Hypernuclear production by the (K^-,π^-) reaction at p_K= 1.5, 1.8 GeV/c

2014/3/20

T. O. Yamamoto , Tohoku Univ.

for the E13 collaboration

Contents

- Introduction
  - Hypernucler γ-ray spectroscopy (J-PARC E13 1st)
  - Spectrometer system for the (K^-,π^-) reaction: SksMinus
- Hypernuclear production via the (K^-,π^-) reaction
  - Σ^+ cross section (testing of detector system)
  - ${}^{12}_{\Lambda}C$ cross section
  - Yield estimation for ${}^{19}_{\Lambda}F$ (Beam momentum selection)
- Summary

J-PARC E13(1st) @K1.8 beam line

- **Target：^{4}He**
  - **γ-ray spectroscopy of $^{4}_{\Lambda}He$** ($1^{+} \rightarrow 0^{+}$ transition)

    Charge symmetry breaking in ΛN interaction

    Difference of ground state spin doublets (1^{+},0^{+}) spacing is unexpectedly large in mirror hypernuclei ($^{4}_{\Lambda}H$, $^{4}_{\Lambda}He$)

    → Recheck with high precision and statistics
  - **Missing mass spectroscopy of $^{4}_{\Sigma}He$**

    Study of Σ hypernuclei

    The first measurement in high momentum transfer condition
- **Target：^{19}F**
  - **γ-ray spectroscopy of $^{19}_{\Lambda}F$**

    Study of spin-dependent ΛN interaction (*in sd*-shell)

    The first γ-ray spectroscopy experiment in *sd*-shell hypernuclei

    Energy spacing between ground state spin doublets

    → Strength of spin-spin interaction

Experimental setup

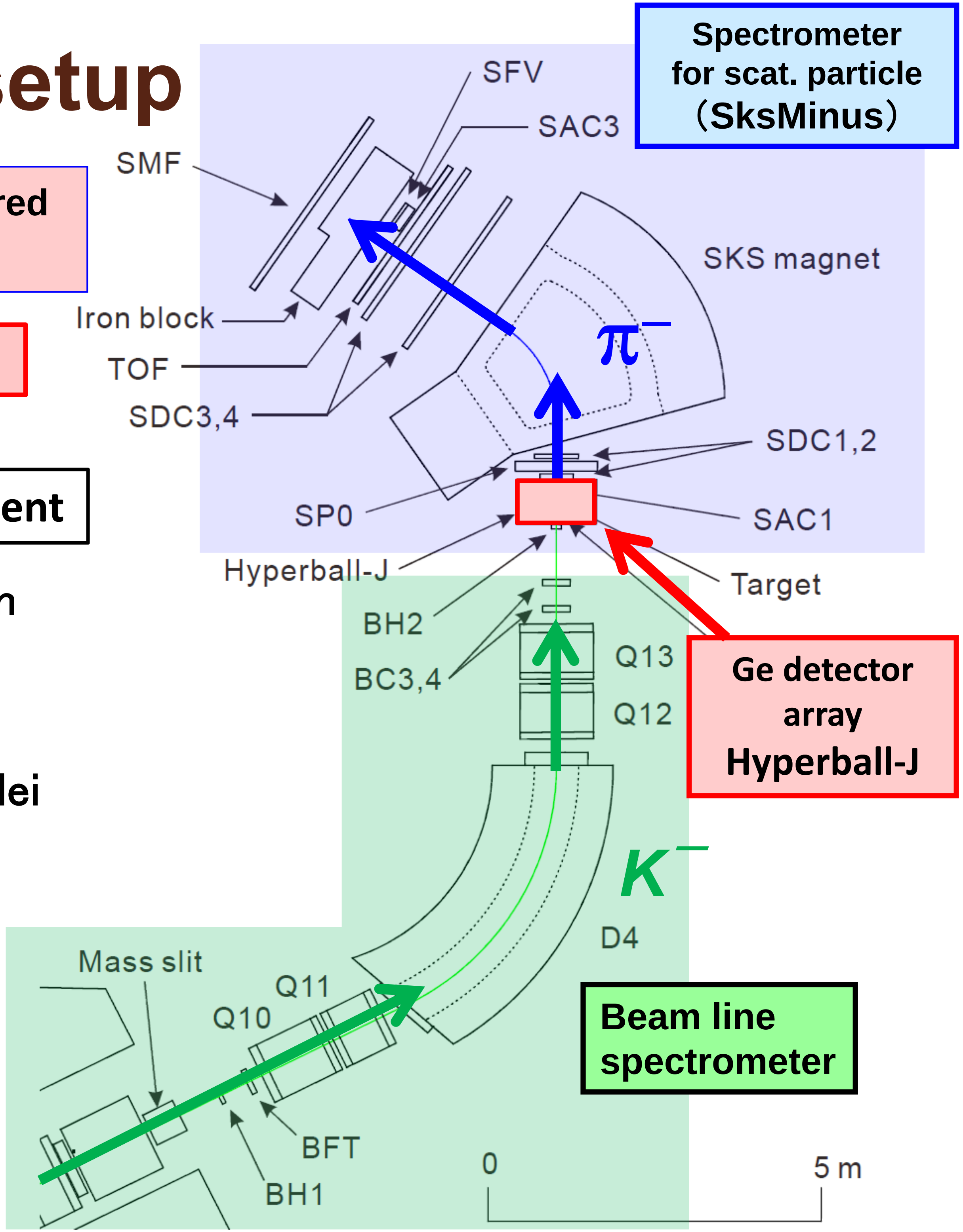
Use high intensity K- beam delivered from J-PARC K1.8 beam line

$^{A}Z(K^-, \pi^-)\, ^{A}_{\Lambda}Z^* \rightarrow \, ^{A}_{\Lambda}Z + \gamma$

reaction-γ coincidence experiment

- Tag hypernuclear production
  - Beam line spectrometer
  - SksMinus spectrometer
- Detect γ ray from hypernuclei
  - Hyperball-J

$^4_\Lambda$He : liq.He terget (2.5 g/cm^2)
p_K = 1.5 GeV/c
$^{19}_\Lambda$F : HF target (20 g/cm^2)
p_K = 1.8 GeV/c



Hyperball-J new Ge detector array

Y. Yamamoto

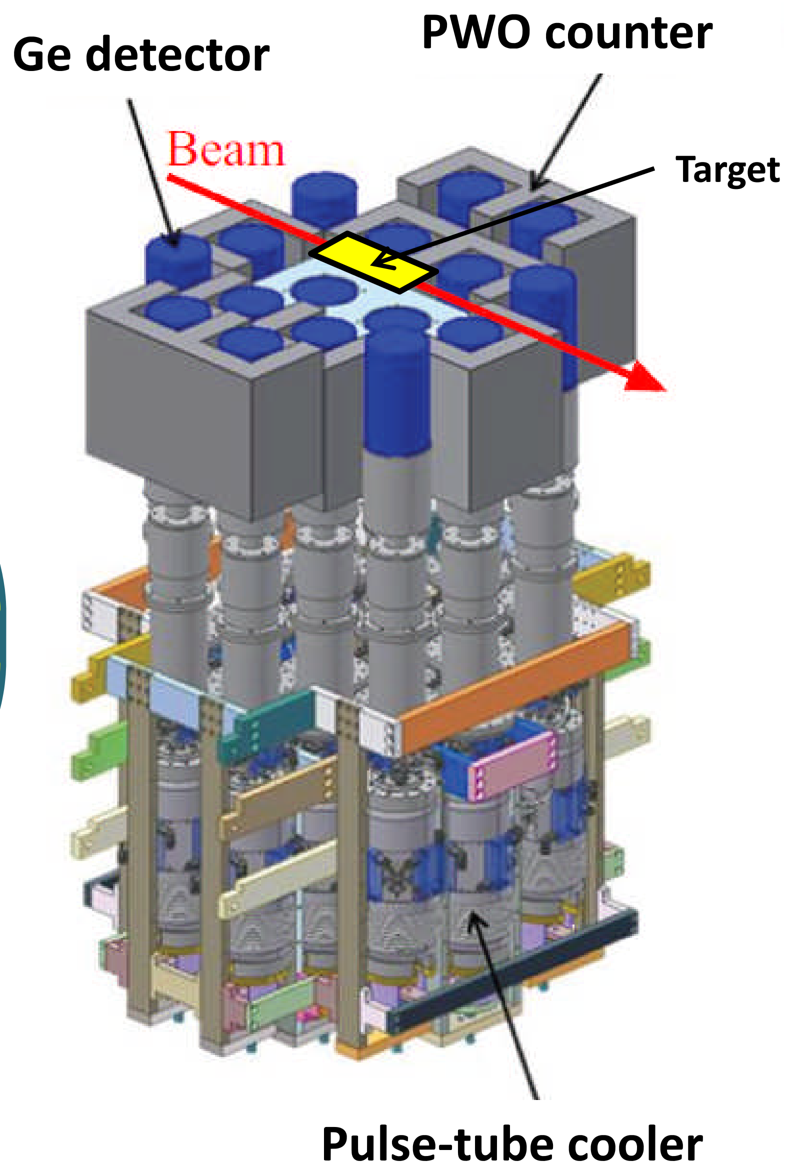
Features

- **Large photo-peak efficiency**
  → ε ~6 % @1 MeV with 32 Ge detectors
- **Fast readout system** T. Koike
- **Radiation-hard Ge detector**
  → Mechanical cooling
- **Fast background suppressor**
  → PWO counter

J-PARC conditions

- high count and energy deposit rate
- radiation damage due to hadron beam

Lower half of Hyperball-J

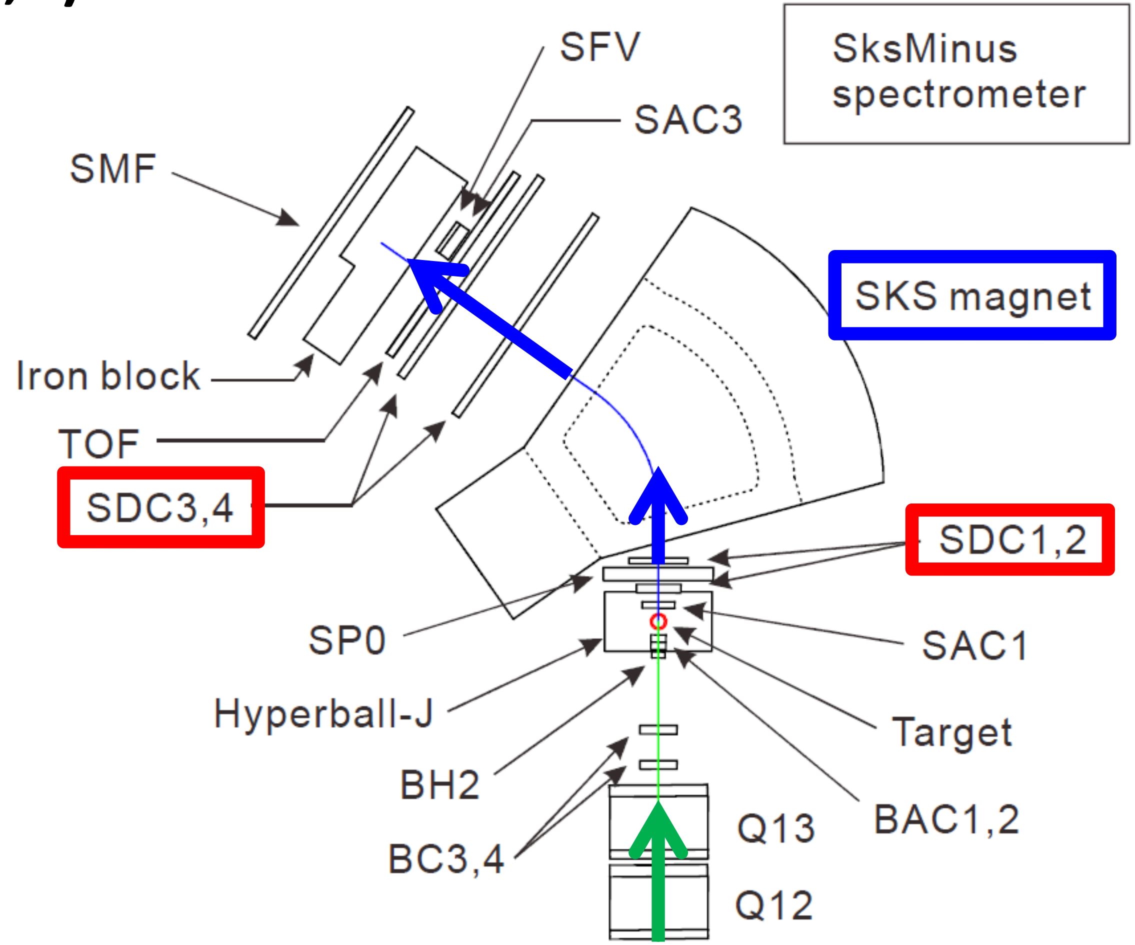


SksMinus

Spectrometer for the (K,π) reaction

＜Functions＞

- Momentum analysis
  - SKS magnet (2.5 T)
  - Drift chambers
    SDC 1 – 4



Bending angle : 55 deg.
(for 1.5 GeV/c)
Path length : 5 m

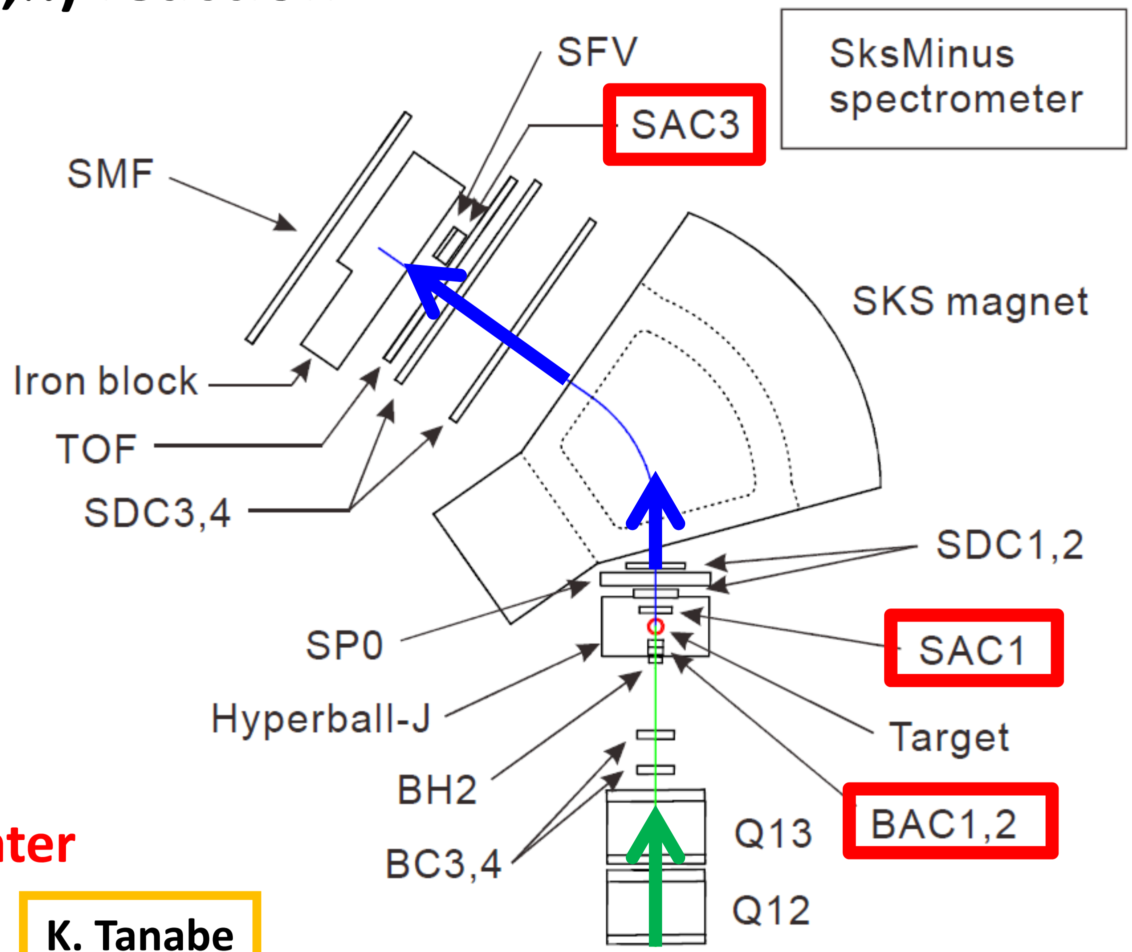
SksMinus

Spectrometer for the (K,π) reaction

＜Functions＞

- **Momentum analysis**
  - **SKS magnet (2.5 T)**
  - **Drift chambers**
    SDC 1 – 4
- **PID (π/K)**
  - **Timing counter**
    [for time-of-flight]
    BH2, TOF, SFV
  - **Aerogel Cherenkov counter**
    [for trigger]
    BAC1,2, SAC1, SAC3

K. Tanabe



Bending angle : 55 deg.
(for 1.5 GeV/c)
Path length : 5 m

SksMinus

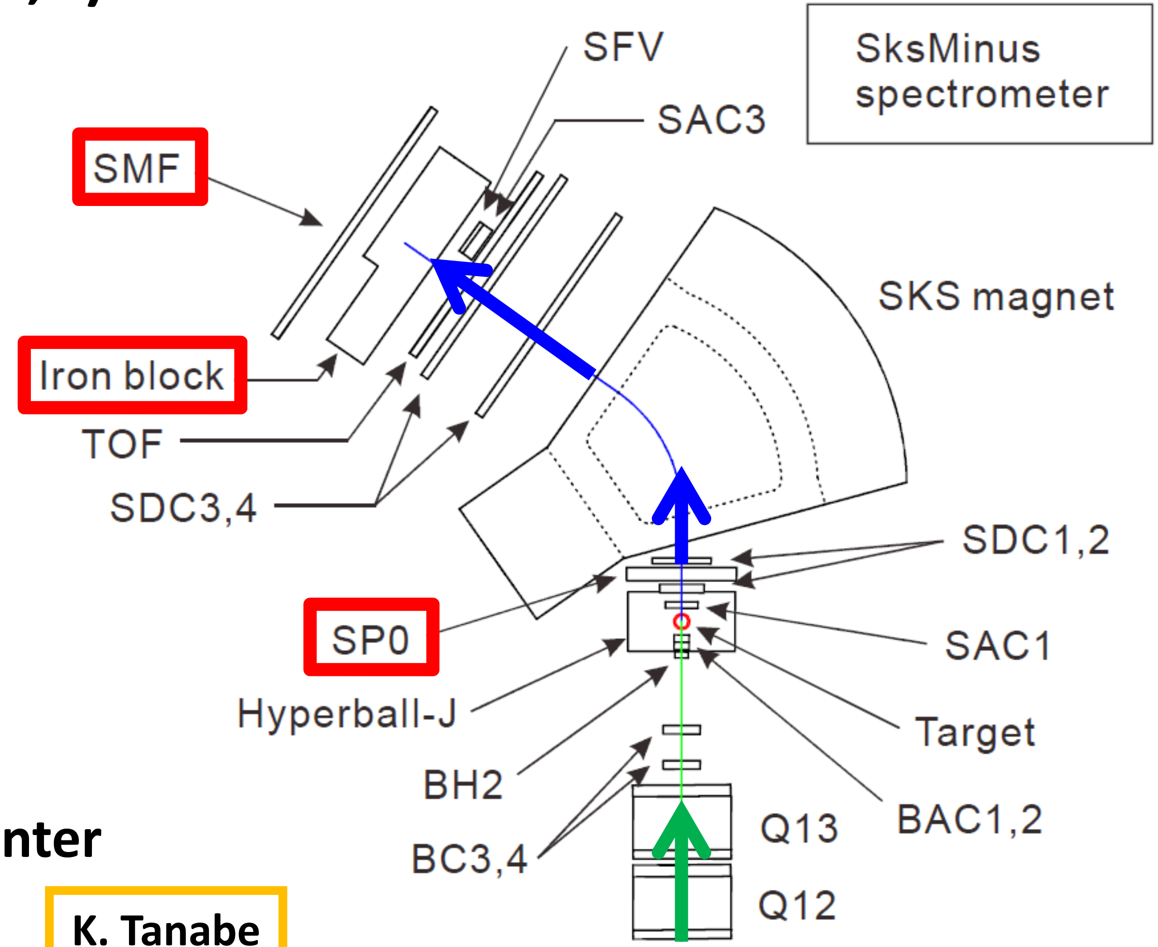
Spectrometer for the (K,π) reaction

＜Functions＞

- **Momentum analysis**
  - **SKS magnet (2.5 T)**
  - **Drift chambers**
    SDC 1 – 4
- **PID (π/K)**
  - **Timing counter**
    [for time-of-flight]
    BH2, TOF, SFV
  - **Aerogel Cherenkov counter**
    [for trigger]
    BAC1,2, SAC1, SAC3
- **K beam decay suppressor**
  - **$K^- \rightarrow \mu^- + \nu$ (BR:64%) ← SMF**
  - **$K^- \rightarrow \pi^- + \pi^0$ (BR:21%) ← SP0**

K. Tanabe

Y. Sasaki



Bending angle : 55 deg.
(for 1.5 GeV/c)
Path length : 5 m

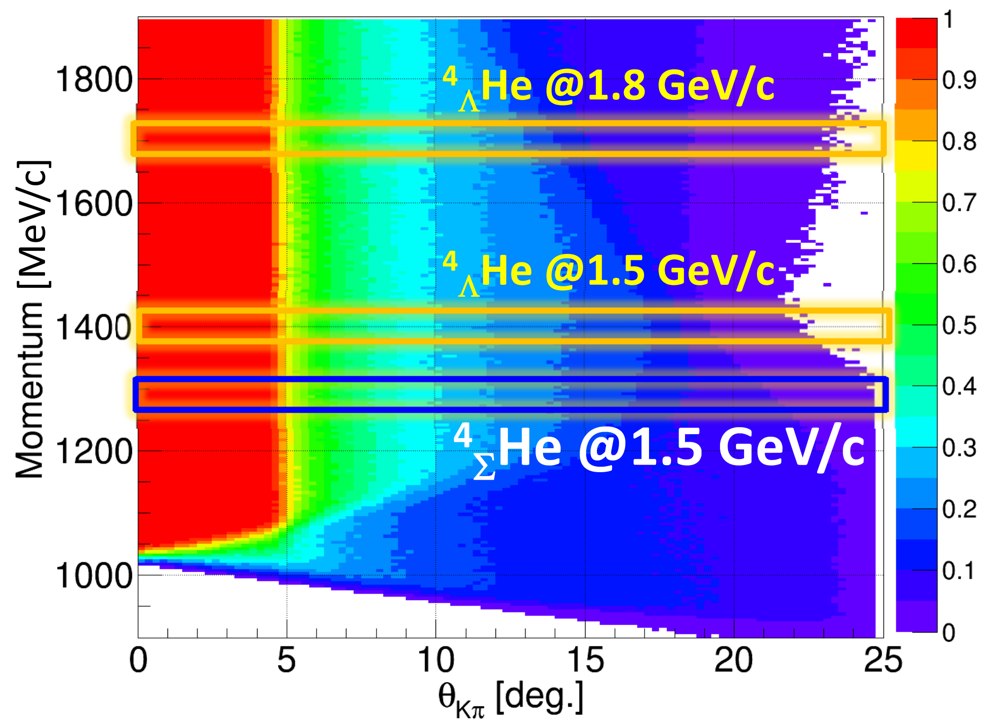
Acceptance of SksMinus

- wide momentum acceptance
  : 1.1 ~ 2.0 GeV/c
- wide angular acceptance
  : 0 ~ 20 deg.

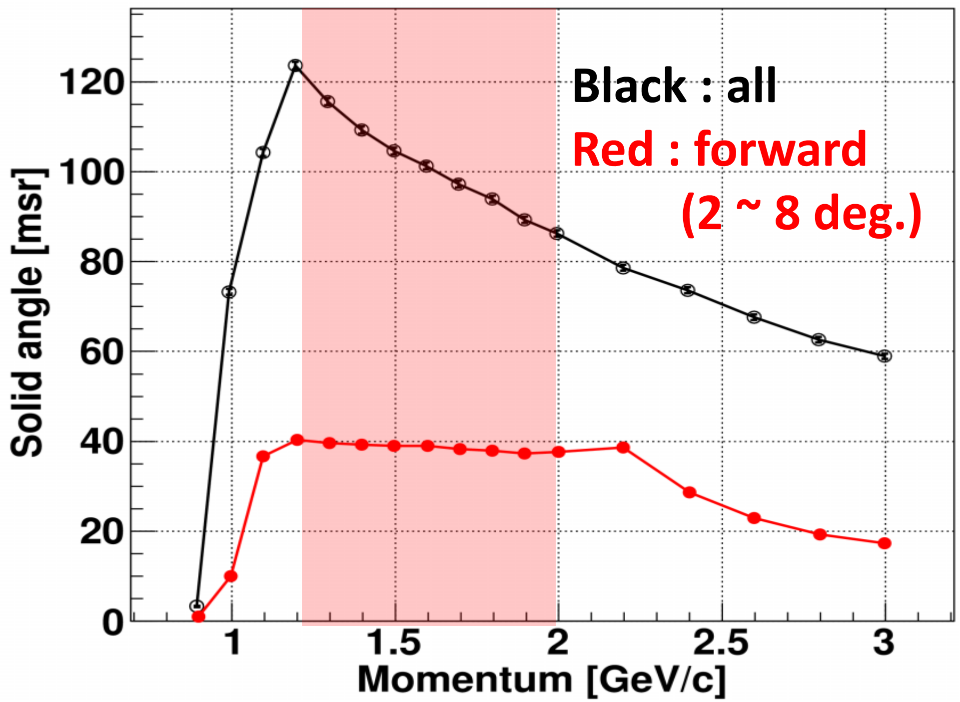
- Optimal positioning of the magnet
- Use of large size detectors

Σ hypernuclear spectroscopy
can be performed with the same setup

Acceptance table



Solid angle vs $P_{scat.}$



Preparation and commissioning

2012.8 Install Hyperball-J

2012.12 E10 @K1.8 [$^{6}Li(\pi^{-},K^{+})^{6}{}_{\Lambda}H$]

2013.1 Install SksMinus spectrometer

2013.3 Commissioning beam time 1 (3/8~3/17)

- Check SksMinus system

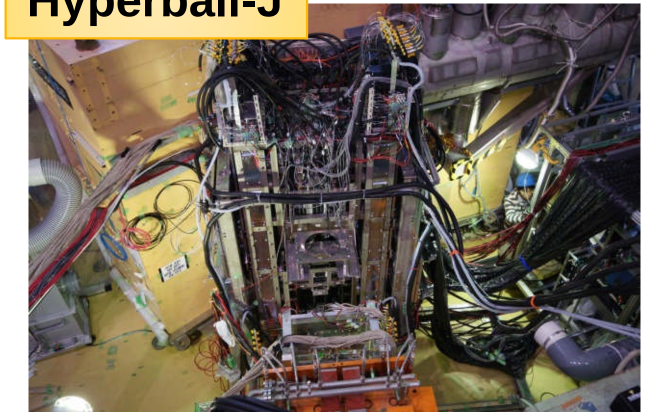
2013.4 Commissioning beam time 2 (4/28~5/2)

- K^{-} beam tuning
- Check Hyperball-J system

2013.5 Commissioning beam time 3 (5/13~5/18)

- CH_2 Target (2.9 g/cm²)
  - Check performance of SksMinus
  - Reaction spectroscopy of Σ^{+}, $^{12}{}_{\Lambda}C$

  New data
- CF_2 Target (20 g/cm²)
  - Check performance of SksMinus
  - Check performance of Hyperball-J



Hypernuclear production via the (K^-,π^-) reaction

at p_K=1.5 , 1.8 GeV/c

- Σ^+ cross section
- $^{12}{}_{\Lambda}C$ cross section
- Yield estimation for $^{19}{}_{\Lambda}F$

Strategy

Yield estimation of $^{19}_{\Lambda}$F done before commissioning was not based on realistic conditions.

Goal: Yield estimation of $^{19}_{\Lambda}$F considering realistic conditions and cross section of $^{12}_{\Lambda}$C

< Procedure >

(1) Analysis of CH_2 target data (p_K = 1.5 & 1.8 GeV/c)

(1-1) Differential cross section of Σ^+ **New data**

→ compare with calculation to check spectrometer system.

(1-2) Differential cross section of $^{12}_{\Lambda}$C (s_{Λ}-state) **New data**

→ relative cross section for p_K= 1.5 & 1.8 GeV/c

(2) Yield estimation of $^{19}_{\Lambda}$F

-> Select beam momentum (1.5 or 1.8 GeV/c)

Data set

Calibration data taken in commissioning beam time (May, 2013)

- Target : CH_2 (2.9 g/cm^2)
- Beam condition : K-beam rate = ~300k /spill (K/all = ~75%)
- Trigger : (K,π) trigger w/ SMF

Ge detector not included in trigger

< p_K = 1.5 GeV/c >

~5h data taking $\rightarrow$ total K- beam on target : ~1.0G

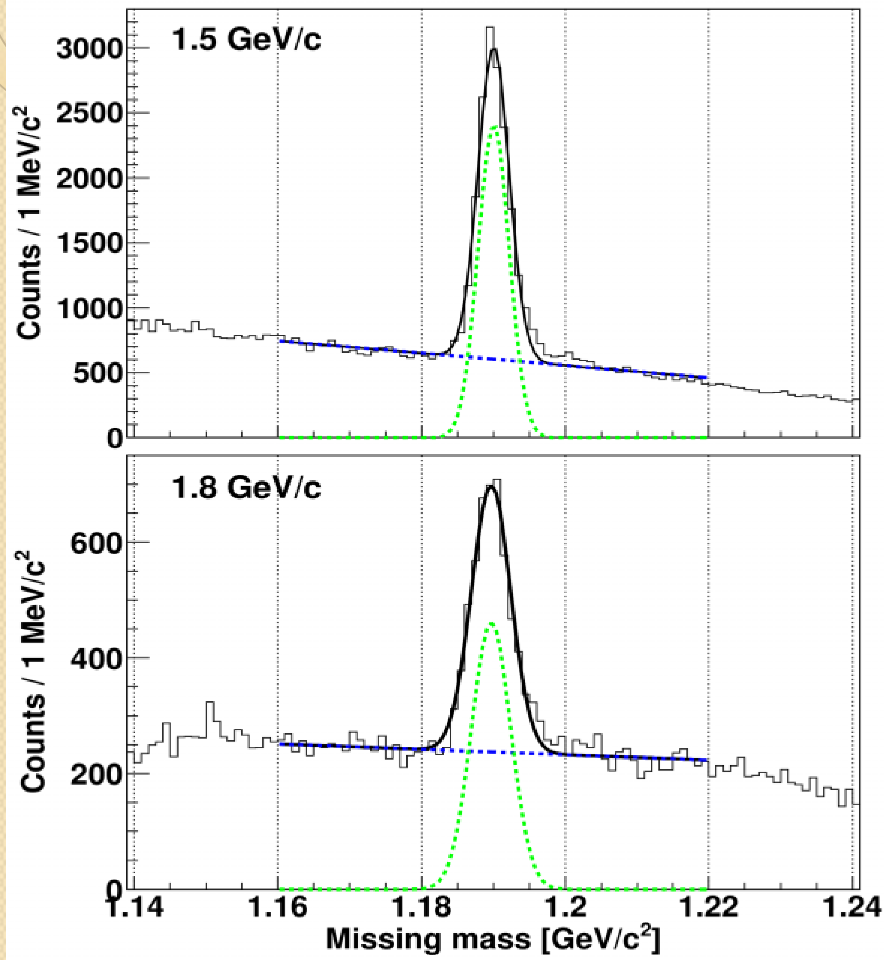
< p_K = 1.8 GeV/c >

~3h data taking $\rightarrow$ total K- beam on target : ~0.5G

Enough statistics to obtain shape of differential cross section

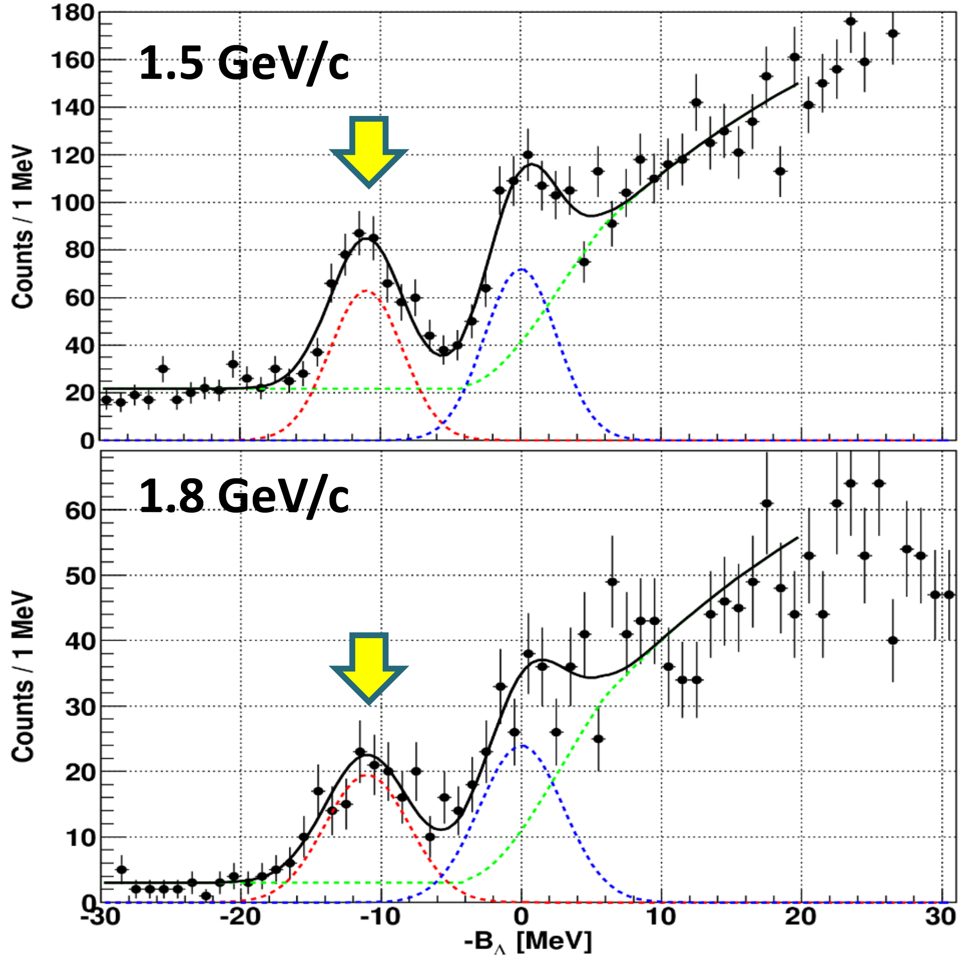
Missing mass analysis

Σ^+ missing mass



Binding energy of $^{12}_{\Lambda}C$

θ: 4~14 deg.



Hypernuclear production can be identified using our detector system

Obtaining differential cross section

$$\frac{d\sigma}{d\Omega} = \frac{1}{T}\frac{1}{N_{\mathrm{BH2}}\cdot f_{\mathrm{Beam}}}\frac{1}{\varepsilon_{\mathrm{DAQ}}\cdot f_{\mathrm{abs}}\cdot\varepsilon_{\mathrm{vertex}}\cdot\varepsilon_{\mathrm{SingleTrack}}}\frac{N_{\mathrm{PeakCounts}}}{\varepsilon_{\mathrm{SKS}}\cdot\Delta\Omega}$$

T : Number of Target (CH_2 target (2.9 g/cm2))

N_BH2 : Total counts of time0 counter

f_Beam : effective beam factor

= εKinTrigger * εBtof * εBFT * εBcOut * εTargeting * εKdecay

εDAQ : DAQ efficiency

f_abs : absorption factor

εvertex : vertex cut efficiency

εSignleTrack : single track ratio in spectrometers

εSKS : efficiency of SKS spectrometer

= εSAC1 * εTof * εSFV * εSdcIn * εSdcOut * εSksTrack * εm2 * εSMF * εDecay

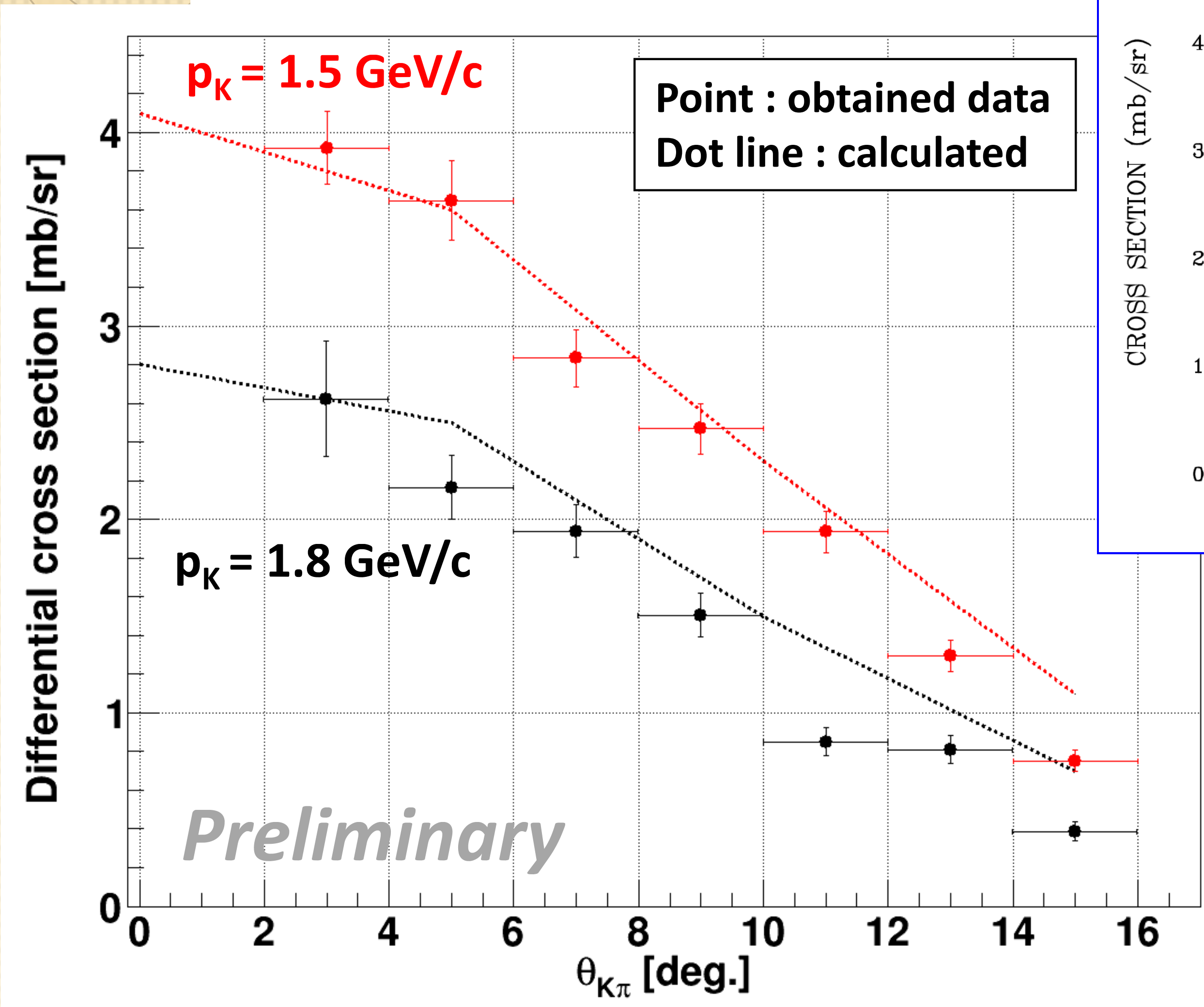
ΔΩ : effective solid angle of SKS spectrometer

Systematic Errors are not considered in this report.

Differential cross section of Σ^+

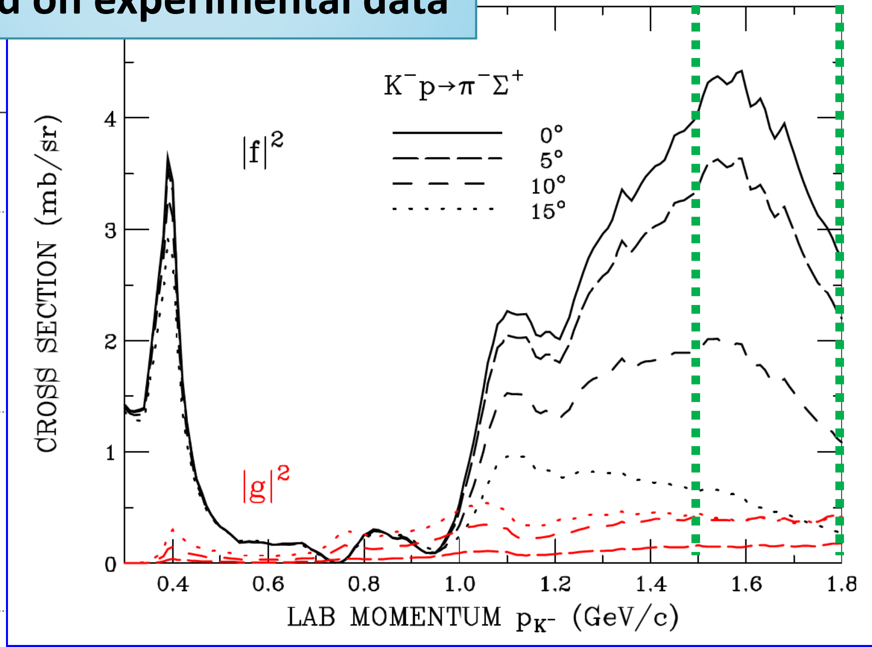
New data

Obtained cross section of $p(K^-,\pi^-)\Sigma^+$



calculated cross section of $p(K^-,\pi^-)\Sigma^+$ based on experimental data

T. Harada, private communication



Obtained cross sections are well reproduced by calculated one.

Absolute cross section can be measured with this system

Differential cross section of $^{12}{}_{\Lambda}C(s_{\Lambda}\text{-state})$

New data

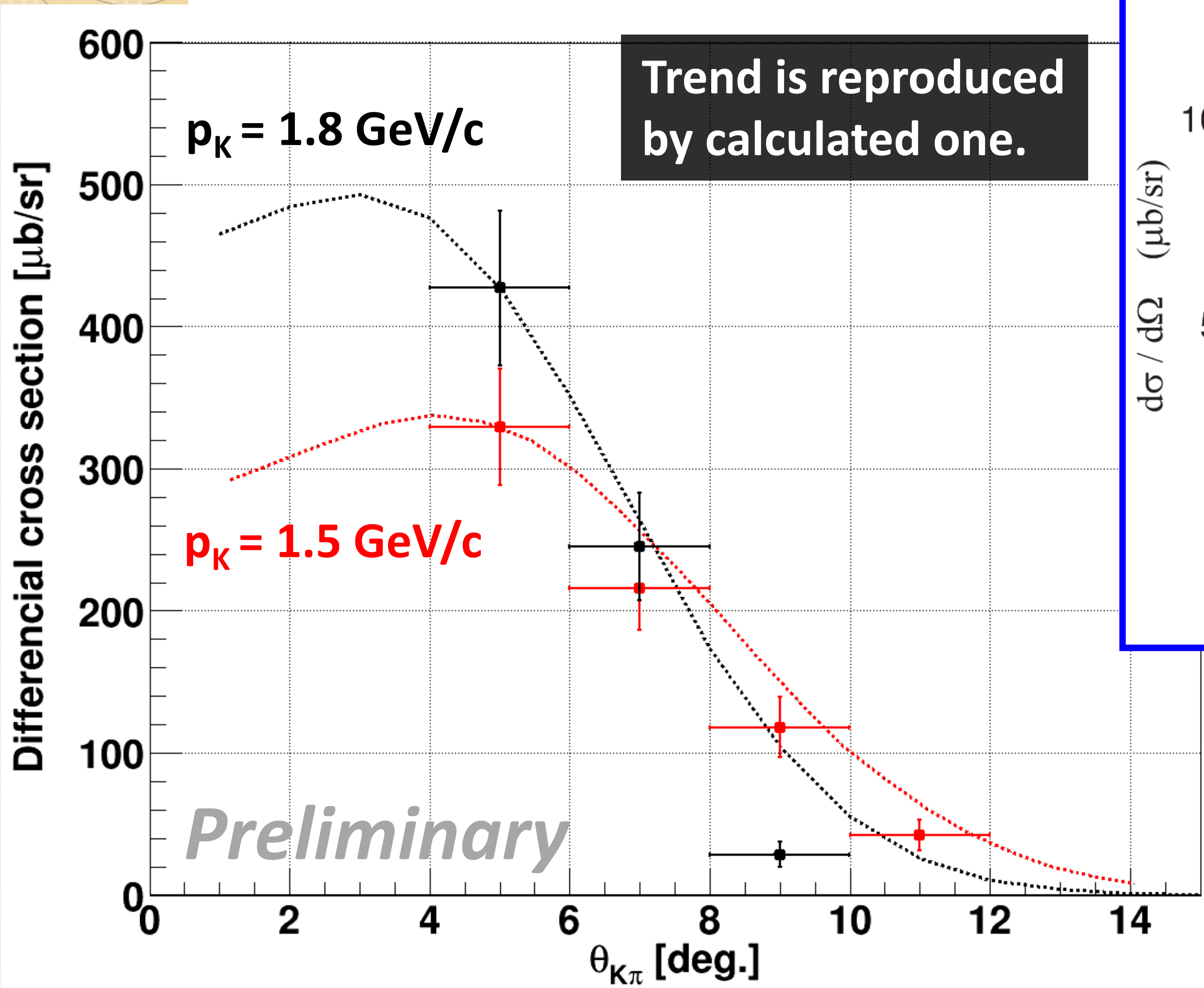
Obtained cross section of $^{12}C(K^-,\pi^-)^{12}{}_{\Lambda}C$ (s_{Λ}-state)

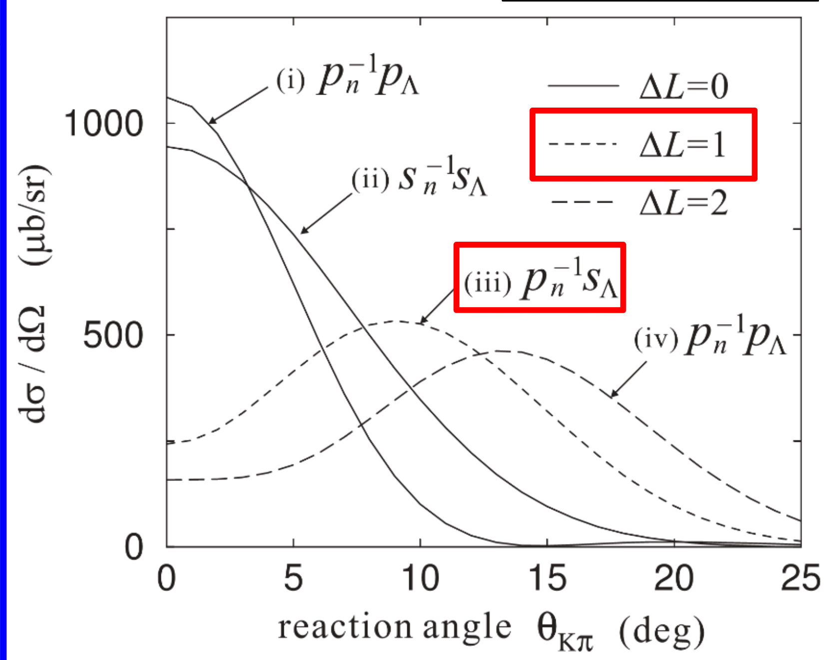
DWIA calculation

Calculated cross section of $^{16}O(K^-,\pi^-)^{16}{}_{\Lambda}O$ @0.9 GeV/c

Ann. Phys. (NY)148, 381(1983).

Phys. Rev. C77, 054315(2008).





Point : obtained data

Dot line : calculated

(scaled with obtained data)

(converted considering momentum transfer)

Yield estimation of ${}^{19}_{\Lambda}F$

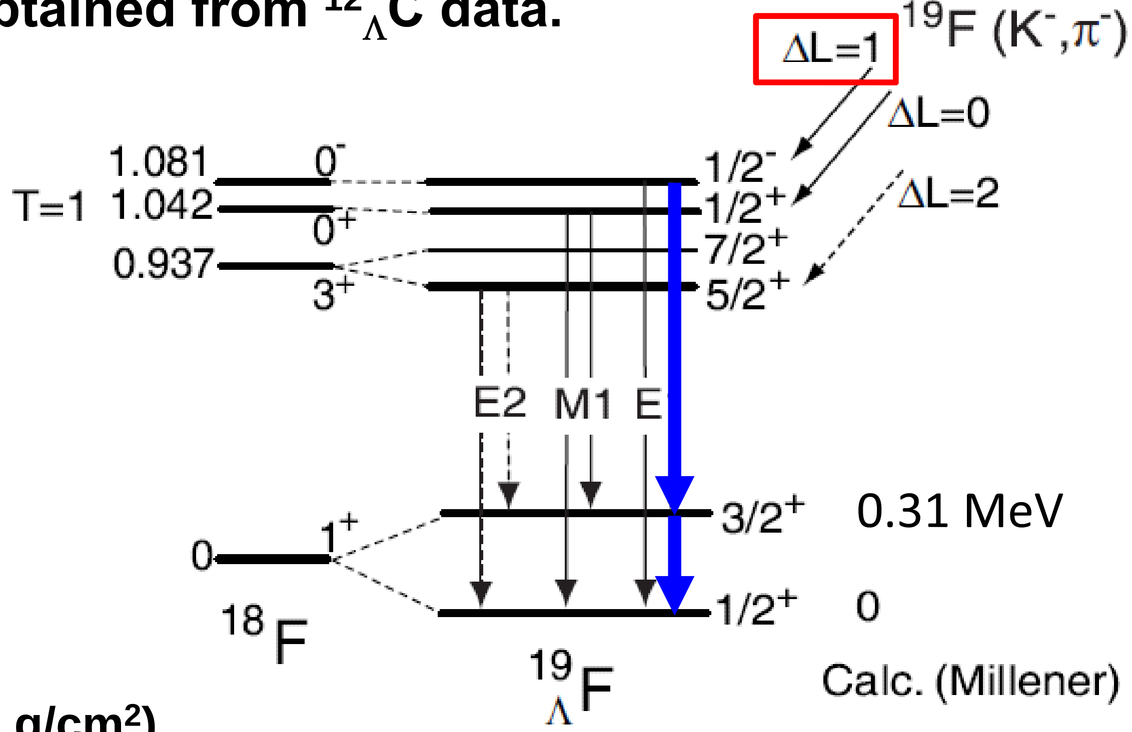
Compare yield of ½- state with p_K = 1.5 & 1.8 GeV/c using relative cross section obtained from ${}^{12}_{\Lambda}C$ data.

Absolute cross section was assumed to be 40 μb/sr

No calculation

$$\left.\frac{d\sigma}{d\Omega}\right|_{\theta=3^\circ} = 40\ \mu\text{b/sr (for 1.8 GeV/c)}$$

$$\left.\frac{d\sigma}{d\Omega}\right|_{\theta=3^\circ} = 25\ \mu\text{b/sr (for 1.5 GeV/c)}$$



Estimated yield

Target : HF(20 g/cm²)

p_K	1.5 GeV/c	1.8 GeV/c
K beam intensity [k/spill]	320k	290k
Mass counts [counts/h]	53	62

Select p_K = 1.8 GeV/c

< Other advantages with 1.8 GeV/c >

- **Selectivity in populated state**
- **High momentum transfer (better for B(M1) measurement)**

Summary

- We will perform γ-ray spectroscopy of $^{4}_{\Lambda}He$ and $^{19}_{\Lambda}F$ at the J-PARC K1.8 beam line (E13 1st @J-PARC K1.8)
- Spectrometer system for the (K^{-},π^{-}) reaction (SksMinus) was developed.
- Hypernuclear production via the (K^{-},π^{-}) reaction
  - Analysis of CH_2 target data
    - Differential cross section of Σ^{+}
    - Differential cross section of $^{12}_{\Lambda}C$ (s_{Λ}-state)

    New data
  - Yield estimation of $^{19}_{\Lambda}F$

    compare yields between p_K = 1.5 and 1.8 GeV/c

    → Select 1.8 GeV/c

We are waiting for beam time!