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

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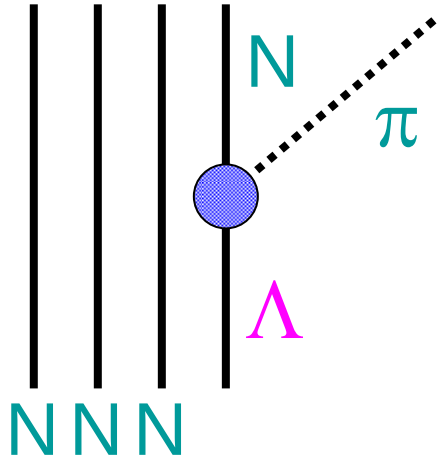
Subjects of this proposal

- Properties of ΛN weak interaction
  - study on non-mesonic weak decay (NMWD) in hypernuclei → 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

    Λn→nn, Λp→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

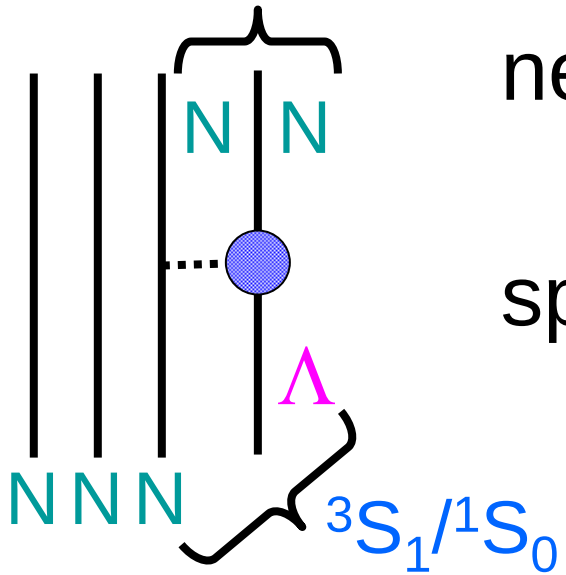
Weak decays in Λ-Hypernuclei



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

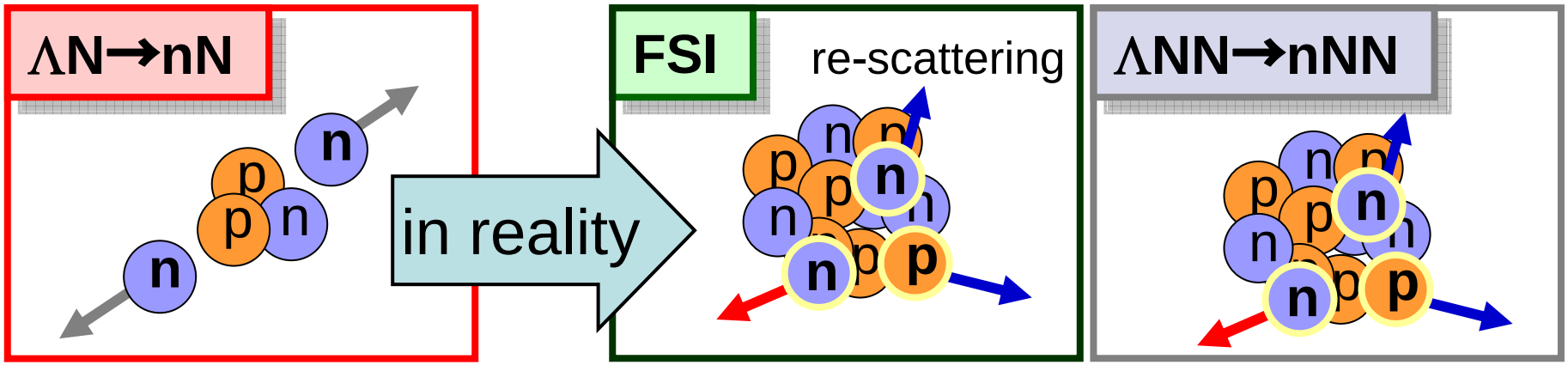
- Old puzzle solved recently
  - np-ratio ($\Gamma_{\Lambda n\to nn}/\Gamma_{\Lambda p\to pn}\equiv\Gamma_n/\Gamma_p$) inconsistent

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

  - Experimental and theoretical improvements

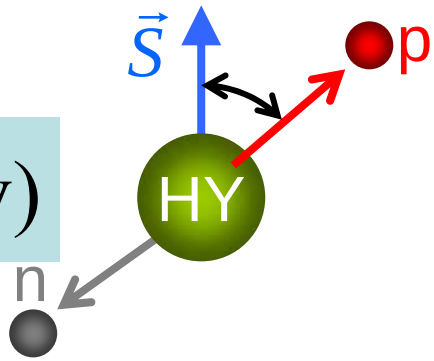
$$\Gamma_n/\Gamma_p \approx 0.5\,(\text{Exp. and Theory})$$

  - (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

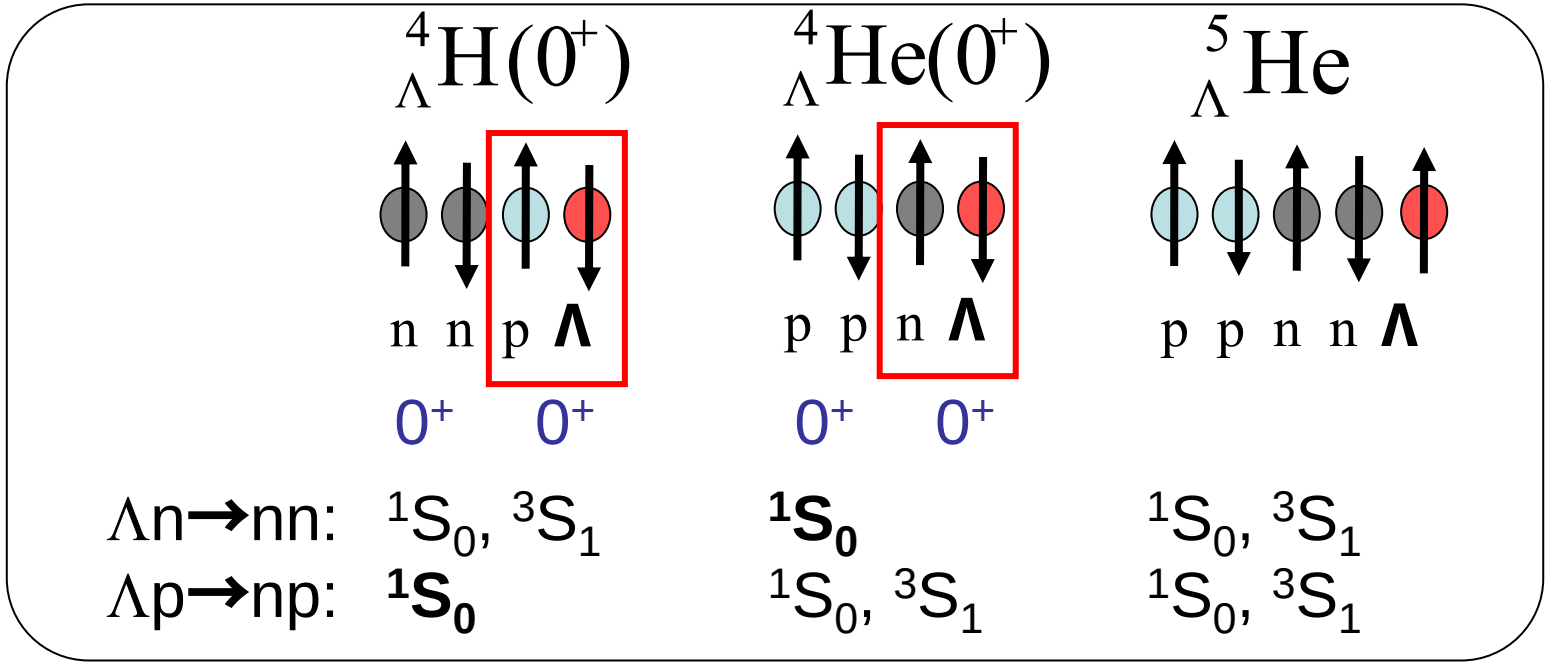
$$\alpha_p^{NM} = \frac{2\sqrt{3}Re[\overbrace{-ae^* + b(c-\sqrt{2}d)^*/\sqrt{3}}^{^1S_0\times{}^3S_1} \overbrace{- f(\sqrt{2}c+d)^*}^{^3S_1\times{}^3S_1}]}{\{a^2+b^2+3(c^2+d^2+e^2+f^2)\}}$$

Large contribution ?

initial	final	amplitude	isospin	parity	
$^1S_0$	$^1S_0$	*a*	1	no	$^1S_0(I=1)$
	$^3P_0$	*b*	1	yes	
$^3S_1$	$^1S_1$	*c*	0	no	$^3S_1(I=0)$
	$^3D_1$	*d*	0	no	
	$^1P_1$	*e*	0	yes	
	$^3P_1$	*f*	1	yes	$^3S_1(I=1)$

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

$^1S_0(I=1)$

$^3S_1(I=0)$

$^3S_1(I=1)$

assuming initial S state

Status of amplitude determination

Current status

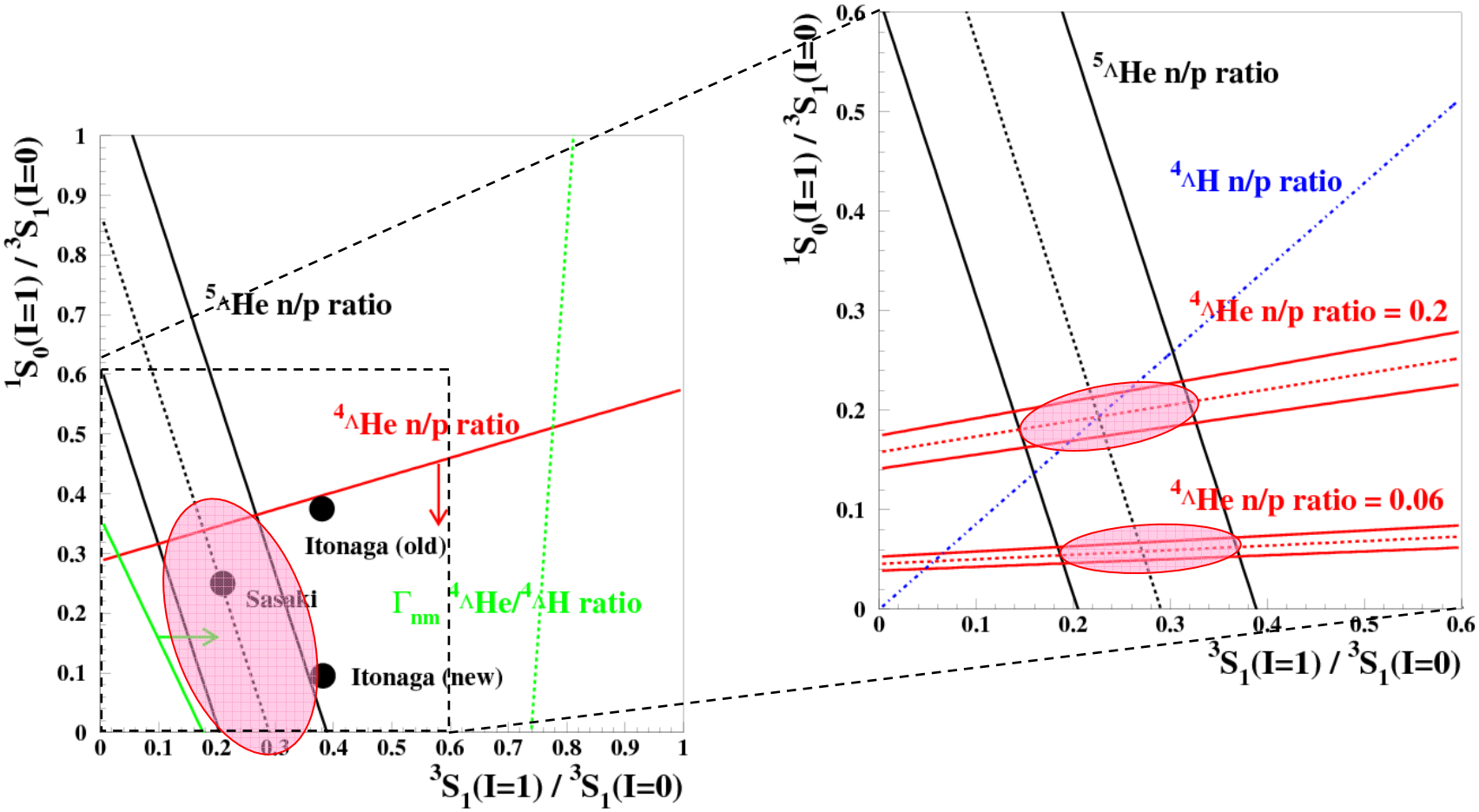
constraint from $^{5}_{\Lambda}$He data

other constraints are loose

Our prospects

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

np-ratio better than 15% error



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

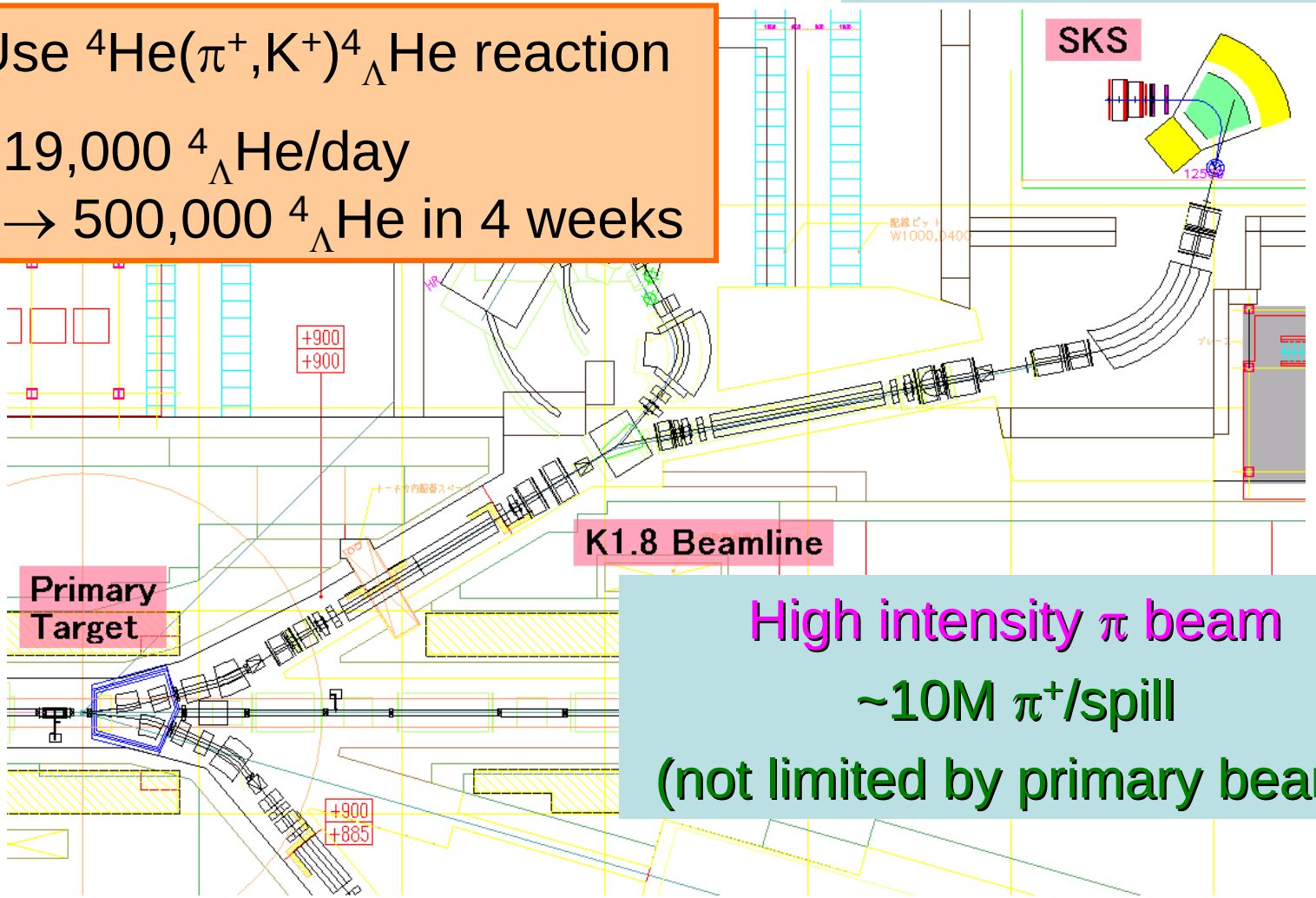
High resolution

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



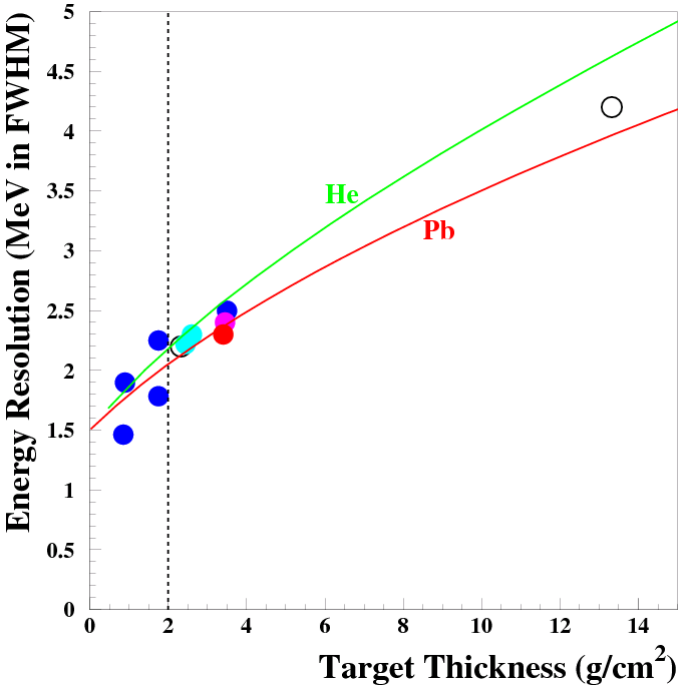
High intensity π beam

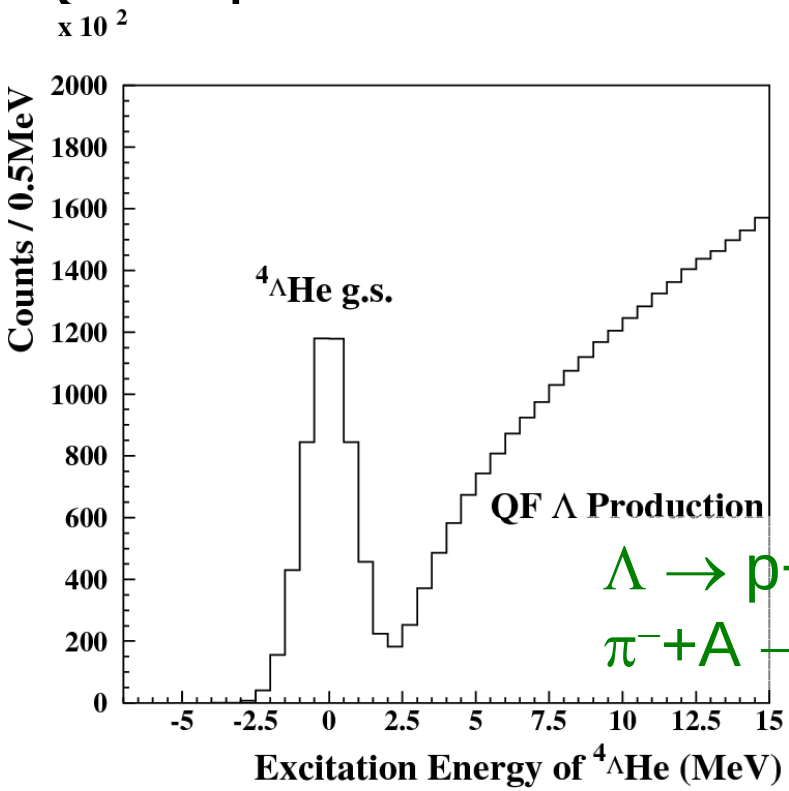
~10M π^{+}/spill

(not limited by primary beam)

Energy resolution

- K1.8 bemline + SKS → 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



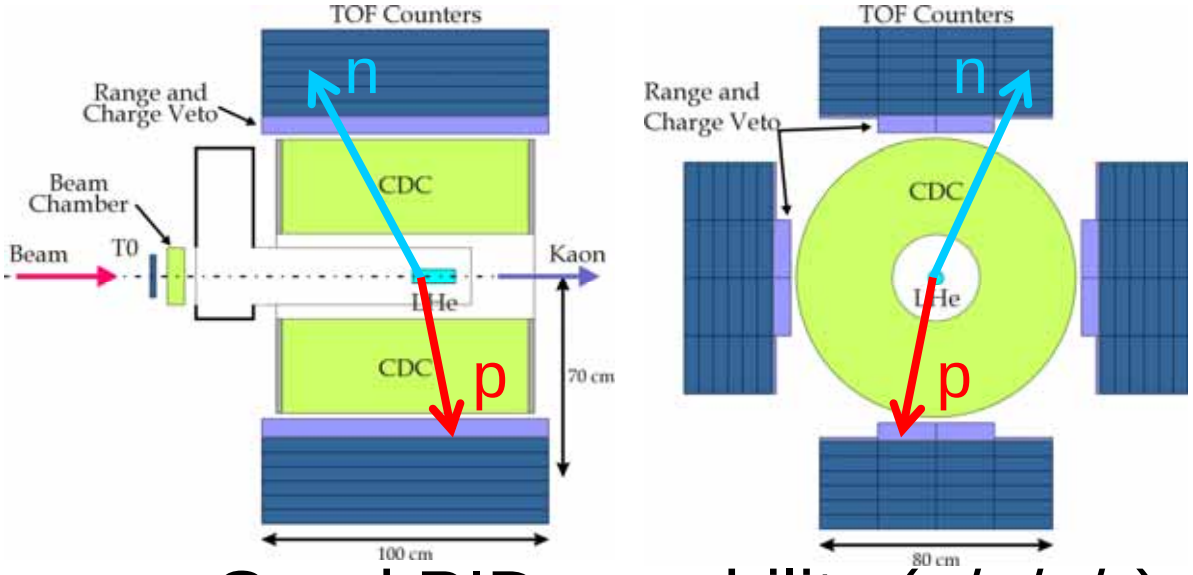


$\Lambda \rightarrow p+\pi^-$

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

Decay arm system

– Large acceptance and high efficiency for NN



$\Omega(n) \approx 0.4$

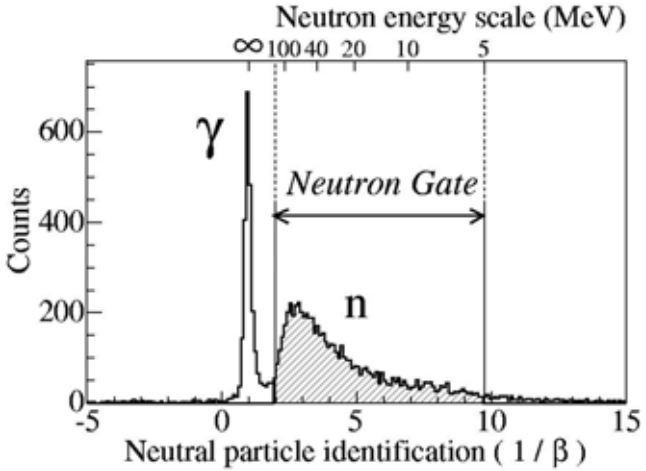
$\varepsilon(n) \approx 30\%$

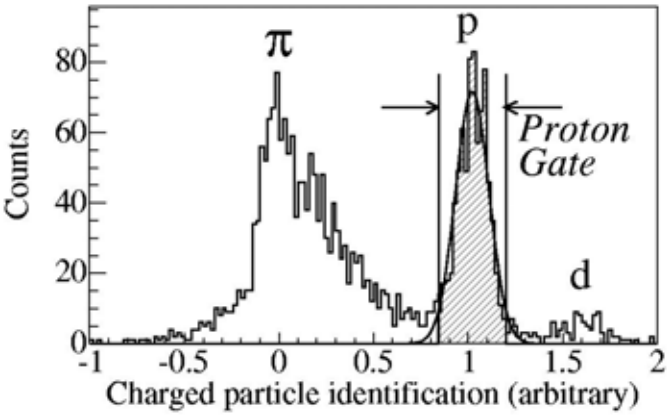
$\Omega(p) \approx 0.25$

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

– 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

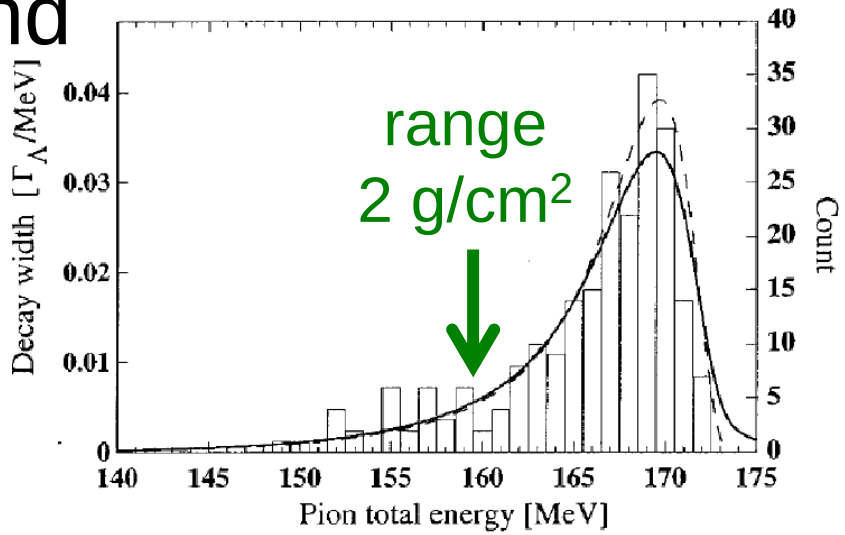
← large acceptance and high efficiency

- 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

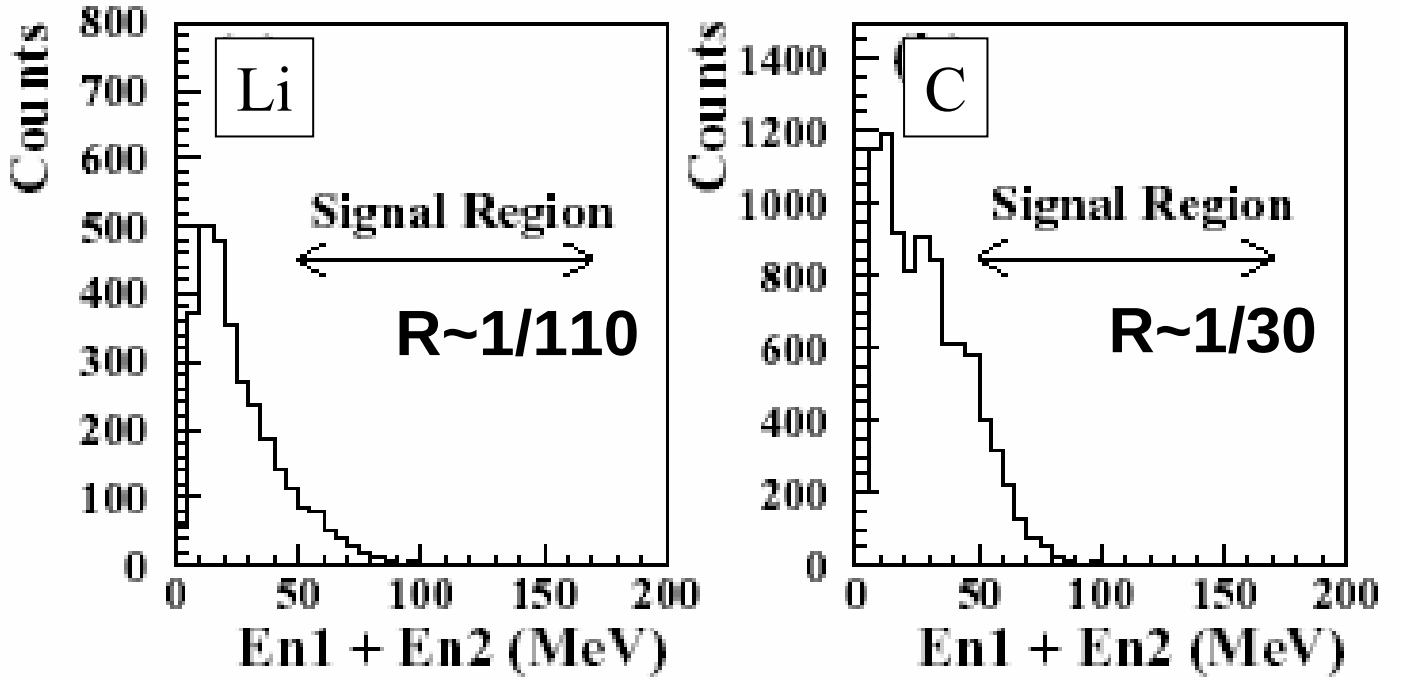
- Background sources
  - QF Λ-production ($\Lambda \rightarrow p+\pi^-$, $\pi^-+A \rightarrow nnX$)
    - cut in Ex spectrum
  - Mesonic weak decay of hypernuclei
    - ${}^{4}_{\Lambda}\mathrm{He} \rightarrow {}^{3}\mathrm{He}+p+\pi^-$, $\pi^-+A \rightarrow nnX$
    - $\Gamma_{\pi^-} \approx 0.3\,\Gamma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

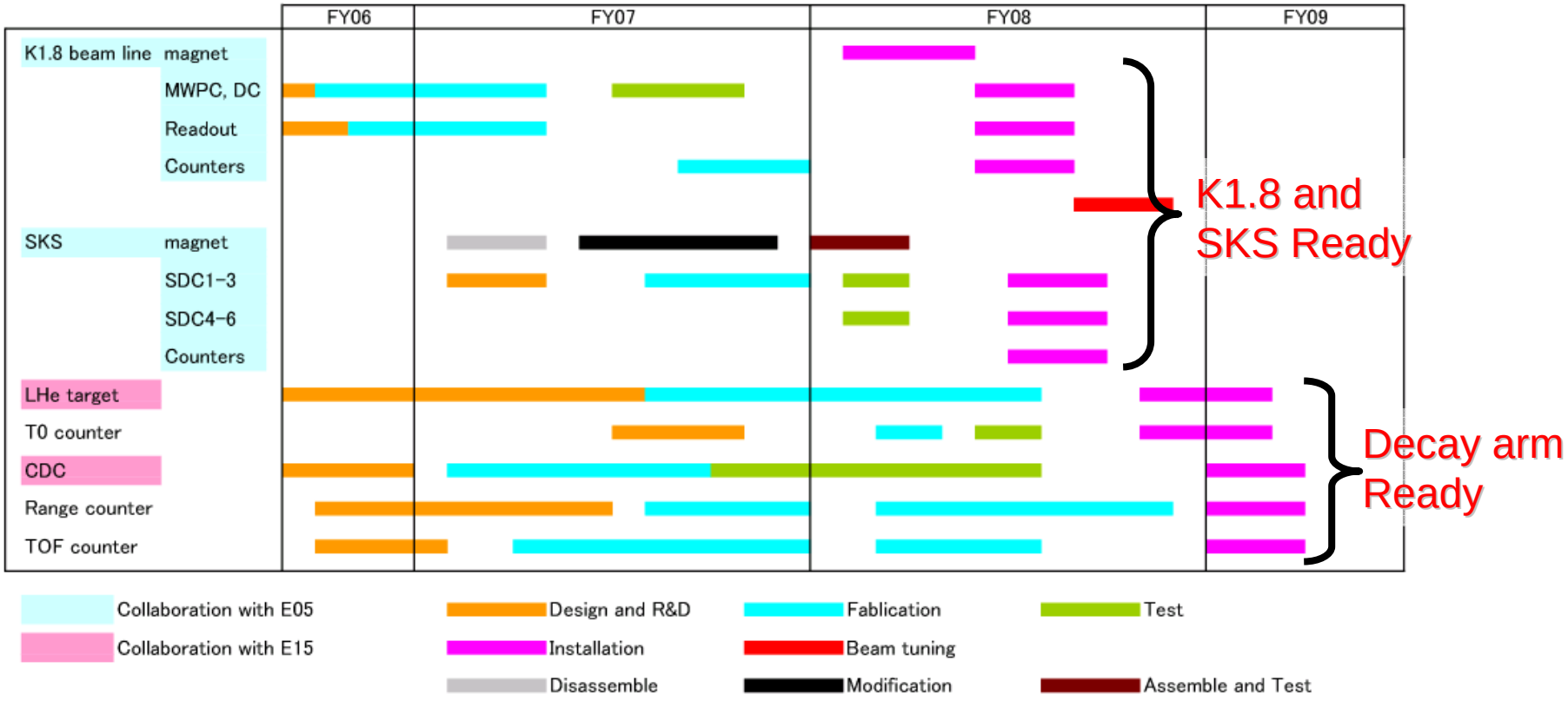


R: Reduction factor (En1+En2>50MeV)

Time schedule

– Ready in 2009

– Collaboration with E05 and E15



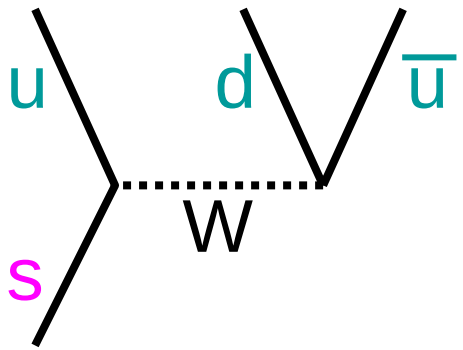
Summary of proposal

- We propose to measure the nonmesonic weak decay of ${}^{4}_{\Lambda}\mathrm{He}$.
  - 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.

Backup Slides

$\Delta S=1$ weak interaction

- Quark description

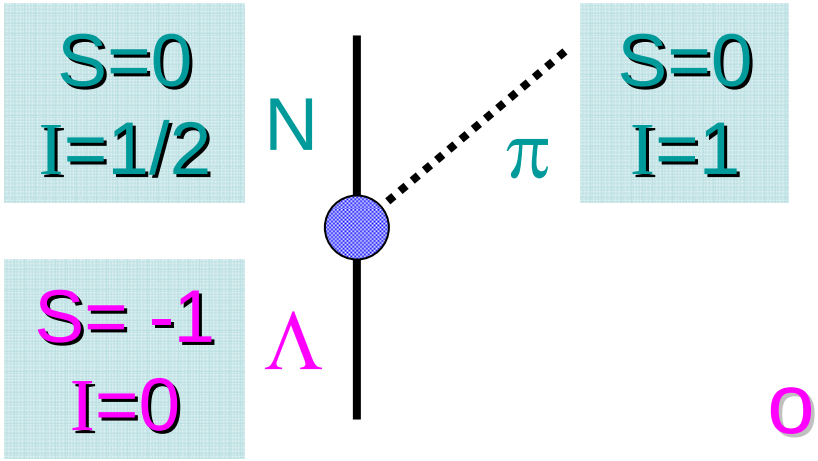


$\Delta S = 1$

~~P~~

$\Delta I \neq 0$

- Case of Λ free decay



$\Delta S = 1$

p/s = 0.38

$\Delta I = 1/2 \Rightarrow \Gamma\pi^-/\Gamma\pi^0 = 2$

or $\Delta I = 3/2 \Rightarrow \Gamma\pi^-/\Gamma\pi^0 = 0.5$

Exp. $\Gamma\pi^-/\Gamma\pi^0 = 1.78$ "$\Delta I=1/2$ rule"

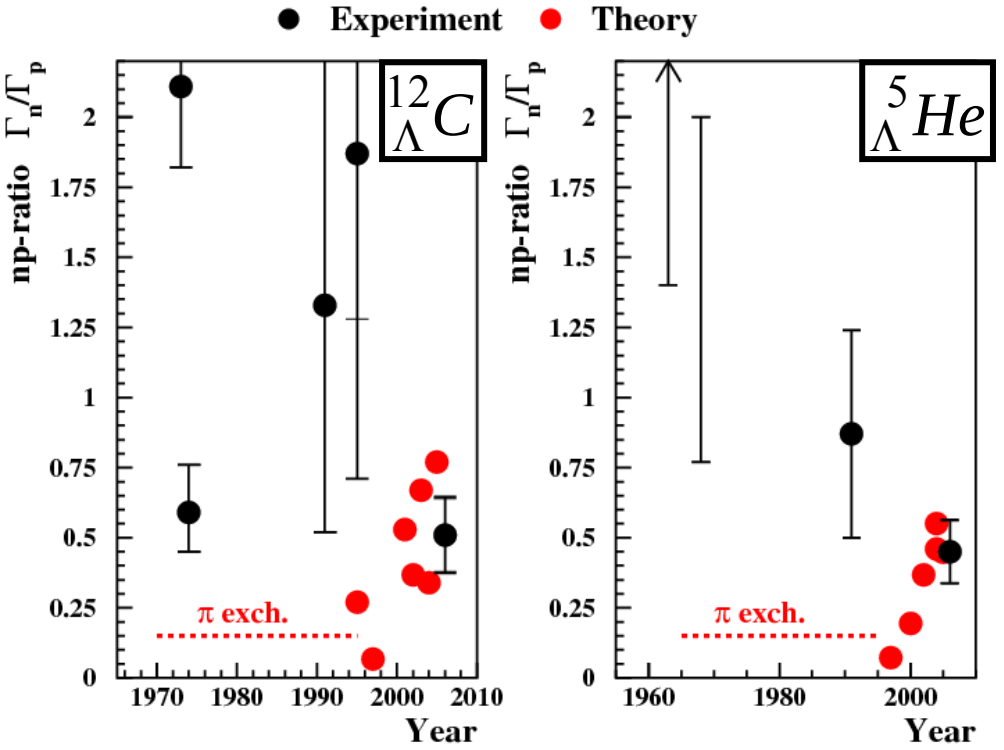
isospin and parity structure well known

Old puzzle

$$\Gamma_n / \Gamma_p \geq 1 \,(\text{Exp.})$$

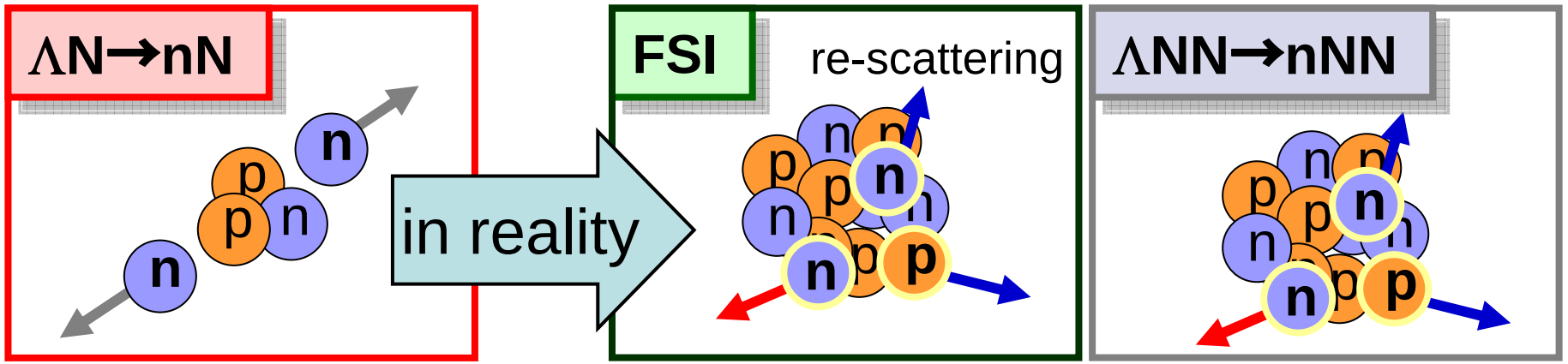
$$\Updownarrow$$

$$\Gamma_n / \Gamma_p \approx 0 \,(\text{Theory})$$



– (Exp.) Overestimation of $\Lambda n \rightarrow nn$ decay

- Assumption of clean $\Lambda N \rightarrow nN$ process

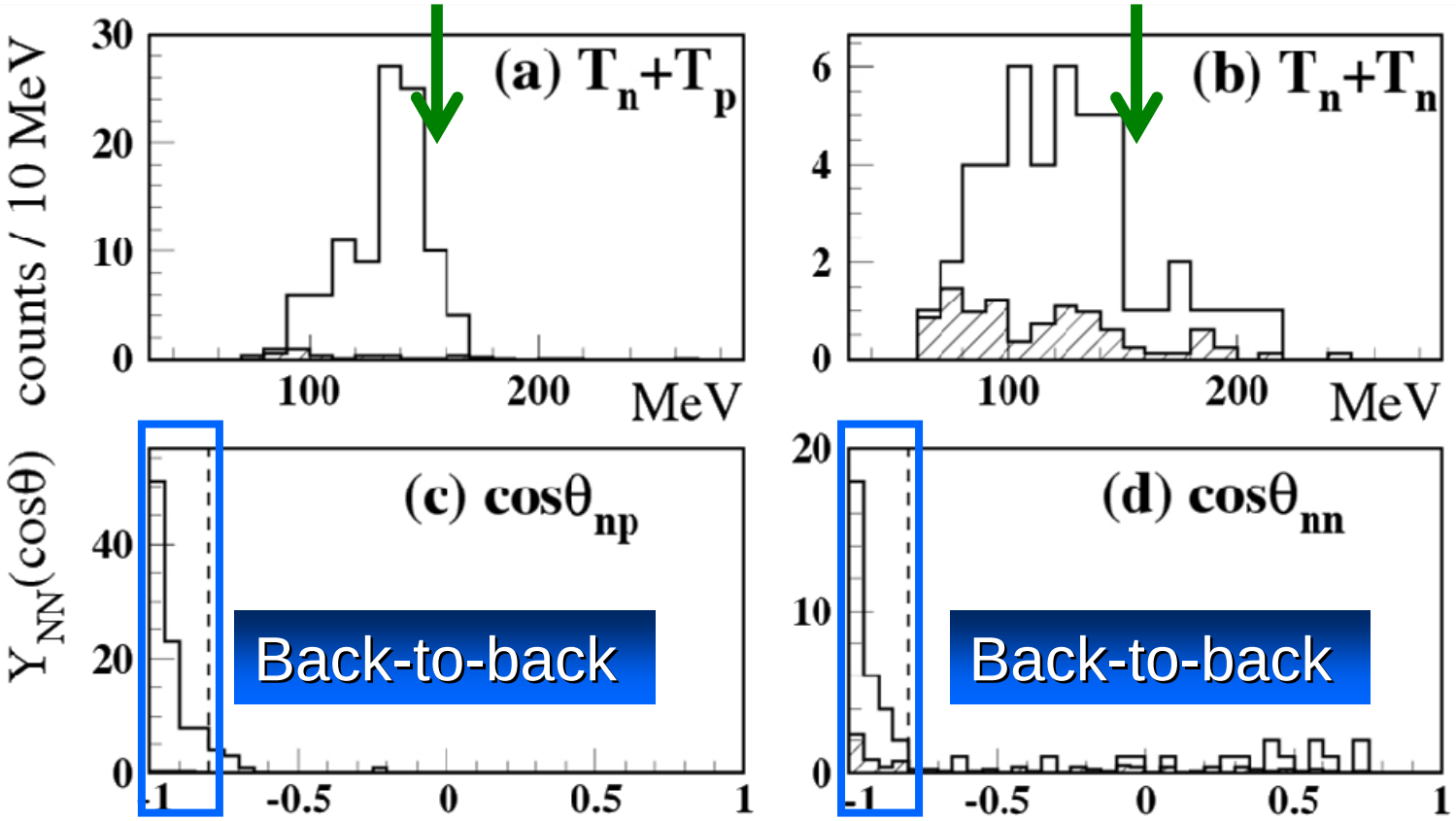


ΛN→nN coincidence necessary

– Back-to-back emission of n+N $\vec{p}_n \approx -\vec{p}_N$

– Sum of n+N kinetic energies

$$T_n + T_N \approx (m_\Lambda - m_N)c^2 \approx 170\ MeV$$

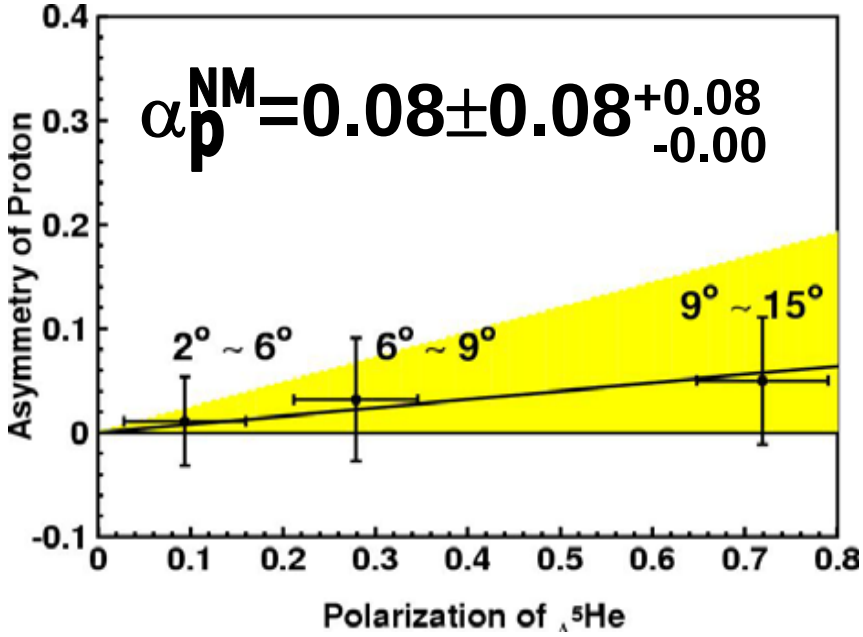


New puzzle in asymmetry

$$\alpha_p^{NM} \sim 0 \text{ (Exp.)}$$

$$\Updownarrow$$

$$\alpha_p^{NM} \sim -0.7 \text{ (Theory)}$$



Asymmetry written by amplitudes

Large contribution ?

$^1S_0 \times {}^3S_1$ $\qquad$ $^3S_1 \times {}^3S_1$

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

Partial decay amplitudes

- Block and Dalitz treatment
  - Initial S-wave (s-shell hypernuclei)
  - isospin=0 or 1 in final states
  - Represent spin/isospin and parity structure

spin isospin parity

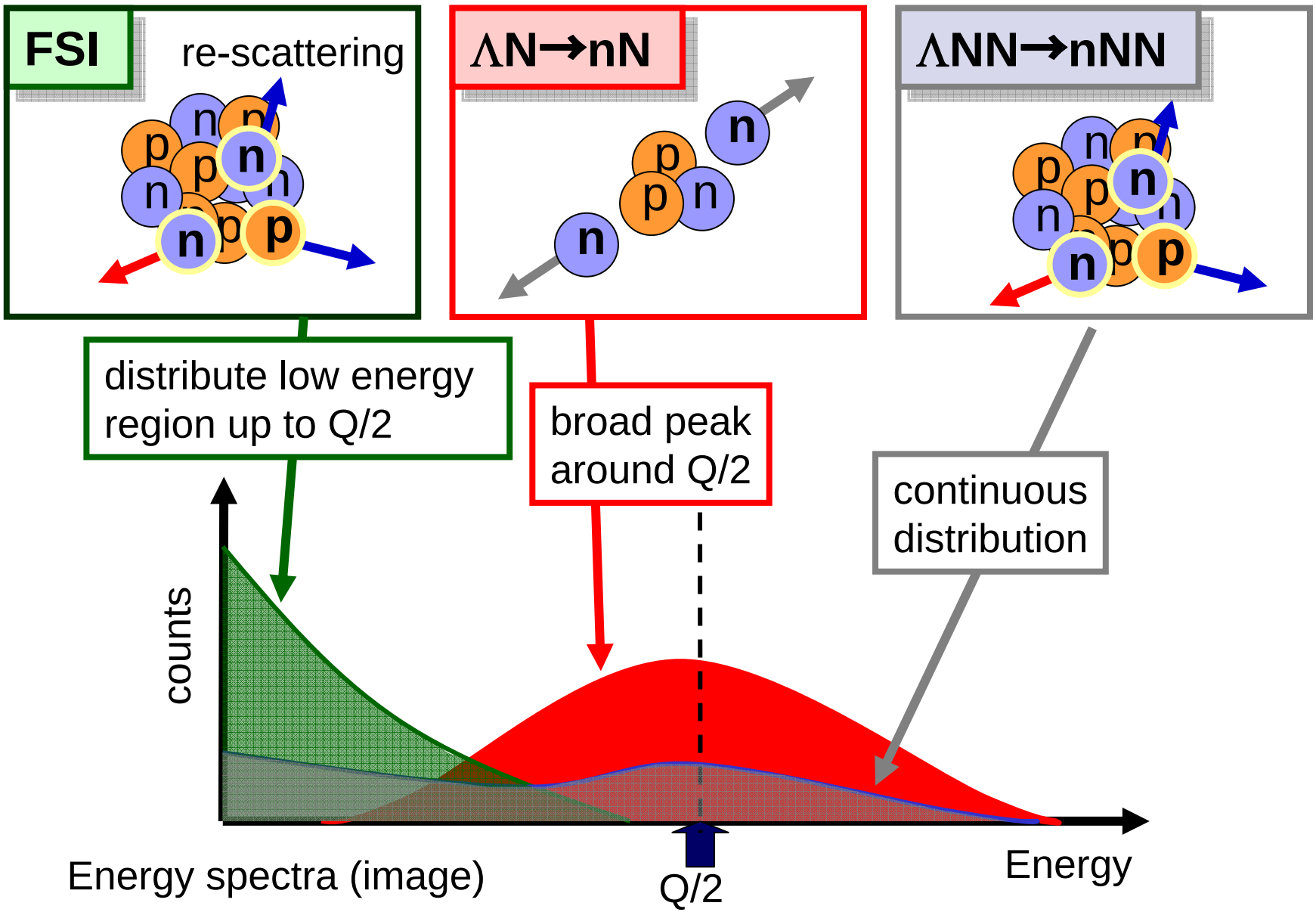
Initial	Final	Matrix element	Rate	I_f	Parity change
$^1S_0$	$^1S_0$	a	a^2	1	no
	$^3P_0$	$\frac{b}{2}(\sigma_1-\sigma_2)q$	b^2	1	yes
$^3S_1$	$^3S_1$	c	c^2	0	no
	$^3D_1$	$\frac{d}{2\sqrt{2}}S_{12}(q)$	d^2	0	no
	$^1P_1$	$\frac{\sqrt{3}}{2}e(\sigma_1-\sigma_2)q$	e^2	0	yes
	$^3P_1$	$\frac{\sqrt{6}}{4}f(\sigma_1+\sigma_2)q$	f^2	1	yes

$^1S_0(I=1)$

$^3S_1(I=0)$

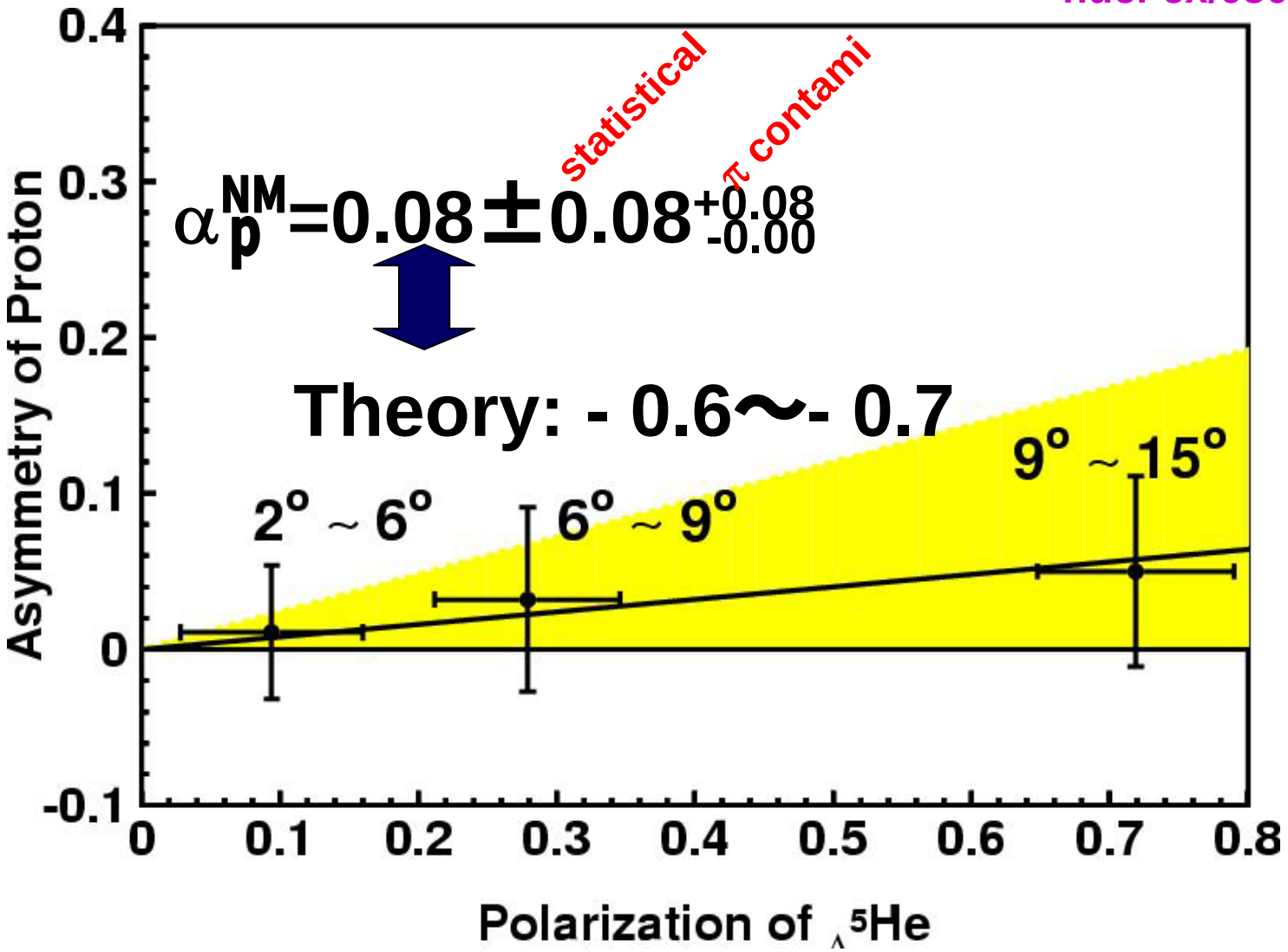
$^3S_1(I=1)$

Expected Spectrum

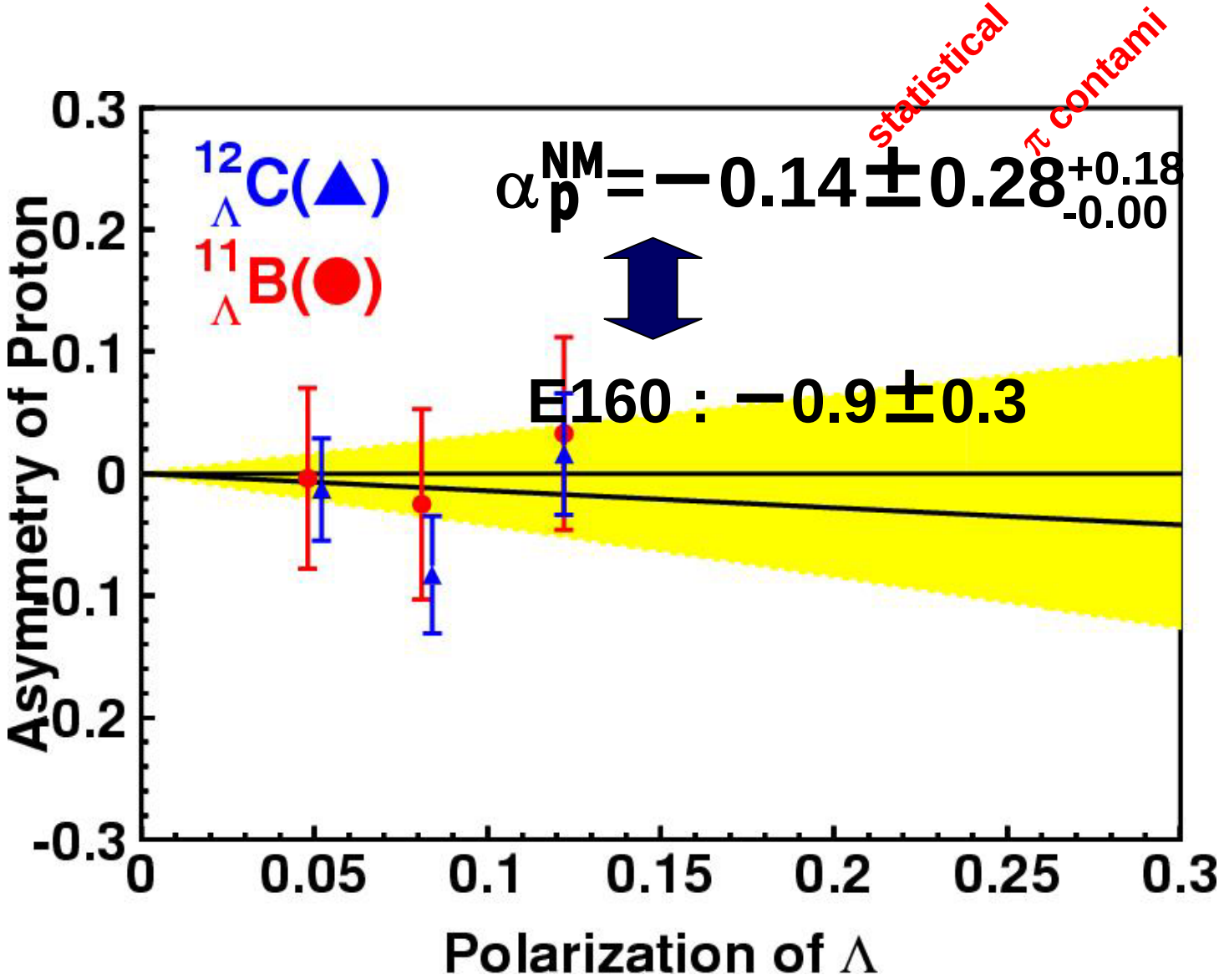


Asymmetry parameter of $^{5}_{\Lambda}$He

Nucl.Phys.A754 (2005) 168c
nucl-ex/050916



Asymmetry parameter of $^{12}_{\Lambda}C$, $^{11}_{\Lambda}B$ Λ

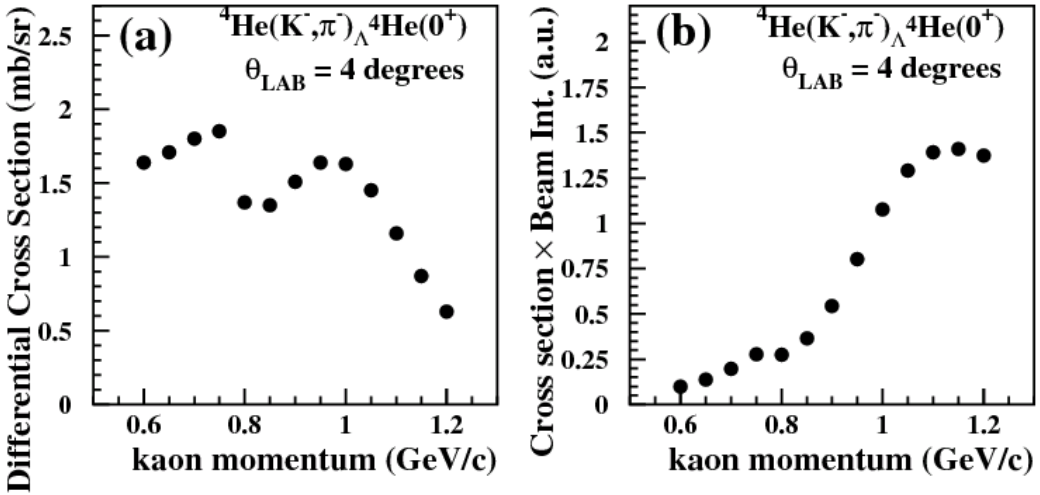


Yield of $^{4}_{\Lambda}$He with (K-,π-) reaction

Parameters	Values
K^- beam momentum	0.90 GeV/c
K^- beam intensity	3.6×10^5 /spill
PS acceleration cycle	3.4 sec/spill
^{4}He target thickness	2 g/cm^2
Reaction cross section	1.5 mb/sr
Spectrometer solid angle	0.02 sr
Spectrometer efficiency	0.8
Analysis efficiency	0.5

← full beam (30GeV)

← SPES2



$\sigma(K,\pi)/\sigma(\pi,K)$

≈ 150

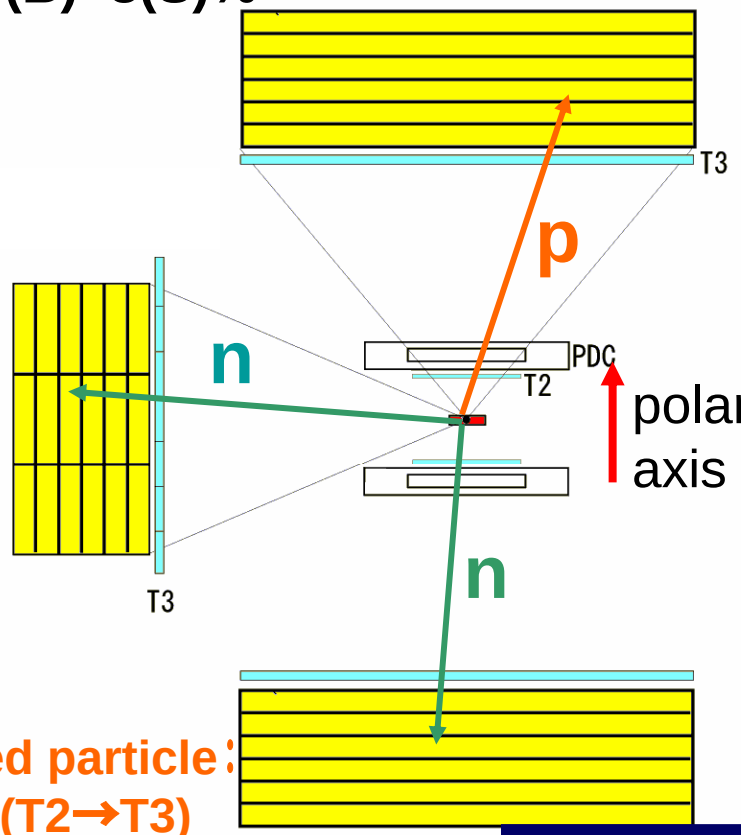
– 33,000 $^{4}_{\Lambda}$He/day: about ×2 of (π+,K+)

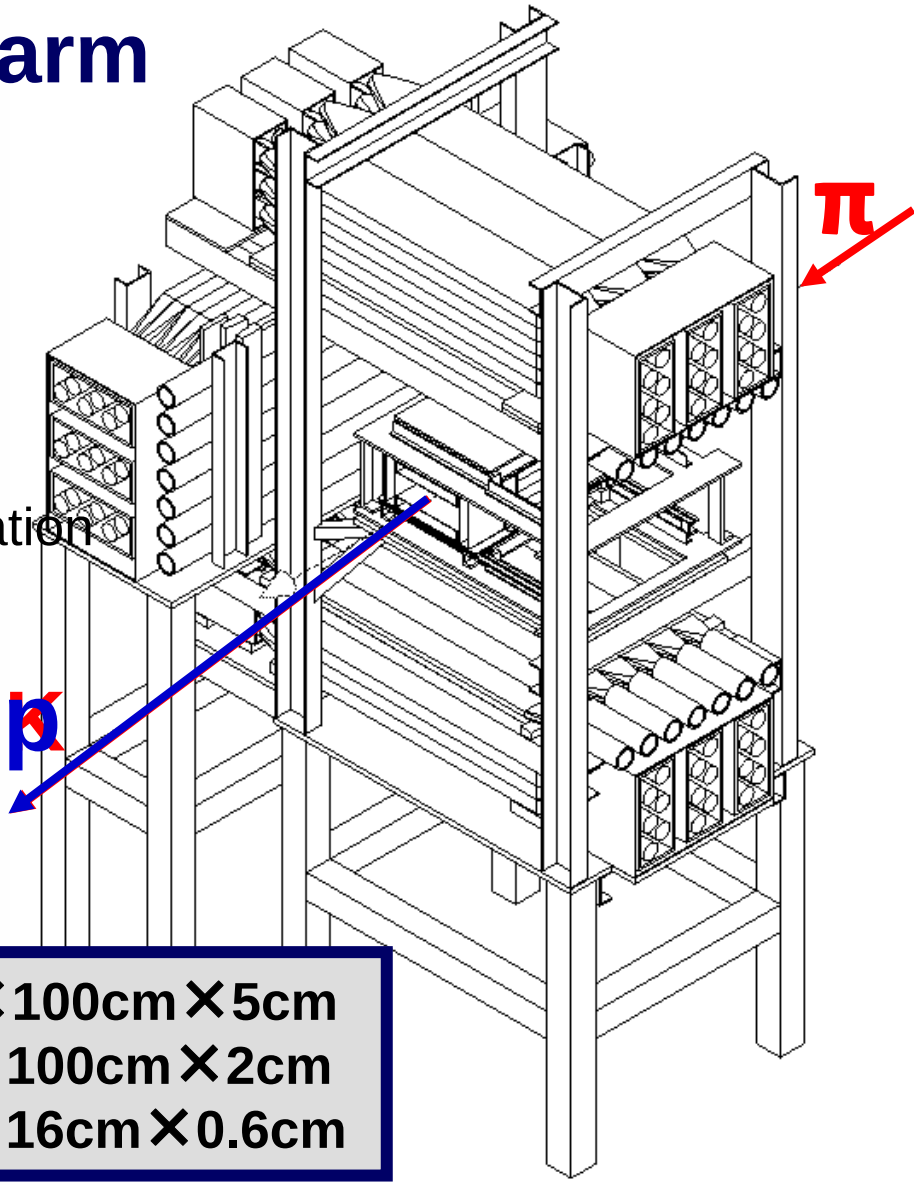
Decay counter Setup

(KEK-PS K6 & SKS)

Solid angle: 26%
9(T)+9(B)+8(S)%

Decay arm





Charged particle:
- **TOF (T2→T3)**
- **tracking (PDC)**

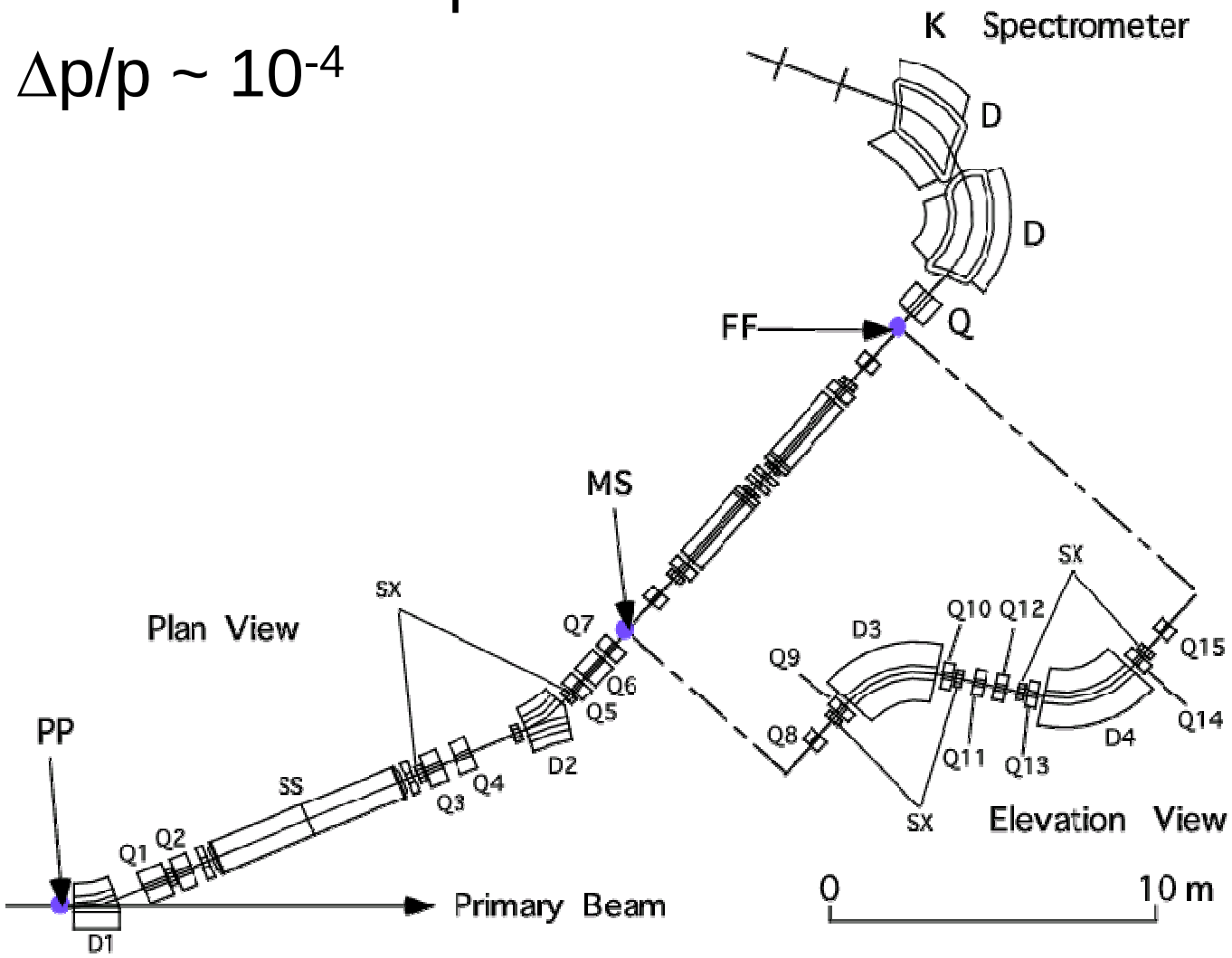
Neutral particle: 20cm
- **TOF (target→NT)**
- **T3 VETO**

N: 20cm×100cm×5cm
T3: 10cm×100cm×2cm
T2: 4cm×16cm×0.6cm

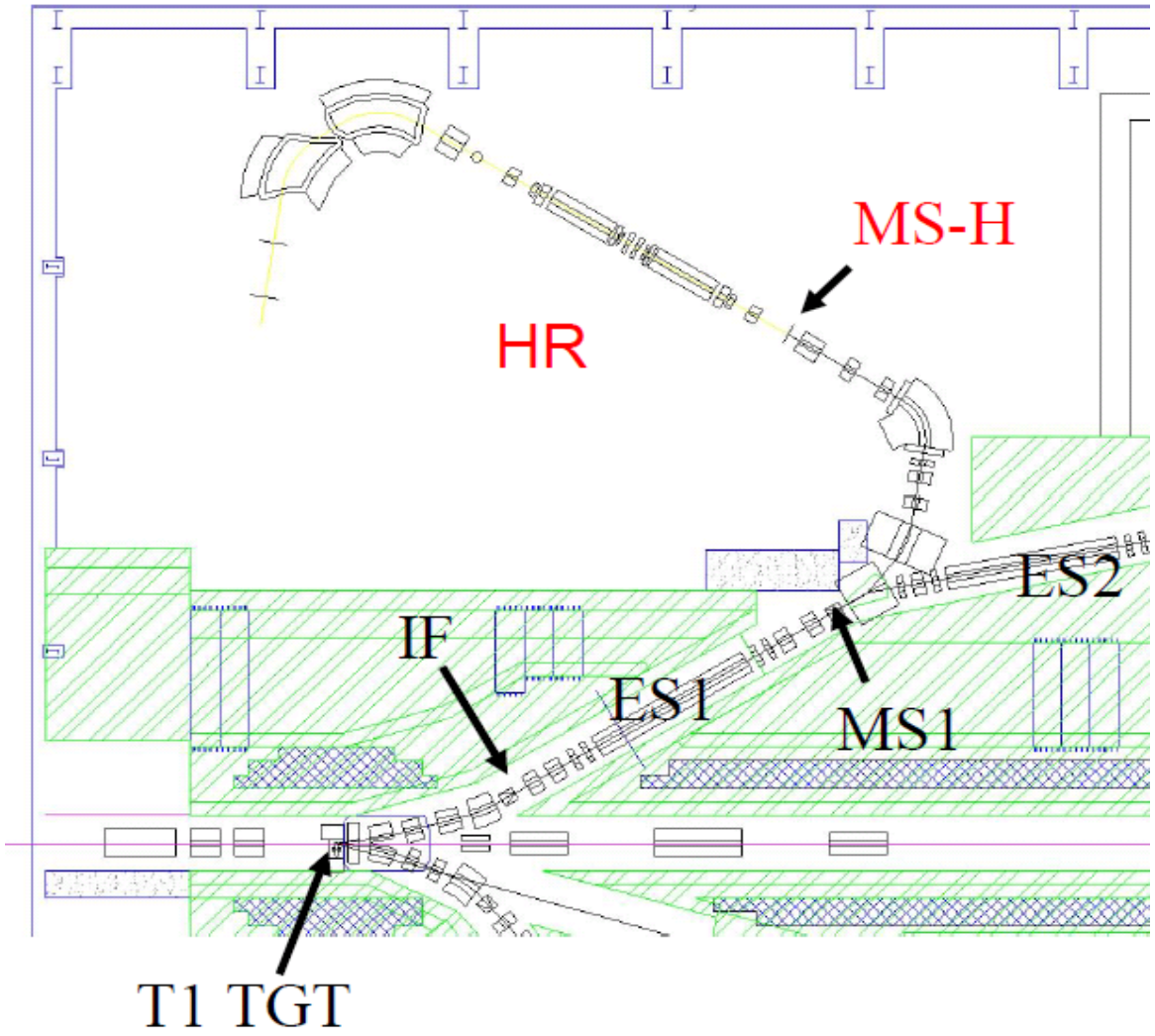
equipment	item	cost (JPY)	source
Beam spectrometer	MWPC 1mm	4,000,000	Grant-In-Aid
	MWPC encoder	20,000,000	Grant-In-Aid
liquid He target	modification	2,500,000	Grant-In-Aid
	LHe	~~3,000,000~~ 700,000	
T0 detector	scintillator	500,000	Grant-In-Aid
	PMT	2,000,000	Grant-In-Aid
CDC	mechanical support	1,500,000	Grant-In-Aid
	chamber gas	1,000,000	
Range counter system	scintillator	4,000,000	Grant-In-Aid
	WLS-fiber	500,000	Grant-In-Aid
	multi-anode PMT	3,200,000	Grant-In-Aid
	PMT	1,600,000	Grant-In-Aid
	cable	800,000	Grant-In-Aid
	ADC	1,600,000	Grant-In-Aid
	TDC	1,600,000	Grant-In-Aid
	HV supply		Recycle
	discriminator		Recycle
TOF detector	mechanical support	1,500,000	Grant-In-Aid
	scintillator	7,500,000	Grant-In-Aid
	PMT	12,000,000	Grant-In-Aid
	cable	1,800,000	Grant-In-Aid
	ADC	2,000,000	Grant-In-Aid
	TDC	2,000,000	Grant-In-Aid
	HV supply		Recycle
	discriminator		Recycle

High Intensity and High Resolution beamline

- handle 10^9 π/spill
- $\Delta p/p \sim 10^{-4}$

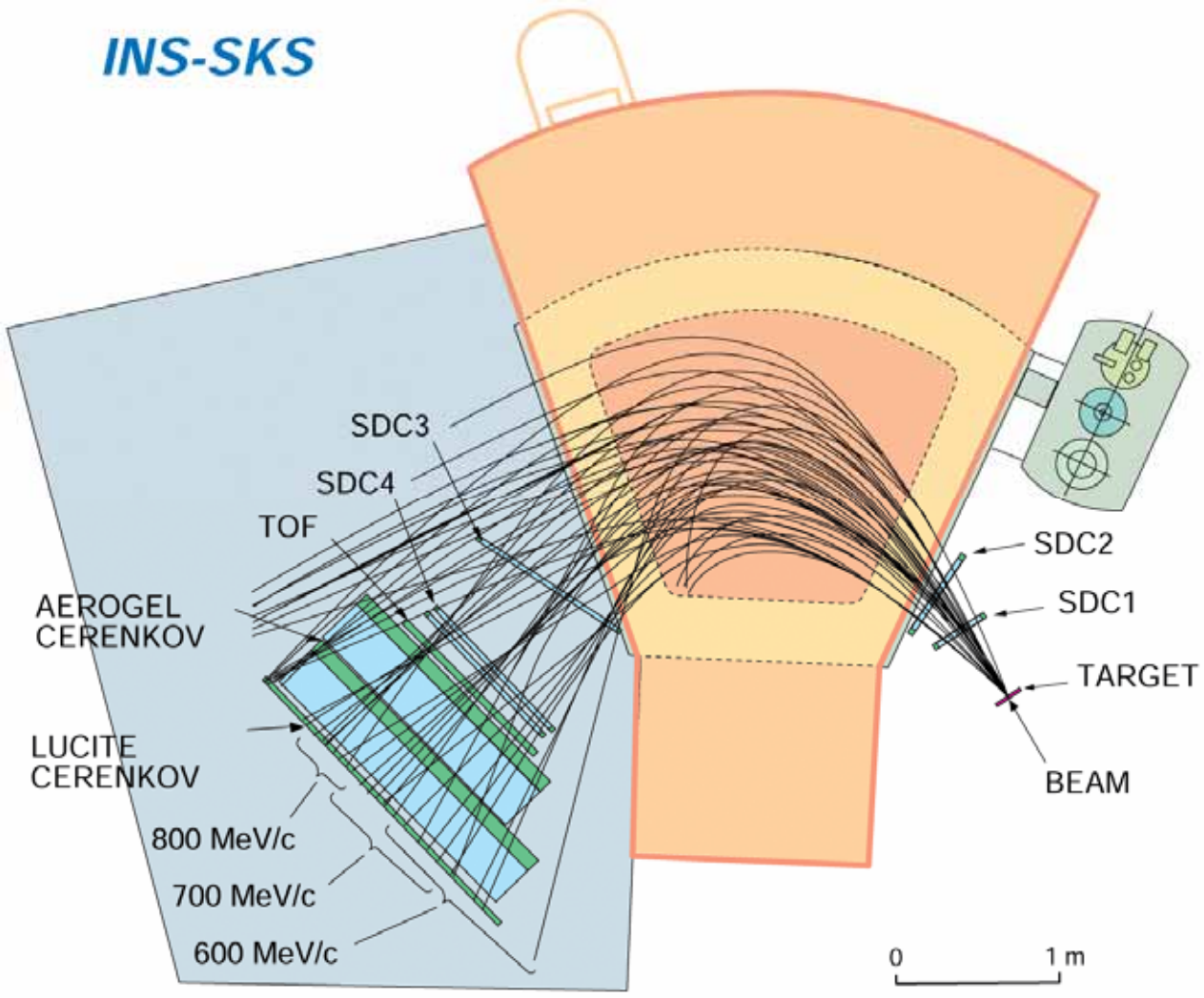


High Intensity and High Resolution beamline (new configuration)



Others

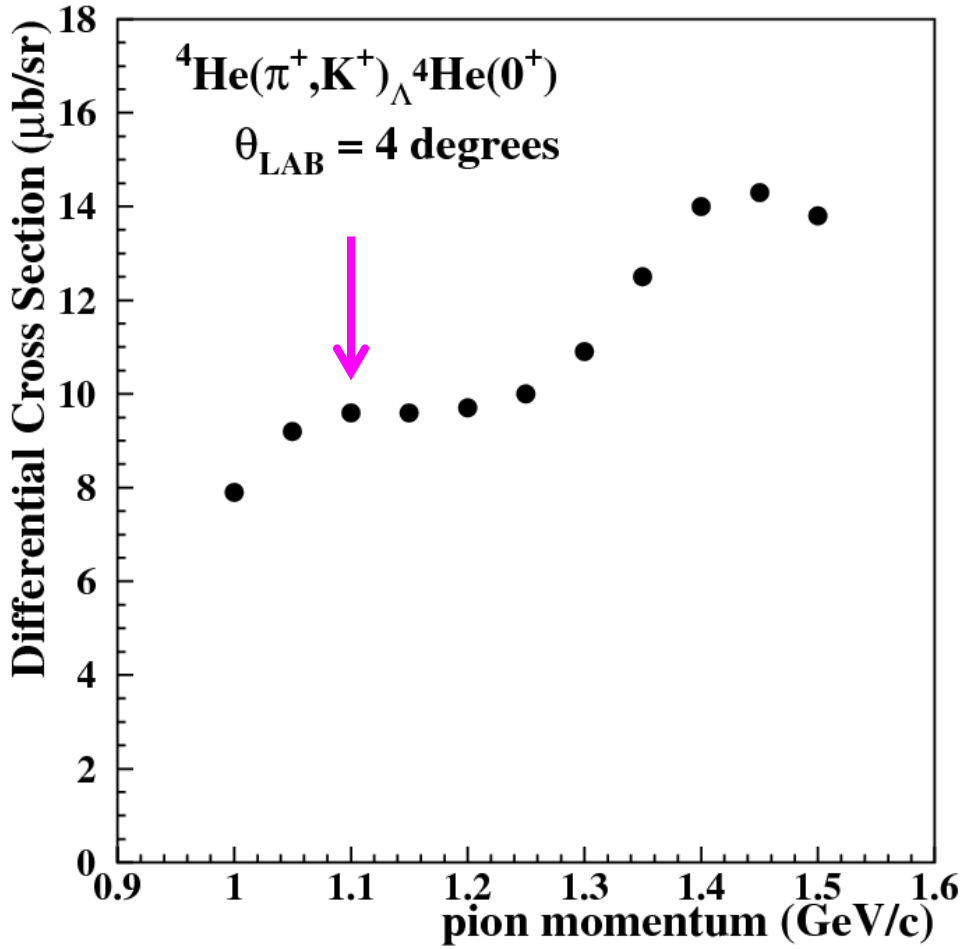
Super Kaon Spectrometer (SKS)



Production cross section

– $^{4}_{\Lambda}$He(g.s., 0+) production

– estimation with DWIA by T. Harada



Decay particle identification

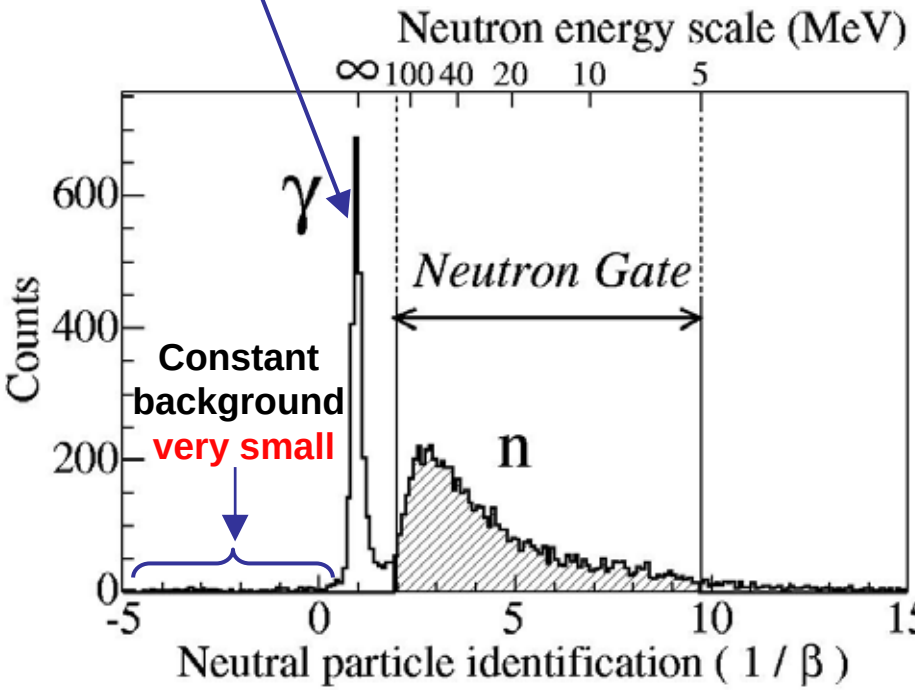
Neutral PID

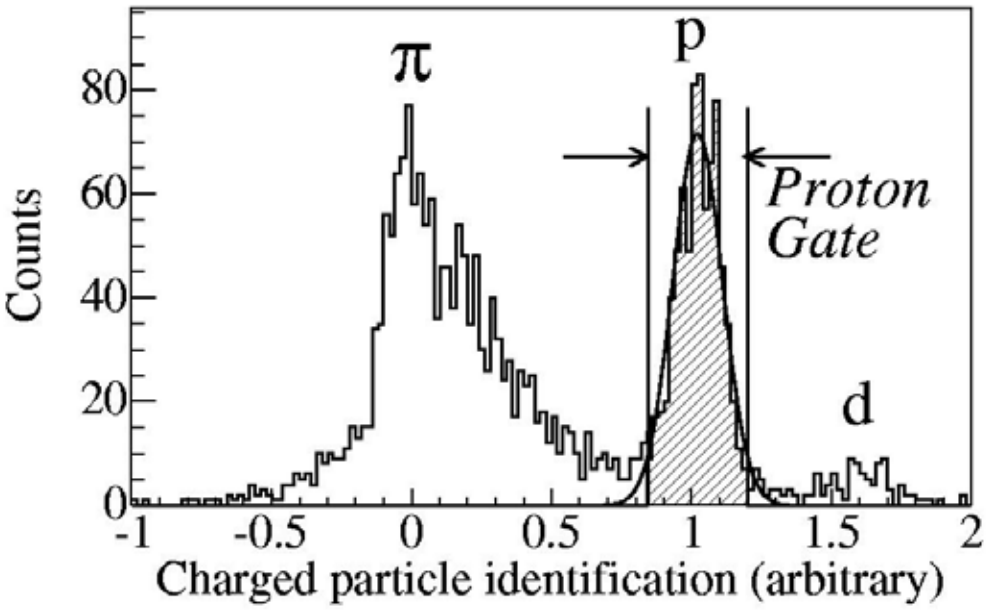
Charged PID

Neutral particles from $^{12}_{\Lambda}C$

Charged particles from $^{5}_{\Lambda}He$

Neutron energy resoltion
→ 7MeV(FWHM) at 75MeV





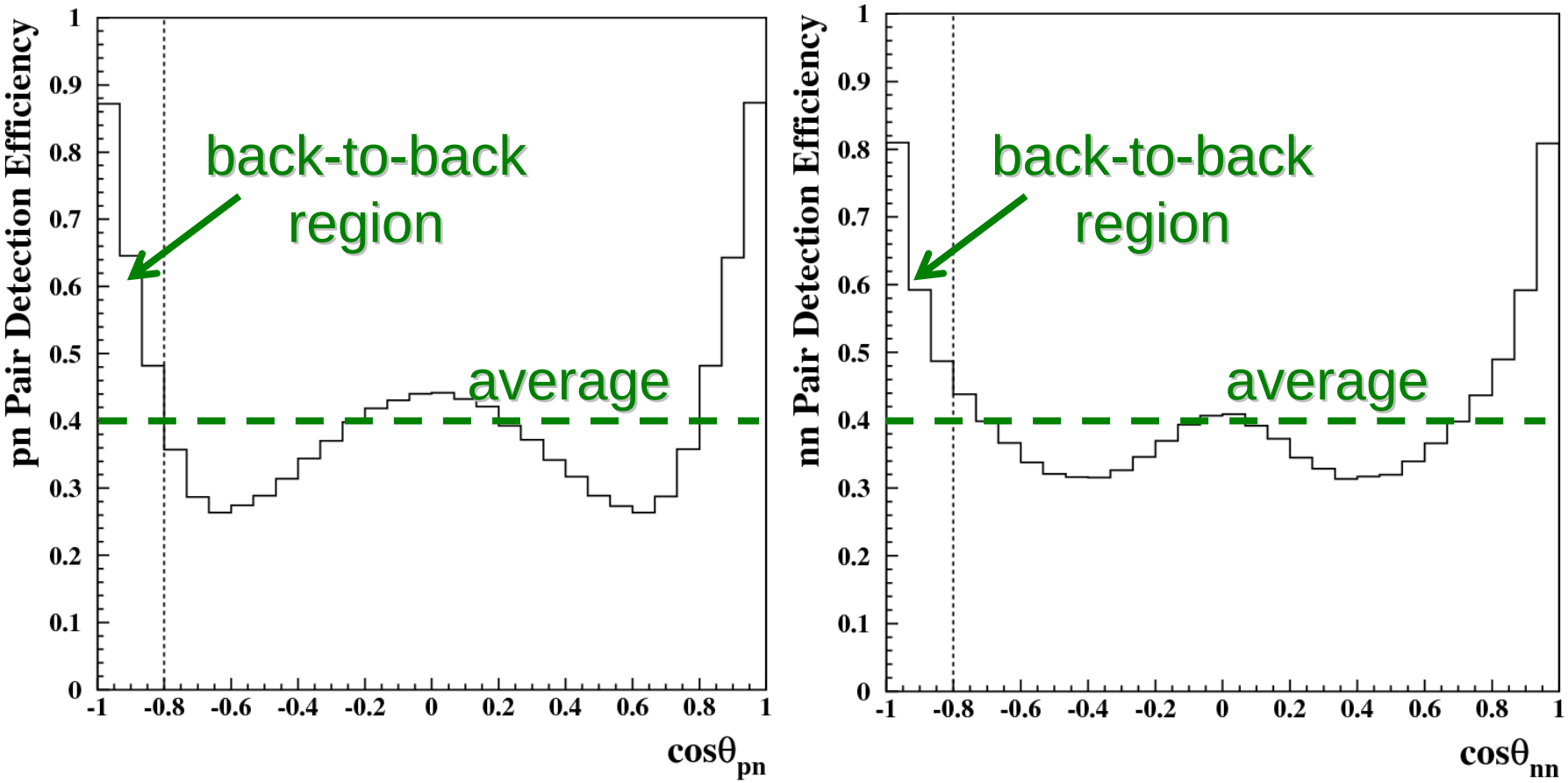
1 / β spectra

PID function

Good γ *n* separation

Good π *p* *d* separation

Nn-pair detection efficiency



– About ×1.5 in back-to-back region