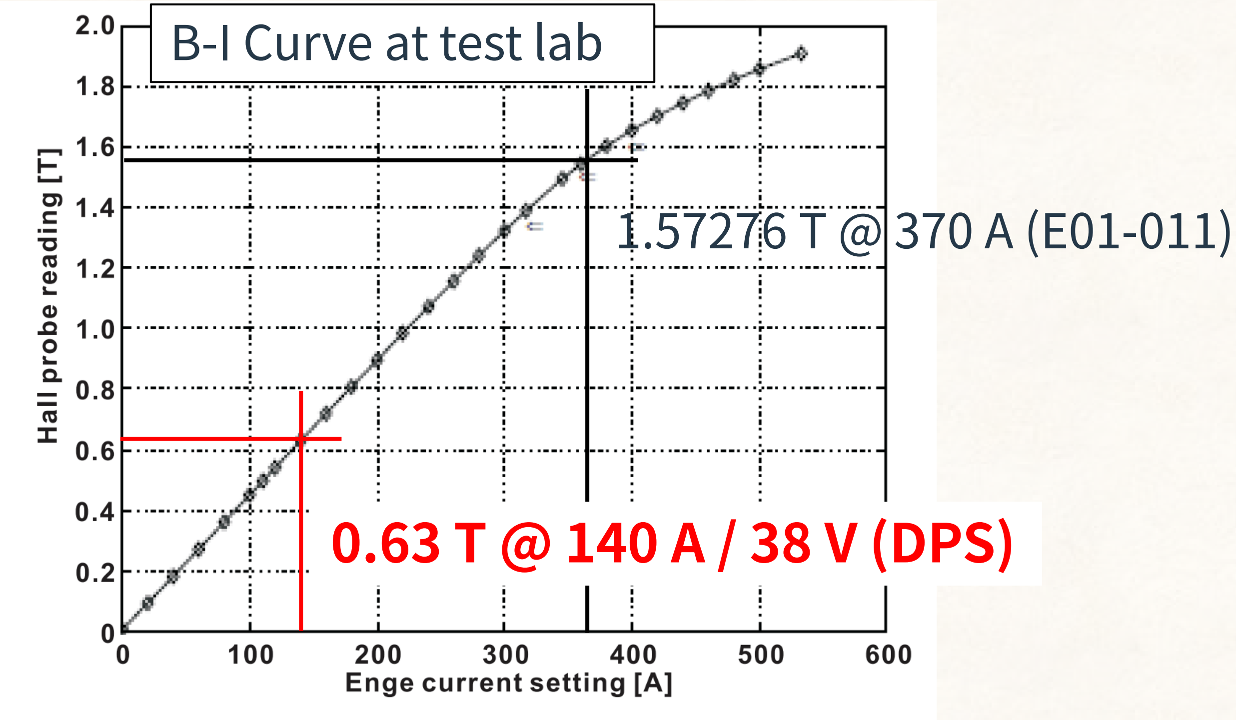
Spin Identification

Calibration source of the (e,e'K$^+$)

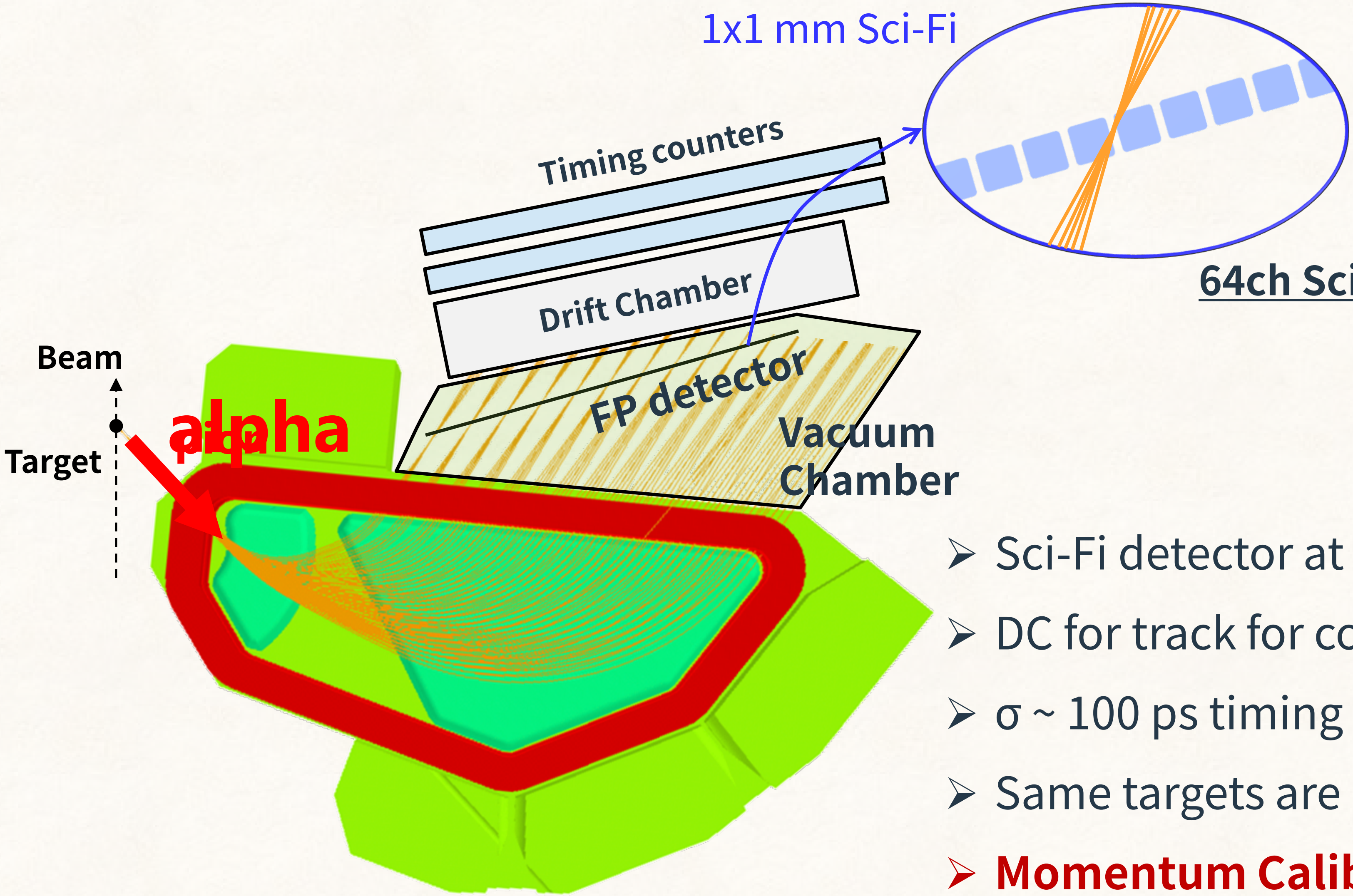
Enge Magnet



Pole Gap	= 46.6 mm
Momentum Acceptance	= ±30%
Momentum Resolution	= 4×10^{-4} (FWHM)
Solid Angle	= 4--7 msr
Weight	= 54.43 tons



Setup of Enge Spectrometer



- Sci-Fi detector at Clear Focal Plane
- DC for track for coincidence time calc.
- σ ~ 100 ps timing counter

Rate: 10 kHz

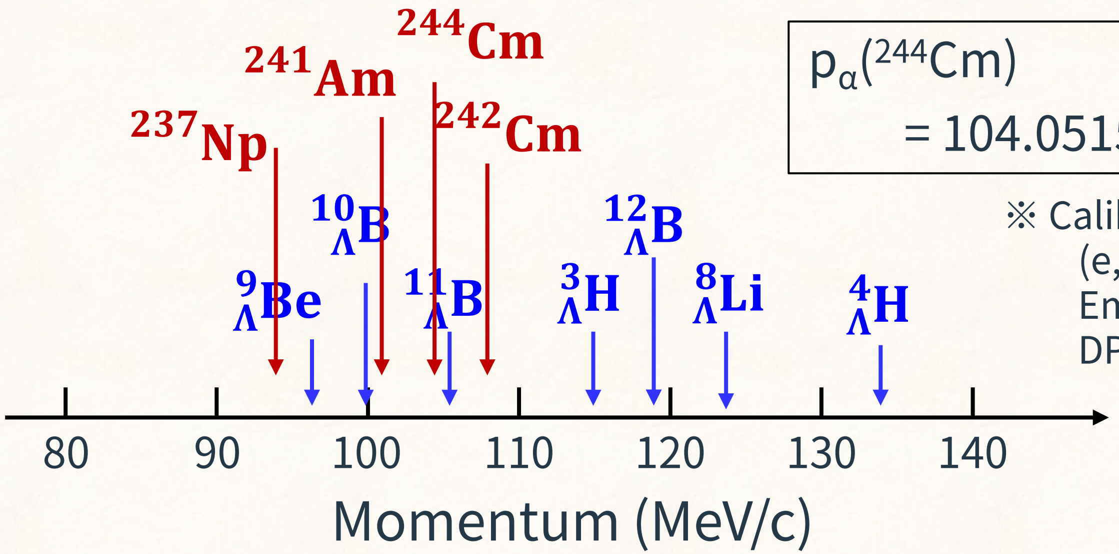
- Same targets are available (thinner ^{12}C is necessary)
- **Momentum Calibration with alpha-sources**

Off-beam calibration, Target--FP det. in vacuum

Unique Momentum Calibration with alpha-sources

alpha-source
with collimator

Momenta of Hypernuclear Decay Pion & Calibration source



$p_{\alpha}(^{244}Cm)$
= 104.0515 (5) MeV/c/q

※ Calibration sources in other exp.
(e,e'K^{+}): Λ (6 keV), Σ (20 keV)
Emlstion: Λ (6 keV)
DPS @MAMI: Ee (10 keV)

Excellent accuracy would be possible

- 0.5 counts / sec for a 37 kBq alpha-source
- Enough statistics with 1 hour calibration measurements

To be discussed...

- **alpha-sources & Collimator**
  - List of possible alpha-sources with ϕ~1mm collimator
  - Mounting method to the target ladder
- **Entrance & Exit Vacuum Extension**
  - ~73 mm from target to Enge entrance
- **Detector & readout**
  - ~1000 ch Sci-Fi detector, ~1100 ch DC with ns resolution
  - ~100 ch Timing detector with a few tens resolution
- **Power Supply**
  - 140V / 38 A
- **Installation Plan**

Summary

- Decay pion spectroscopy provides excellent results about hypernuclear masses
- The precise results would be expected to resolve the problems of hypernuclear physics
- DPS at JLab would be only the experiment which observes pion peaks from heavier hypernucleus
- Small sys. errors would be possible for Hardware spectrometer + alpha-sources
- Installation of Enge would be possible
- Let us work out the details