Plan of SKS experiments (K1.8 beam line)

January 15, 2011

11th J-PARC PN PAC

T.Takahashi (IPNS-KEK)

Outline

- Achieved performace of K1.8 beam line
  - Duty factor & kaon yields
  - Expected performace of K1.8 beam in 2011
- Realistic data-taking plans for each exp.
  - E19 / **E27** / **E10** / **E13** / E05
- Our plan
  - April RUN
  - After Autumn

Achieved in 2010 Autumn RUN (1)

- 3kW stable operation
  - Enough beam power for pion beam
- 16% duty factor during E19 production RUN

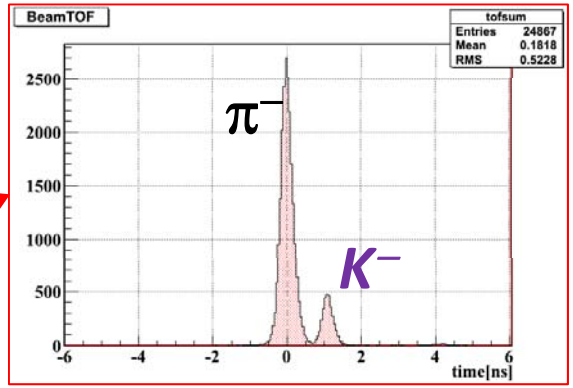
  This limits usable intensity for pion beams
  - 1.1M/spill, spill=2.2sec.
  - Multiplicity$\geq$2 Events
    - 15% @ B.S. within 100ns time window
    - 28% @ B.S. upstream within 70ns time window
    - 8% @ B.S. upstream within 4ns time wondow

Achieved in 2010 Autumn RUN (2)
– K^- Yield@1.8GeV/c –

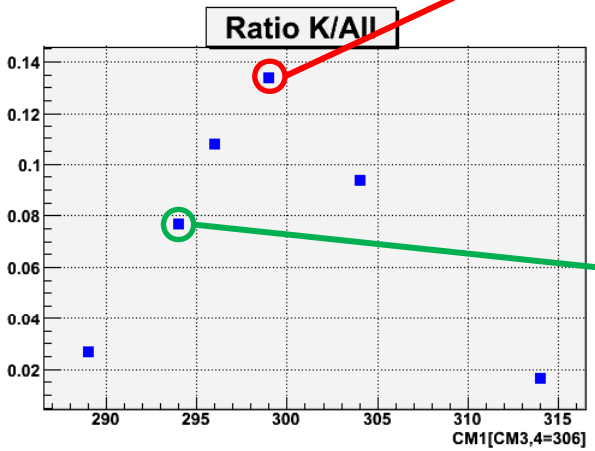
ES1,2	±200 kV
IFX(H)	±130 mm (Full)
IFY(V)	+1.5/+3.5 mm
Mom(H)	±180 mm (Full)
MS1(V)	±2.35 mm
MS2(V)	±2.5 mm

Slit position (offset) and Q-magnets were not tuned well.

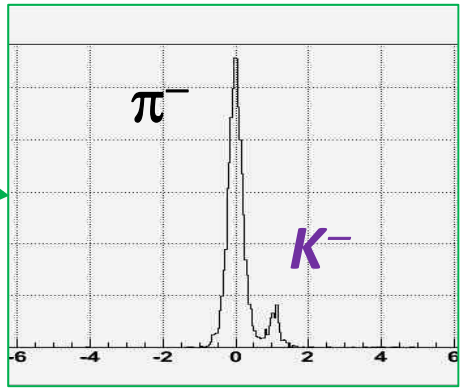
with 1kW beam (1.25×10^{12} ppp), CM3/4 fixed



8k/spill
K/all = 13.8%



CM1 current (A)



12k/spill
K/all = 8.0%

45k/spill@3kW K/all=5.0% after all CMs tuning

How much K/all will be improved ?
– Decay TURTLE Simulation –

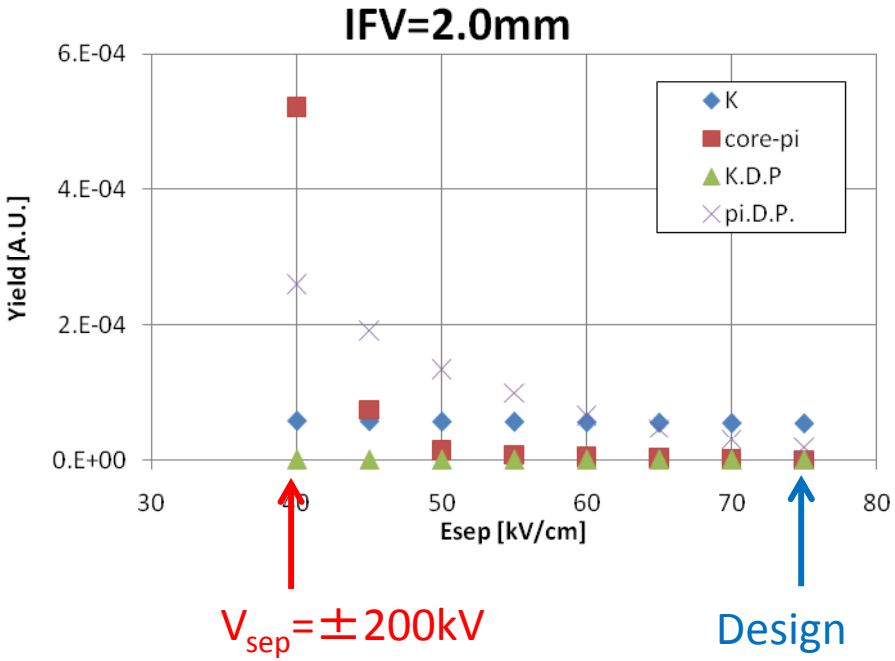
Yield in 10cm x 6cm @FF, 1.8GeV/c

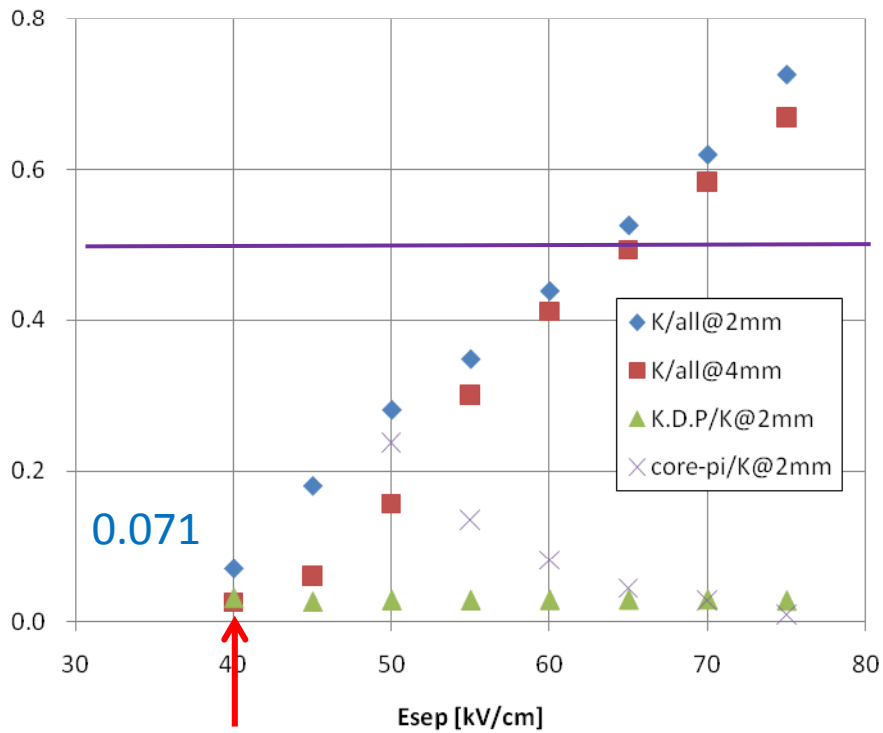
K^- :

core-π^-:

K.D.P: decay product from K^-

pi.D.P: decay product from π^-





K/all=5% (meas.)

V_{sep} > ±325kV → **K/others ≥1**

Expected performance of the beam

π beam	Intensity	Beam Power	Duty factor	Comments
	1.1M/spill	≥3 kW	16%	April
	~2M/spill	≥3 kW	30%	October

K^- beam	Intensity	Beam Power	Duty factor	Comments
1.8 GeV/c	150k/spill	10 kW	16%	* October
1.5 GeV/c	60k/spill	10 kW	16%	** October
1.8 GeV/c	450k/spill	30 kW	≥16%	* 2012~
1.7 GeV/c	420k/spill	30 kW	≥16%	** 2012~
1.65 GeV/c	300k/spill	30 kW	≥16%	** 2012~

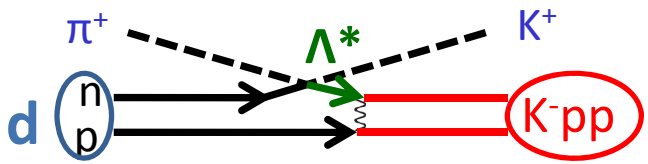
* Based on the measurement: 45k/spill @3kW
** Scaled by Sanford-Wang's parameterization and decay factor

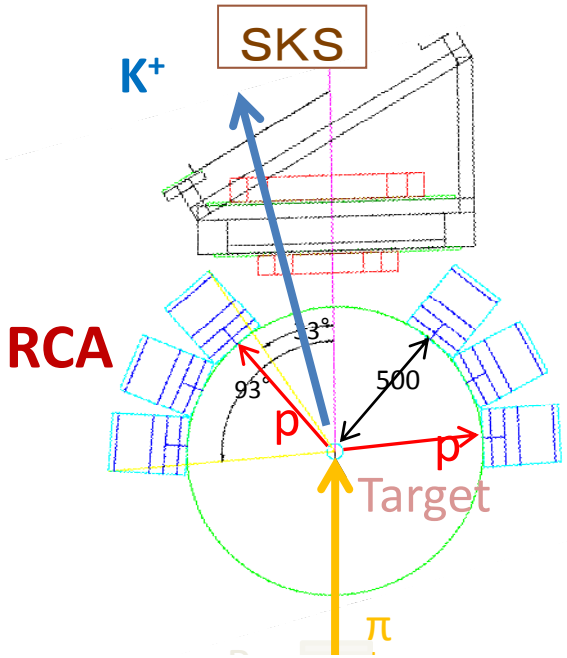
E19: Θ^+ Search via the $p(\pi^-,K^-)X$

- 7.8×10^{10} π^- @1.92GeV/c in 2010 Autumn
  - 16% statistics of the proposal
- Next step (April 2011)
  - Simillar statistics at 2.0 GeV/c (max. at K1.8)
    - 6 days with 1.1M/spill (16% duty factor)
- Further (Autumn 2011 –)
  - To reach 75nb/sr sensitivity
  - p dependence with 3 different momenta

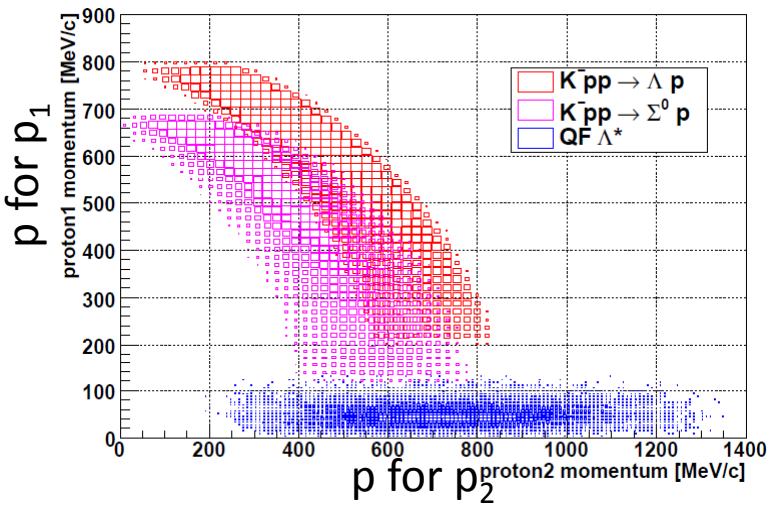
E27: Search for "K^-pp" bound state in the $d(\pi^+,K^+)X$ reaction

- "K^-pp" is produced through Λ^* doorway by the $d(\pi^+,K^+)$ reaction





- Exclusive measurement by Range Counter Array (RCA) in order to suppress quasi-free B.G.
  - $K^-pp \rightarrow \Lambda\ p_1,\ \Lambda \rightarrow p_2\ \pi^-$
  - $K^-pp \rightarrow \Sigma^0\ p_1,\ \Sigma^0 \rightarrow (\Lambda\gamma) \rightarrow p_2\ \pi^-\ \gamma$
  - $d\pi^- \rightarrow \Lambda^*\ K^+\ p_{1s},\ \Lambda^* \rightarrow \Sigma\ \pi,\ \Sigma^+ \rightarrow p_2\ \pi^0$
- 5M/spill beam
  - $6\times10^4\ \Lambda^*$ /day
    Assumed 1% traping probability
  - 600 bound states/day (inclusive)
  - ~300 events/40 days (exclusive)
    with ε_{RCA} ~10% for 1 proton



E27: d(π^+,K^+) spectrum

With the present beam condition, it is very difficult to carry out 2 proton tagging as proposed.

As a first step, we would like to measure
inclusive d(π^+,K^+)X spectrum
in the region of 2.2 < M_x < 2.4 GeV/c^2.

1 M/spill beam for 6 days

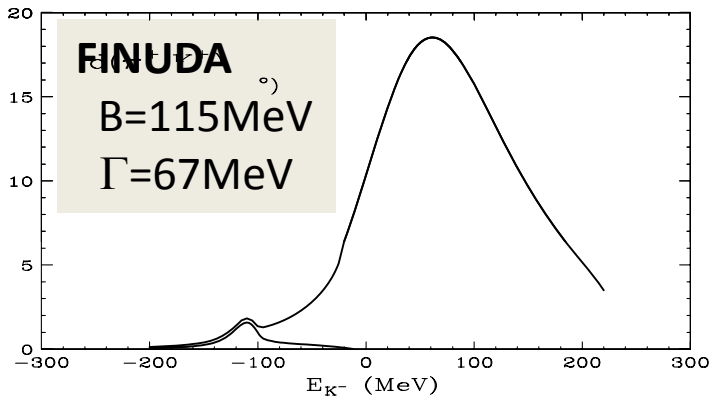
- The first measurement of this reaction & missing mass region
- To understand background spectra
- The (upper limit of the) cross section (including background)
- To see the feasibility of 1 proton / 2 protons tagging for future measurement.

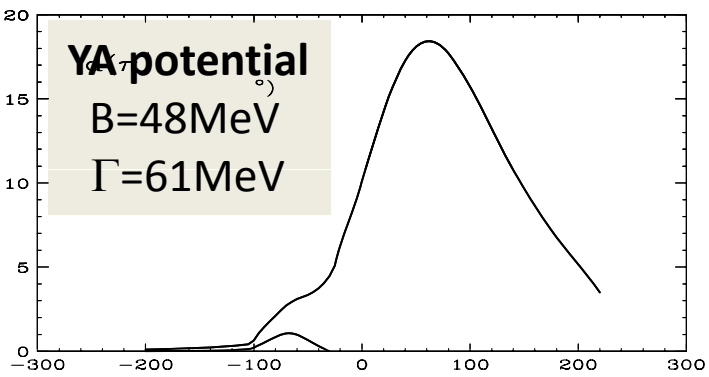
RCA will be installed.

Harada's calculation at P=1.6GeV/c

Λ(1405) process only

A.U



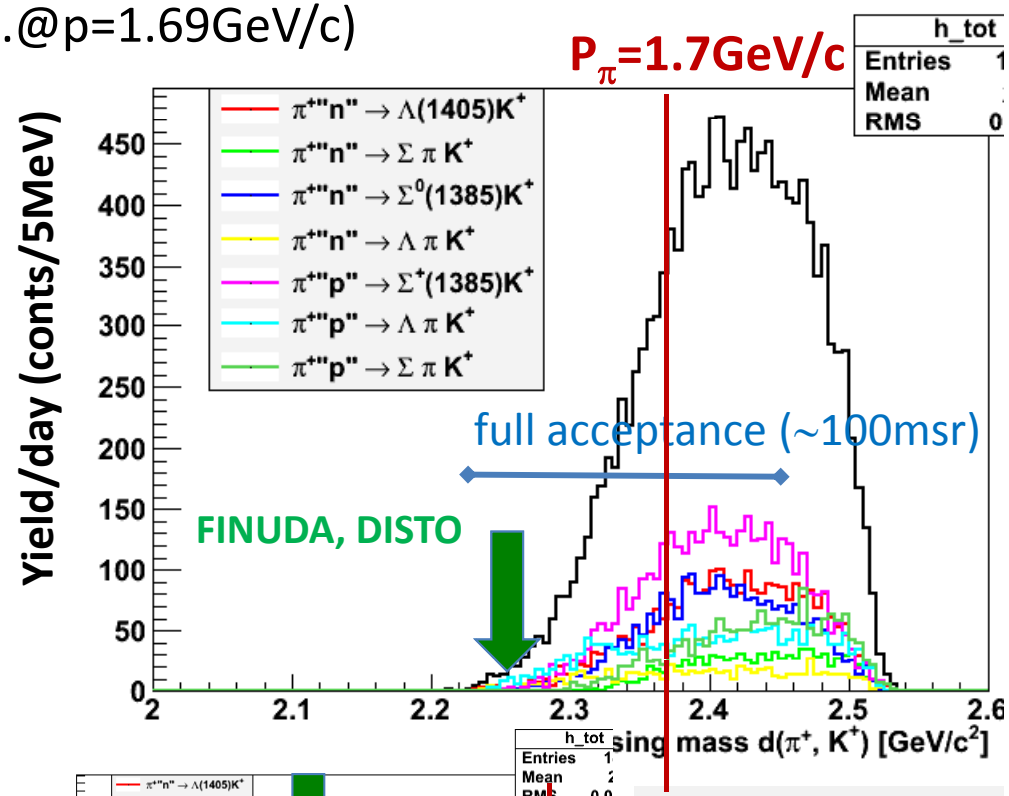


E27: Yield estimate (Expected spectrum by MC)

Background (quasi-free) processes (C.S.@p=1.69GeV/c)

- π^+ "n" $\rightarrow \Lambda(1405)$ K^+ 20.6 μb
- π^+ "n" $\rightarrow \Sigma^0(1385)$ K^+ 76.7
- π^+ "p" $\rightarrow \Sigma^+(1385)$ K^+ 124
- π^+ "n" $\rightarrow \Lambda\ \pi^0$ K^+ (P.S.) 13.7
- π^+ "p" $\rightarrow \Lambda\ \pi^+$ K^+ (P.S.) 40
- π^+ "n" $\rightarrow \Sigma\ \pi$ K^+ (P.S.) 28.9
- π^+ "p" $\rightarrow \Sigma\ \pi$ K^+ (P.S.) 40

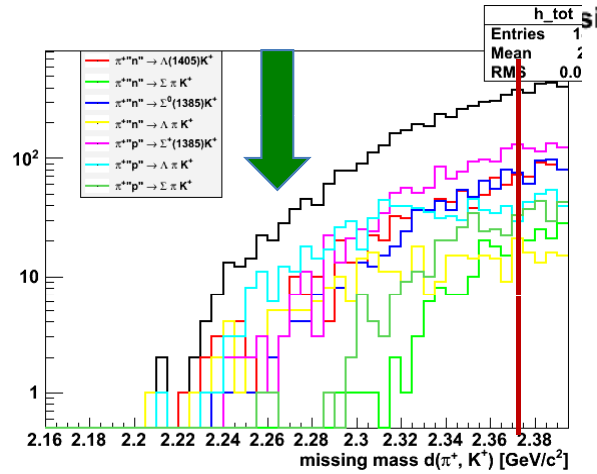
with the same angular distribution as the elem. process + Fermi motion (MC)



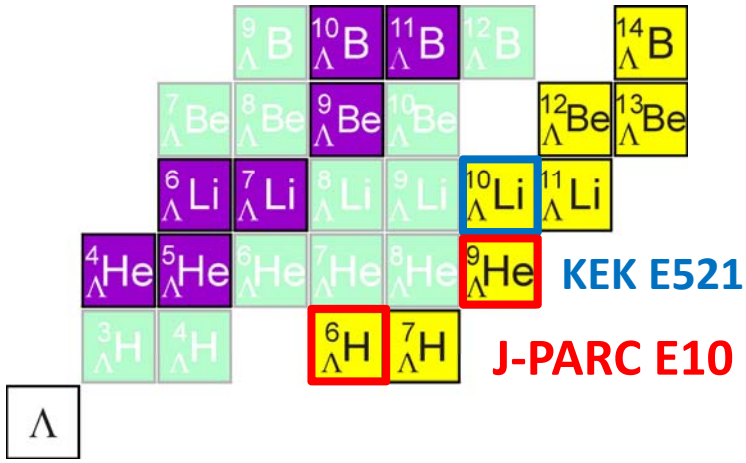
Neglict the following (quasi-free) processes

- π^+ "n" $\rightarrow \Lambda$ K^+
- π^+ "n" $\rightarrow \Sigma^0$ K^+
- π^+ "p" $\rightarrow \Sigma^+$ K^+

with Rescattering (F.S.I)



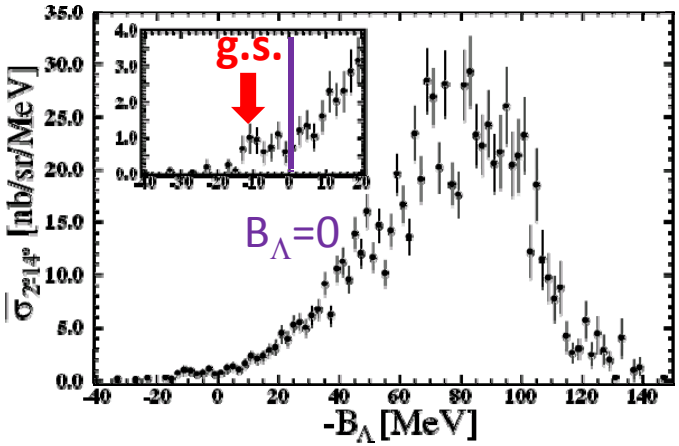
E10: Neutron-rich Λ hypernuclei, $^{6}_{\Lambda}$H and $^{9}_{\Lambda}$He, by the (π^-,K$^+$) reaction



Double Charge eXchange (DCX) reaction to produce *exotic Λ hypernuclei*

- ΛN interaction in N-rich environment
- ΛN-ΣN mixing plays an important role
- EOS of high density nuclear matter such as core of neutron-stars

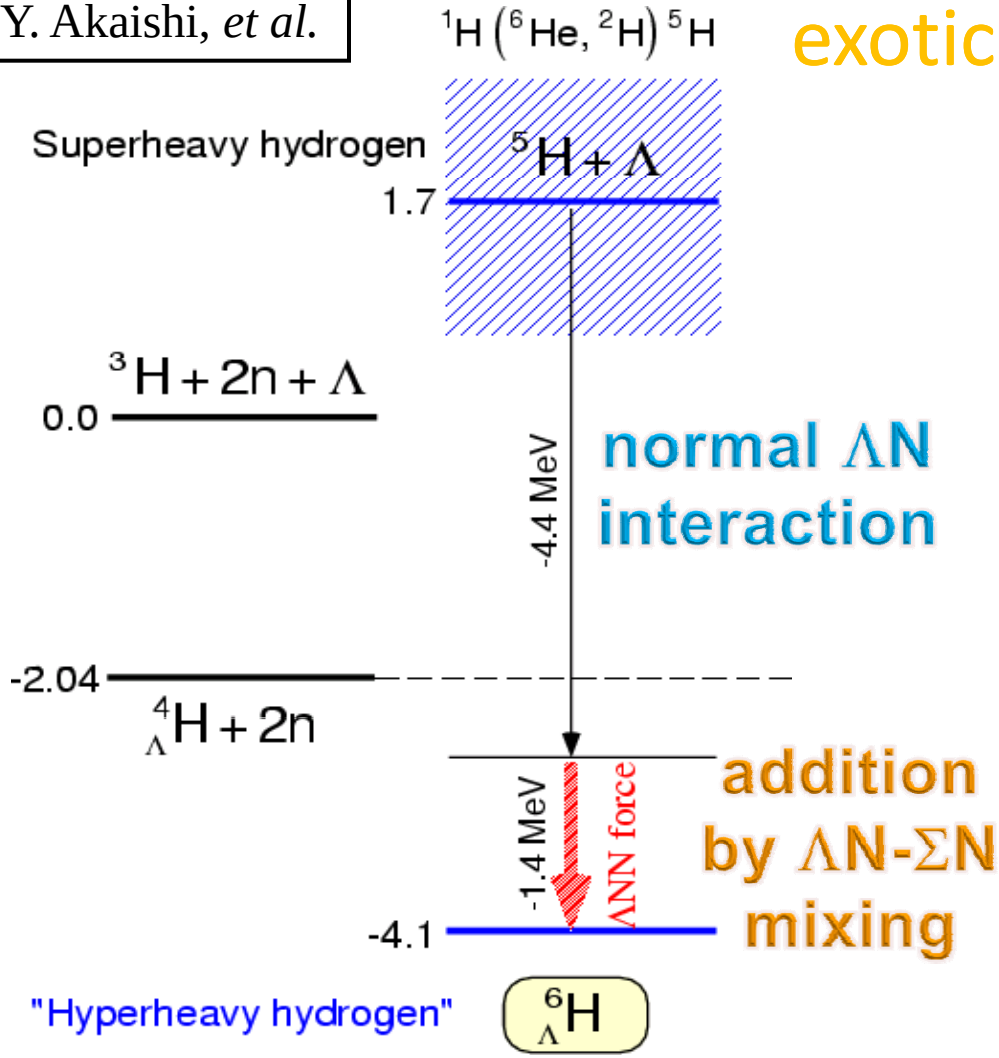
$^{10}_{\Lambda}$Li (KEK E521)



dσ/dΩ (g.s.) ~10nb/sr

E10: Hyperheavy hydrogen $^{6}_{\Lambda}H$

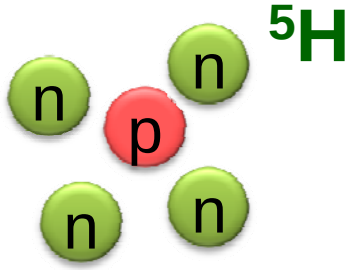
Y. Akaishi, *et al.*



exotic hypernuclei

unbound

exotic nucleus

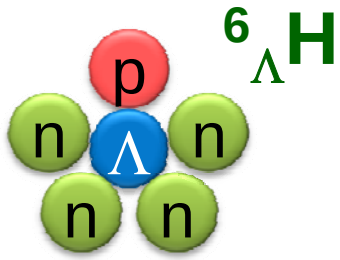


production of exotic "nucleus"

glue-like role of Λ-hyperon

bound

exotic hypernucleus



E10: Yield estimation

- Beam, target, Kaon Spectrometer etc..
  - π^- beam at 1.25 GeV/c,
  - 2M/spill (6s repetition) with 30% duty factor
  - 3.5g/cm^2 ^{6}Li / ^{9}Be
  - Sks0 or Sks0v2 (ΔM=2.8MeV), (SksMinus, ΔM=3.1MeV)
  - 10nb/sr (assumption) and 4 weeks data-taking

N_π = 2x10^6 x 10 (spill/min) x 60 (min) x 24 (hour) x 28 (day) = 8.06x10^{11}

N_{Li} = 3.5/6 x 6.02x10^{23} = 3.5x10^{23} /cm^2

N_{Be} = 3.5/9x 6.02x10^{23} = 2.34x10^{23}/cm^2

Y($^6_\Lambda$H) = 10x10^{-33}(cm^2/sr) x 0.1(sr) x 8.06x10^{11} x 3.5x10^{23} (/cm^2)
x 0.8 (analysis) x 0.9 (DAQ) x 0.4 (decay)
= 81

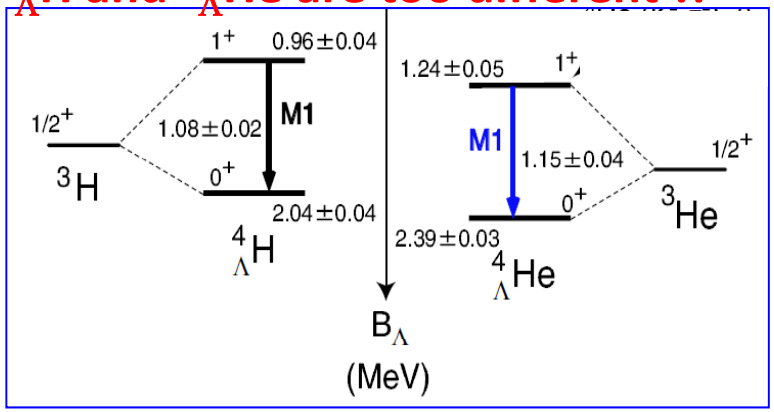
Y($^9_\Lambda$He) = 2/3xY($^6_\Lambda$H) = 54

E13: γ-ray spectroscopy of Λ hypernuclei, ${}^{4}_{\Lambda}$He, ${}^{7}_{\Lambda}$Li, ${}^{10}_{\Lambda}$B, ${}^{11}_{\Lambda}$B, and ${}^{19}_{\Lambda}$F

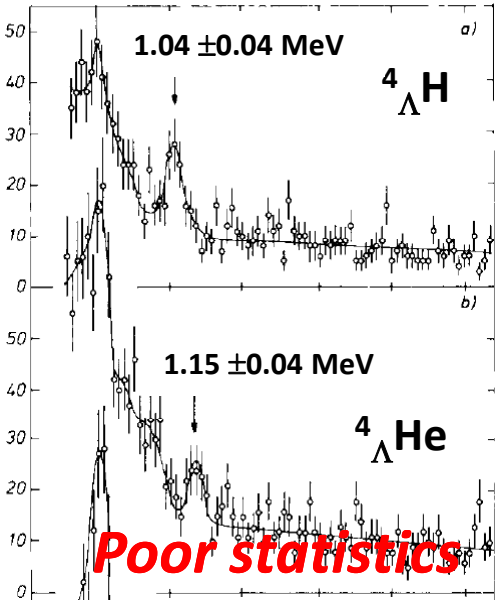
- Among those targets, ${}^{4}_{\Lambda}$He and ${}^{19}_{\Lambda}$F are able to be carried out even at 10 kW beam.
  - ${}^{4}_{\Lambda}$He 60k/spill K^- beam at 1.5 GeV/c
    - Charge symmetry breaking
    - spin-flip / spin-non-flip amplitudes for the (K^-, π^-)
  - ${}^{19}_{\Lambda}$F 150k/spill K^- beam at 1.8 GeV/c
    - ΛN spin-spin interaction in *sd*-shell hypernuclei
    - B(M1) measurement
      - g-factor of Λ in a nucleus (medium effect of baryons)

E13 $^{4}_{\Lambda}$He : Charge Symmetry Breaking & spin-flip/spin-non-flip amplitudes

CSB: Binding energy & level spacing of $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He are too different !!



– a long-standing puzzle in ΛN interaction

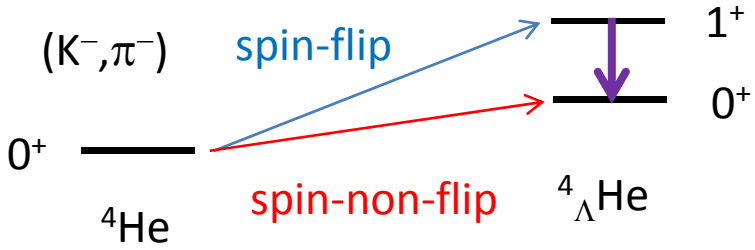


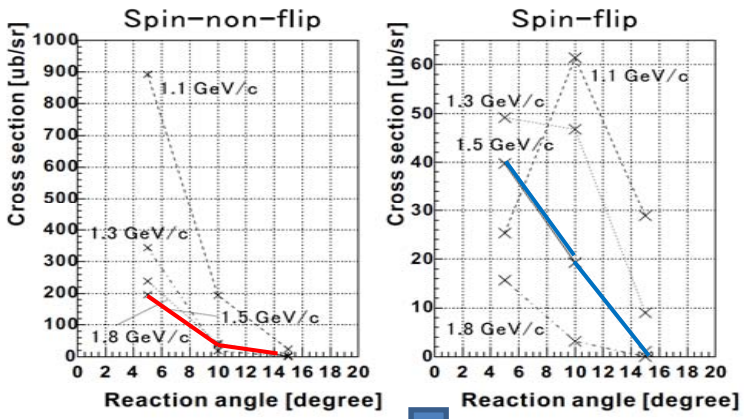
γ-ray spectroscopy by NaI detector

M. Bedjidian et al., Phys. Lett. 83B (1979) 252.

Precise determination of the level spacing by Hyperball-J

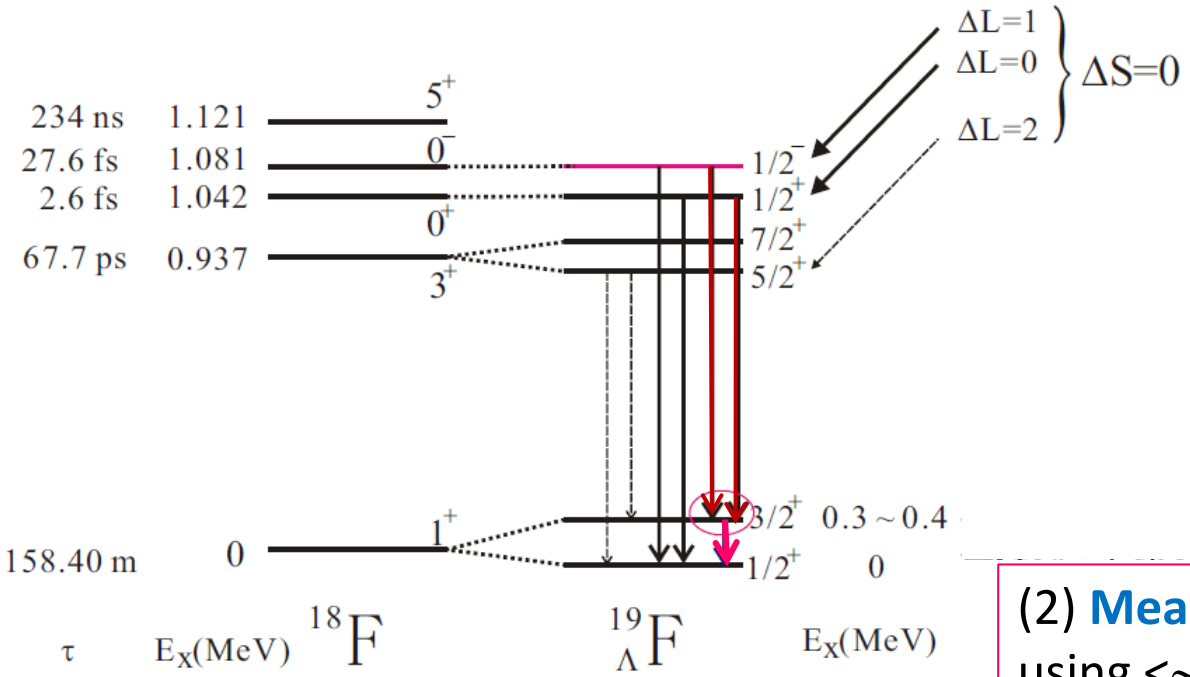
To obtain spin-flip/spin-non-flip amplitude from $1^{+} \rightarrow 0^{+}$ γ-ray yield



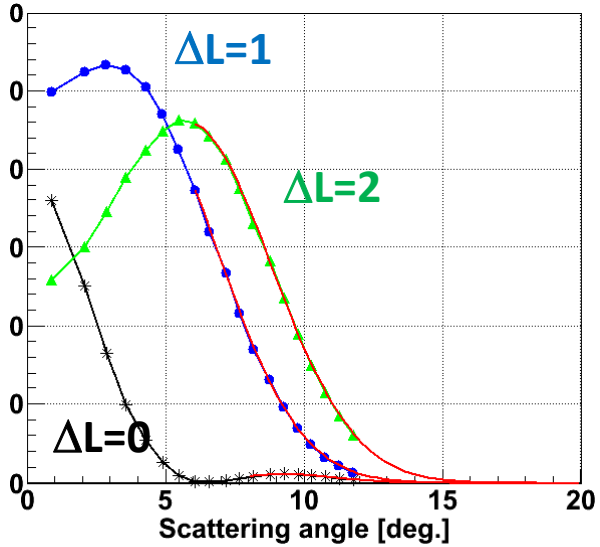


important for further γ spectroscopy of various hypernuclei

E13 $^{19}{}_{\Lambda}$F: ΛN spin-spin interaction in *sd*-shell hypernuclei & B(M1)



(K⁻,π⁻) at 1.8GeV/c



(1) 3/2⁺, 1/2⁺ spacing is determined by **ΛN spin-spin interaction**

The first data for *sd*-shell ⟺ The value of p-shell Δ=0.43MeV

Radial dependence of the interaction.

(2) **Measurement of B(M1)** by DSAM using <~1g/cm³ target

if 1000 counts, 10% accuray

→ g-factor of Λ in a nucleus for the first time

(3) higher excited states of $^{19}{}_{\Lambda}$F γ-rays from $^{18}{}_{\Lambda}$O

E13: Yield Estimate

- $^{4}_{\Lambda}$He
  - 60k/spill @1.5GeV/c
  - 25cm Liq.-^{4}He target
  - SksMinus configuration
  - Hyperball-J
    - 6% Efficiency @ 1.15MeV

➢ 100 events for 111 hours (4.6 days)

- $^{19}_{\Lambda}$F
  - 150k/spill @ 1.8GeV/c
  - 19g/cm^2 of F
    - 20g/cm^2 for HF
    - 25g/cm^2 for Teflon
  - SksMinus + Hyperball-J
  - 400keV for $3/2^+ \rightarrow 1/2^+$

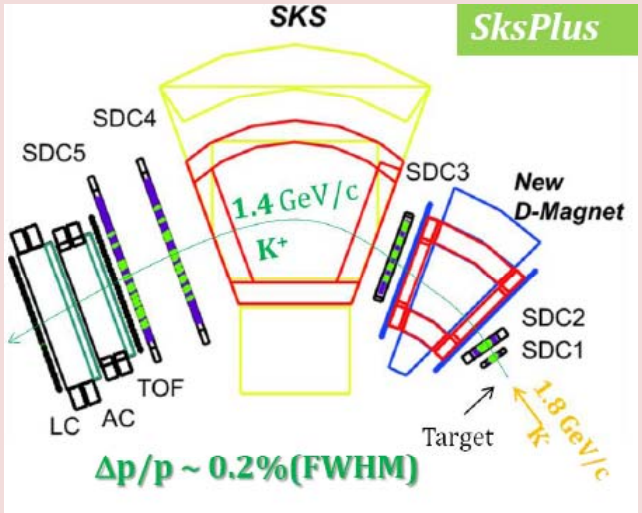
➢ Level spacing for 7 days

➢ B(M1) for +2 weeks

E05: Spectroscopy of Ξ hypernucleus via the $^{12}C(K^-,K^+)^{12}{}_{\Xi}Be$

P_K=1.8GeV/c
5.4g/cm^2 target

Original



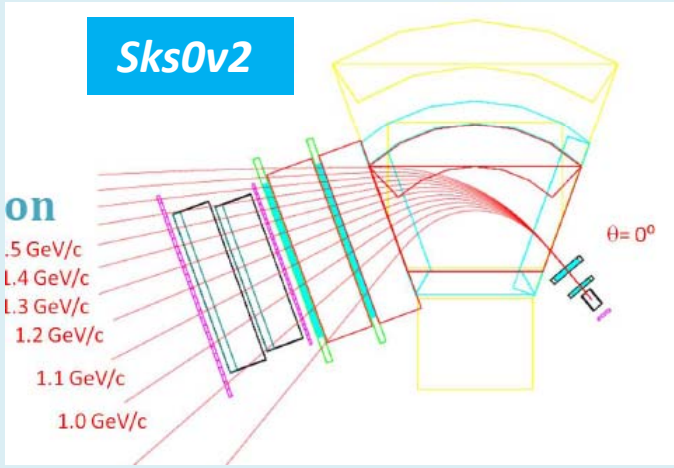
$\Delta\Omega$=30msr

I_K=1.4x10^6/spill (~3.7sec., 270kW, Ni)

190 events/month

ΔM=3.3MeV(FWHM)

First step



Δp/p=0.24%(FWHM)

$\Delta\Omega$=80msr

I_K=1.5x10^5/spill (6sec., 30kW,Pt)

70 events/month

ΔM=3.7MeV (FWHM)

E05: Spectrometer resolution check

- at 10kW (150k/spill)
  - Resolution check by the $p(K^-,K^+)\Xi^-$ with CH_2 target
- $Y_{elem}(\Xi^-) = N_{beam} \times N_{target} \times d\sigma/d\Omega \times \Delta\Omega \times f_{decay} \times f_{analysis} \times f_{DAQ}$

  $= 1.5\times10^5$[/spill] x 24x3600/6[spill/day]

  x 5[g/cm^2] x 2/14 x 6.02×10^{-7}[cm^2/g/μb]

  x 35[μb/sr] x 0.1[sr] x 0.6 x 0.5 x 0.9

  = **880 events/day**

  - with the 4–5 days data-taking, enough events can be accumulated to calibrate Spectrometer.

RUN plan

2011 April RUN

Allowed intensity ≤ 5 kW by law
Assumed the same condition as the 2010 autumn, ~1M/spill pion beam, ~20% duty factor.

(1)	E27 data taking	7 days
(2)	E19 data taking at 2.0 GeV/c	6 days
(3)	$^{12}C(\pi^+,K^+)^{12}{}_{\Lambda}C$ measurement for resolution study	1 day
(4)	K^- beam tuning	2 days

Additional 1–2 days are necessary for detector commissioning and trigger study for E27.
A few days without beam are necessary to change D_2 to H_2 targets between (1) and (2).
1 or half day is need to remove liq. target for (3).

2011 Autumn RUN

Beam power of 10 kW would be realized after the MR study,
then we can start E13 after kaon beam tuning.

• E10	$^{6}{}_{\Lambda}H$	4 weeks
• E13	$^{4}{}_{\Lambda}He$, $^{19}{}_{\Lambda}F$	2 (level spacing)+2 weeks (B(M1))
• E19		
• E05	calibration with CH_2 target	several days

Necessary time above is in the case of the best SKS setup.
We will decide the priority after the April RUN.
Since the detail beam conditions such as beam power and duty factor can be estimated reliably based on the MR and SX studies as well as K1.8 beam line tuning in April RUN.

Table.1 Summary of the necessary beam time for each experiment.

E10 $^{6}_{\Lambda}$H (^{6}Li) $^{9}_{\Lambda}$He(^{9}Be)	4 weeks 4 weeks	3 kW is enough 30% duty 2M/spill	Sks0/ Sks0v2	10 nb/sr (assumed) 81 bound states ($^{6}_{\Lambda}$H) 54 bound states ($^{9}_{\Lambda}$He) Resolution with 3.5 g/cm^2 target ~2.8 MeV for Sks0 ~2.8 MeV for Sks0v2 (~3.1 MeV for SksMinus)
E19 @2.0GeV/c @1.87GeV/c @1.92GeV/c @2.0GeV/c	6 days 3 weeks +2.5 weeks +2.5 weeks	3 kW is enough 16% duty 1.1M/spill 30% duty 2M/spill 30% duty 2M/spill 30% duty 2M/spill	Sks0	Same statistics Achieve full proposal Achieve full proposal Achieve full proposal
E27	1 week	3 kW is enough 20% duty 1M/spill	Sks0	w/o decay products ~300 bound states
E05 $^{12}_{\Xi}$Be p(K$^-$,K$^+$)Ξ^-	1 month ~1 week	30 kW 450k/spill K$^-$ @1.8GeV/c 10kW 150k/spill	Sks0v2 Sks0v2	70 bound states resolution 3.3 MeV(SksPlus) 3.7 MeV(Sks0v2) Resolution check (CH_2)

E13 $^{4}_{\Lambda}$He $^{19}_{\Lambda}$F level spacing (B(M1)) $^{7}_{\Lambda}$Li (B(M1)) $^{10}_{\Lambda}$B, $^{11}_{\Lambda}$B	5 days [6 days] 7 days [10 days] +14 days [+20 days] ~4 weeks	10 kW (60k/spill)@1.5 GeV/c 10 kW (150k/spill)@1.8 GeV/c 30 kW (450k/spill)@1.8 GeV/c	SksMinus [Sks0v2] SksMinus [Sks0v2] SksMinus	^{4}He target is ready by 2011 autumn 100 counts Fine-powder Teflon or HF 1000 counts for B(M1)
E03 Ξ-Fe	21 days	30 kW 300k/spill@1.65 GeV/c	KURAMA	Shift>0.5 keV and Width<3 keV case
E07	1 week (setup) 5 weeks (prod.)	30 kW 300k/spill @1.7GeV/c K/π > 6	KURAMA	Emulsion (190L) will be ready 2012 autumn. # of double hypernuclei ~10^2 in triggered ~10^3 in un-triggered X-rays from Ξ^- absorption ~10^2 events
E18	24 days	3 kW is enough 3M/spill >30% duty factor	Sks0 + Decay Counter	Total 1T pions ~65 triple coincidence events