Study on Λ-hypernuclei at J-PARC with intense pion beams

S.Ajimura, H.Bhang, L.Busso, D.Faso,
T.Fukuda, T.Kishimoto, Y.Mizoi,
O.Morra, H.Noumi, H.Outa, P.K.Saha,
A.Sakaguchi, T.Takahashi

Osaka, Seoul, Torino, INFN, OsakaEC,
INAF-IFSI, KEK, RIKEN, JAEA
Collaboration

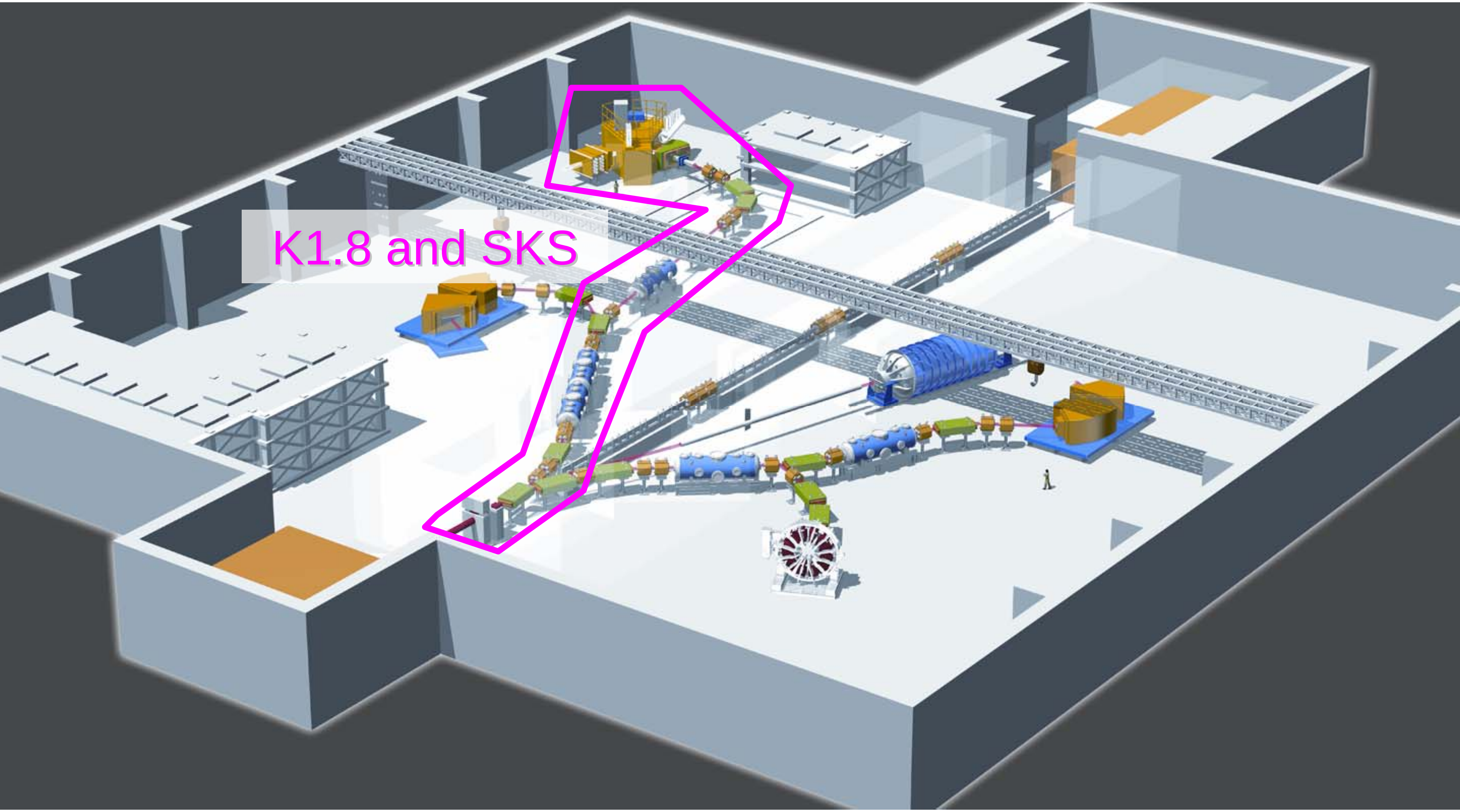
Motivation

- Intense kaon beams will be available
  - beam intensity is a few X 10^6 kaons/spill
    - with 30GeV, 9μA primary proton beams

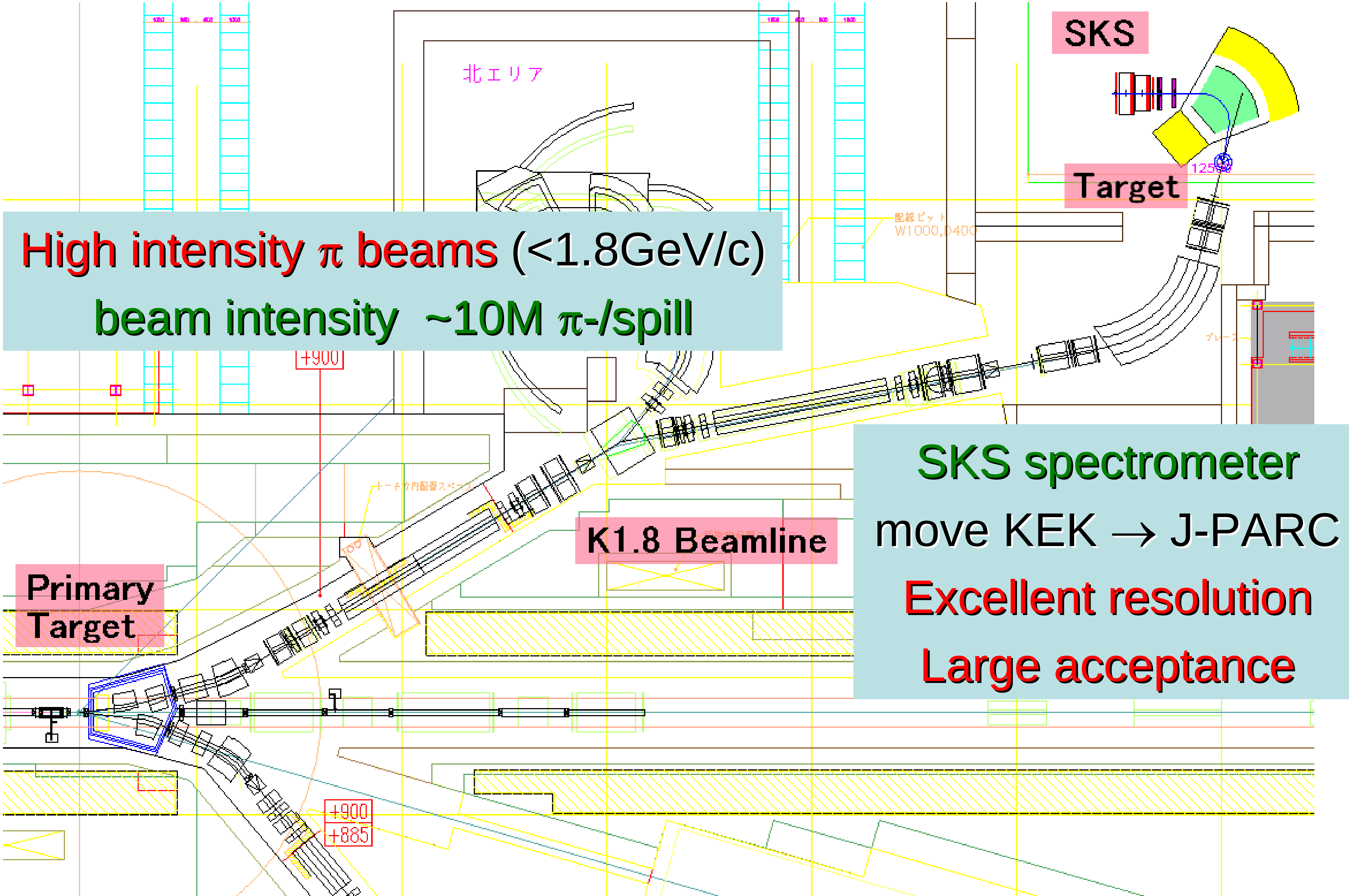
- Provide us also very intense pion beams
  - roughly X1000 higher than kaons
    - a few X 10^7 pions/spill with conventional detectors
    - one order higher than experiments in the past

- experiments with intense pion beams
  - available even at the beginning of J-PARC

Hadron Experimental Hall



K1.8 beam line and SKS



High intensity π beams (<1.8GeV/c)

beam intensity ~10M π-/spill

SKS spectrometer

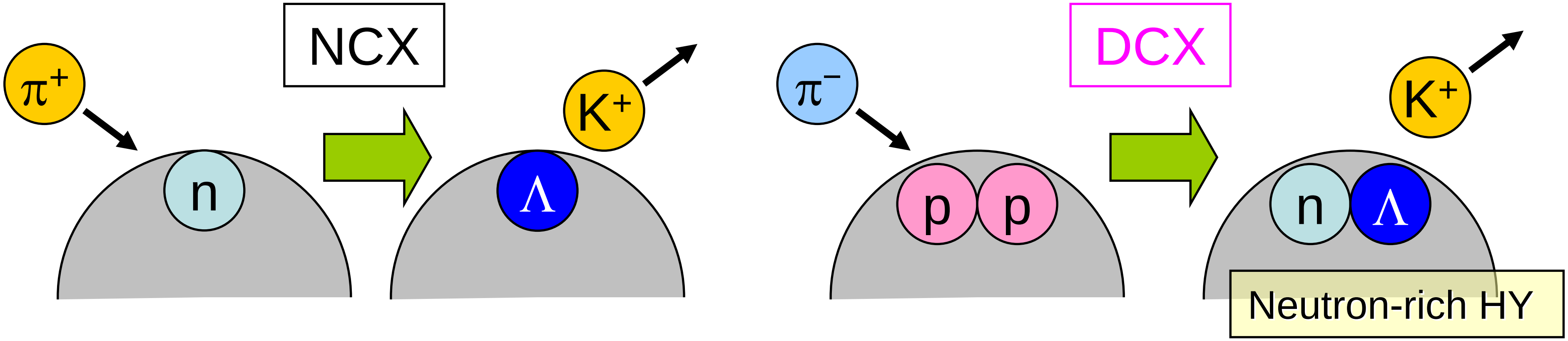
move KEK → J-PARC

Excellent resolution

Large acceptance

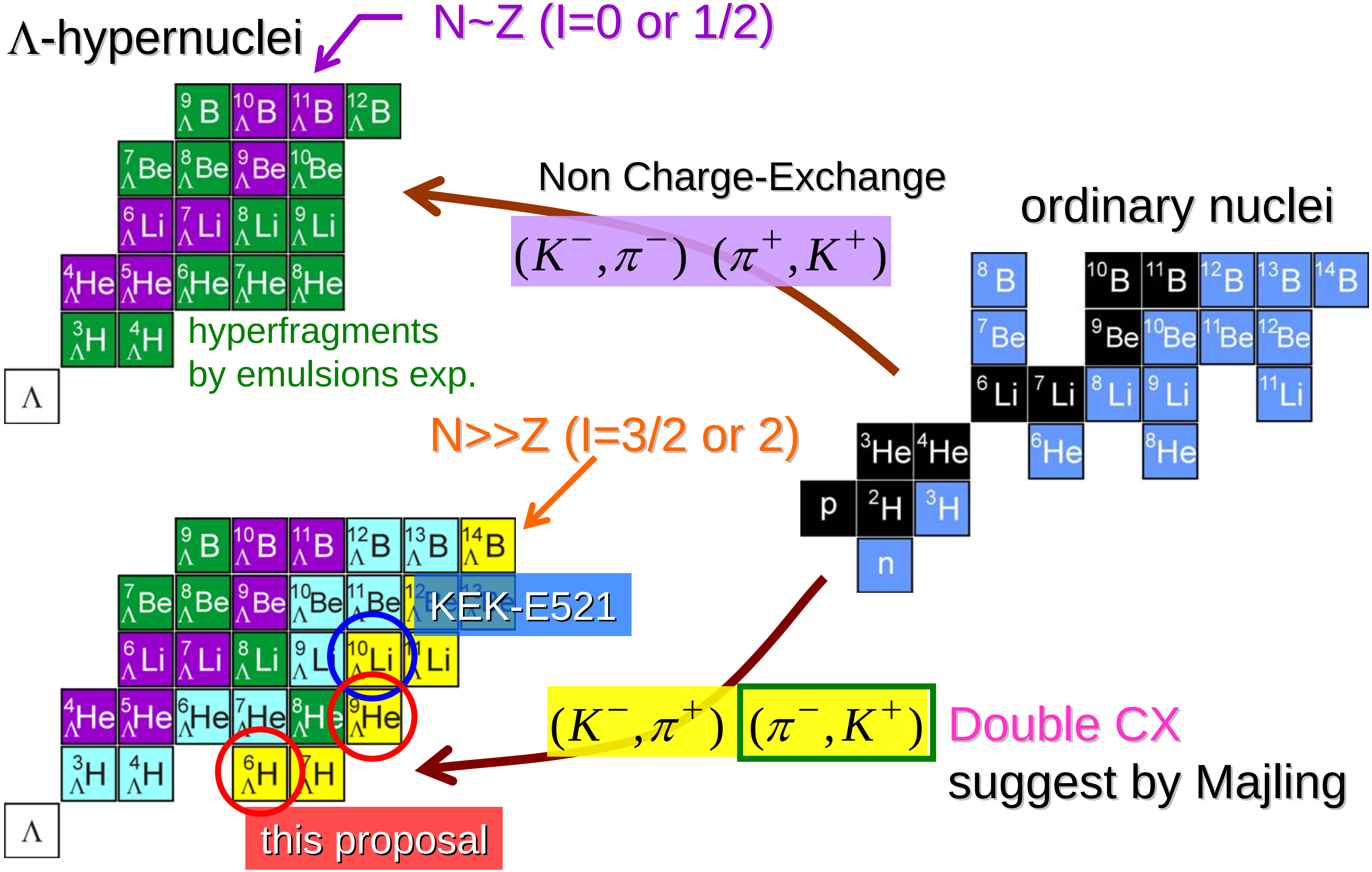
Proposing 2 experiments at J-PARC E10 and E22

- Production of neutron-rich hypernuclei
  - Double Charge-eXchange (DCX) reaction



- Study on non-mesonic weak decay
  - Weak decay of A=4 hypernuclei (${}^{4}_{\Lambda}He$, ${}^{4}_{\Lambda}H$)
  - Precise determination of decay amplitudes

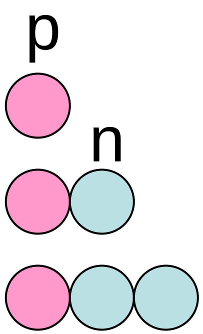
E10: Neutron-rich hypernuclei



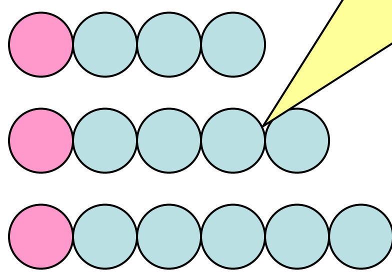
Exotic Λ-hypernuclei

- Example of “hydrogen”

Super Heavy Hydrogen

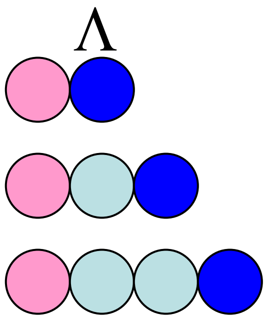


^{1}H	Stable
^{2}H	Stable
^{3}H	Stable

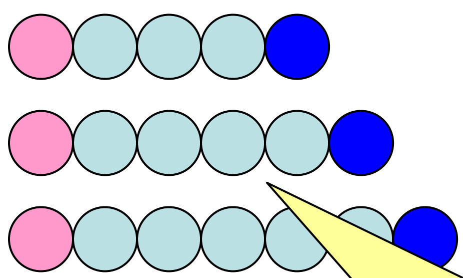


^{4}H	No evidence
^{5}H	Resonance
^{6}H	No evidence

glue like role of Λ



$^{2}_{\Lambda}$H	Not bound
$^{3}_{\Lambda}$H	Stable
$^{4}_{\Lambda}$H	Stable



$^{5}_{\Lambda}$H	No evidence
$^{6}_{\Lambda}$H	Stable ?
$^{7}_{\Lambda}$H	Stable ?

We can produce at J-PARC

Hyper Heavy Hydrogen

Yield estimation: $^{9}_{\Lambda}He$ production

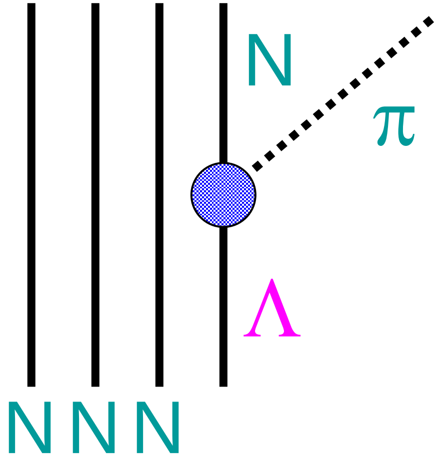
– Cross section ~10nb/sr (1/1000 of NCX)

– Major difficulty in this experiment

Parameters	Values
π^- beam momentum	1.2 GeV/c
π^- beam intensity	1 x 10^7 /spill ← High intensity beams
PS acceleration cycle	3.4 s/spill
^{9}Be target thickness	3.5 g/cm^2
Reaction cross section	10 nb/sr
Spectrometer solid angle	0.1 sr ← Large acceptance
Spectrometer efficiency	0.5
Analysis efficiency	0.5

– 310 events in 3 weeks
  - 7 times larger ← KEK-E521 (47 events)
  - Discussion on level structure possible

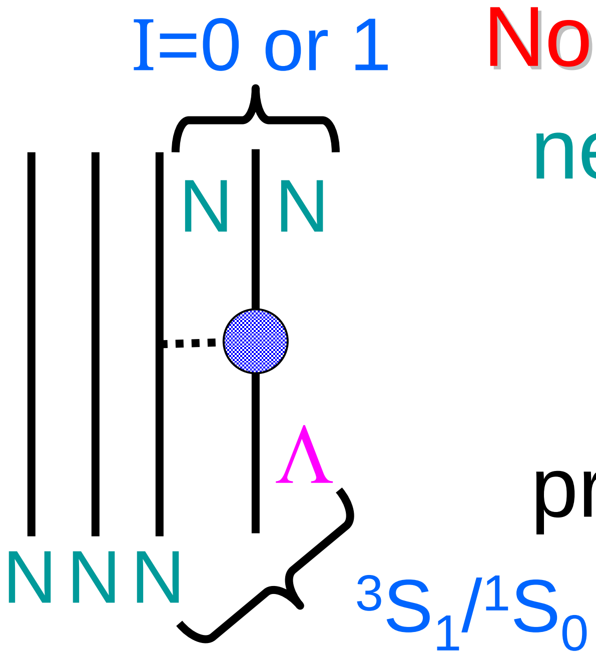
E22: Non-mesonic weak decay



Mesonic weak decay (MWD)

similar with free decay of Λ

properties are predictable



Non-Mesonic weak decay (NMWD)

new decay mode in hypernuclei

proton- and neutron-stimulated

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

properties are not well known yet

Decay amplitudes

- Block and Dalitz approach
  - Initial Λ-N in S-wave (s-shell hypernuclei)
  - Introduced 6 independent amplitudes (a ~ f)
    - Initial spin ($^1S_0$ or $^3S_1$)
    - Final isospin (0 or 1)
    - Parity change (yes or no)

spin isospin parity Branching Ratios

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

Status of amplitudes

Status of measurements

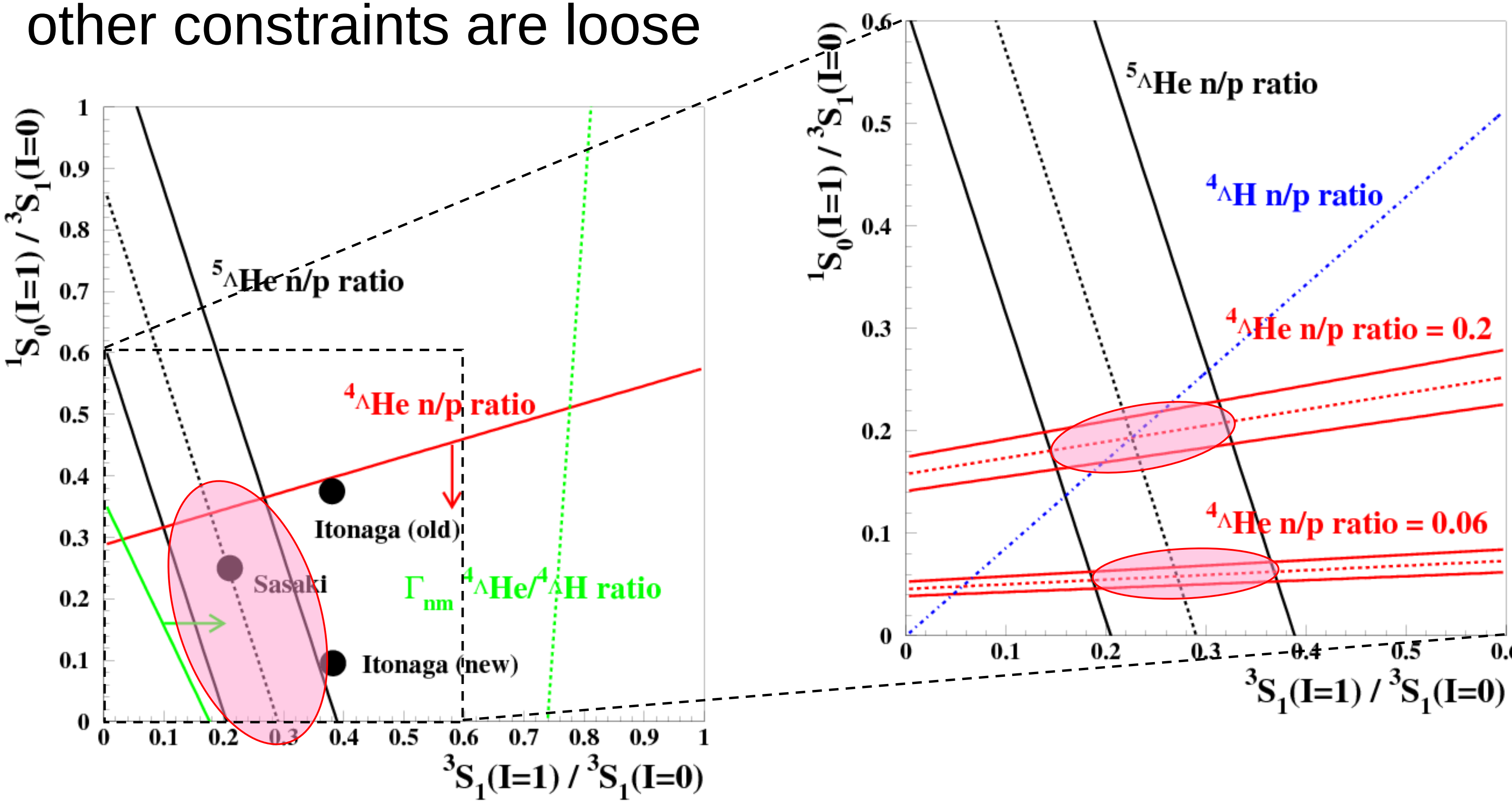
A=4 and 5 ($^4_\Lambda$H, $^4_\Lambda$He, $^5_\Lambda$He)

strong constraint from $^5_\Lambda$He

other constraints are loose

Our prospects

new measurement of $^4_\Lambda$He np-ratio with 15% accuracy



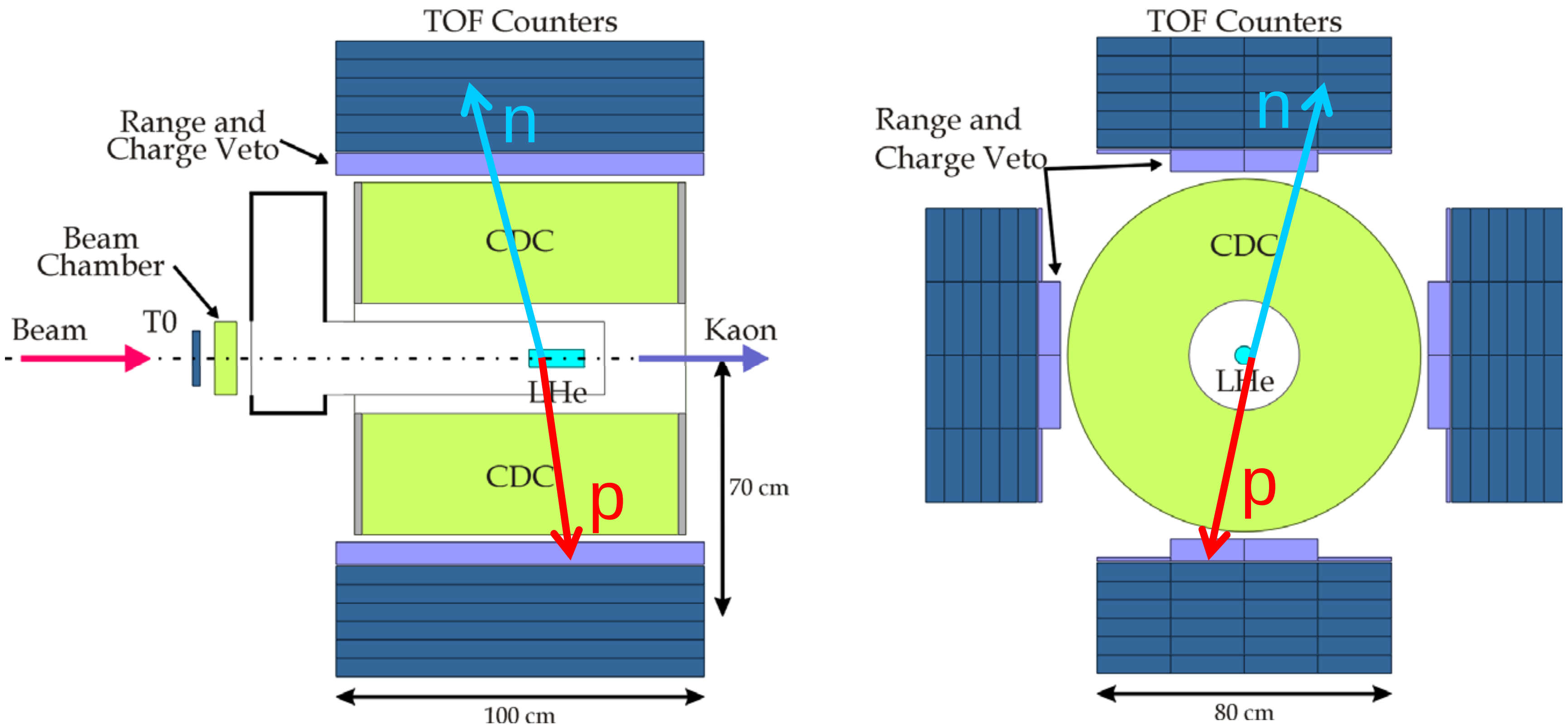
Estimation of ${}^{4}_{\Lambda}$He Yield

- Important factor in design of experiment
  - Tiny branching ratio of $\Lambda n \rightarrow nn$ channel
  - BR(${}^{4}_{\Lambda}$He,$\Lambda n \rightarrow nn$) ~ 0.01 (?)
  - BR(${}^{4}_{\Lambda}$He,$\Lambda p \rightarrow np$) = 0.16 ± 0.02

- Produce ${}^{4}_{\Lambda}$He as much as possible
  - use ^{4}He(π^{+},K^{+})${}^{4}_{\Lambda}$He reaction ($d\sigma/d\Omega$~10μb/sr)
  - high intensity pion beams (K1.8 beam line)
  - large acceptance spectrometer (SKS)
- 19,000 ${}^{4}_{\Lambda}$He/day $\rightarrow$ 0.5M ${}^{4}_{\Lambda}$He in 4 weeks

Setup for decay measurement

– Large acceptance and high efficiency for NN
– Good PID capability (n/p/π/γ)



$\text{neutron}: \Omega / 4\pi \approx 0.4,\ \varepsilon \approx 30\%$ $\text{proton}: \Omega / 4\pi \approx 0.25,\ \varepsilon \approx 80\%$

Estimation of yield of NMWD

Parameters	Values
Acceptance for decay proton	0.25
Acceptance for decay neutron	0.4
Efficiency for proton	0.8
Efficiency for neutron	0.3
Branching ratio of Λp→np process	0.01
Branching ratio of Λn→nn process	0.1

large acceptance and high efficiency

– 1,300 Λp→np and 75 Λn→nn in 4 weeks
  in case of 10% BR (Λp→np); in case of 1% BR (Λn→nn)

– We can achieve 15% statistical error

Summary

- Experiments with intense pion beams
  - Feasible even very early stage of Day-1
- Two experimental proposals
  - Production of neutron-rich hypernuclei
    - New neutron-rich hypernuclei (${}^{9}_{\Lambda}He$ and ${}^{6}_{\Lambda}H$)
    - Information on ΛN interaction in n-rich hypernuclei
    - Production of exotic hypernucleus ${}^{6}_{\Lambda}H$
  - Study on non-mesonic weak decay
    - Detailed study on A=4 hypernuclei (${}^{4}_{\Lambda}He$ and ${}^{4}_{\Lambda}H$)
    - Precise determination of decay amplitudes