P10-2: Exclusive Study on the ΛN Weak Interaction in A=4 Λ-Hypernuclei (update from P10)

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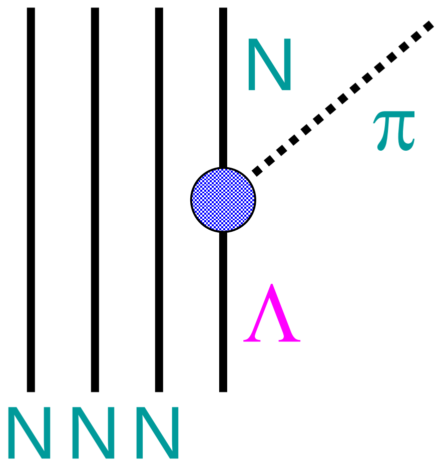
Subjects of this proposal

- Properties of ΛN weak interaction
  - study on non-mesonic weak decay (NMWD) in hypernuclei $\rightarrow$ ΛN weak interaction
    - spin/isospin structure
    - parity information

    determination of partial decay amplitudes
  - measurement of np-ratio (Γ_n/Γ_p) of ${}^{4}_{\Lambda}$He

    $\Lambda n \rightarrow nn$, $\Lambda p \rightarrow np$
- Studies toward test of "ΔI=1/2 rule"
  - "ΔI=1/2 rule" valid or not in NMWD
  - Study on A=4 hypernuclei (${}^{4}_{\Lambda}$He and ${}^{4}_{\Lambda}$H)
  - 1st step for the study

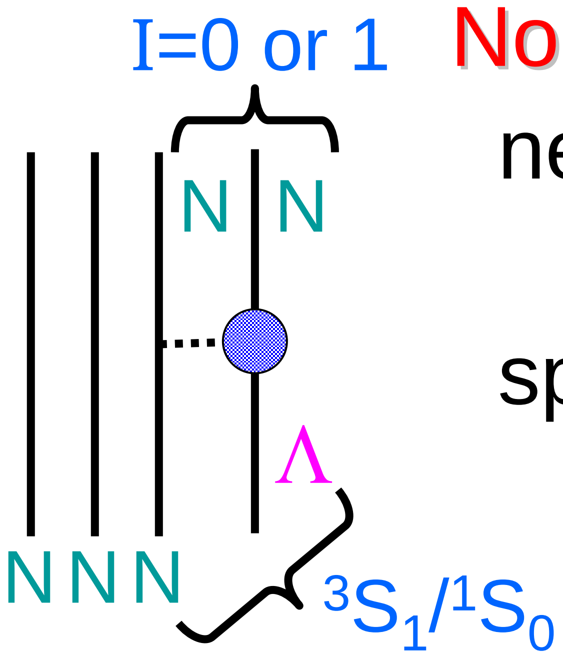
Weak decays in Λ-Hypernuclei



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**

Status of NMWD studies

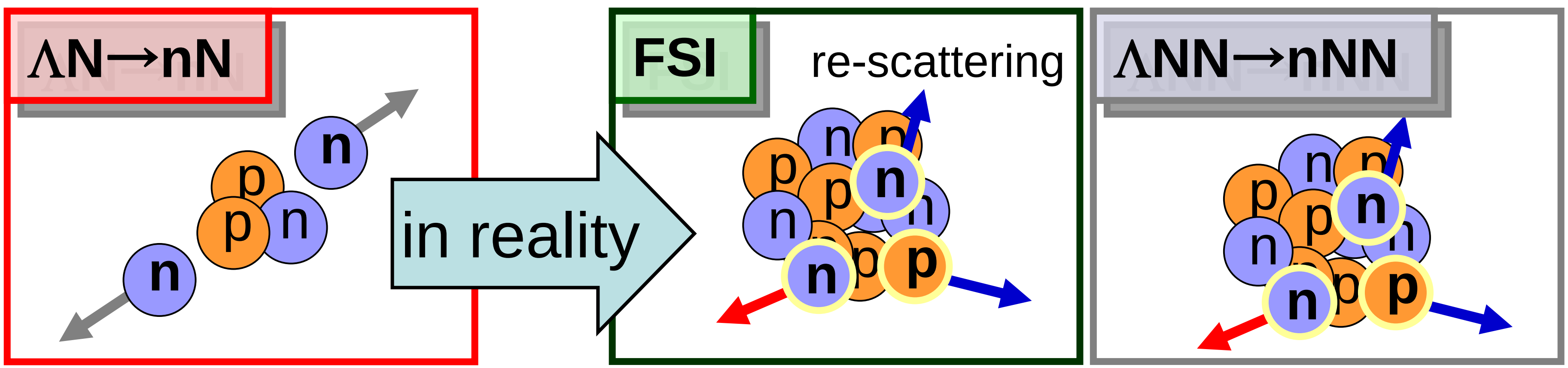
- Old puzzle solved recently
  - np-ratio ($\Gamma_{\Lambda n \to nn}/\Gamma_{\Lambda p \to pn} \equiv \Gamma_n/\Gamma_p$) inconsistent

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

  - Experimental and theoretical improvements

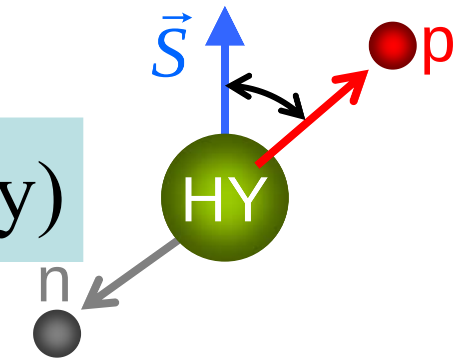
$$\Gamma_n / \Gamma_p \approx 0.5 \,(\text{Exp. and Theory})$$

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



- 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

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

${}^1S_0 \times {}^3S_1$ (red box) ; ${}^3S_1 \times {}^3S_1$ (teal box)

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

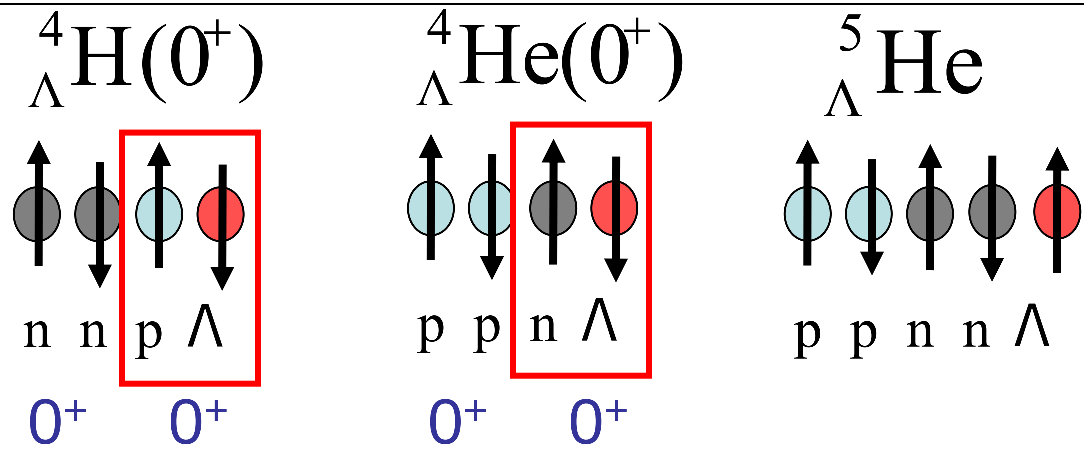
${}^1S_0(I=1)$

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

${}^3S_1(I=1)$

assuming initial S state

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



	$^{4}_{\Lambda}\mathrm{H}(0^{+})$	$^{4}_{\Lambda}\mathrm{He}(0^{+})$	$^{5}_{\Lambda}\mathrm{He}$
$\Lambda n \to nn$:	$^1S_0$, $^3S_1$	$\mathbf{^1S_0}$	$^1S_0$, $^3S_1$
$\Lambda p \to np$:	$\mathbf{^1S_0}$	$^1S_0$, $^3S_1$	$^1S_0$, $^3S_1$

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

$^1S_0(I=1)$

$^3S_1(I=0)$

$^3S_1(I=1)$

assuming initial S state

Status of amplitude determination

Current status

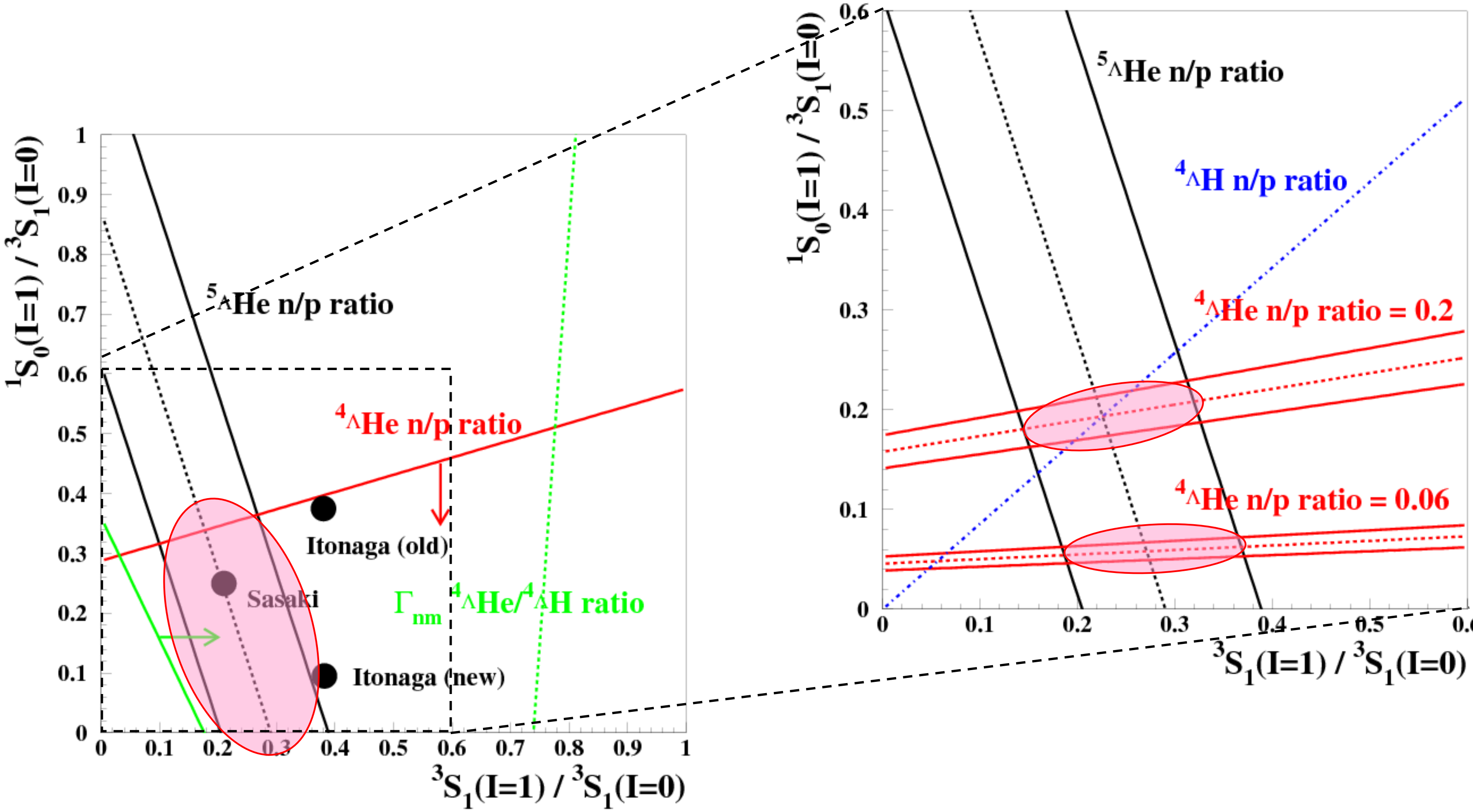
constraint from $^{5}{}_{\Lambda}$He data

other constraints are loose

Our prospects

new constraint from $^{4}{}_{\Lambda}$He

np-ratio better than 15% error



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

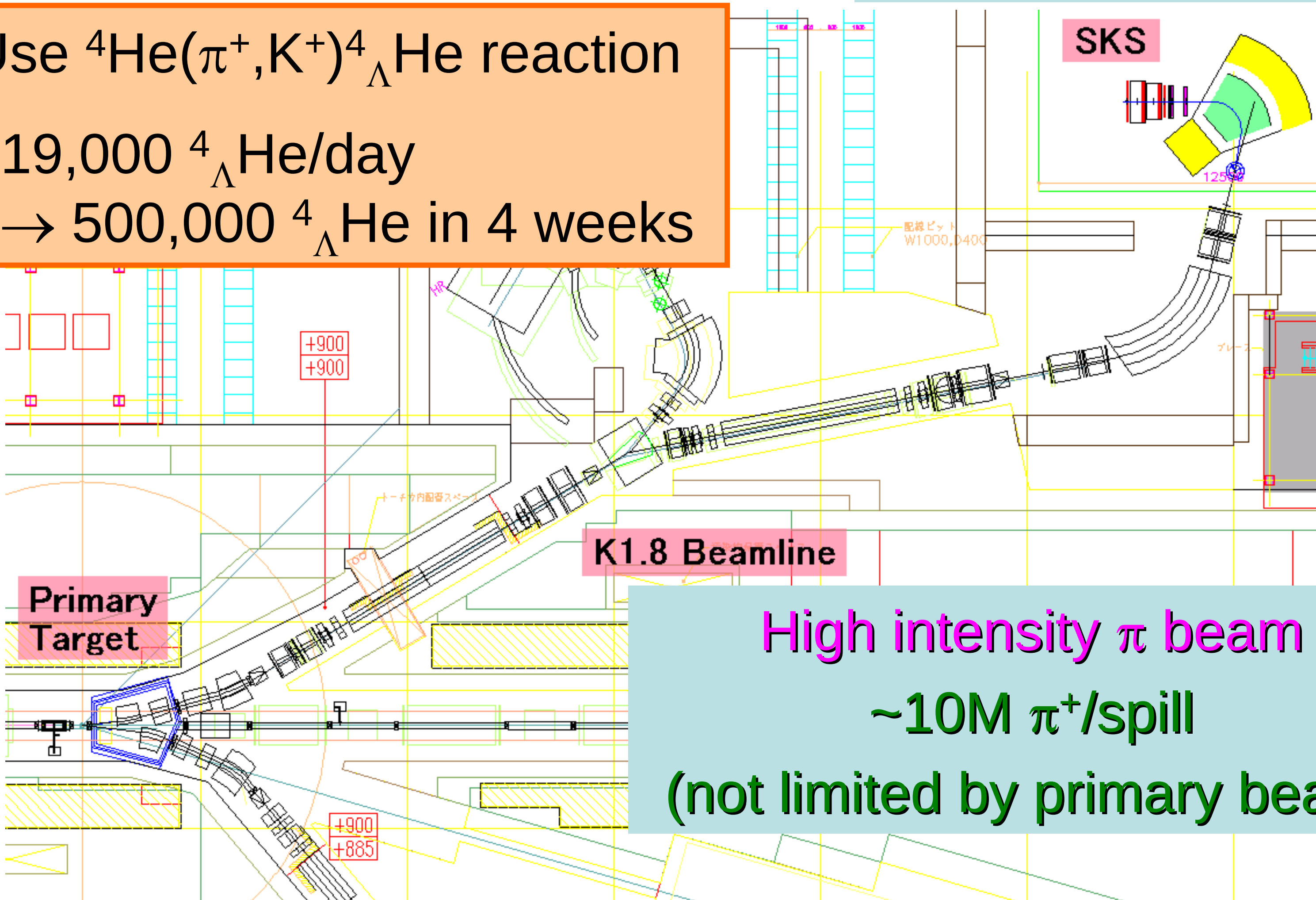
High resolution

Efficient K+ detection

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

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

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



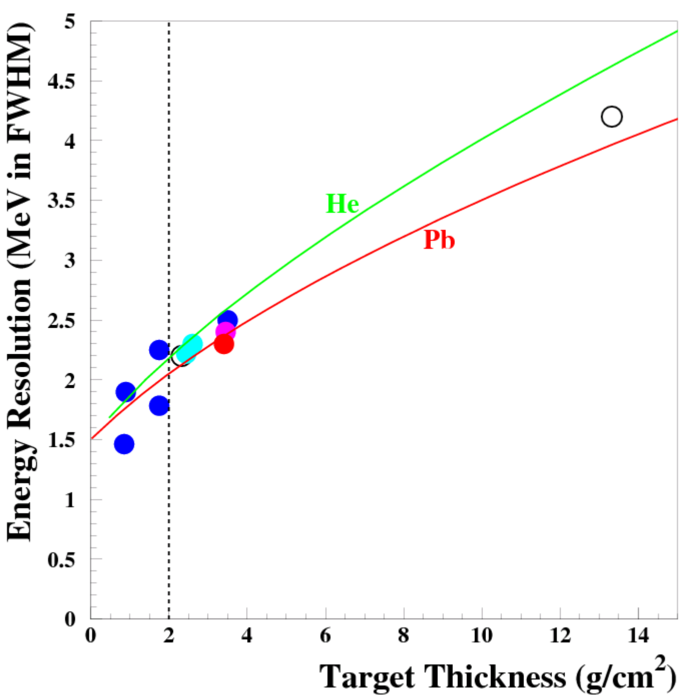
High intensity π beam

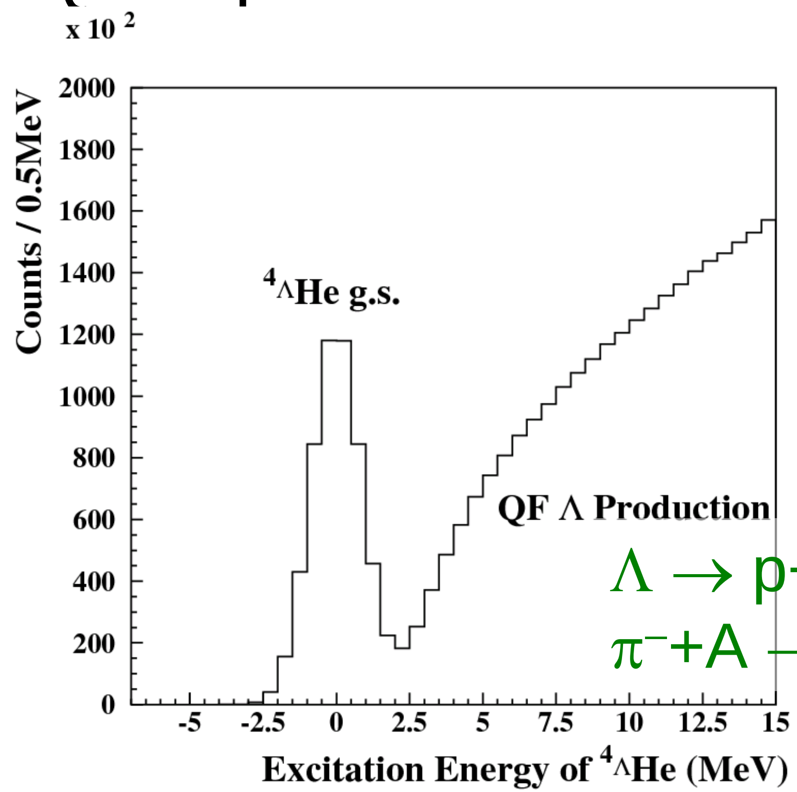
~10M π^{+}/spill

(not limited by primary beam)

Energy resolution

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



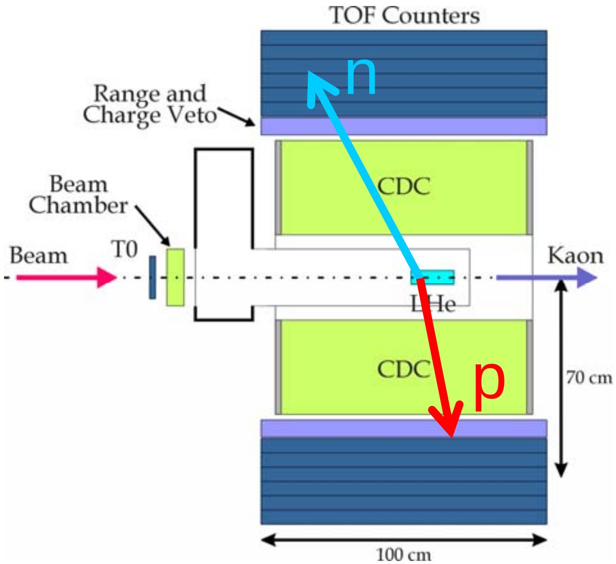


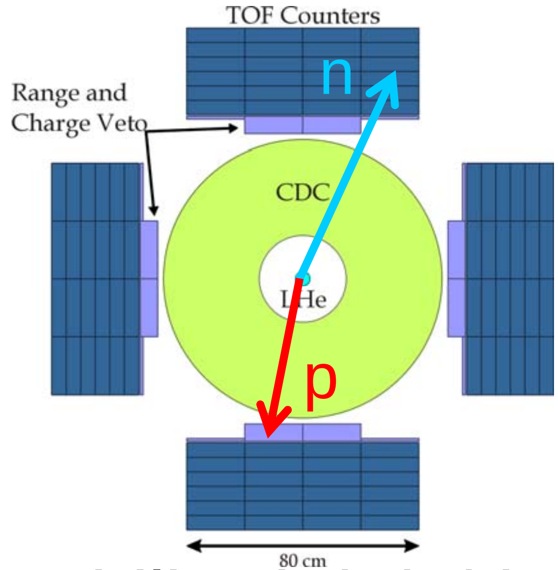
$\Lambda \rightarrow p+\pi^-$

π^-+A $\rightarrow$ nnX, npX

Decay arm system

– Large acceptance and high efficiency for NN





$\Omega(n) \approx 0.4$

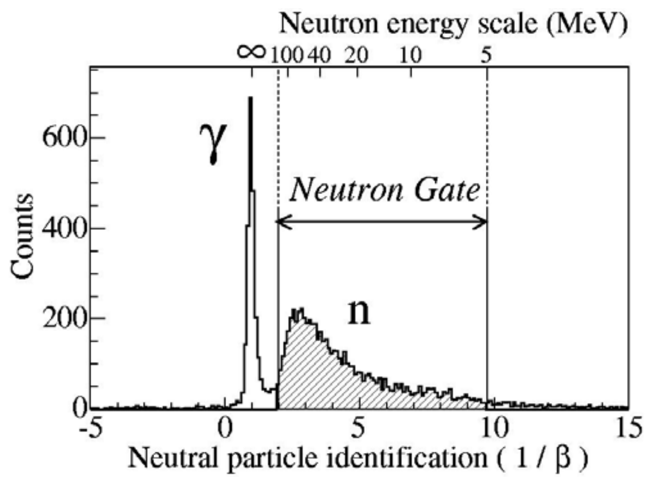
$\varepsilon(n) \approx 30\%$

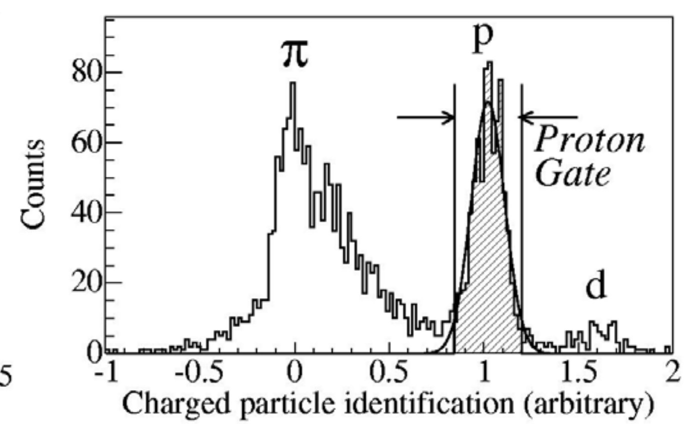
$\Omega(p) \approx 0.25$

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

– 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

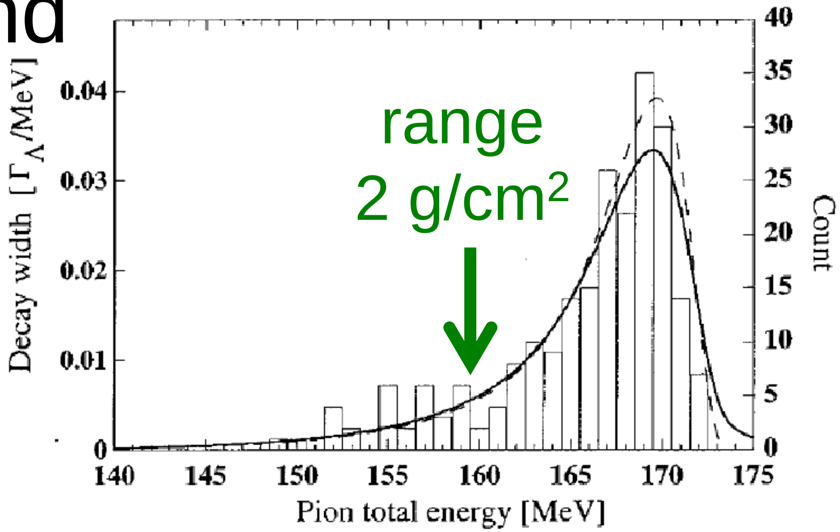
– 19,000 $^4_\Lambda$He/day → 500,000 $^4_\Lambda$He in 4 weeks

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

in case of
1% BR

Background estimation

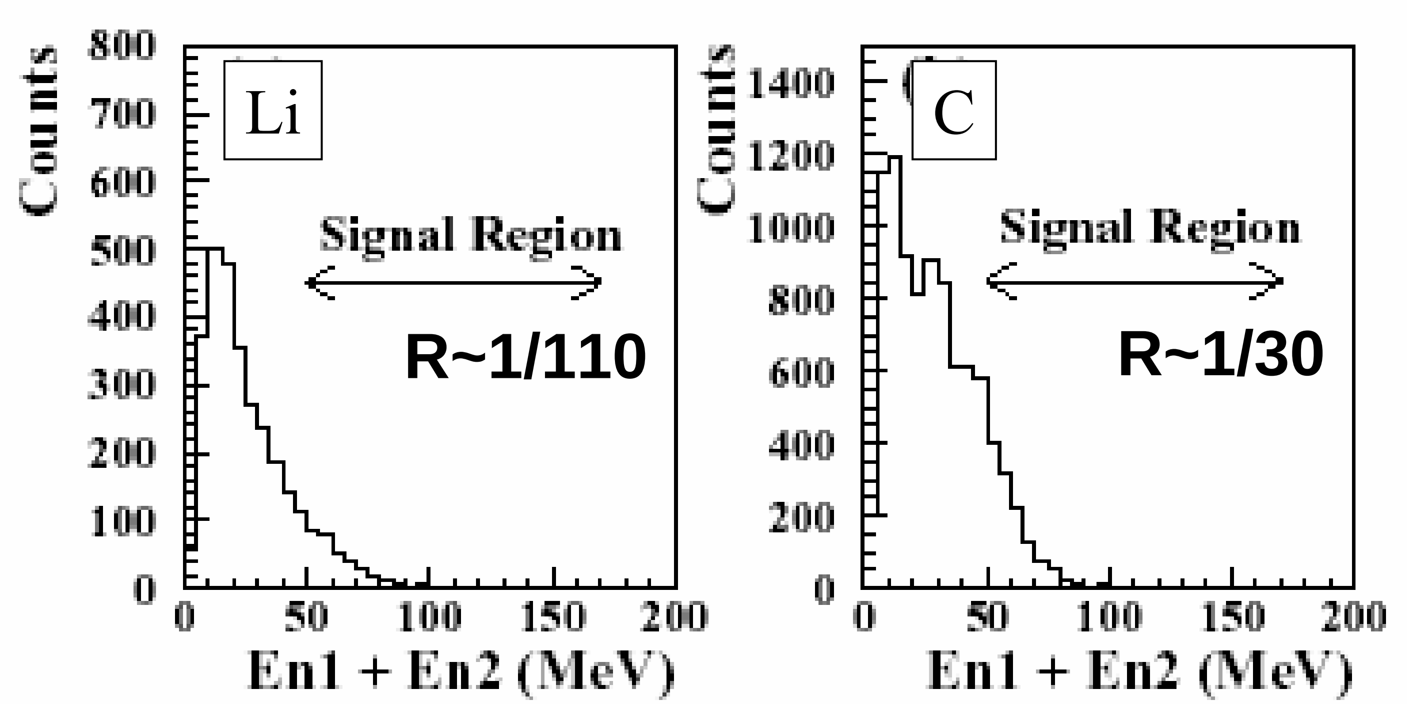
- Background sources
  - QF Λ-production ($\Lambda \to p+\pi^-$, $\pi^- + A \to nnX$)
    - cut in Ex spectrum
  - Mesonic weak decay of hypernuclei
    - ${}^4_\Lambda He \to {}^3He + p + \pi^-$, $\pi^- + A \to nnX$
    - $\Gamma_{\pi-} \approx 0.3\,\Gamma \Leftrightarrow \Gamma_n \approx 0.01\,\Gamma$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



Background MC simulation

- Simulation of worst case
  - 1/5 of $\pi-$ stop in material around target

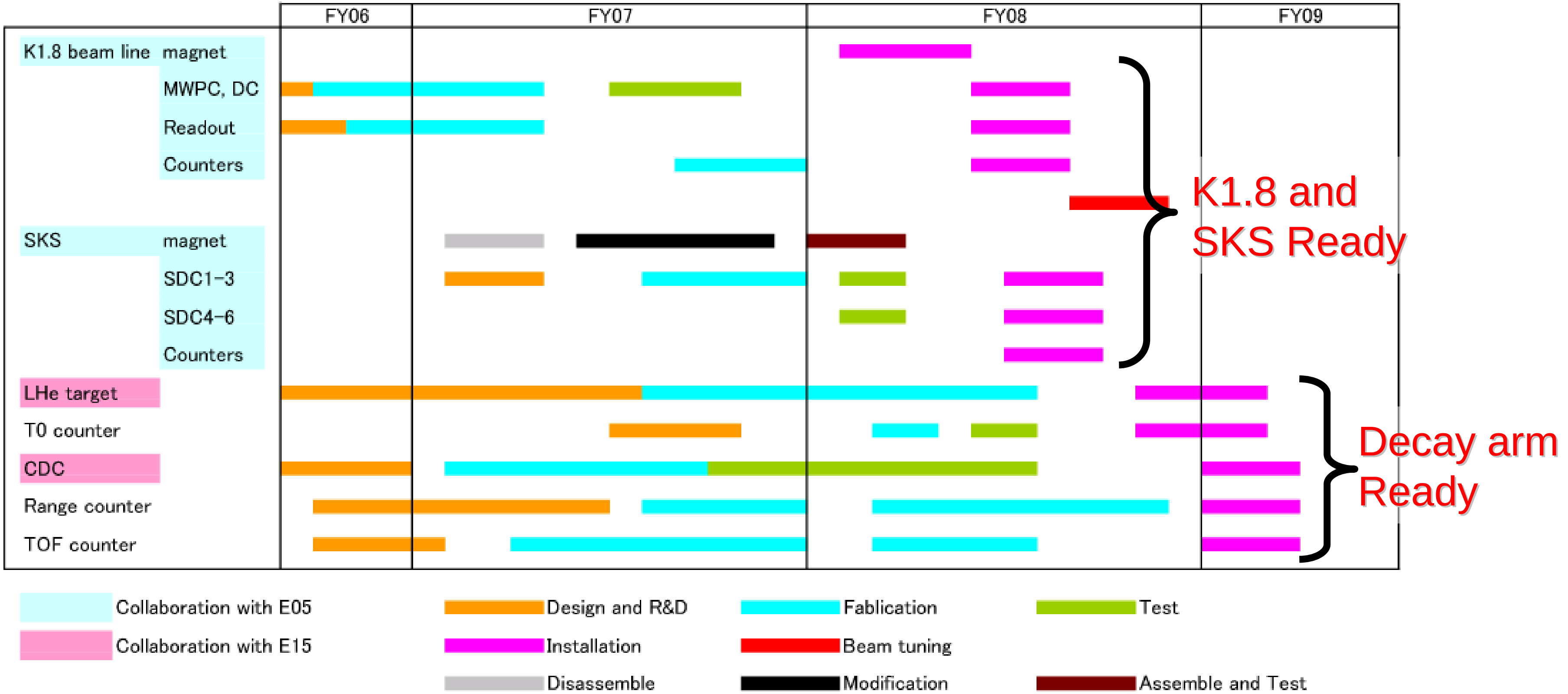
    1/5 $\Gamma\pi$- ~ 0.06 ⇔ Γn ~ 0.01
  - GEANT4 base simulation



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

Time schedule

- Ready in 2009
- Collaboration with E05 and E15



Summary of proposal

- We propose to measure the nonmesonic weak decay of ${}^{4}_{\Lambda}He$.
  - select initial spin state (${}^{1}S_{0}/{}^{3}S_{1}$)
  - first step to check the validity of $\Delta I=1/2$ rule
- 1300 np-decay and 75 nn-decay are expected in 4 weeks if B.R.(nn)=1%.
- Main background, π^{-} absorption, will not affect the measurement
- Experiment will be ready in FY 2009.