

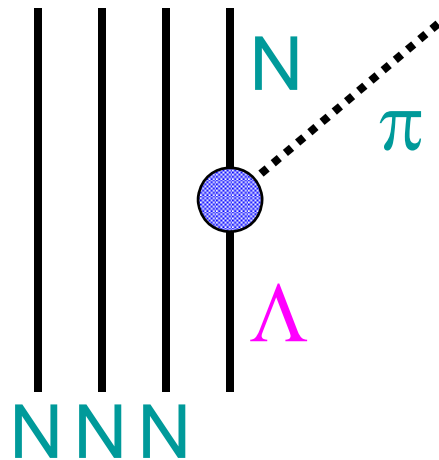
Study of the nonmesonic weak decay of 4-body Λ hypernuclei

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- Nonmesonic weak decay of hypernuclei
- E22 experiment (${}^4_{\Lambda}\text{He}$)
- Future experiment (${}^4_{\Lambda}\text{H}$)

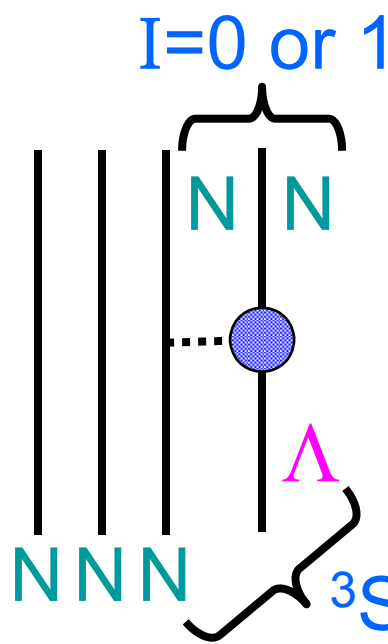
Weak decays in Λ -Hypernuclei



Mesonic weak decay (MWD)

similar with free Λ decay

spin/isospin structure well known



Non-Mesonic weak decay (NMWD)

new decay modes

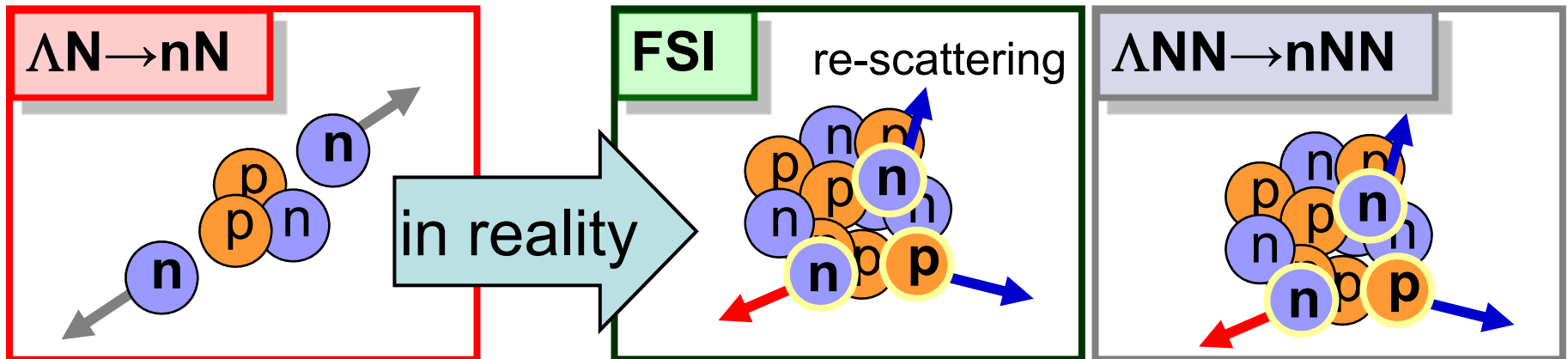
$\Lambda p \rightarrow np, \Lambda n \rightarrow nn$

spin/isospin structure: **unknown**

ΛN weak interaction

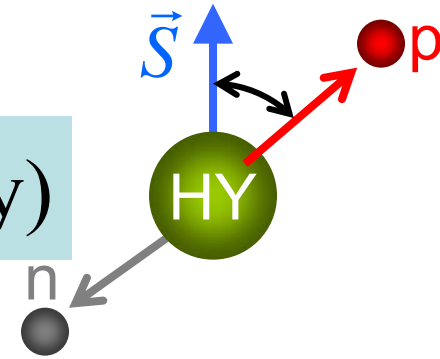
Status of NMWD studies

- Old puzzle solved recently
 - np-ratio ($\Gamma_{\Lambda n \rightarrow nn} / \Gamma_{\Lambda p \rightarrow pn} \equiv \Gamma_n / \Gamma_p$) inconsistent
 - $\Gamma_n / \Gamma_p \geq 1$ (Exp.) \Leftrightarrow $\Gamma_n / \Gamma_p \approx 0$ (Theory)
 - Experimental and theoretical improvements
 - $\Gamma_n / \Gamma_p \approx 0.5$ (Exp. and Theory)
 - (Exp.) Back-to-back coincidence for final two nucleons (E462/508)



- A **new puzzle** arises
 - Decay asymmetry inconsistent

$$\alpha_p^{NM} \approx 0 \text{ (Exp.)} \Leftrightarrow \alpha_p^{NM} \approx -0.7 \text{ (Theory)}$$



Asymmetry written
by amplitudes

$$\alpha_p^{NM} = \frac{2\sqrt{3}\text{Re}[-ae^* + b(c - \sqrt{2}d)^*/\sqrt{3} - f(\sqrt{2}c + d)^*]}{\{a^2 + b^2 + 3(c^2 + d^2 + e^2 + f^2)\}}$$

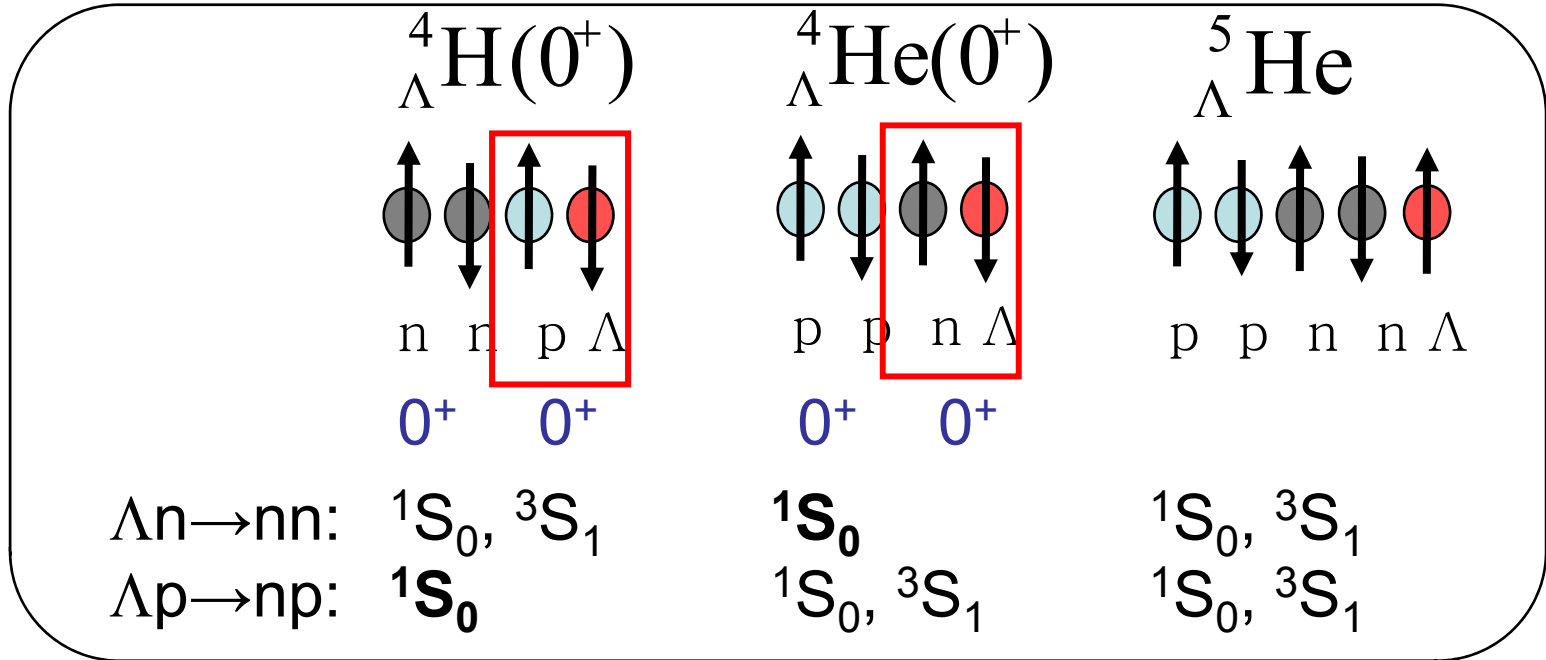
Large contribution ?

initial	final	amplitude	isospin	parity
1S_0	1S_0	a	1	no
	3P_0	b	1	yes
3S_1	1S_1	c	0	no
	3D_1	d	0	no
	1P_1	e	0	yes
	3P_1	f	1	yes

} $^1S_0 (I=1)$
 } $^3S_1 (I=0)$
 — $^3S_1 (I=1)$

assuming initial S state

- NMWD of 4-, 5-body hypernuclei
 - allowed initial ΛN states



initial	final	amplitude	isospin	parity
1S_0	1S_0	a	1	no
	3P_0	b	1	yes
3S_1	1S_1	c	0	no
	3D_1	d	0	no
	1P_1	e	0	yes
	3P_1	f	1	yes

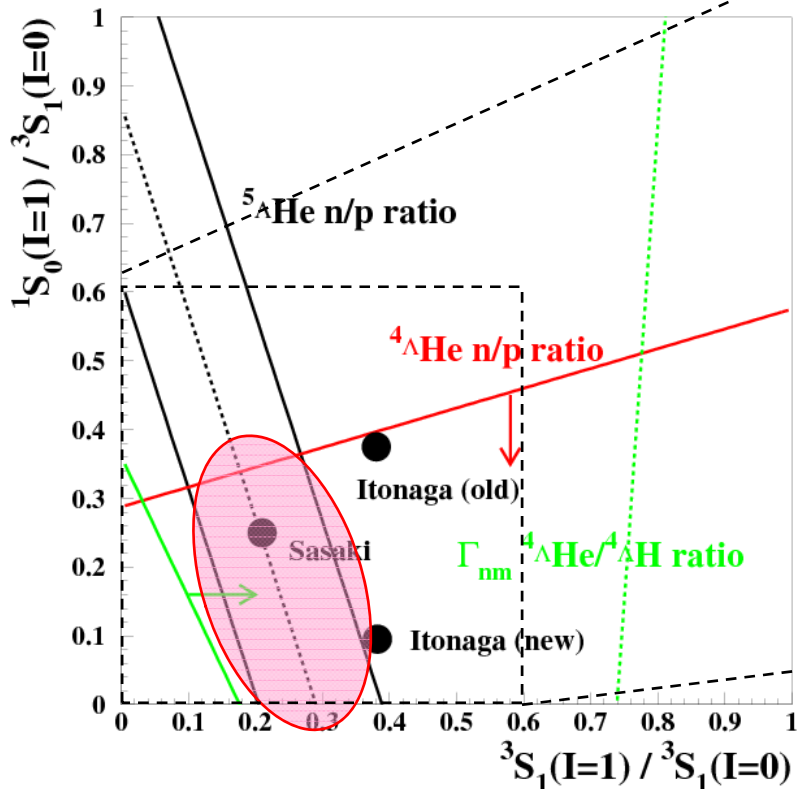
$\left. \begin{array}{l} \text{no} \\ \text{yes} \end{array} \right\} {}^1S_0 (I=1)$
 $\left. \begin{array}{l} \text{no} \\ \text{no} \end{array} \right\} {}^3S_1 (I=0)$
 $\text{— } {}^3S_1 (I=1)$

assuming initial S state

Status of amplitude determination

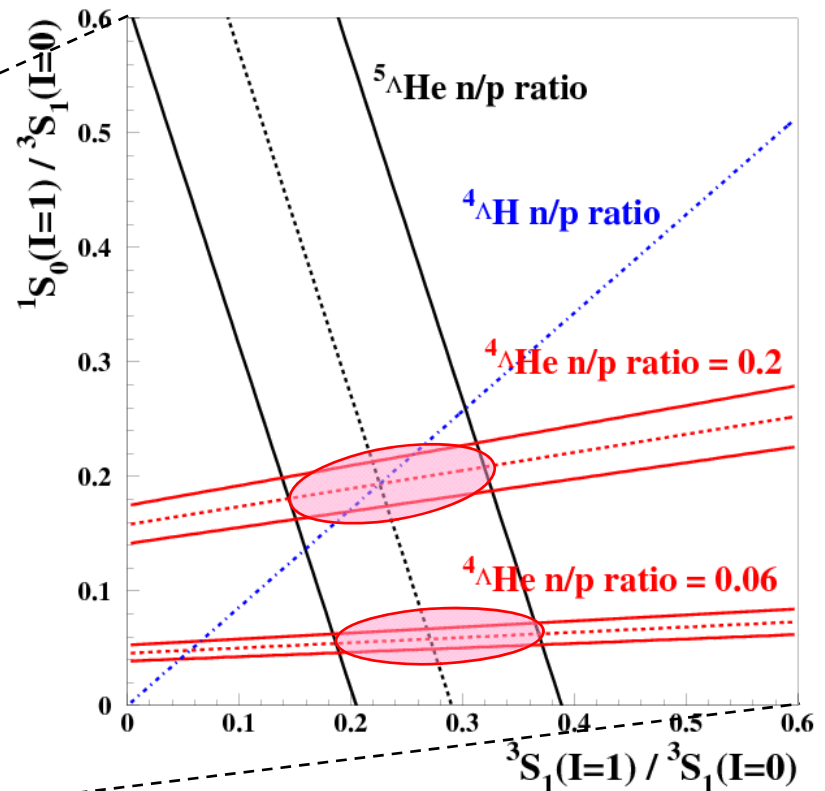
Current status

constraint from ${}^5_{\Lambda}\text{He}$ data
other constraints are loose



Our prospects

new constraint from ${}^4_{\Lambda}\text{He}$
np-ratio better than 15% error



Sakaguchi-plot: assuming $\Delta I=1/2$

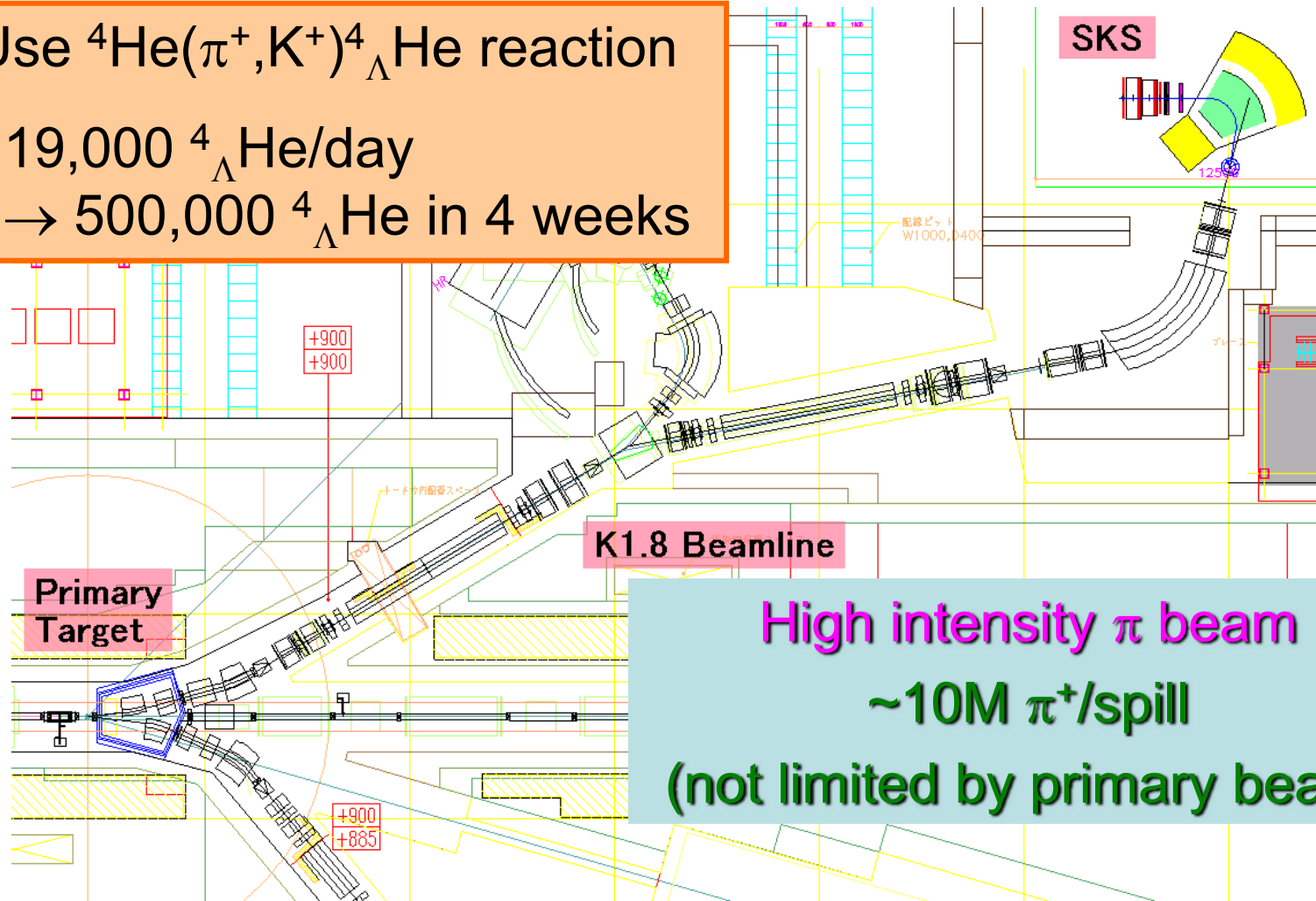
Production of ${}^4_{\Lambda}\text{He}$

Use ${}^4\text{He}(\pi^+, K^+){}^4_{\Lambda}\text{He}$ reaction

19,000 ${}^4_{\Lambda}\text{He}/\text{day}$

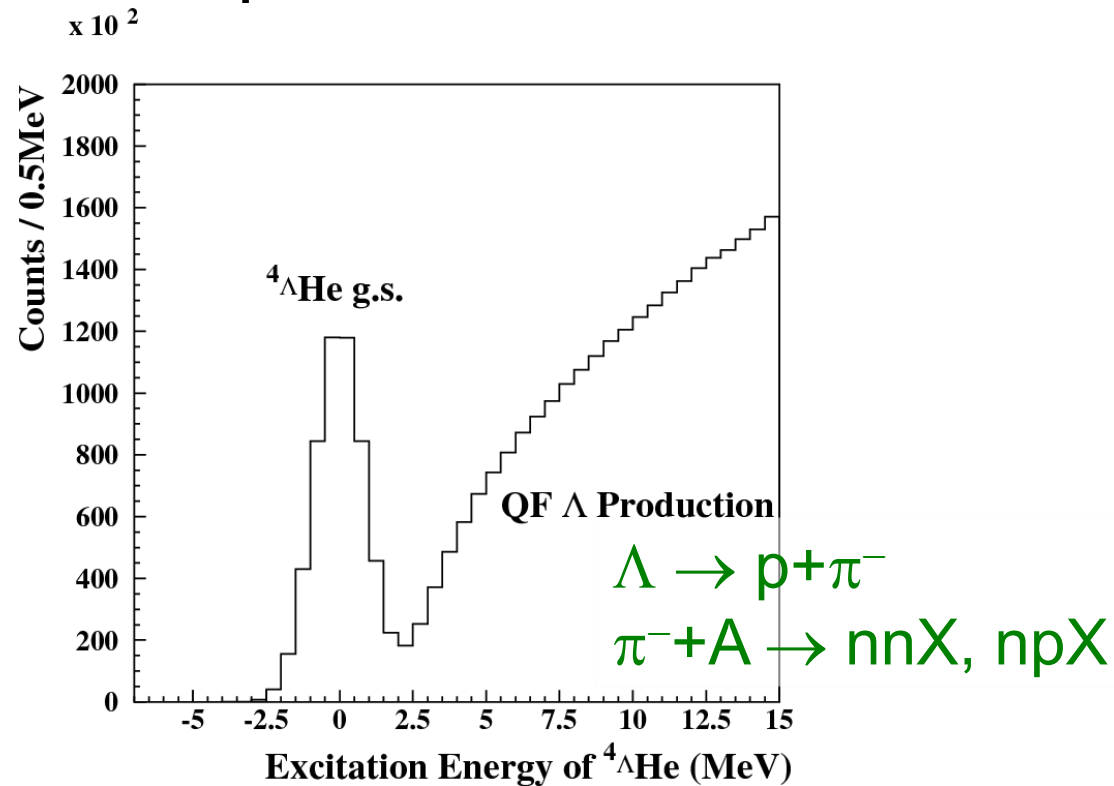
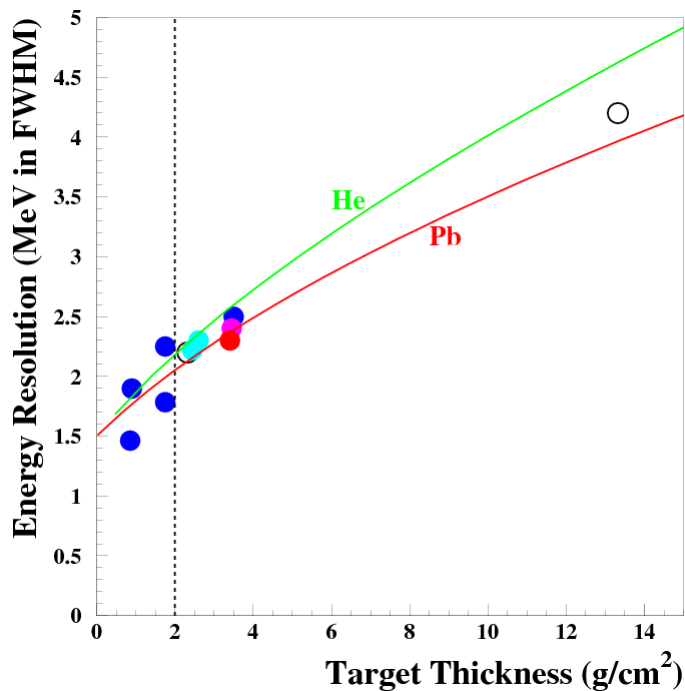
→ 500,000 ${}^4_{\Lambda}\text{He}$ in 4 weeks

High resolution
Efficient K^+ detection



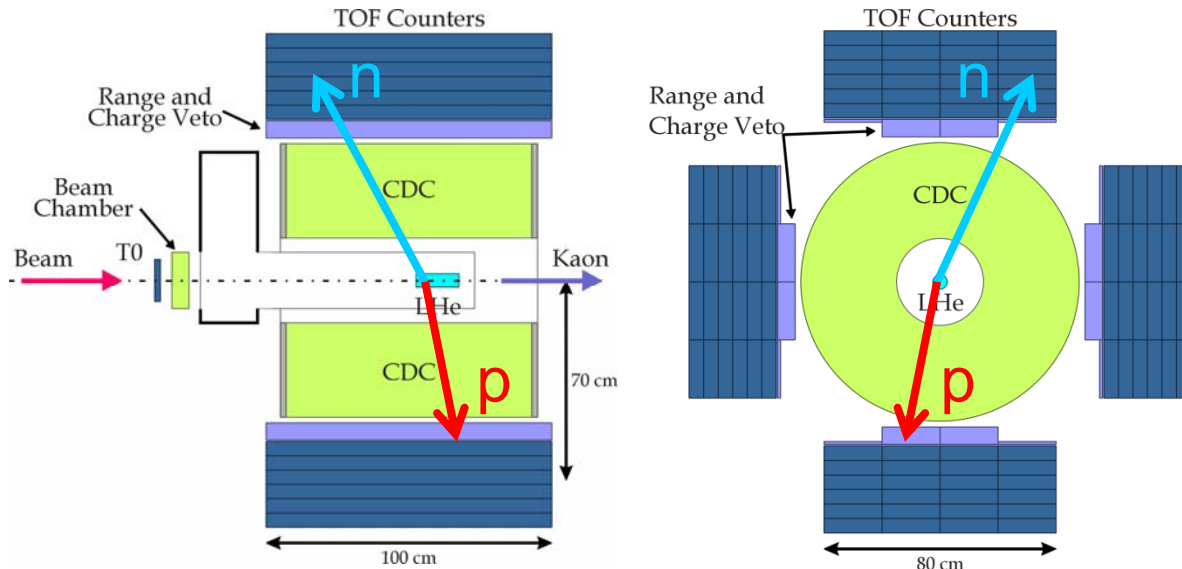
Energy resolution

- K1.8 beamline + SKS → excellent resolution
 - Liquid ${}^4\text{He}$ 2 g/cm 2 → $\Delta E_x \sim 2$ MeV
 - $\text{BE}({}^4_{\Lambda}\text{He}) = 2.42 \pm 0.04$ MeV
- Separation from QF Λ production essential



Decay arm system

- Large acceptance and high efficiency for NN



$$\Omega(n) \approx 0.4$$

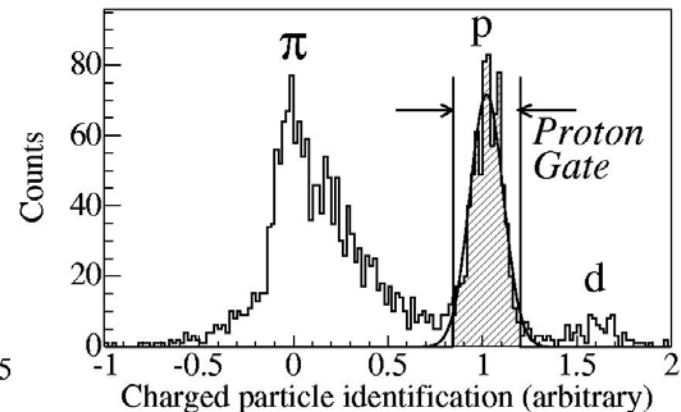
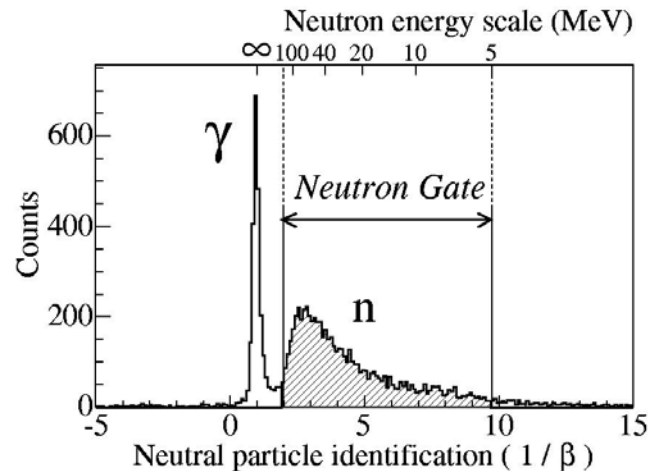
$$\varepsilon(n) \approx 30\%$$

$$\Omega(p) \approx 0.25$$

$$\varepsilon(p) \approx 80\%$$

- Good PID capability (n/p/ π / γ)

n/ γ TOF
 p/ π E/ Δ E/range
 n/p charge-veto



Yield estimation

Parameters	Values	
π^+ beam momentum	1.1 GeV/c	
π^+ beam intensity	1×10^7 /spill	← high beam intensity
PS acceleration cycle	3.4 sec/spill	
^4He target thickness	2 g/cm^2	
Reaction cross section	$10 \mu\text{b/sr}$	
Spectrometer solid angle	0.1 sr	← large acceptance
Spectrometer efficiency	0.5	
Analysis efficiency	0.5	
Decay counter acceptance for proton	0.25	} ← large acceptance and high efficiency
Decay counter acceptance for neutron	0.4	
Efficiency for decay protons	0.8	
Efficiency for decay neutrons	0.3	
Branching ratio of $\Lambda n \rightarrow nn$ process	0.01	
Branching ratio of $\Lambda p \rightarrow np$ process	0.1*	

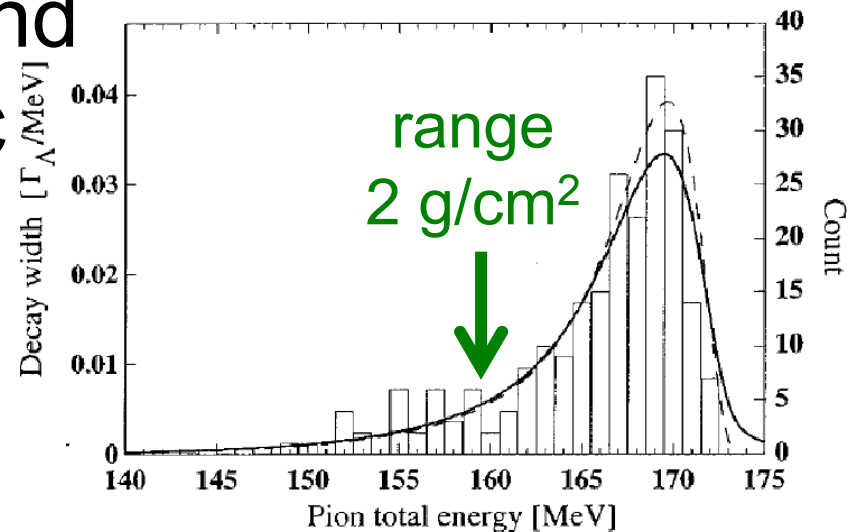
– 19,000 $^4_{\Lambda}\text{He}$ /day \rightarrow 500,000 $^4_{\Lambda}\text{He}$ in 4 weeks

– 1,300 $\Lambda p \rightarrow np$ and 75 $\Lambda n \rightarrow nn$ in 4 weeks

in case of
1% BR

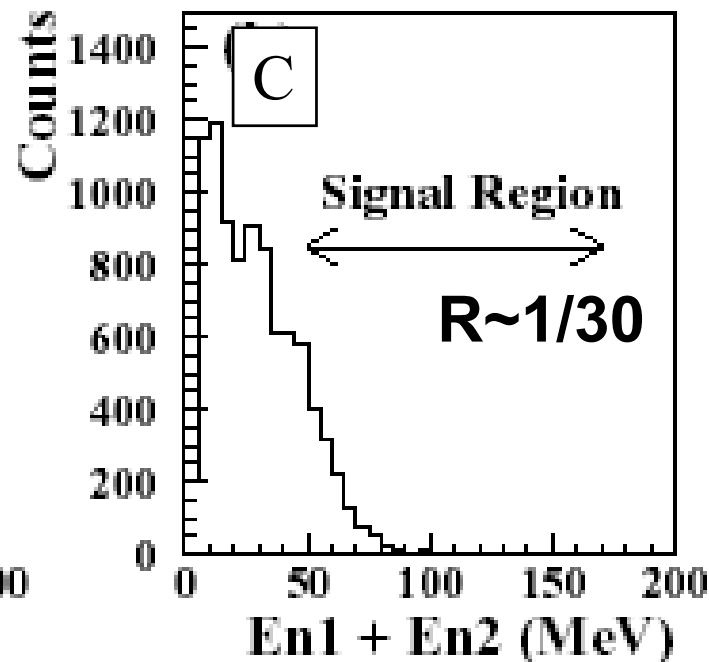
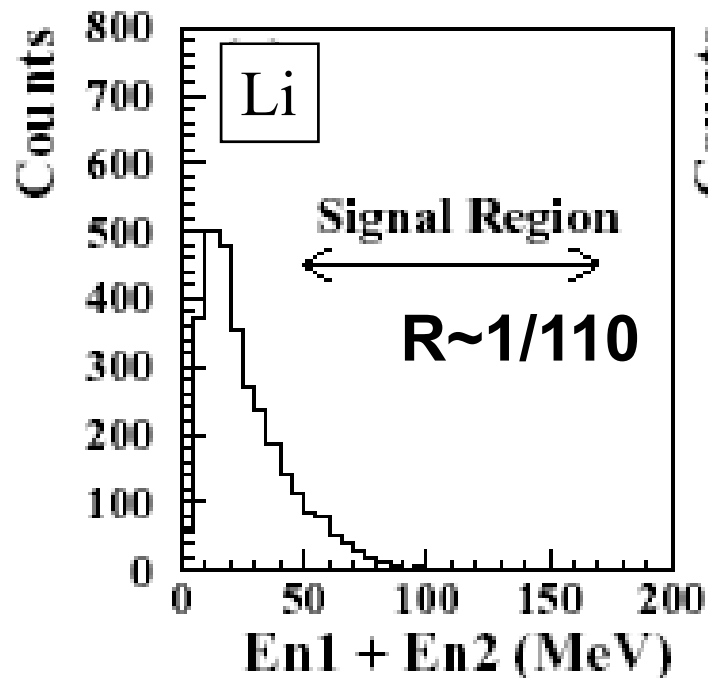
Background estimation

- Background sources
 - QF Λ -production ($\Lambda \rightarrow p + \pi^-$, $\pi^- + A \rightarrow nnX$)
 - cut in Ex spectrum
 - Mesonic weak decay of hypernuclei
 - ${}^4_{\Lambda}\text{He} \rightarrow {}^3\text{He} + p + \pi^-$, $\pi^- + A \rightarrow nnX$
 - $\Gamma_{\pi^-} \approx 0.3 \Gamma \Leftrightarrow \Gamma_n \approx 0.01 \Gamma$
- Reduction of background
 - veto: no π track in CDC
 - less material at target
 - LHe target $\leq 2 \text{ g/cm}^2$
 - range(π^-) $\leq 5 \text{ g/cm}^2$



Background MC simulation

- Simulation of worst case
 - 1/5 of π^- stop in material around target
 $1/5 \Gamma_{\pi^-} \sim 0.06 \Leftrightarrow \Gamma_n \sim 0.01$
 - GEANT4 base simulation



R : Reduction factor ($En1+En2>50MeV$)

Nonmesonic decay of A=4 hypernuclei

Allowed initial states for A=4, 5 hypernuclei

hypernucleus	$\Lambda n \rightarrow nn$	$\Lambda p \rightarrow np$
${}^4_{\Lambda}\text{H}$	${}^1S_0, {}^3S_1$	1S_0
${}^4_{\Lambda}\text{He}$	1S_0	${}^1S_0, {}^3S_1$
${}^5_{\Lambda}\text{He}$	${}^1S_0, {}^3S_1$	${}^1S_0, {}^3S_1$

- $\Gamma p({}^4_{\Lambda}\text{H}), \Gamma n({}^4_{\Lambda}\text{He})$

⇒ we can measure 1S_0 amplitudes directly.

- If $\Delta I=1/2$ rule holds, $\Gamma n({}^4_{\Lambda}\text{He})/\Gamma p({}^4_{\Lambda}\text{H})=2$.

⇒ we can check the validity of the $\Delta I=1/2$ rule in B-B weak interaction.

Existing experimental results

$$\Gamma n({}^4_{\Lambda}\text{He}) / \Gamma_{\Lambda} = 0.01^{+0.04}_{-0.01} \text{ (KEK)}, 0.04 \pm 0.02 \text{ (BNL)} \text{ NP A639(1998)261c}$$

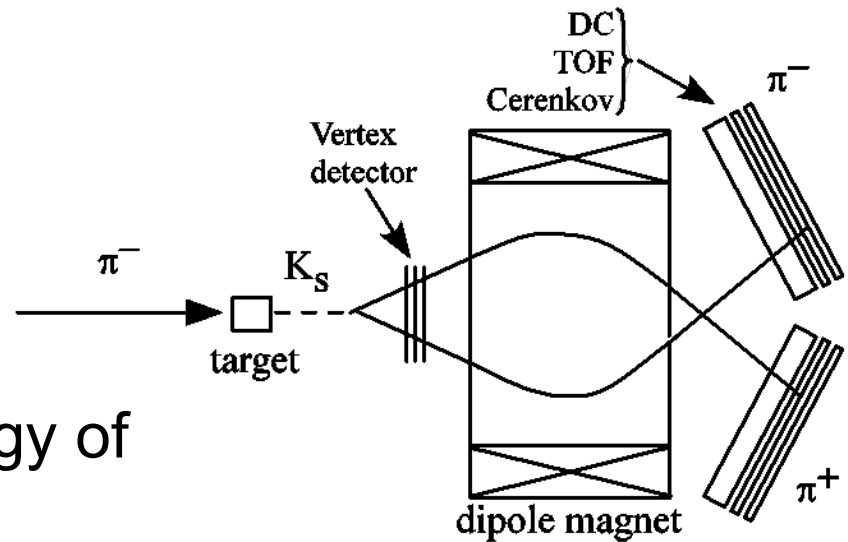
$$\Gamma p({}^4_{\Lambda}\text{He}) / \Gamma_{\Lambda} = 0.16 \pm 0.02 \text{ (KEK)}, 0.16 \pm 0.02 \text{ (BNL)} \text{ NP A639(1998)251c}$$

(π^-, K^0) reaction

The final state of K^0 is two
“charged” pions.



It is easy to measure the energy of
pions and their opening angle,
compared with gamma-ray in π^0 case.



background

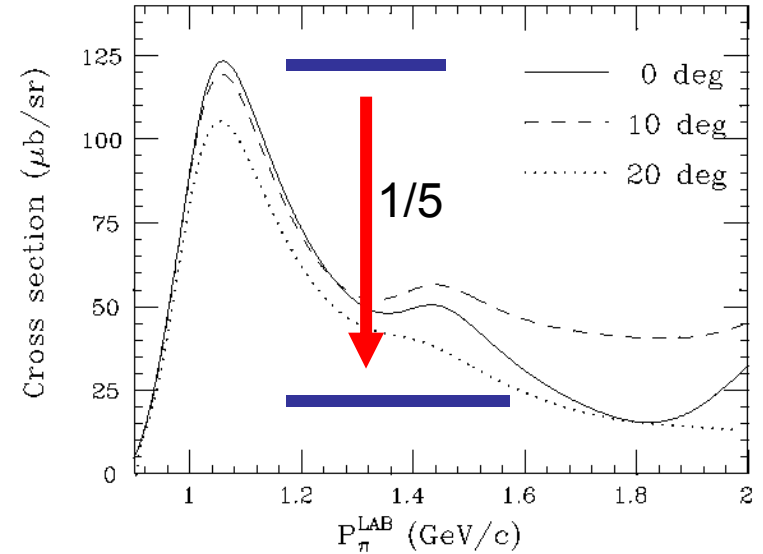
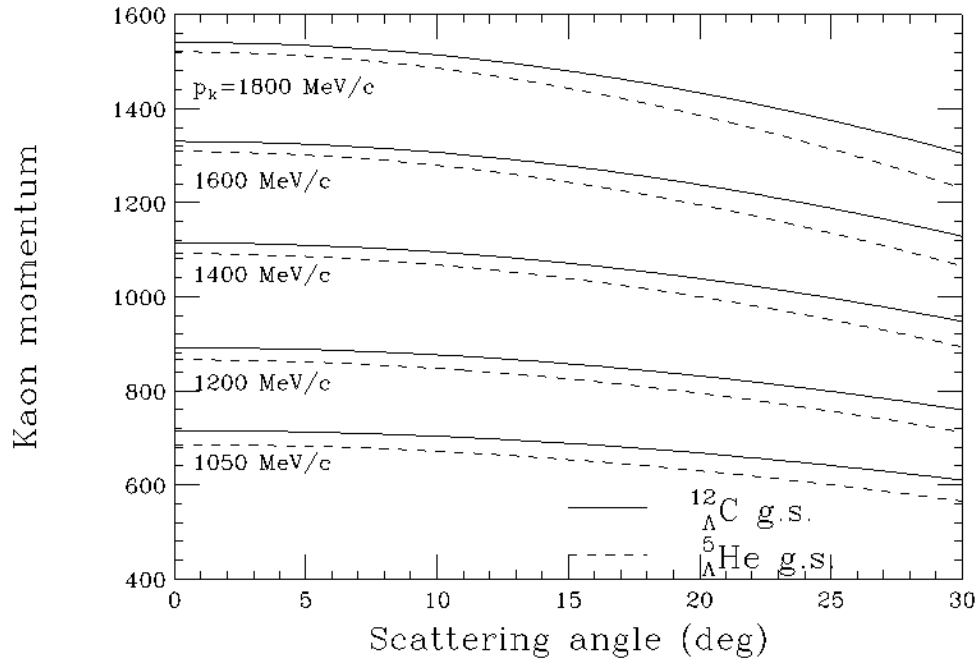
Multi-pion production in the target or other material
around target should be most serious background.



Such background can be rejected
by measuring K^0 decay point.

Beam Momentum

(π^-, K^0) kinematics

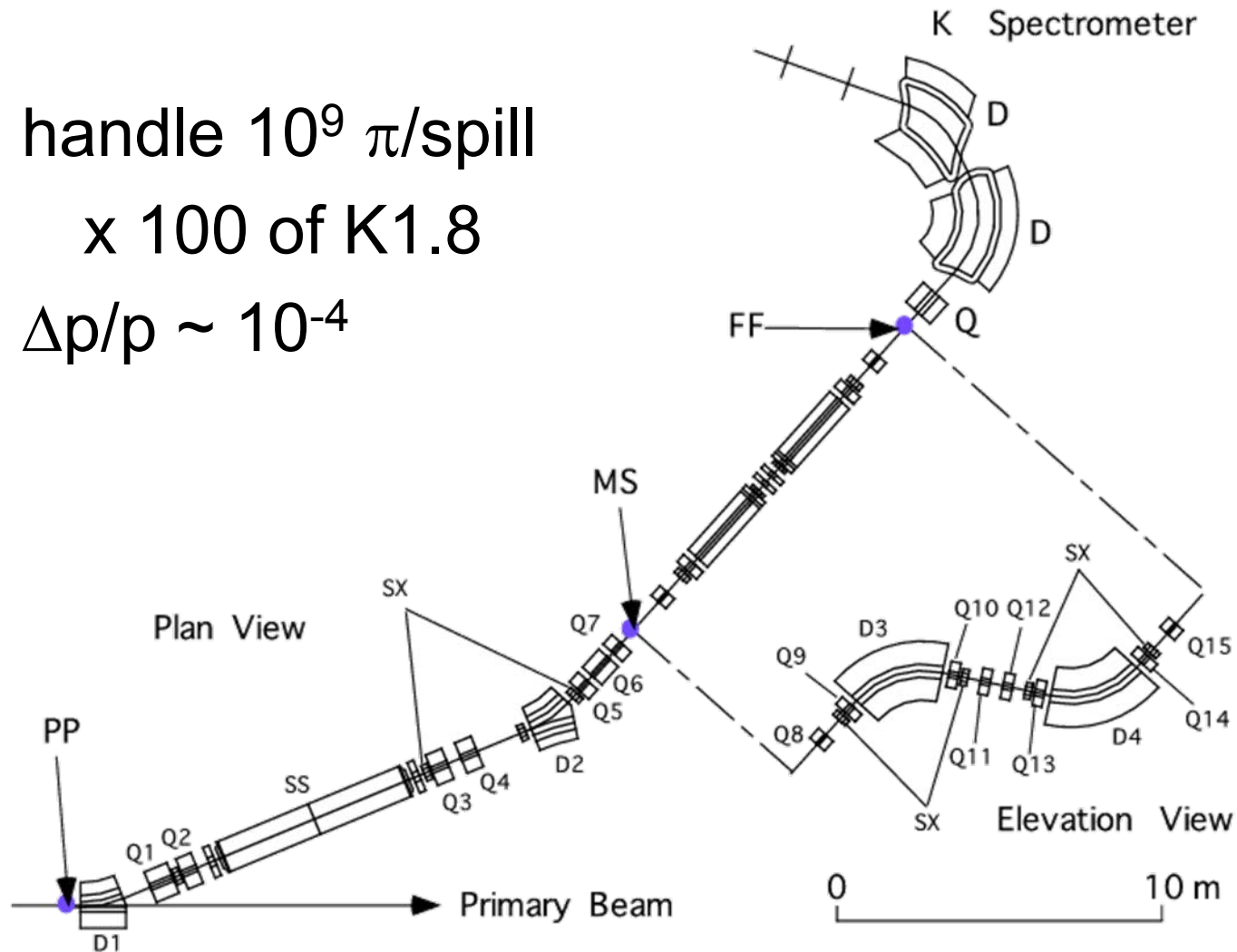


At standard momentum for (π, K) reaction, 1050 MeV/c, $\beta\gamma c\tau$ for kaon is 3.9cm.

$$\beta\gamma c\tau = 9.7 \text{ cm @ } P_K = 1.53 \text{ GeV/c}$$

High Intensity and High Resolution beamline (proposed by H. Noumi: 2nd NPFC L08)

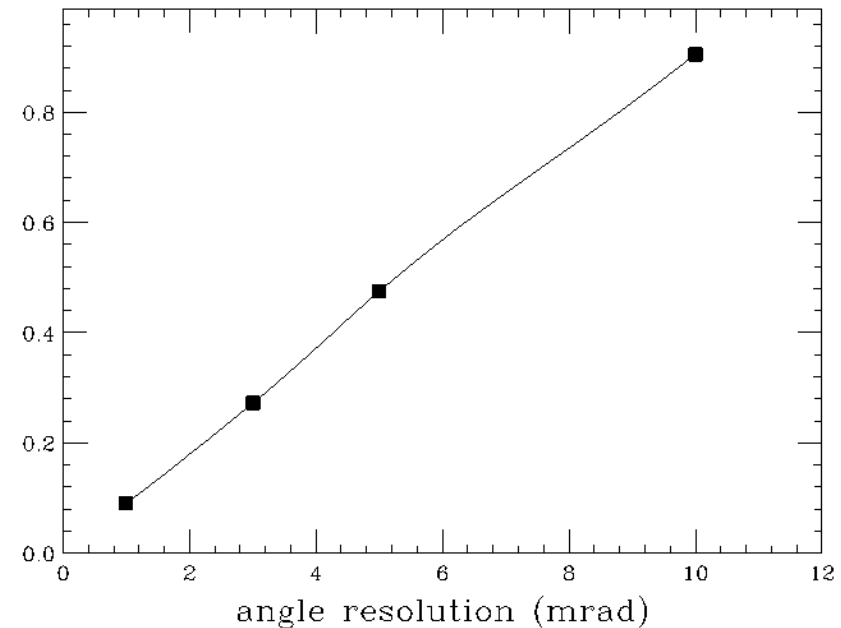
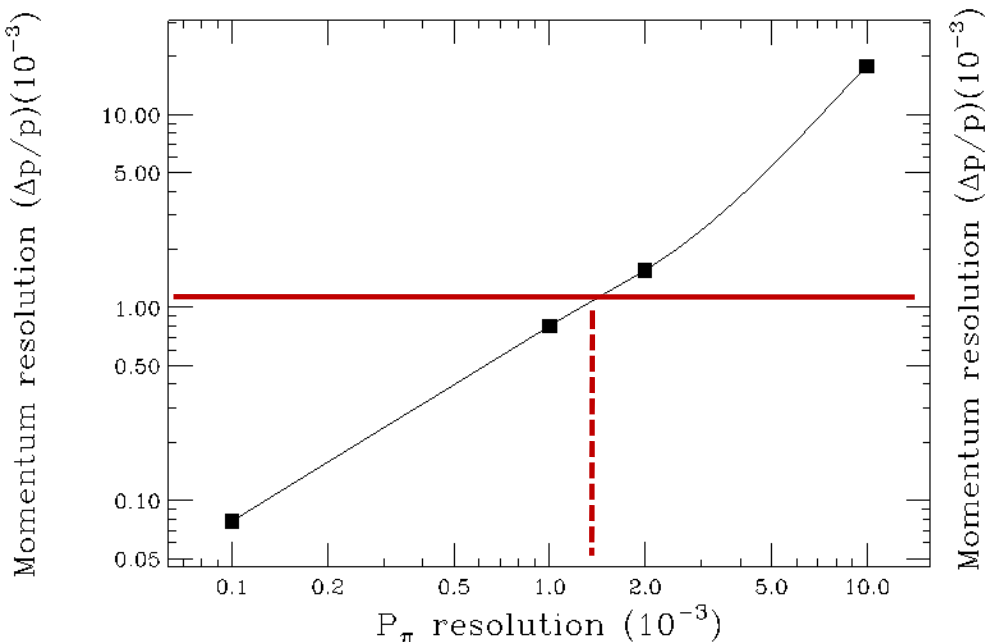
- handle $10^9 \pi/\text{spill}$
x 100 of K1.8
- $\Delta p/p \sim 10^{-4}$



Resolution OK ? – angle/momentum of pion

E_x resolution

$\Delta p/p = 1 \times 10^{-5}$:	$\Delta E_x = 0.013 - 0.014$
1×10^{-4} :	$0.133 - 0.142$
1×10^{-3} :	$1.332 - 1.417$



Summary

- We propose to measure the nonmesonic weak decay of 4-body Λ hypernuclei (${}^4_{\Lambda}\text{He}/\text{H}$).
 - select initial spin state (${}^1S_0/{}^3S_1$)
 - check the validity of $\Delta I=1/2$ rule in baryon weak interaction
- We are now preparing E22 exp. (${}^4_{\Lambda}\text{He}$) at K1.8 beamline.
- High intensity and high resolution beamline by H. Noumi, is suitable for measurement of ${}^4_{\Lambda}\text{H}$.