Study of the Λ g-factor in hypernuclei via the γ-ray spectroscopy at J-PARC

Mifuyu Ukai
Dept. of Phys. Tohoku Univ.
for the E13 collaboration

Outline

Physics motivation of Λ g-factor in hypernuclei

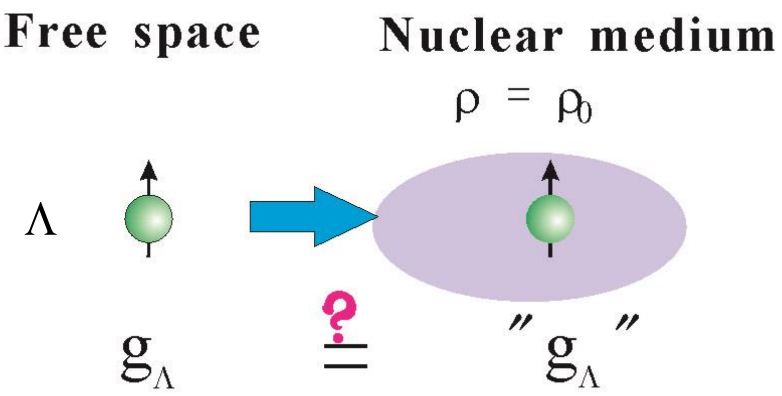
$^{19}_{\Lambda}F(3/2^{+} \rightarrow 1/2^{+})$ case

$^{7}_{\Lambda}Li(3/2^{+} \rightarrow 1/2^{+})$ case

E13 commissioning in 2013

Summary

Medium effect of Λ hyperon
Modification of magnetic moment in medium



Λ in 0s orbit
deep inside nuclei

$\mu_\Lambda = \mu_s$

$\mu_q = \dfrac{e\hbar}{2m_q c}$

m_q : Constituent quark mass

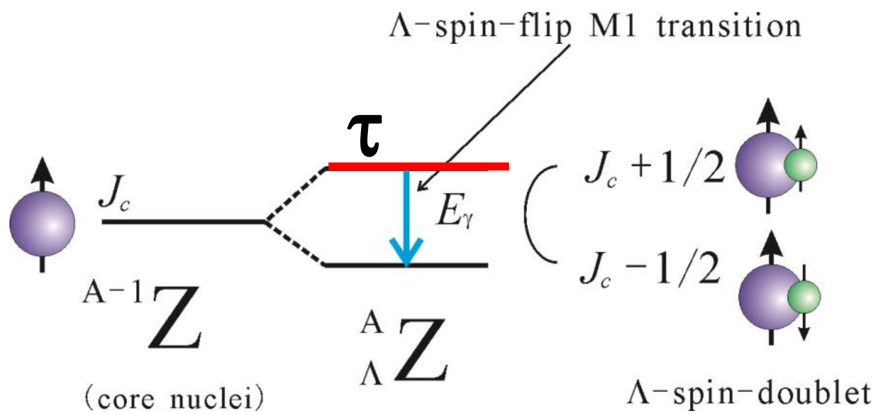
Light quark mass might be reduced by
Partial restoration of chiral symmetry breaking

Reduced m_s => increases μ_Λ?

Direct measurement of magnetic moment
of Λ-hypernuclei is extremely difficult

Medium effect of Λ hyperon

Modification of magnetic moment in medium



$$B(M1) = (2J_{up}+1)^{-1} |\langle \Psi_{low} \| \mu \| \Psi_{up} \rangle|^2$$
$$= (2J_{up}+1)^{-1} |\langle \psi_{\Lambda\downarrow} \psi_c \| \mu \| \psi_{\Lambda\uparrow} \psi_c \rangle|^2$$

$$\mu = g_c \boldsymbol{J}_c + g_\Lambda \boldsymbol{J}_\Lambda = g_c \boldsymbol{J} + (g_\Lambda - g_c)\boldsymbol{J}_\Lambda$$

$$= \frac{3}{8\pi} \frac{2J_{low}+1}{2J_c+1} (g_\Lambda - g_c)^2 \quad [\mu_N^2]$$

g_c ; g-factor of core nuclei
g_Λ; g-factor of Λ

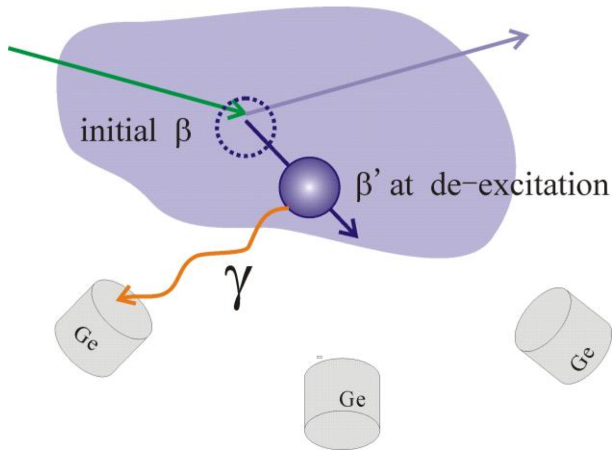
$$\Gamma = BR/\tau = \frac{16\pi}{9} E_\gamma^3 B(M1)$$

(If Br M1 =100%, $\tau = 1/\Gamma_{M1}$)

Eγ and lifetime (τ) can be measured by γ-ray spectroscopy using Ge detectors of a few keV resolution

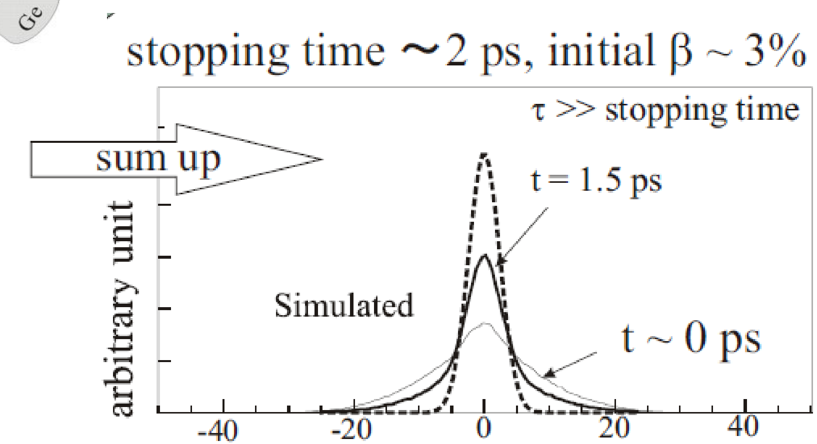
Main motivation of J-PARC E13

Lifetime measurement ;
Doppler-shift attenuation method (DSAM)



Stopping time and lifetime should be of the same order

$$E^{measred} = E_0 / \gamma(1-\beta' \cos\theta)$$



lifetime (τ) can be obtained by peak shape fitting

To measure the lifetime of excited states of hypernuclei, only DSAM is available

Lifetime of g.s. doublet of light hypernuclei

$$B(M1) = \frac{9}{16\pi} \frac{\Gamma_{M1}}{E_\gamma^3} \propto (g_c - g_\Lambda)^2 \qquad (1)$$

(If BR M1 =100%, $\tau = 1/\Gamma_{M1}$)

	g.s. doublet	**E_γ [keV]**	**g_c [μN]**	**Expected $1/\Gamma_{M1}$ [ps]**
$^{4}_{\Lambda}$He	$1^+, 0^+$	~1100 (exp.)	-4.2552	0.1
$^{7}_{\Lambda}$Li	$3/2^+, 1/2^+$	692 (exp.)	0.8220	0.5
$^{11}_{\Lambda}$B	$7/2^+, 5/2^+$	262 (exp.)	0.6002	9
$^{12}_{\Lambda}$C	$2^-, 1^-$	160 (exp.)	-0.643	440
$^{19}_{\Lambda}$F	$3/2^+, 1/2^+$	300 (calc.)	0.849 (calc.)	6

g_Λ in free space : 1.226(8) [μ_N]

Lifetime of g.s. doublet of light hypernuclei

Stopping times roughly estimated to be 1 ~ 5 ps for the (K^-,π^-) or the (π^+,K^+) reactions

DSAM acceptable range

Stopping time = Lifetime x 1 ～ 5

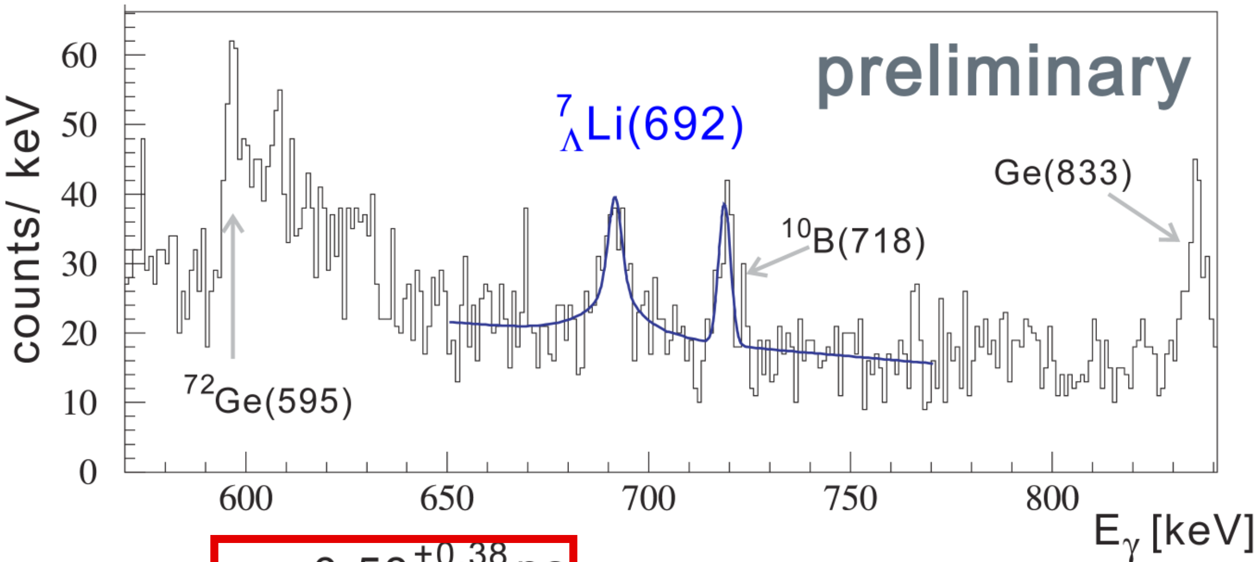
	g.s. doublet	**E_γ [keV]**	**g_c [μN]**	**Expected $1/\Gamma_{M1}$ [ps]**
${}^{4}_{\Lambda}He$	1^+, 0^+	~1100 (exp.)	-4.2552	0.1
${}^{7}_{\Lambda}Li$	$3/2^+$, $1/2^+$	692 (exp.)	0.8220	0.5
${}^{11}_{\Lambda}B$	$7/2^+$, $5/2^+$	262 (exp.)	0.6002	9
${}^{12}_{\Lambda}C$	2^-, 1^-	160 (exp.)	-0.643	440
${}^{19}_{\Lambda}F$	$3/2^+$, $1/2^+$	300 (calc.)	0.849 (calc.)	6

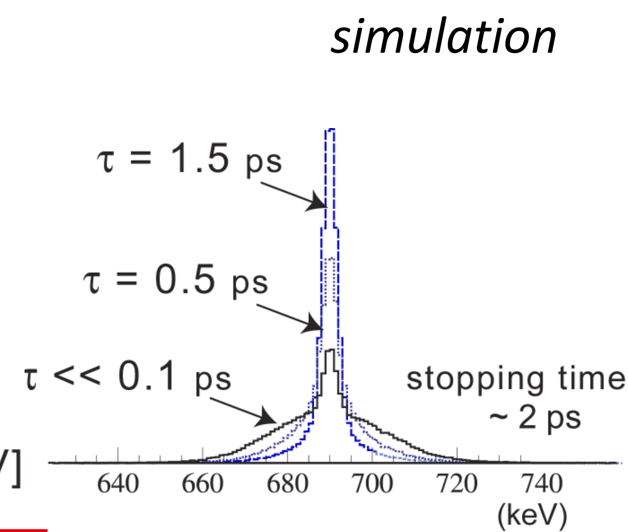
${}^{7}_{\Lambda}Li$ case: Smaller recoil momentum, higher target density

${}^{19}_{\Lambda}F$ case: Larger recoil momentum, lower target density

Previous study on B(M1) in ${}^{7}_{\Lambda}$Li (BNL E930)

${}^{10}B\,(K^-, \pi^-)\,{}^{10}_{\Lambda}B^*$, ${}^{10}_{\Lambda}B^*(3^+) \rightarrow {}^{7}_{\Lambda}Li^*(3/2^+) + {}^{3}He$ indirect population





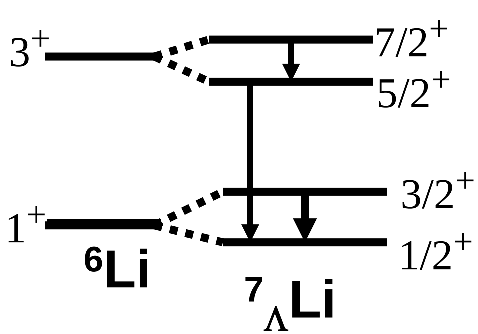
$\tau = 0.58^{+0.38}_{-0.20}$ ps

BR(M1)=100%

$B(M1) = 0.30^{+0.12}_{-0.16}\ [\mu_N^2]$

$-g_\Lambda = 1.1^{+0.4}_{-0.6}\ \mu_N$

preliminary
(statistical error only)



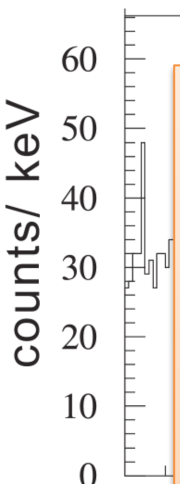
$-g_\Lambda(\text{free}) = 1.226\ \mu_N$

First data of g_Λ in nucleus

Large error not only from small γ-ray yield but….
-bad missing mass resolution ; 15 MeV (FWHM)
-huge background from *K*⁻ beam decays

Previous study on B(M1) in $^{7}_{\Lambda}$Li (BNL E930)

^{10}B (K$^-$, π^-) $^{10}_{\Lambda}$B*, $^{10}_{\Lambda}$B*(3$^+$) -> $^{7}_{\Lambda}$Li*(3/2$^+$) + ^{3}He indirect population



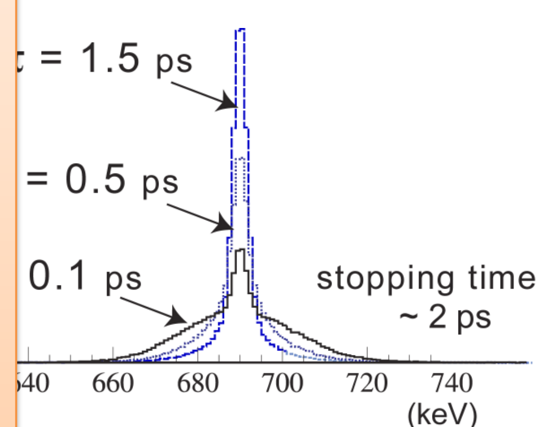
To get better sensitivity of lifetime, selection of optimum stopping time and better S/N of γ-ray spectrum are essential

* Stopping time
  - target density
  - beam momentum

* Production event selection --SksMinus
  - missing mass resolution
  - suppress beam decay background

* γ-ray event selection -- Hyperball-J

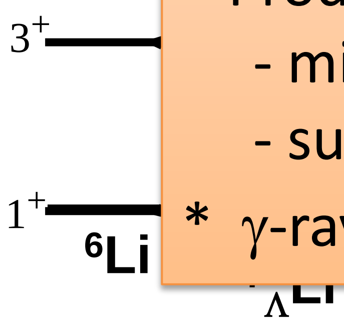
simulation



nary

rror only)

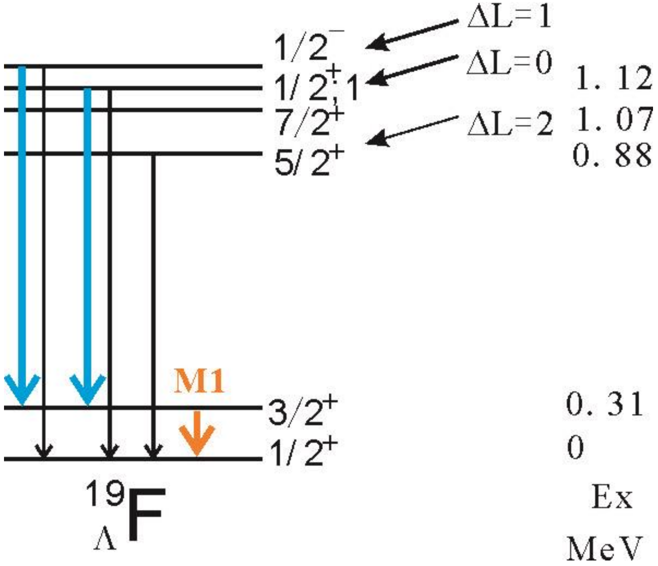
ata of g_{Λ} in nucleus

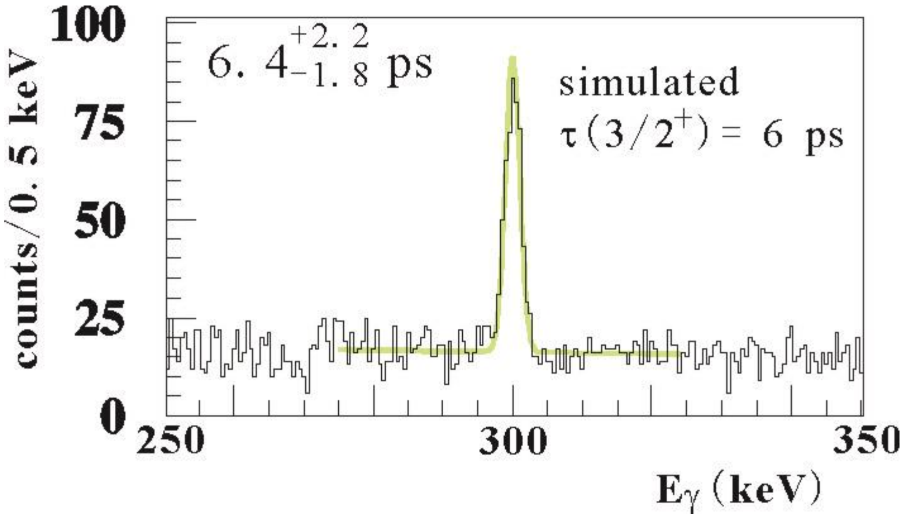


Simulation result; $^{19}{}_{\Lambda}$F case

Optimum conditions

(K^{-},π^{-}) at p_K=1.8 GeV/c, HF(hydro fluoride) target ρ=1.0 g/cm^3





Nucl.Phys. A881 (2012) 310

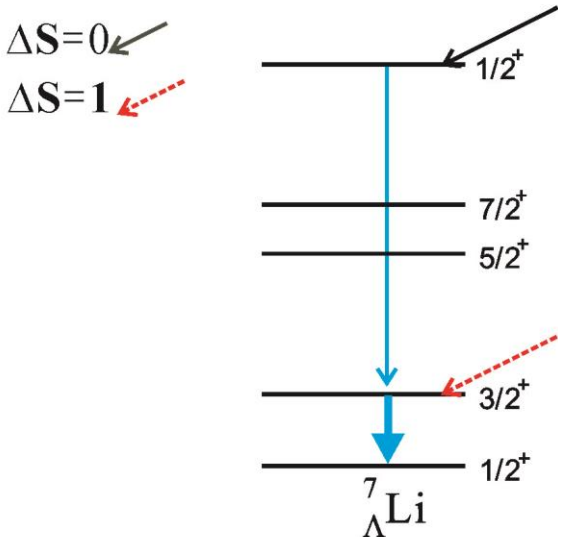
～ 30 % B(M1) accuracy, 15 % for (g_c-g_Λ) accuracy, is expected
For 10-days beam time (20 kW operation)

A large deviation of g_Λ can be detected

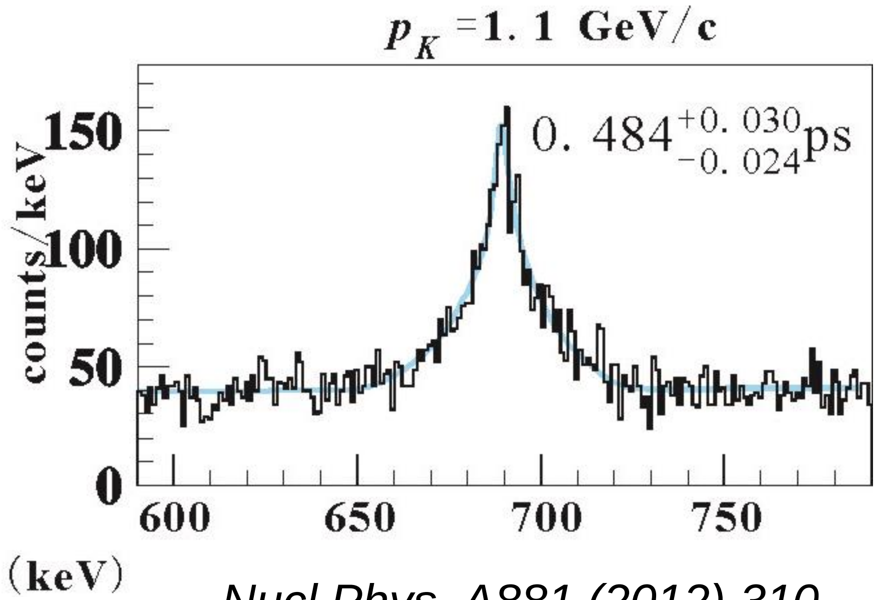
Simulation result; ${}^{7}_{\Lambda}$Li case

Optimum conditions

(K^-,π^-) at p_K=1.1 GeV/c, Li_2O target ρ=2.0 g/cm^3



3/2+→1/2+
3.0 counts/h

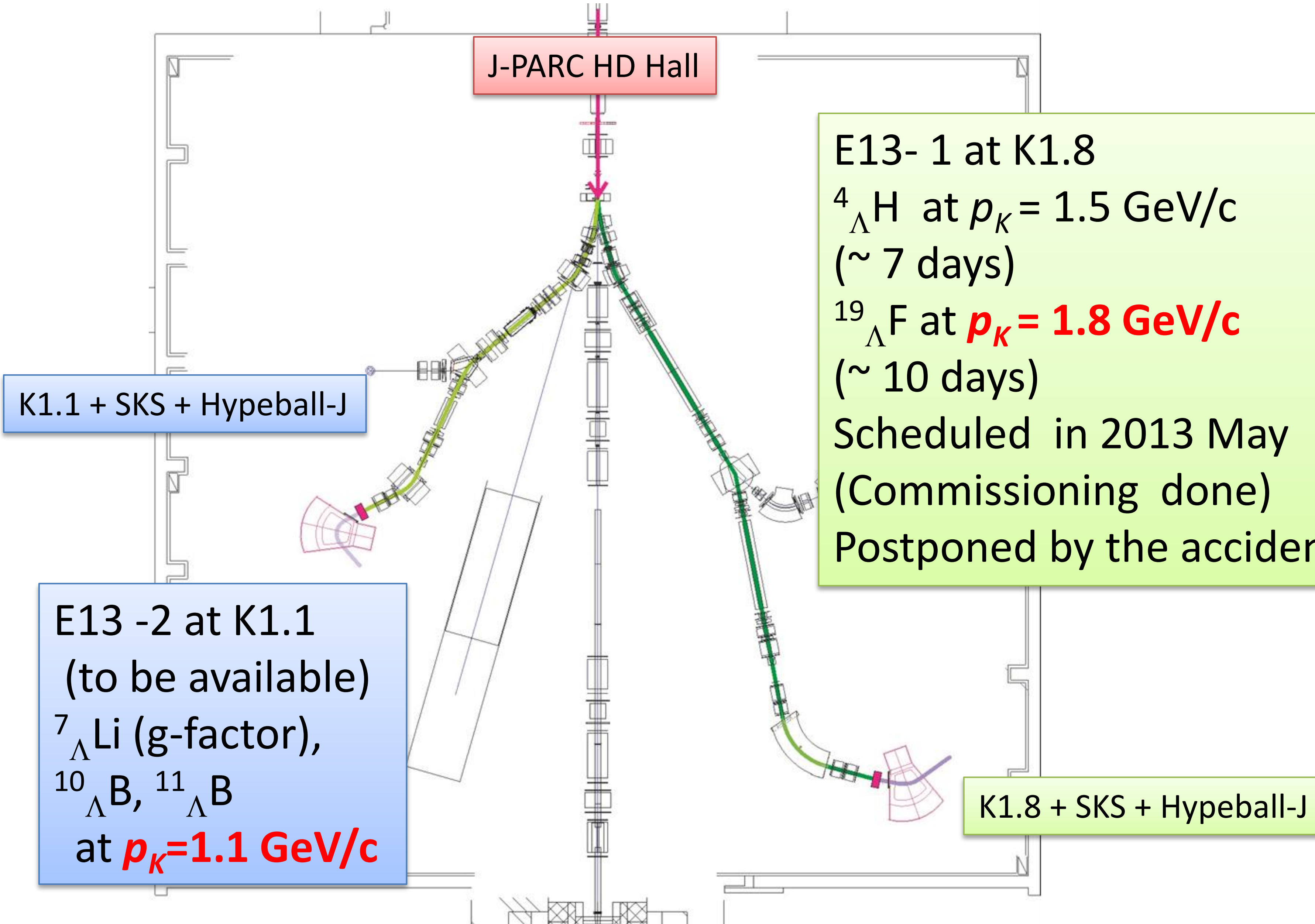


Nucl.Phys. A881 (2012) 310

~ 6 % B(M1) accuracy, 3 % for (g_c-g_Λ) accuracy is expected for one month beam time (50 kW operation)

First precision measurement of g_Λ value

E13 Phase-1 and Phase-2



E13- 1 at K1.8

${}^{4}_{\Lambda}H$ at p_K = 1.5 GeV/c

(~ 7 days)

${}^{19}_{\Lambda}F$ at **p_K = 1.8 GeV/c**

(~ 10 days)

Scheduled in 2013 May

(Commissioning done)

Postponed by the accident

E13 -2 at K1.1

(to be available)

${}^{7}_{\Lambda}Li$ (g-factor),

${}^{10}_{\Lambda}B$, ${}^{11}_{\Lambda}B$

at **p_K=1.1 GeV/c**

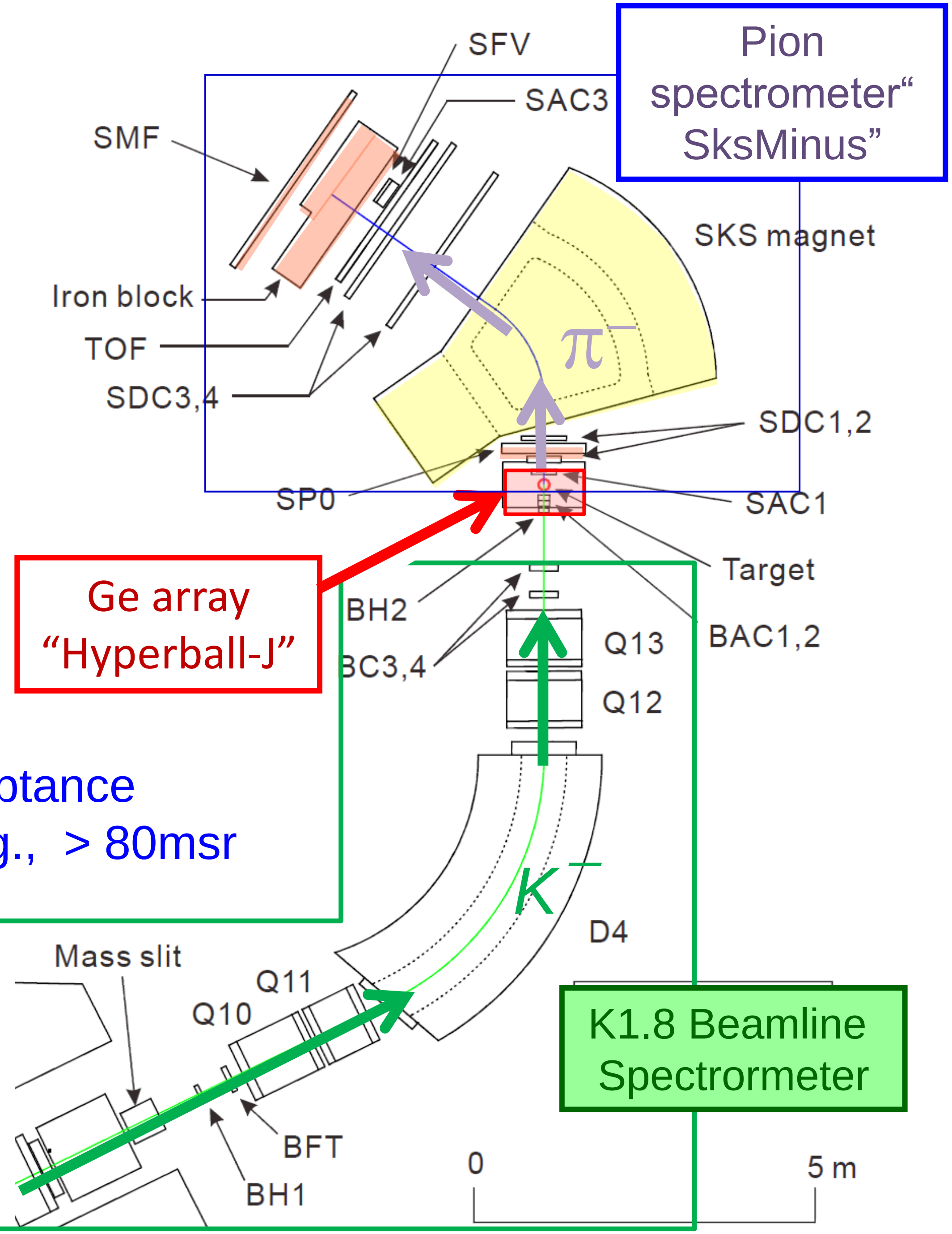
E13 Setup at K1.8

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

- Tag production of hypernuclei
- Detect gamma-rays from hypernuclei

SksMinus: wide and large acceptance
1.2 ~ 2.0 GeV/c, 0 ~ 20 deg., > 80msr

$^{4}_{\Lambda}He$: liq.He target (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



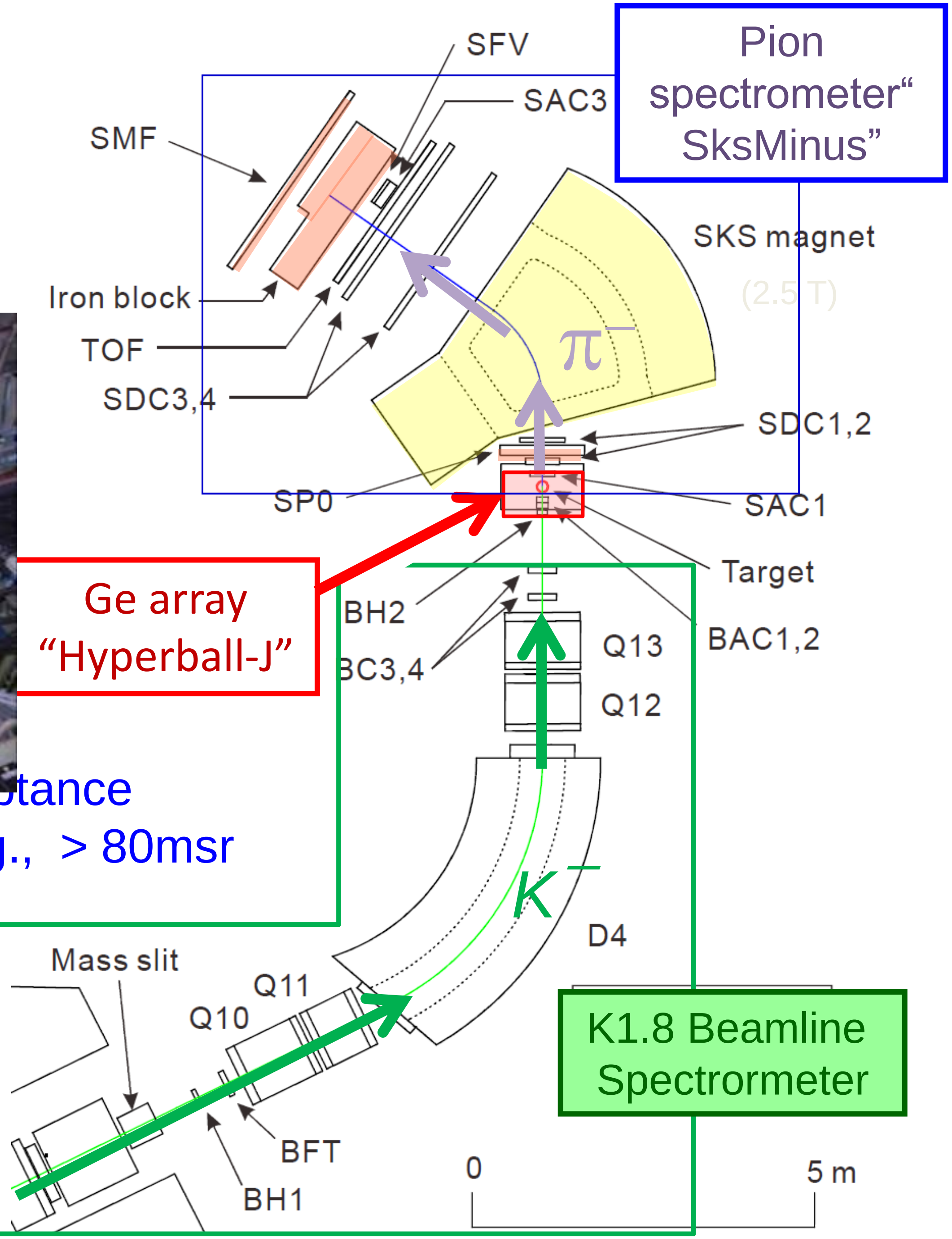
E13 Setup at K1.8

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

SksMinus: wide and large acceptance

1.2 ~ 2.0 GeV/c, 0 ~ 20 deg., > 80msr

$^{4}_{\Lambda}$He : liq.He target (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



E13 Setup at K1.8

$^{A}Z(K^{-}$

- Tag produ
- Detect ga
  from hype

SksMinus
1.2 ~

array
erball-J”

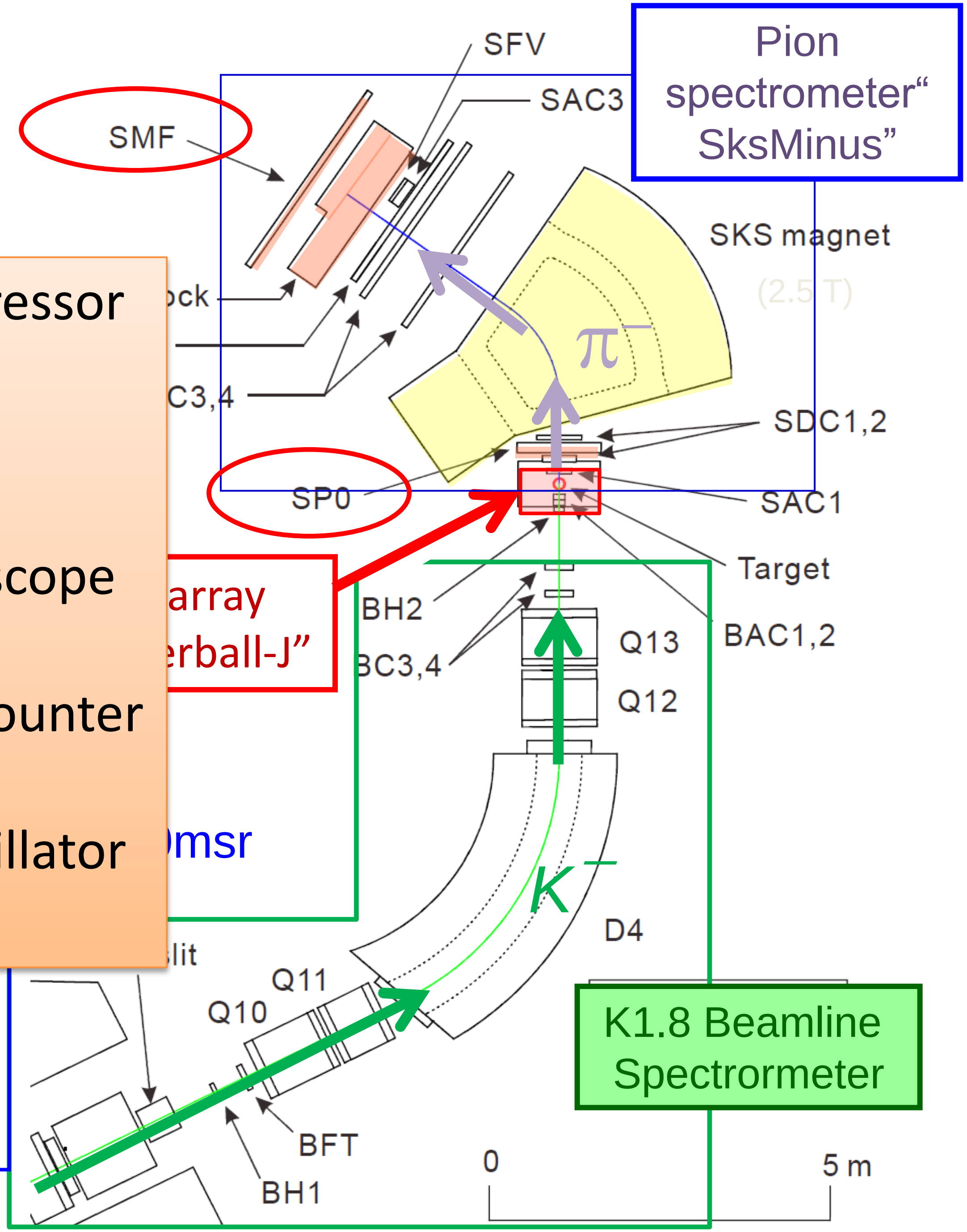
msr

Beam decay suppressor

SMF; Muon filter
($K^{-} \to \mu^{-}\nu$)
Iron block + hodoscope

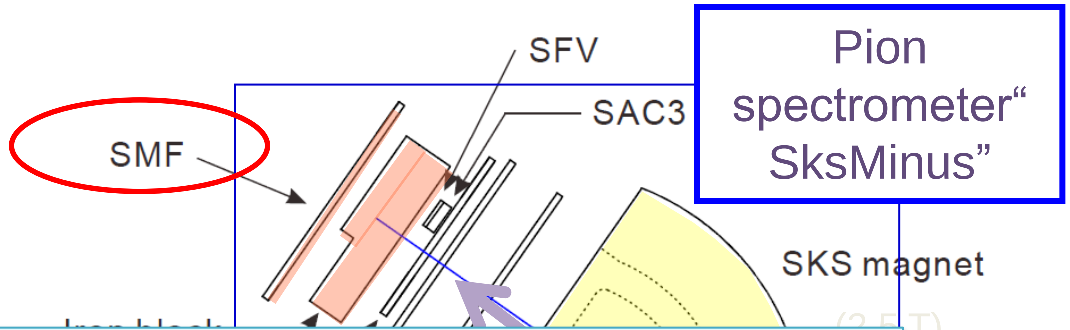
SP0; EM shower counter
($K^{-} \to \pi^{-}\pi^{0}$)
Lead sheet + scintillator
x 8 layer

$^{4}{}_{\Lambda}$He : liq.He target (2.3 g/cm^3)
p_K = 1.5 GeV/c
$^{19}{}_{\Lambda}$F : HF target (20 g/cm^2)
p_K = 1.8 GeV/c



E13 Setup at K1.8

$^{A}Z(K^{-},\pi^{-})^{A}Z^{*}$



Commissioning of whole system was done in 2013 May

Test data were taken

CH_2 target run; Σ^+, $^{12}_{\Lambda}C$ production

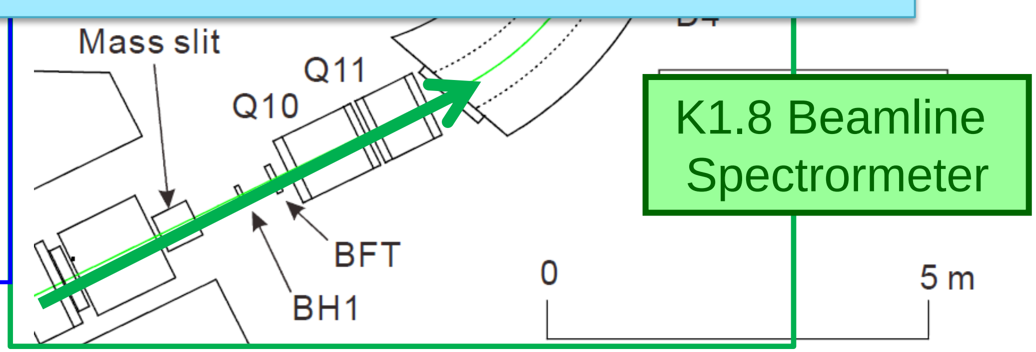
CF_2 target run ; γ from reaction

$^{4}_{\Lambda}He$: liq.He target (2.5 g/cm^2)

p_K = 1.5 GeV/c

$^{19}_{\Lambda}F$: HF target (20 g/cm^2)

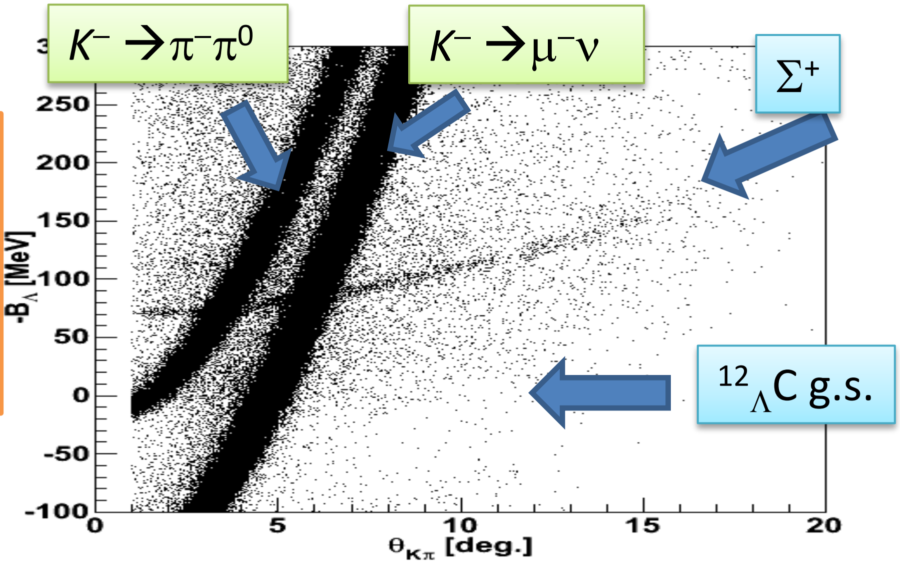
p_K = 1.8 GeV/c



K^- decay rejection

CH_2 target run data
(K^-,π^-) reaction

Missing mass spectrum for $^{12}C(K^-,\pi^-)$ kinematics



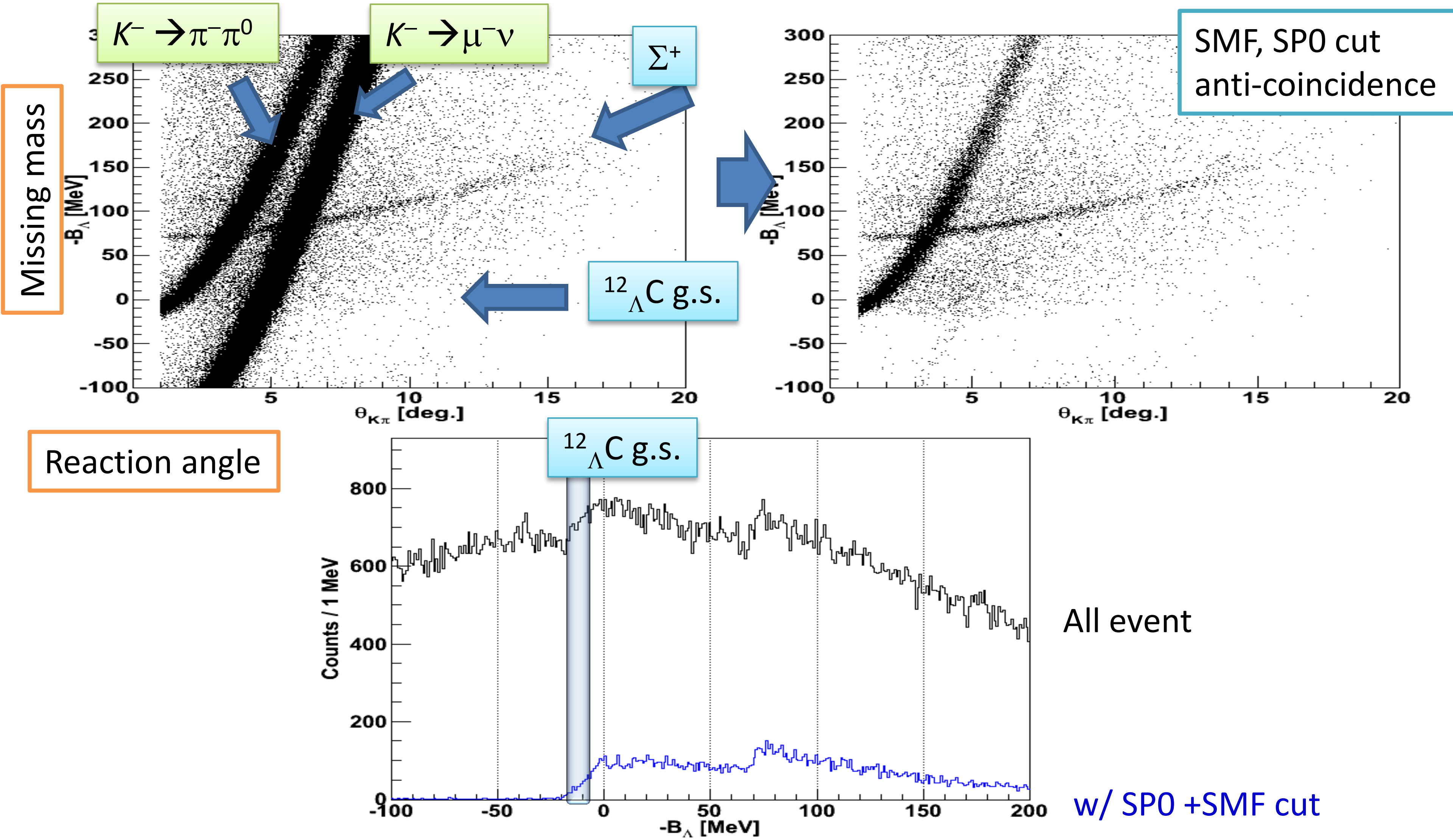
Missing mass

Reaction angle

K- decay rejection

CH$_2$ target run data
(K^-,π^-) reaction

Missing mass spectrum for ^{12}C(K^-,π^-) kinematics

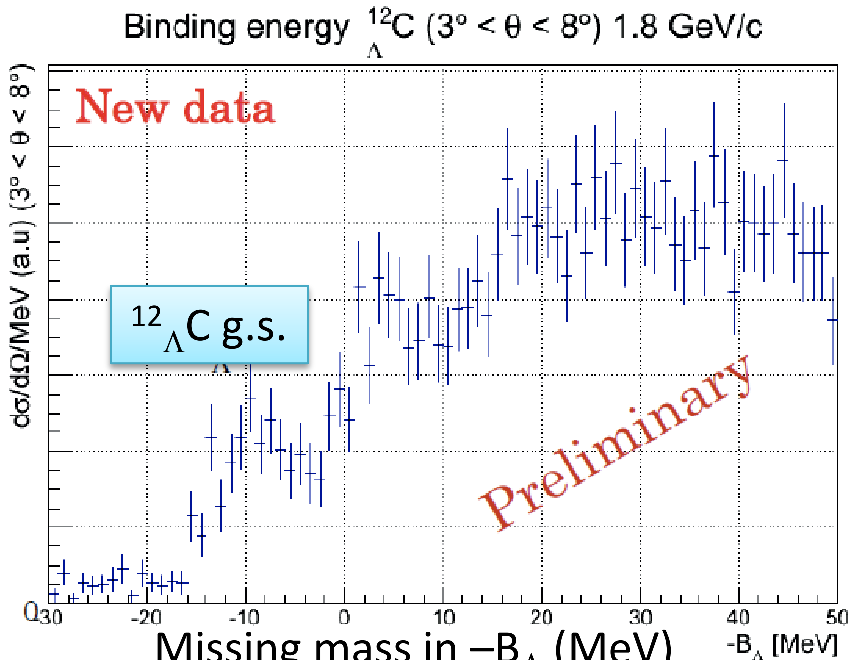


Missing mass spectrum

SksMinus performance

CH_2 target run data
(K^-,π^-) reaction

Missing mass spectrum for $^{12}C(K^-,\pi^-)$ kinematics



Missing mass in $-B_\Lambda$ (MeV)

With tight angle cut

Peak center: -9.5 (9) MeV

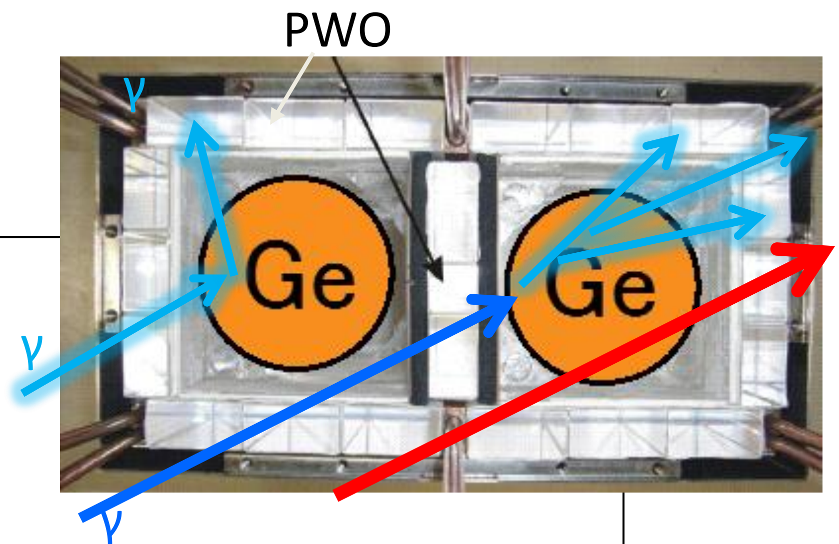
- shift from emulsion value by -1.26 MeV

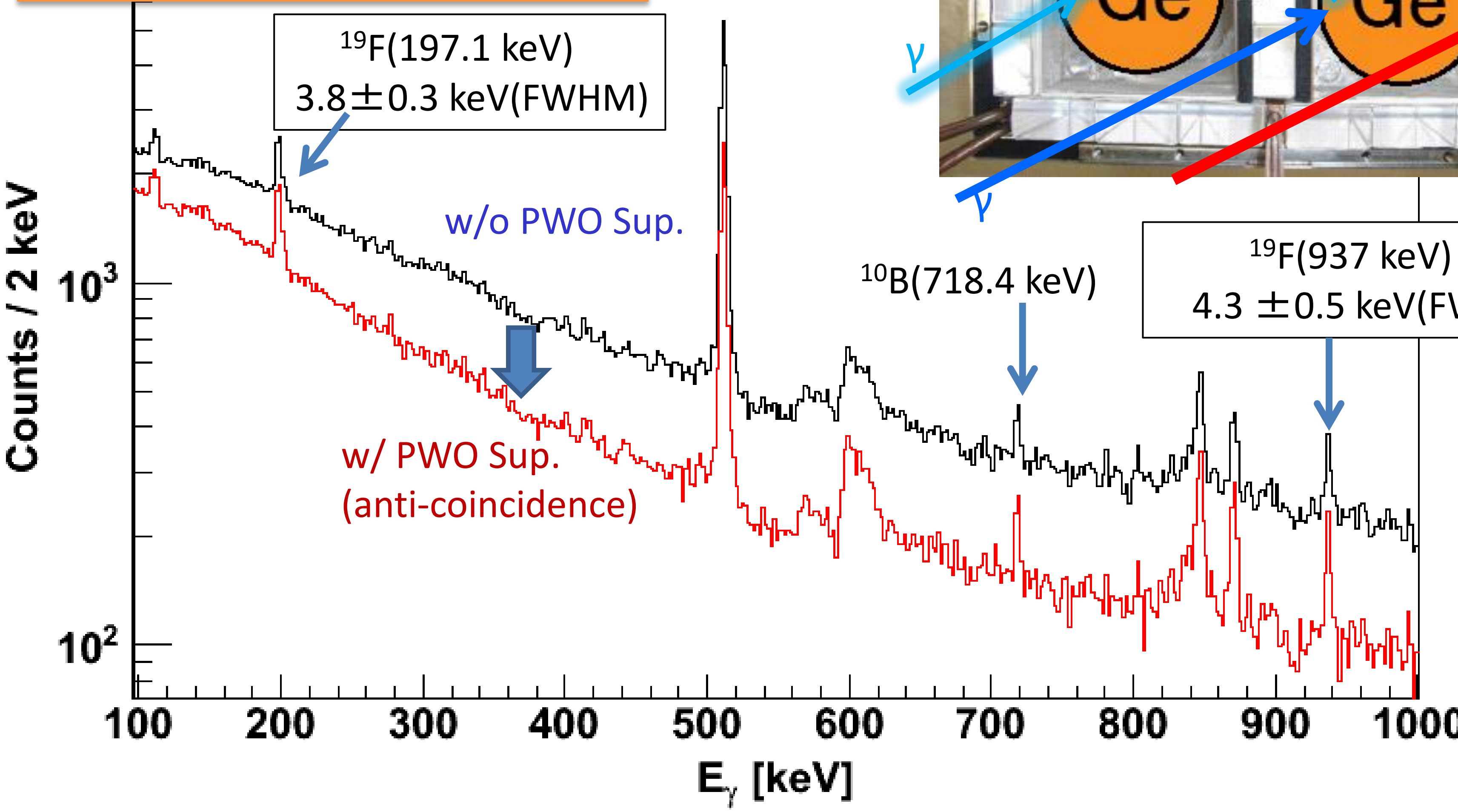
Resolution: 8.3 MeV (FWHM)

Sufficient resolution for γ-ray spectroscopy

Performance of Hyperball-J

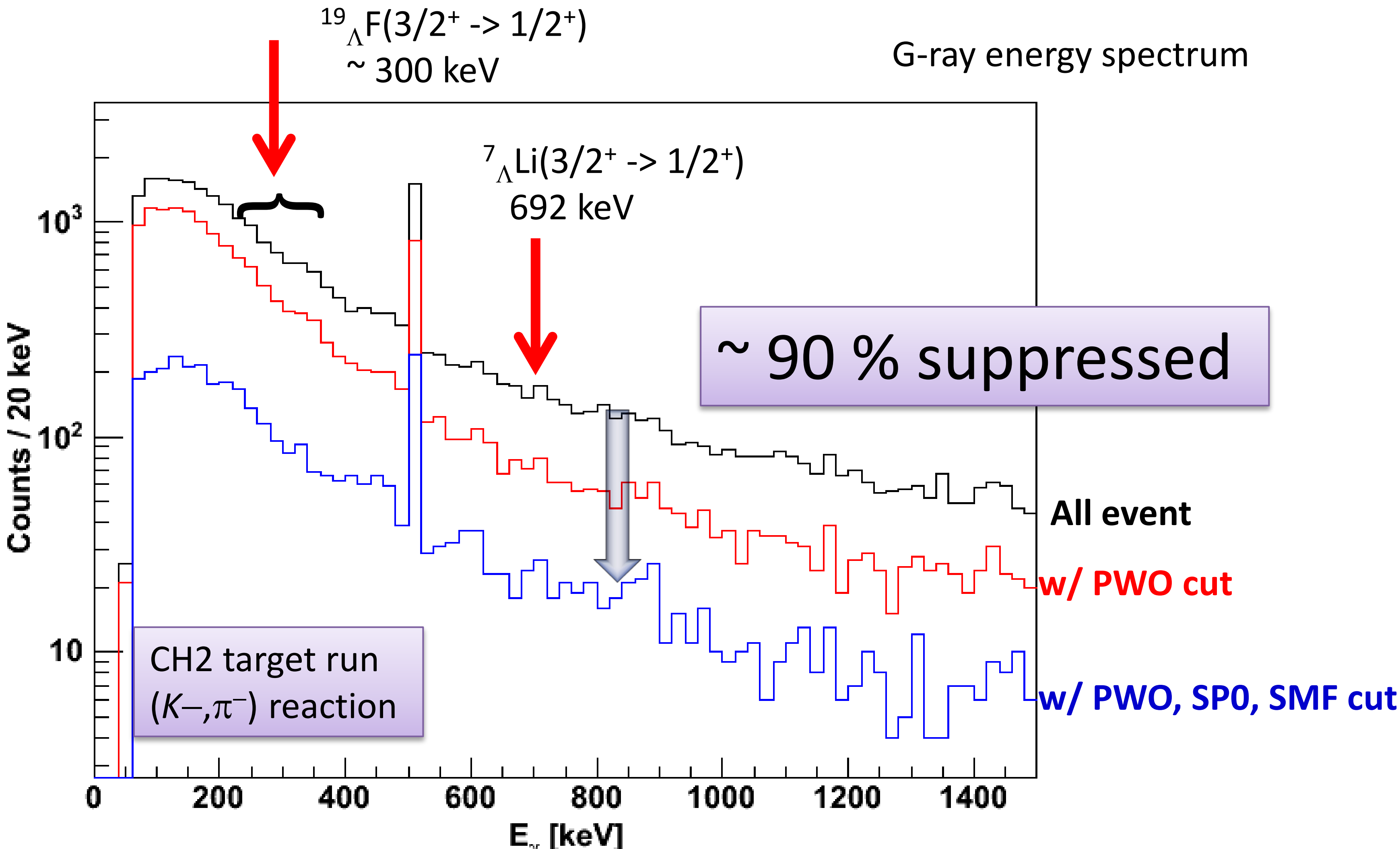
CF_2(teflon) target run data
(K^-, scat. γ) reactoin





γ-ray energy spectrum of Ge detectors (Sum of 16 Ge ADC)

Background suppression for γ-ray spectrum



γ-ray energy spectrum after summing 16 Ge ADC

Sensitivity of lifetime drastically increased

Summary

Magnetic moment of Λ could be changed in nuclear medium

g-factor of Λ in hypernuclei can be extracted by measuring the lifetime of g.s. doublet.

Λ g-factor of $^{19}_{\Lambda}F(3/2^{+}\text{->}1/2^{+})$ with ~ 15 % accuracy is expected
for 10-days beam time at K1.8 beam line (20 kW)

Λ g-factor of $^{7}_{\Lambda}Li(3/2+ \text{->} 1/2+)$ with ~ 3 % accuracy is expected
for one-month beam time at K1.1 beam line (50 kW)

E13 commissioning have been carried out in 2013 Mar. ~ May.

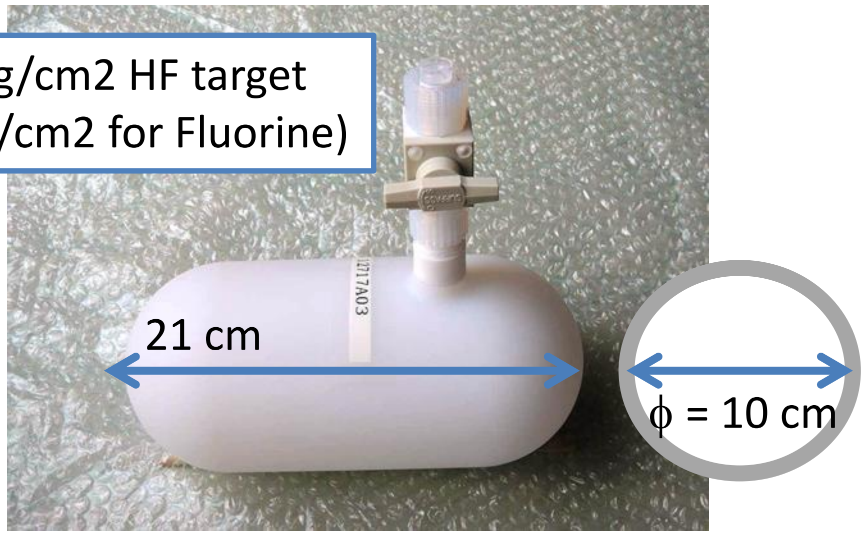
Whole system was confirmed working very well.

After recovering J-PARC, we can take data for $^{19}_{\Lambda}F$ and $^{4}_{\Lambda}He$ γ-ray s as soon.

Theoretical calculations of g_{Λ} in hypernuclei are not enough at present,
theoretical support is very welcome.

Development of hydro fluoride (HF) target

~ 20 g/cm2 HF target
(19 g/cm2 for Fluorine)



Multiple protection system for safety

Pure hydrofluoride

Sealed pressure container (0 MPa ~ 0.4 Mpa tested)
4 mm thickness Teflon
20 ℃ boiling point
Min/Max pressure 0℃~ 50 ℃ (0.05 ~ 0.2MPa)

Best density of fluoride compound material

Preparation/commissioning history

2012.8 Hyperball-J installed at K1.8

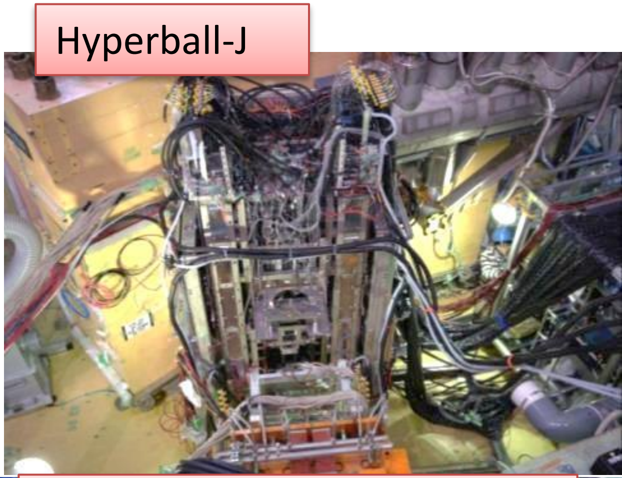
(2012.12 E10@K1.8 [$^{6}Li(\pi^{-},K^{+})^{6}_{\Lambda}H$])

2013.1 Changed to SksMinus setup
(All the SKS detectors re-installed)

2013.3 Commissioning beam time (22 hrs, 3/8~3/17)
- Tuning of SksMinus system

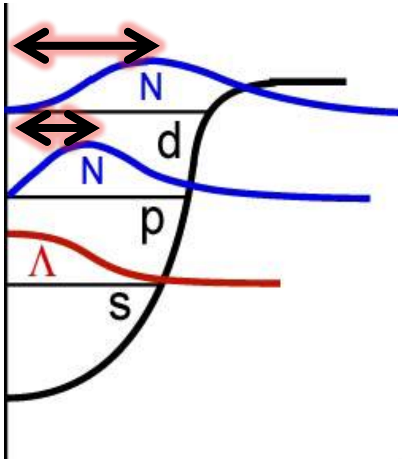
2013.4 Commi. beam time 2 (39 hrs, 4/28~5/2)
- K^{-} beam tuning
- Hyperball-J tuning (w/more than ½ detectors)

2013.5 Commi. beam time 3 (~40hrs, 5/13~5/18)
- Final tuning of K- beam and the whole system
-16/28 Ge detectors installed
-Ready to install experimental targets
(postponed by the accident)

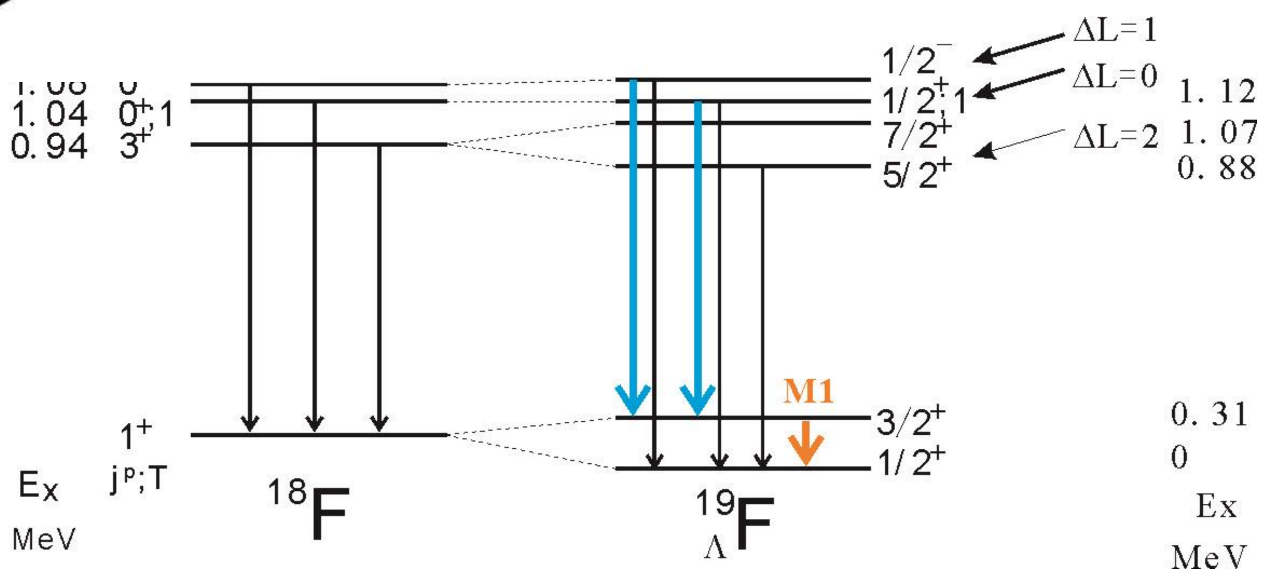


CH_2 (2.9 g/cm^2 ; equiv. He target)
CF_2 (20 g/cm^2 ; equiv. HF target)
-> Σ^{+}, $^{12}_{\Lambda}C$ reaction spectra
-> γ-rays from F

γ-ray spectroscopy of $^{19}_{\Lambda}F$



ΛN spin-spin interaction study
For s-, p- and sd-shell hyperncuelei



Estimate possibility of B(M1) measurement