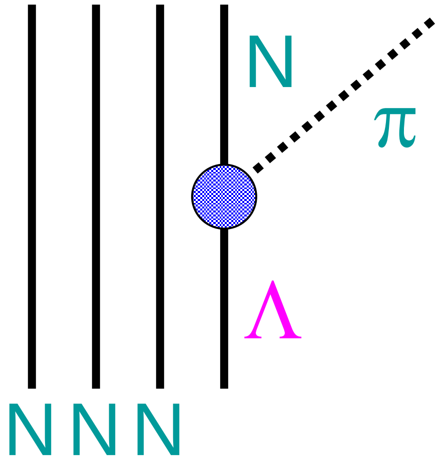
Λハイパー核の弱崩壊実験

S. Ajimura (RCNP)

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

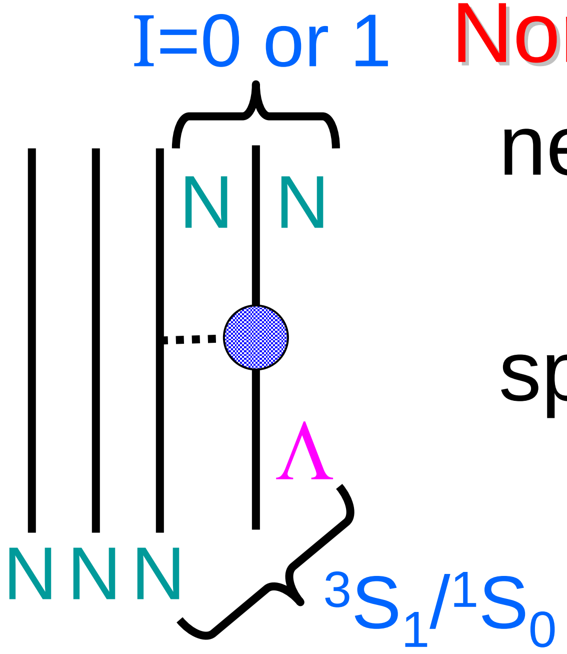
Weak decays in Λ-Hypernuclei



Mesonic weak decay (MWD)

similar with free Λ decay

spin/isospin structure well known



Non-Mesonic weak decay (NMWD)

new decay modes

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

spin/isospin structure: **unknown**

ΛN weak interaction

Status of NMWD studies

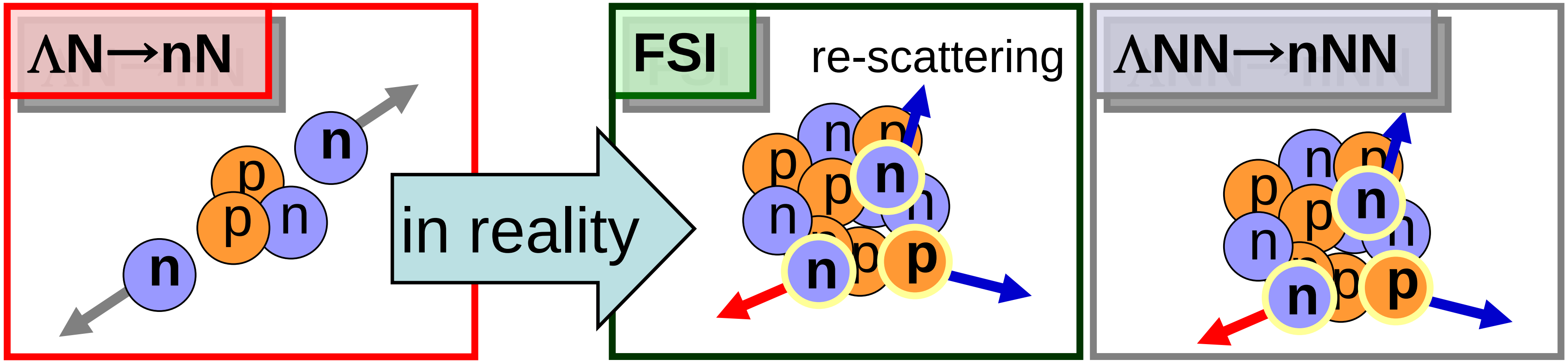
- Old puzzle solved recently
  - np-ratio ($\Gamma_{\Lambda n\to nn}/\Gamma_{\Lambda p\to pn}\equiv\Gamma_n/\Gamma_p$) inconsistent

$$\Gamma_n/\Gamma_p \geq 1\,(\text{Exp.}) \quad \Leftrightarrow \quad \Gamma_n/\Gamma_p \approx 0\,(\text{Theory})$$

  - Experimental and theoretical improvements

$$\Gamma_n/\Gamma_p \approx 0.5\,(\text{Exp. and Theory})$$

  - (Exp.) Back-to-back coincidence for final two nucleons (E462/508)



ΛN→nN

in reality

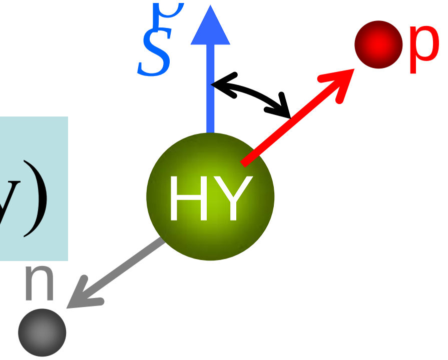
FSI

re-scattering

ΛNN→nNN

- 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

$$\alpha_p^{NM} = \frac{2\sqrt{3}Re[\overbrace{\boxed{-ae^* + b(c-\sqrt{2}d)^*/\sqrt{3}}}^{{}^1S_0\times{}^3S_1}\overbrace{\boxed{-f(\sqrt{2}c+d)^*}}^{{}^3S_1\times{}^3S_1}]}{\{a^2+b^2+3(c^2+d^2+e^2+f^2)\}}$$

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

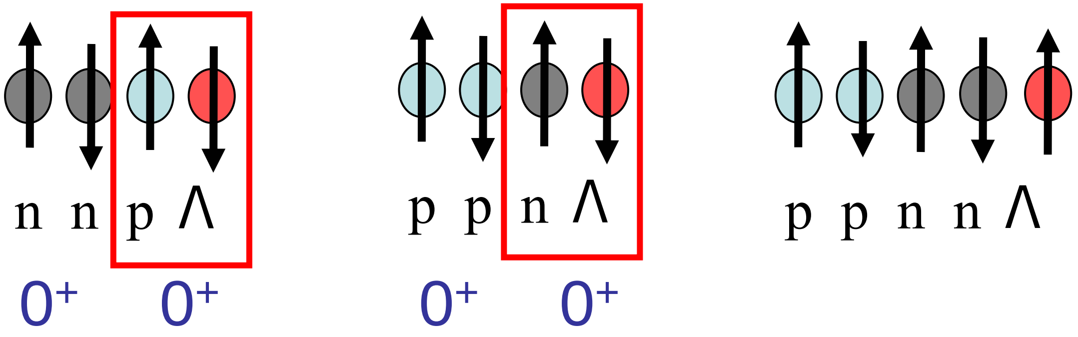
assuming initial S state

a, b: $^1S_0(I=1)$

c, d, e: $^3S_1(I=0)$

f: $^3S_1(I=1)$

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



	$^{4}_{\Lambda}\mathrm{H}(0^+)$	$^{4}_{\Lambda}\mathrm{He}(0^+)$	$^{5}_{\Lambda}\mathrm{He}$
Λn→nn:	$^1S_0$, $^3S_1$	**$^1S_0$**	$^1S_0$, $^3S_1$
Λp→np:	**$^1S_0$**	$^1S_0$, $^3S_1$	$^1S_0$, $^3S_1$

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

assuming initial S state

$\}\ ^1S_0(I=1)$

$\}\ ^3S_1(I=0)$

$—\ ^3S_1(I=1)$

Status of amplitude determination

Our prospects

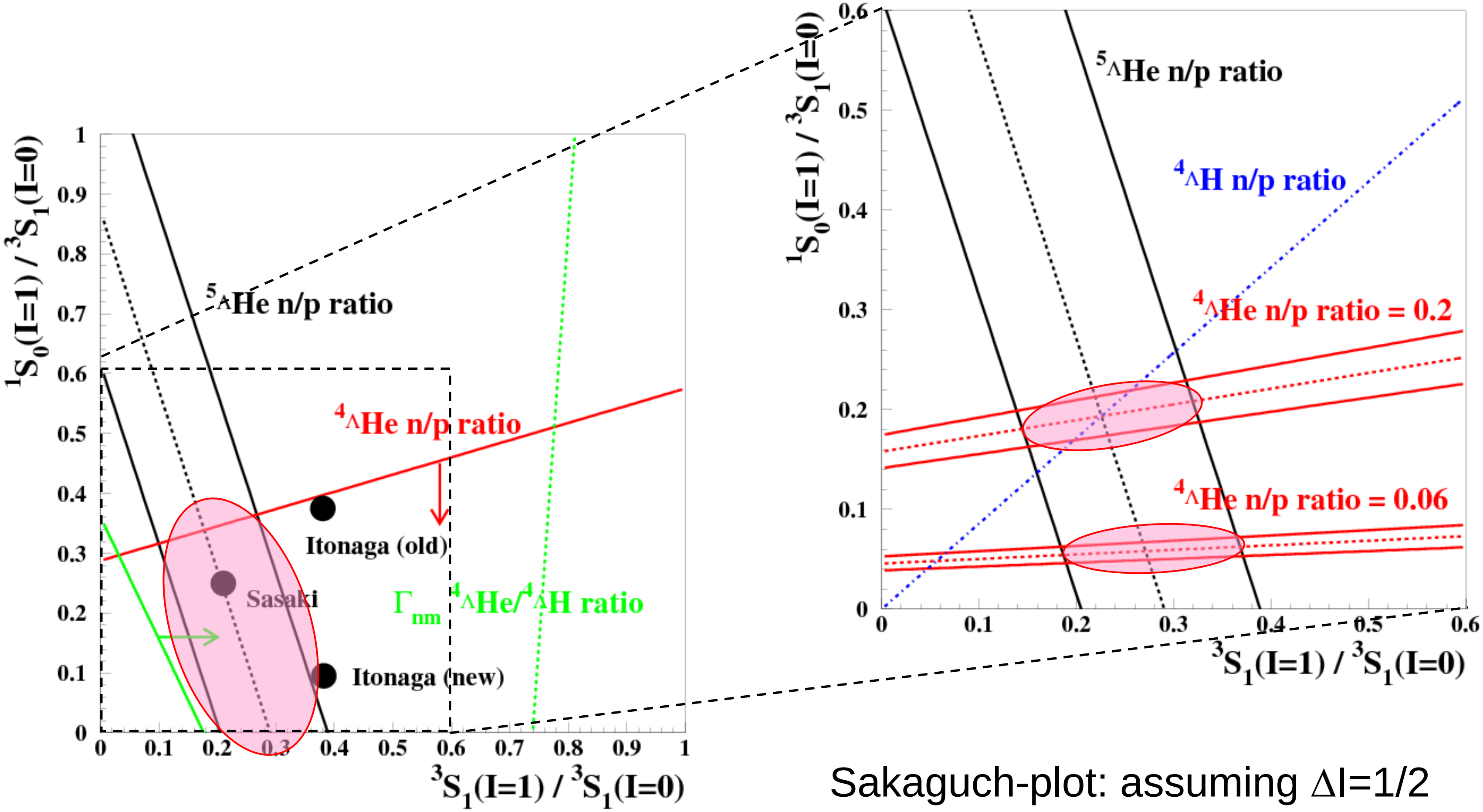
new constraint from $^4_\Lambda$He

np-ratio better than 15% error

Current status

constraint from $^5_\Lambda$He data

other constraints are loose



Sakaguch-plot: assuming ΔI=1/2

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

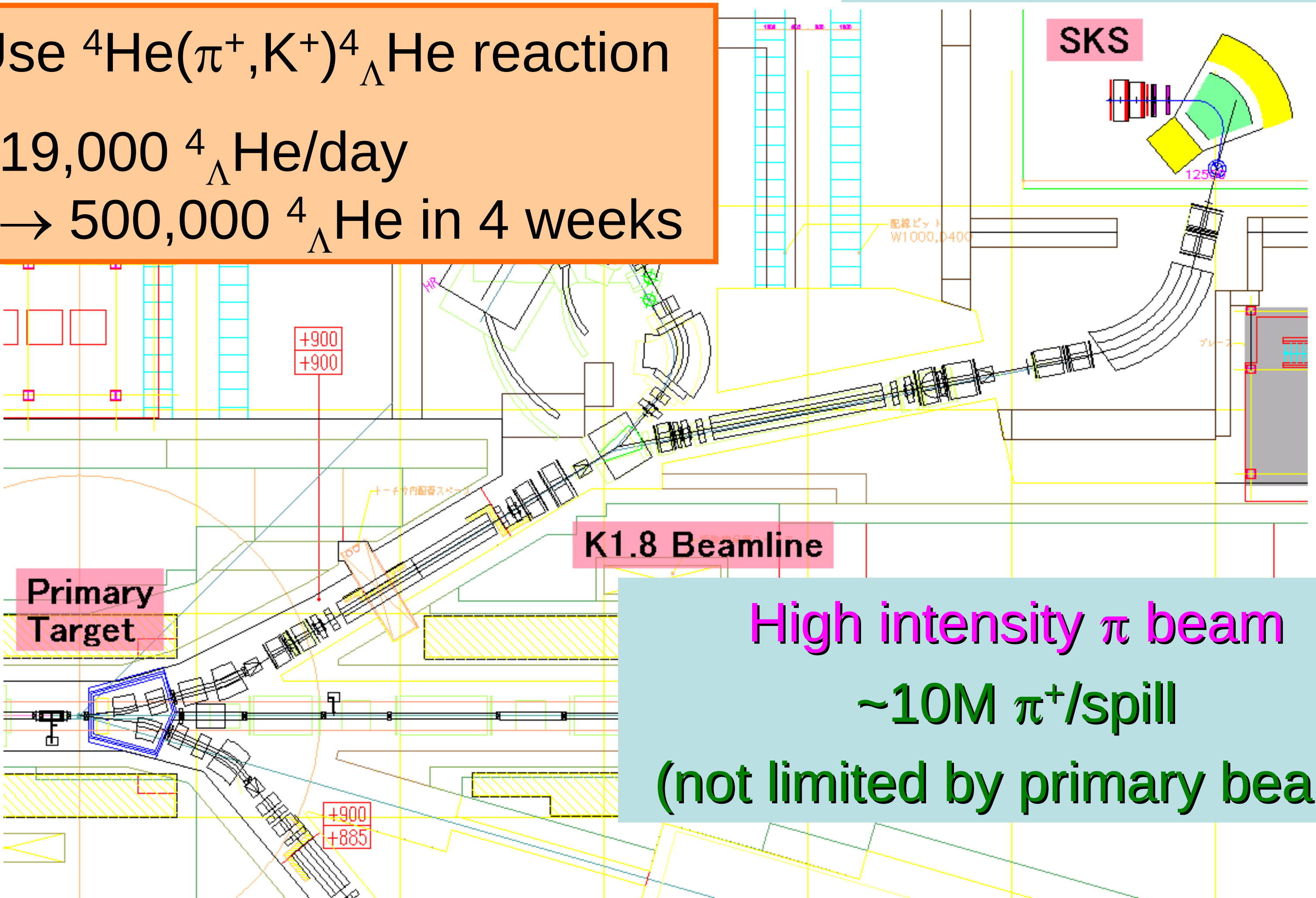
High resolution

Efficient K+ detection

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

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

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



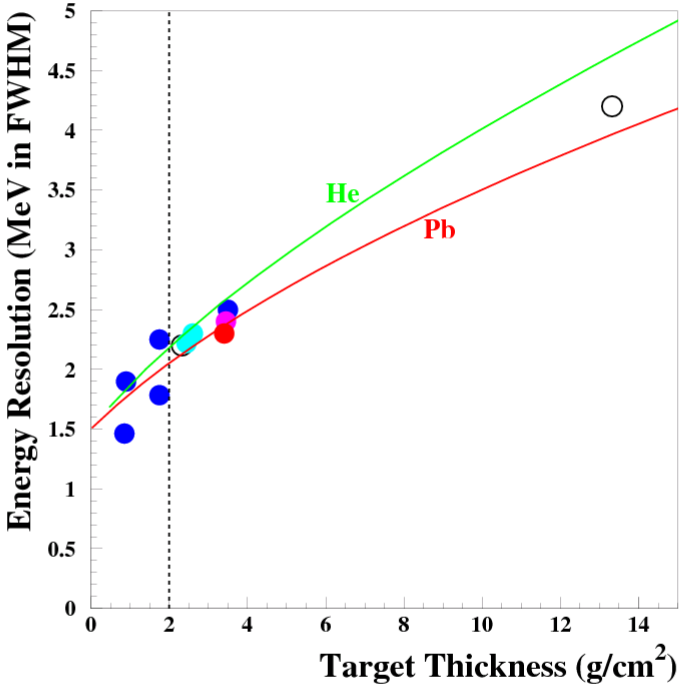
High intensity π beam

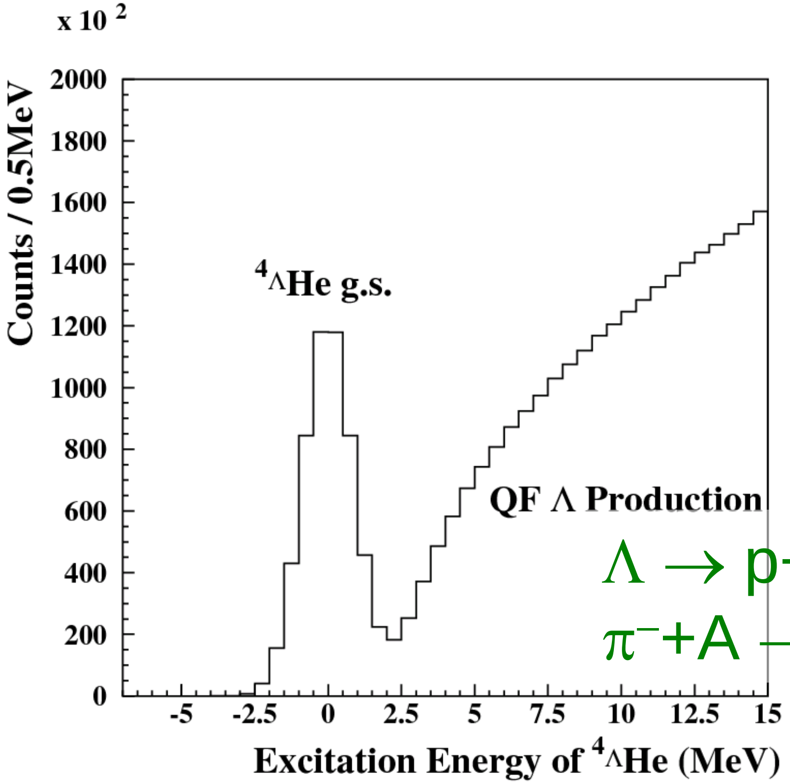
~10M π^{+}/spill

(not limited by primary beam)

Energy resolution

- K1.8 bemline + SKS → excellent resolution
  - Liquid ^{4}He 2 g/cm^2 → ΔEx ~ 2 MeV
  - BE($^4_\Lambda$He) = 2.42 ± 0.04 MeV
- Separation from QF Λ production essential



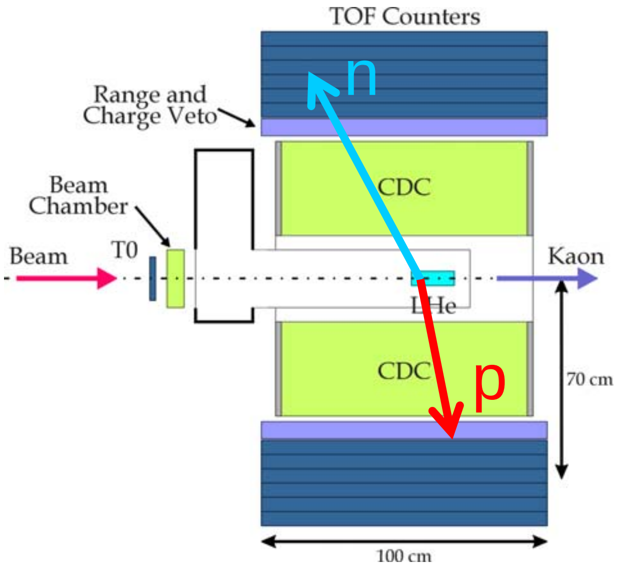


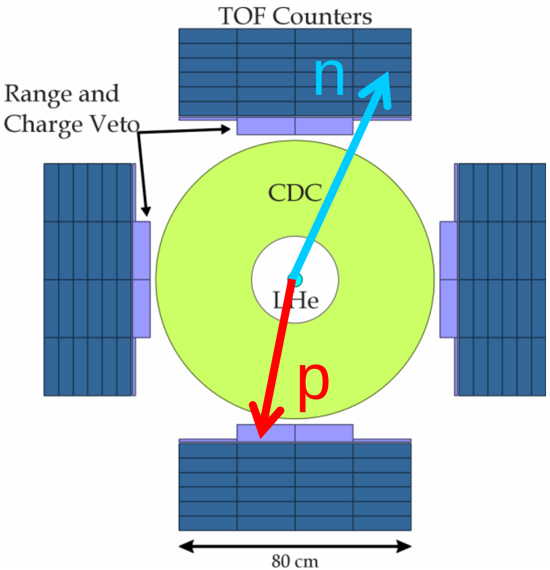
$\Lambda \rightarrow p+\pi^-$

$\pi^-+A \rightarrow nnX, npX$

Decay arm system

– Large acceptance and high efficiency for NN





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

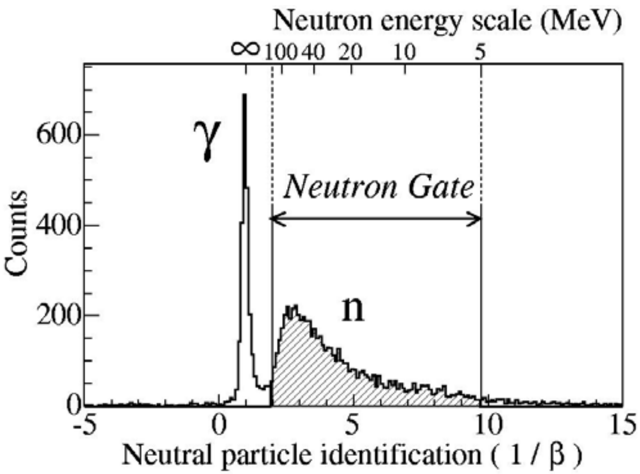
$$\varepsilon(n) \approx 30\%$$

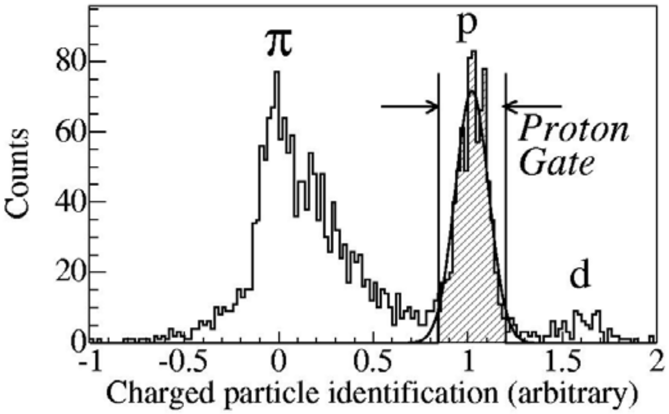
$$\Omega(p) \approx 0.25$$

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

– Good PID capability (n/p/π/γ)

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





Yield estimation

Parameters	Values
π^+ beam momentum	1.1 GeV/c
π^+ beam intensity	1×10^7 /spill
PS acceleration cycle	3.4 sec/spill
^{4}He target thickness	2 g/cm^2
Reaction cross section	10 μb/sr
Spectrometer solid angle	0.1 sr
Spectrometer efficiency	0.5
Analysis efficiency	0.5
Decay counter acceptance for proton	0.25
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^*

← high beam intensity

← large acceptance

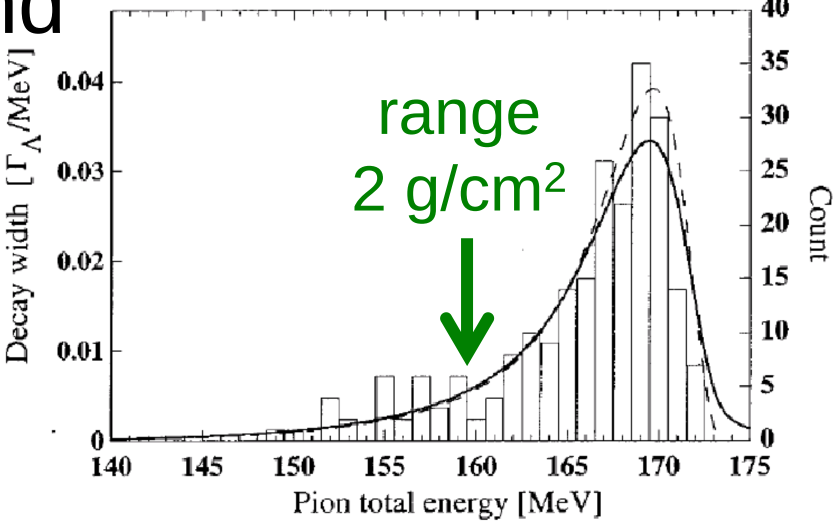
← large acceptance and high efficiency

- 19,000 $^4_\Lambda$He/day → 500,000 $^4_\Lambda$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 ($\Lambda \to p+\pi^-$, $\pi^- + A \to nnX$)
    - cut in Ex spectrum
  - Mesonic weak decay of hypernuclei
    - ${}^4_\Lambda He \to {}^3He + p + \pi^-$, $\pi^- + A \to nnX$
    - $\Gamma_{\pi-} \approx 0.3\,\Gamma \Leftrightarrow \Gamma_n \approx 0.01\,\Gamma$
- Reduction of background
  - veto: no π track in CDC
  - less material at target
    - LHe target ≤ 2 g/cm^2
    - range($\pi-$) ≤ 5 g/cm^2

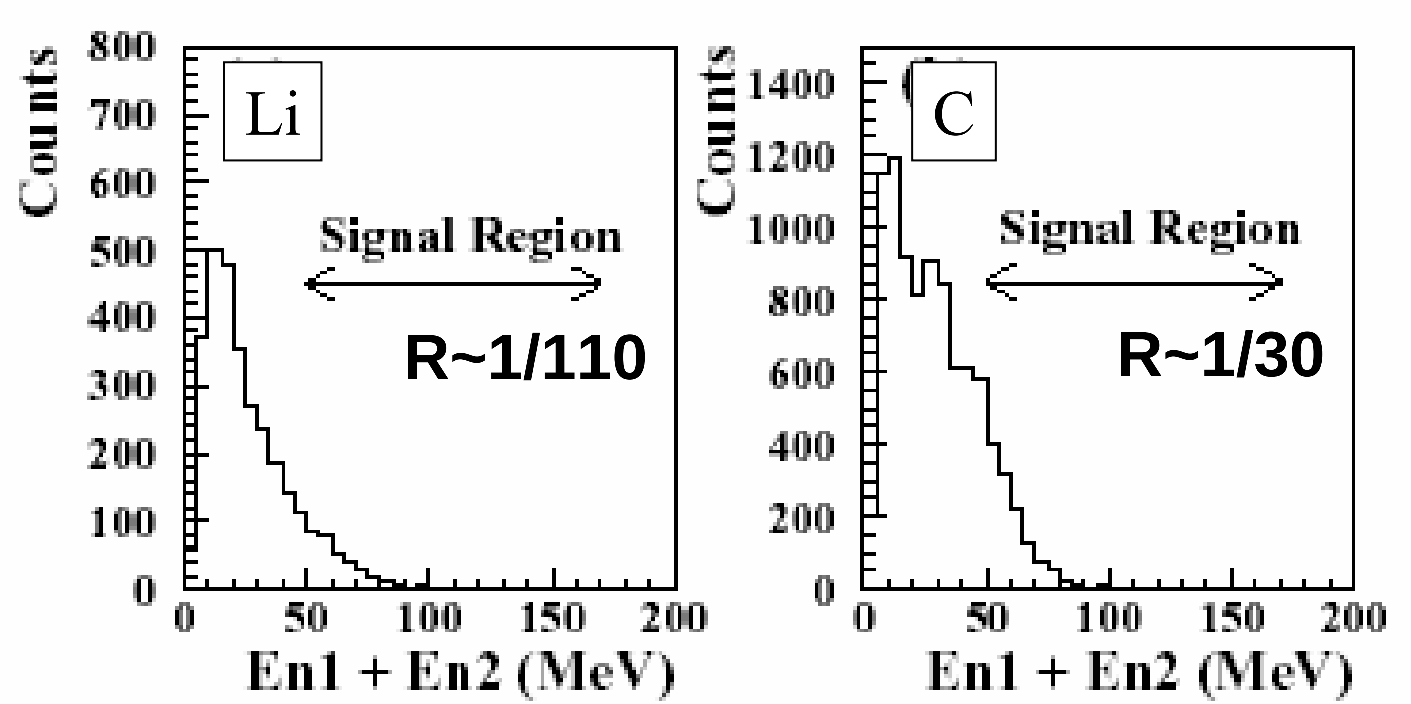


range
2 g/cm^2

Background MC simulation

- Simulation of worst case
  - 1/5 of π– stop in material around target

    1/5 Γπ- ~ 0.06 ⇔ Γn ~ 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	$\Lambda n \rightarrow nn$	$\Lambda p \rightarrow np$
${}^{4}_{\Lambda}H$	${}^{1}S_{0}$, ${}^{3}S_{1}$	${}^{1}S_{0}$
${}^{4}_{\Lambda}He$	${}^{1}S_{0}$	${}^{1}S_{0}$, ${}^{3}S_{1}$
${}^{5}_{\Lambda}He$	${}^{1}S_{0}$, ${}^{3}S_{1}$	${}^{1}S_{0}$, ${}^{3}S_{1}$

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

$\Rightarrow$ we can measure ${}^{1}S_{0}$ amplitudes directly.

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

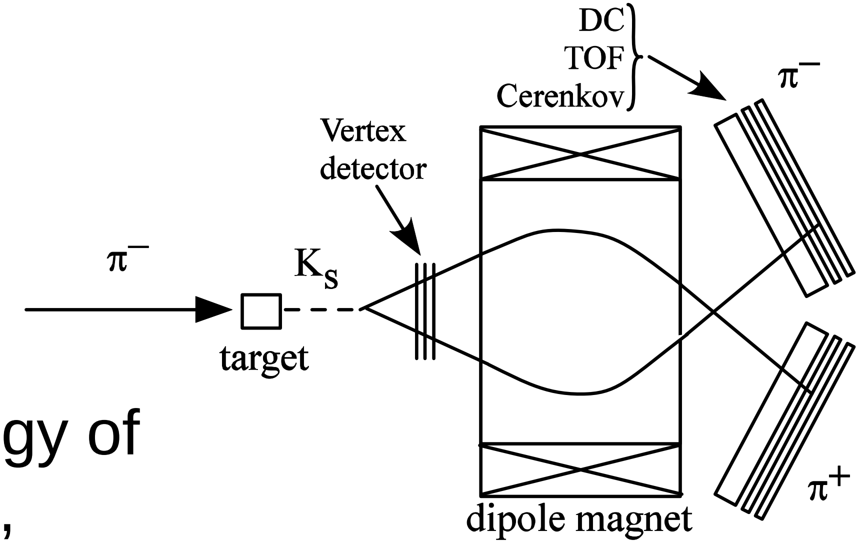
$\Rightarrow$ we can check the validity of the $\Delta I=1/2$ rule in B-B weak interaction.

Existing experimental results

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

$\Gamma p({}^{4}_{\Lambda}He)/\Gamma_{\Lambda}= 0.16\pm0.02$(KEK), 0.16 ± 0.02(BNL) 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.

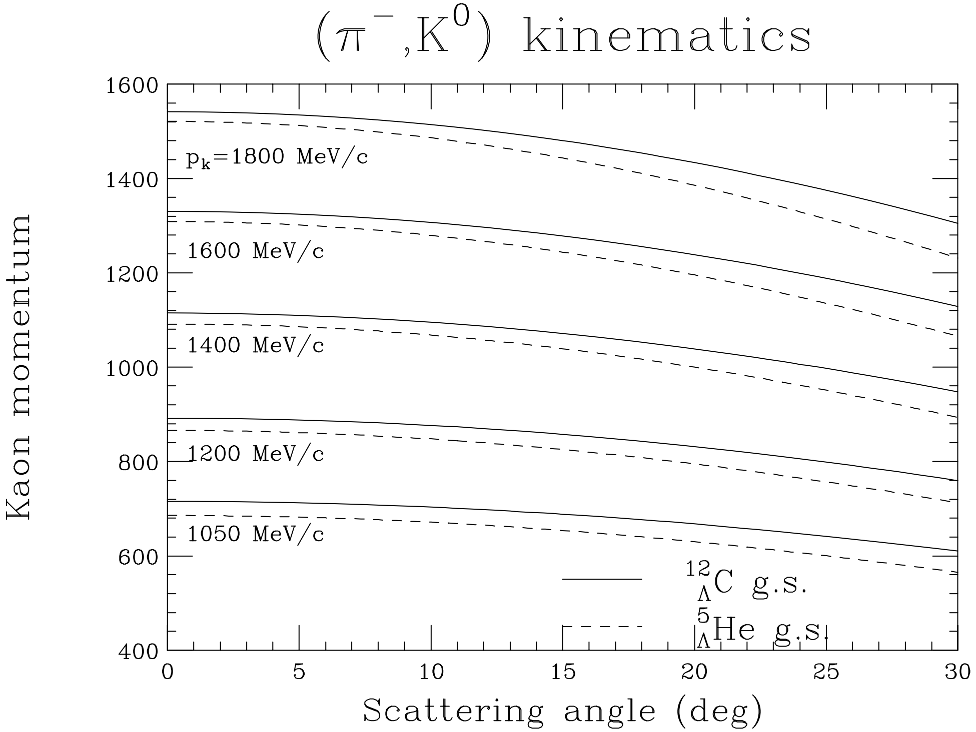
background

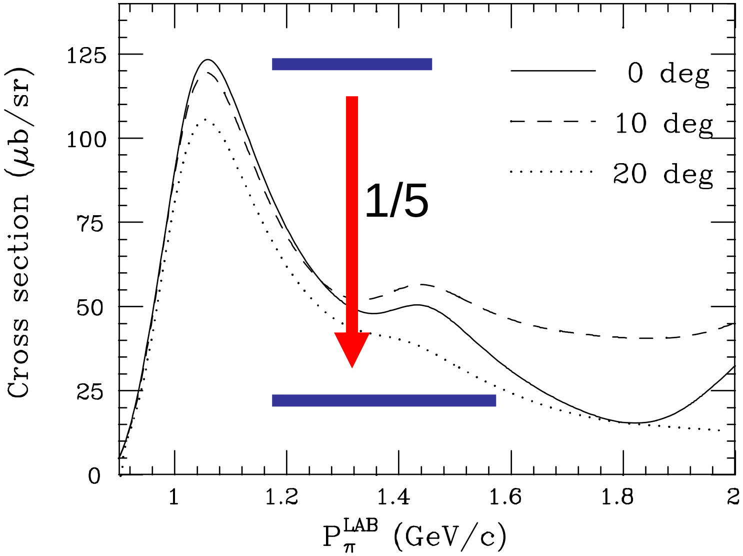
Multi-pion production in the target or other material around target should be most serious background.

↓

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

Beam Momentum





At standard momentum for (π,K) reaction, 1050 MeV/c, βγcτ for kaon is 3.9cm.

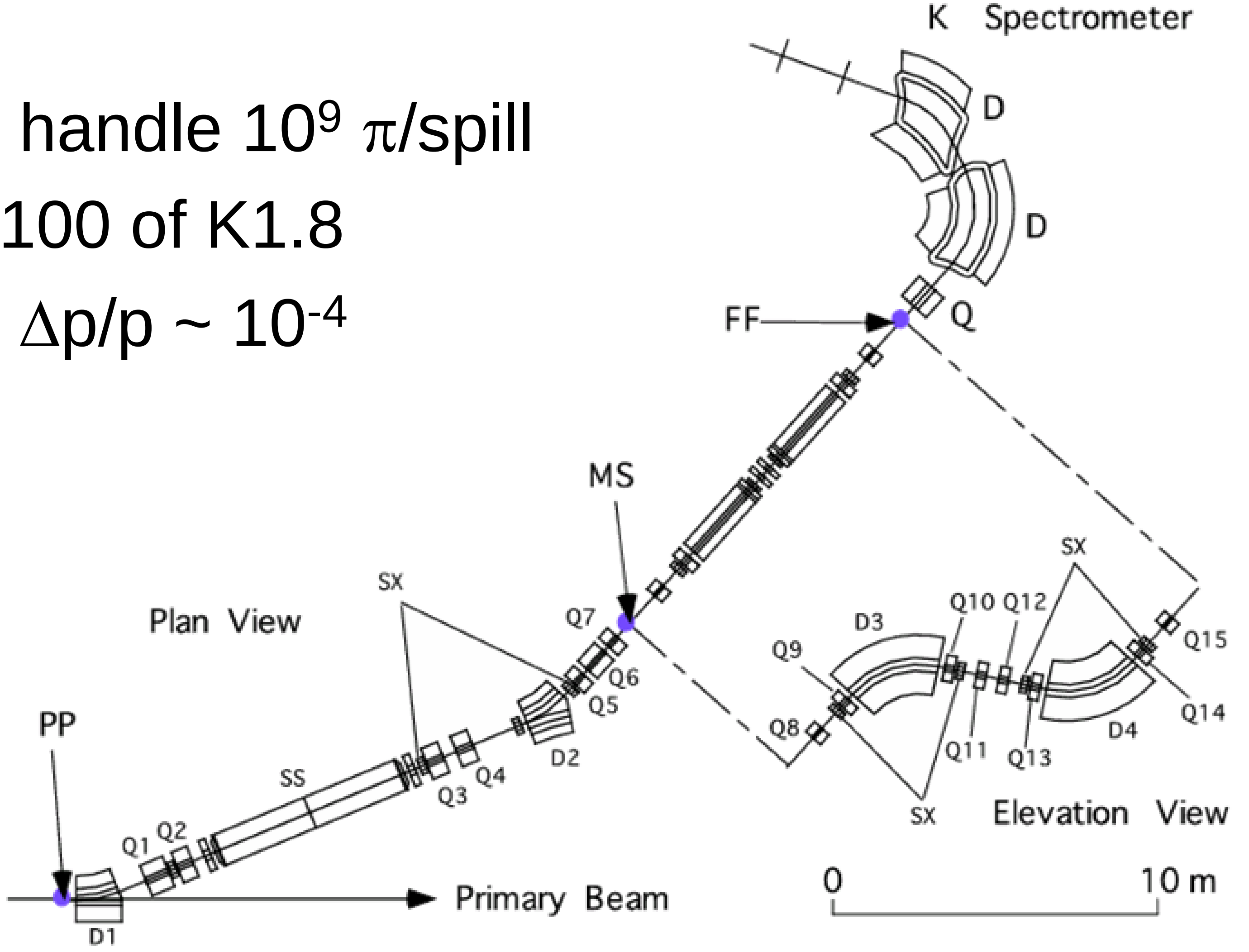
$\beta\gamma c\tau$ = 9.7 cm @ P_K=1.53 GeV/c

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

- handle 10^9 π/spill

x 100 of K1.8

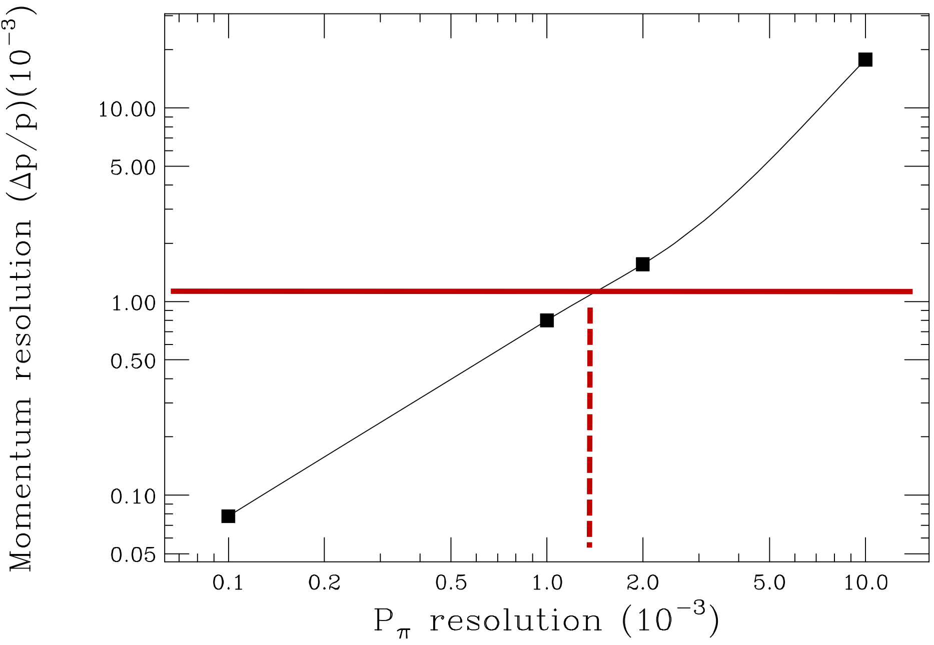
- Δp/p ~ 10^{-4}

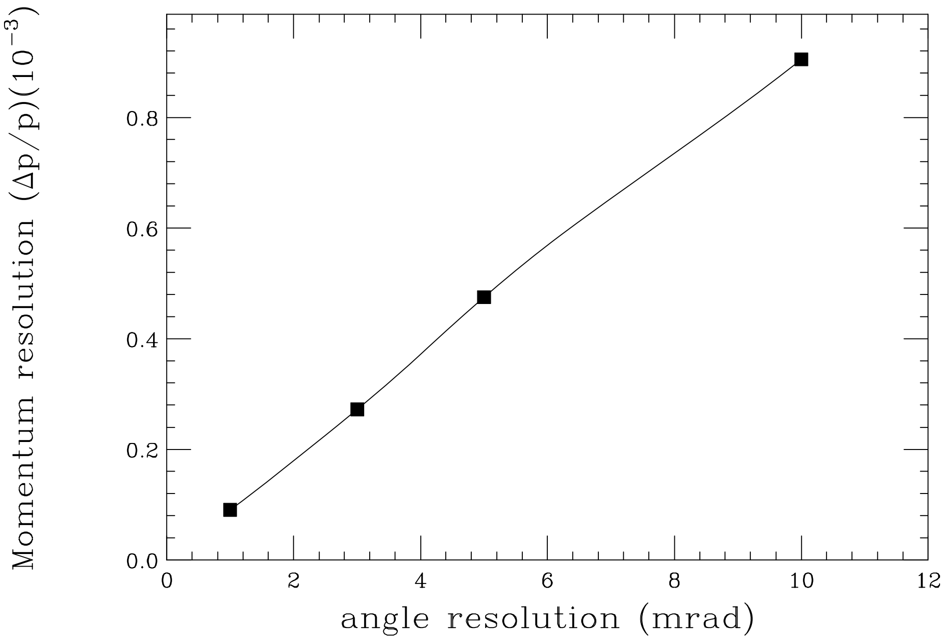


Resolution OK ? – angle/momentum of pion

E_x resolution

$\Delta p/p=$	$1x10^{-5}$:	$\Delta E_x=$	0.013 – 0.014
	$1x10^{-4}$:		0.133 – 0.142
	$1x10^{-3}$:		1.332 – 1.417





Summary

- We propose to measure the nonmesonic weak decay of 4-body Λ hypernuclei (${}^{4}_{\Lambda}$He/H).
  - select initial spin state (${}^{1}S_{0}/{}^{3}S_{1}$)
  - check the validity of $\Delta I=1/2$ rule in baryon weak interaction
- We are now preparing E22 exp. (${}^{4}_{\Lambda}$He) at K1.8 beamline.
- High intensity and high resolution beamline by H. Noumi, is suitable for measurement of ${}^{4}_{\Lambda}$H.