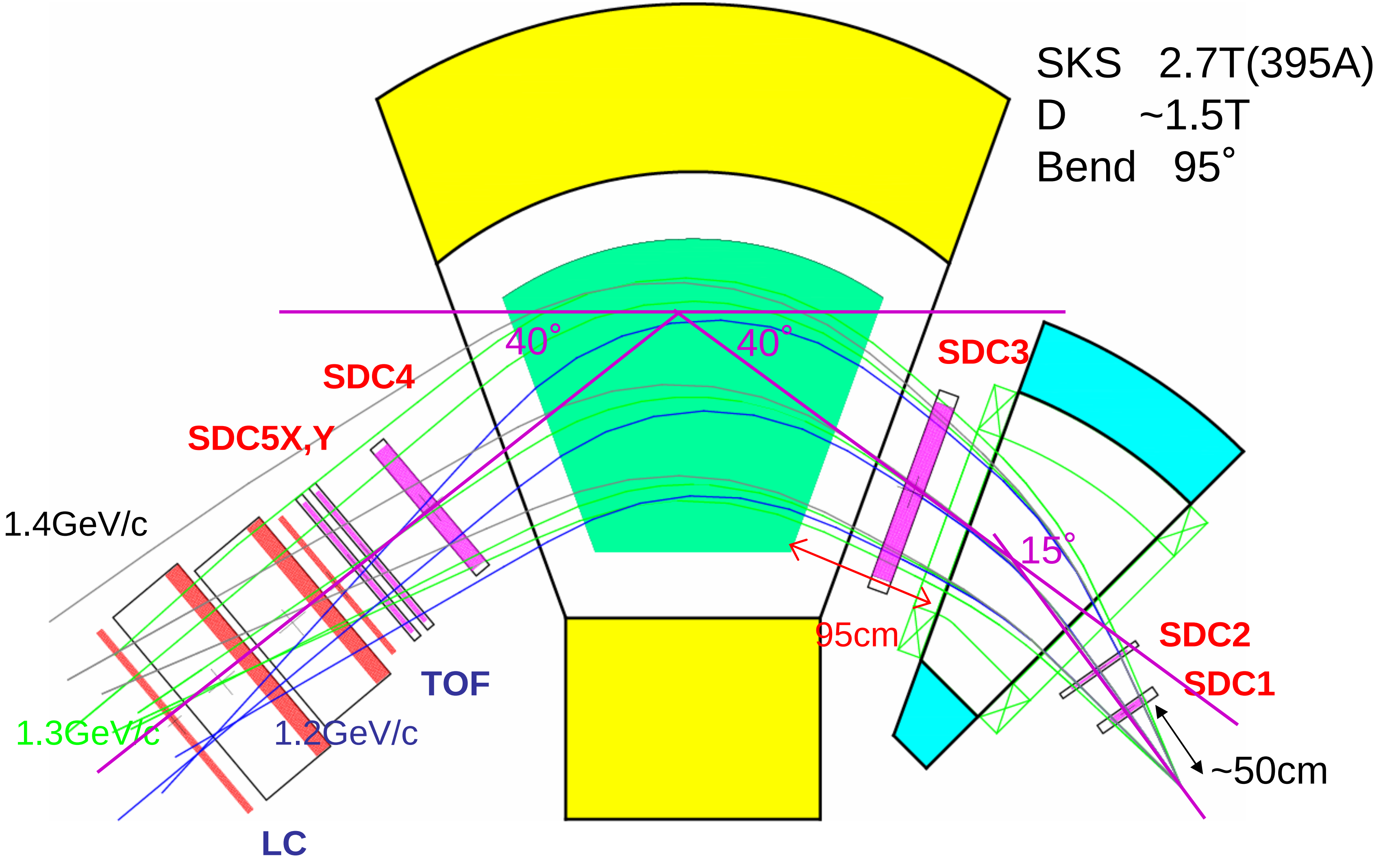
Ξ hypernuclear spectroscopy via (K^-,K^+) reaction at J-PARC

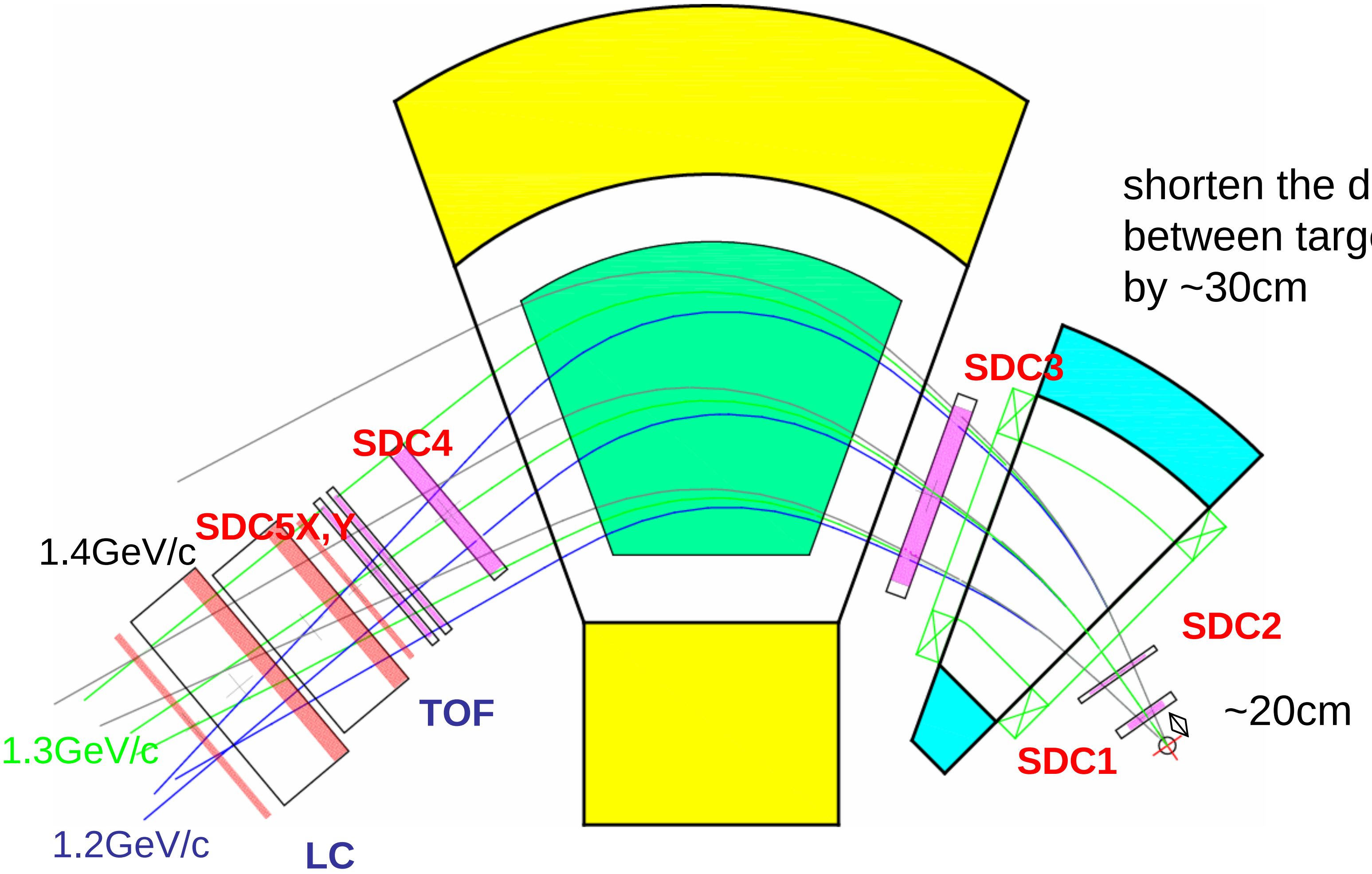
Overview of Proposal

- Construction of SksPlus Spectrometer at K1.8 beamline.
- Spectrometer tuning using $H(K^{-},K^{+})\Xi^{-}$ reaction.
- Measurement of $^{12}C(K^{-},K^{+})^{12}{}_{\Xi}Be$ reaction.
- Measurement of $^{3}He(K^{-},K^{+})$ reaction in future.

SksPlus Spectrometer
SksPlus01

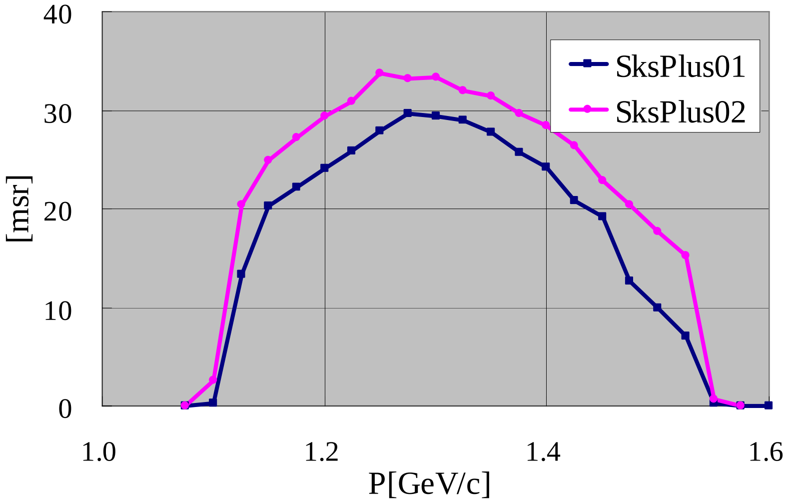


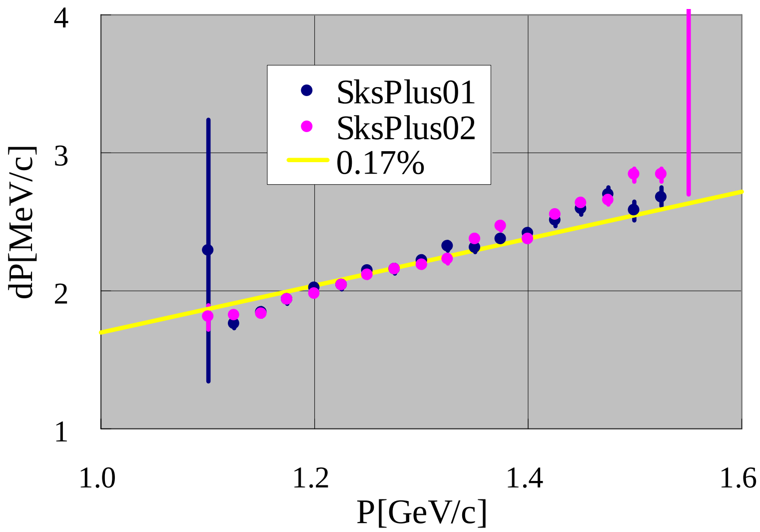
SksPlus02



shorten the distance between target and SDC1 by ~30cm

Acceptance & Resolution by Simulation





Ω~30msr for SksPlus02

Δp/p ~ 0.17% (FWHM)

Detector Size

	Size [mm^2]	configuration	rate?
SDC1	250^H x 200^V	u-u’-v-v’	Y
SDC2	400^H x 250^V	x-x’(-u-u’-v-v’)	Y
SDC3	1100^H x 450^V	(3-4)x	
SDC4	900^H x 900^V	x-x’-y-y’	
SDC5XY	1000^H x 1000^H	x,y	
TOF	1050^H x 1000^H	15seg.	
LC	1400^H x 1000^H	14seg.	

Cherenkov Detectors

β^{-1} for particles

p [GeV/c]	π	K	p
1.2	1.007	1.083	1.270
1.3	1.006	1.071	1.234
1.4	1.005	1.062	1.204

π/K discrimination
Aerogel (n=1.05)

K/p discrimination

Lucite (n=1.5)
Water (n=1.33)

TOF-AC1-AC2-LC-WC
TOF1-AC1-AC2-TOF2-WC

Missing Mass Resolution

$$M^2 = (E_B + m_T - E_S)^2 - (\vec{p}_B - \vec{p}_S)^2$$

$$= m_B^2 + m_S^2 + m_T^2 + 2(m_T E_B - m_T E_S - E_B E_S + p_B p_S \cos\theta)$$

$$M \Delta M = (m_T - E_S)\Delta E_B + p_S \cos\theta \cdot \Delta p_B - (m_T + E_B)\Delta E_S$$

$$+ p_B \cos\theta \cdot \Delta p_S - p_B p_S \sin\theta \cdot \Delta\theta$$

$$\frac{\partial M}{\partial p_B} = \frac{1}{M}\left[\beta_B (m_T - E_S) + p_S \cos\theta\right],$$

$$\frac{\partial M}{\partial p_S} = -\frac{1}{M}\left[\beta_S (m_T + E_B) - p_B \cos\theta\right],$$

$$\frac{\partial M}{\partial \theta} = -\frac{p_B \cdot p_S}{M}\sin\theta$$

$$\Delta M^2 = \left(\frac{\partial M}{\partial p_B}\right)^2 \Delta p_B^2 + \left(\frac{\partial M}{\partial p_S}\right)^2 \Delta p_S^2 + \left(\frac{\partial M}{\partial \theta}\right)^2 \Delta\theta^2 + \Delta E_{\text{strag.}}^2$$

Missing Mass Resolution

$$\Delta M^2 = \left(\frac{\partial M}{\partial p_B}\right)^2 \Delta p_B^2 + \left(\frac{\partial M}{\partial p_S}\right)^2 \Delta p_S^2 + \left(\frac{\partial M}{\partial \theta}\right)^2 \Delta \theta^2 + \Delta E_{\mathrm{strag.}}^2$$

$\theta \sim 5^\circ$

$H(K^-,K^+)\Xi^-$

p_B=1.8 GeV/c

p_S=1.29 GeV/c

$^{12}C(K^-,K^+)^{12}{}_{\Xi}Be$

p_B=1.8 GeV/c

p_S=1.37 GeV/c

K1.8BS $\Delta p/p \sim 1.4 \times 10^{-4}$(RMS)

Δp=0.6MeV/c(FWHM)

SksPlus $\Delta p \sim 2.5$MeV/c(FWHM)

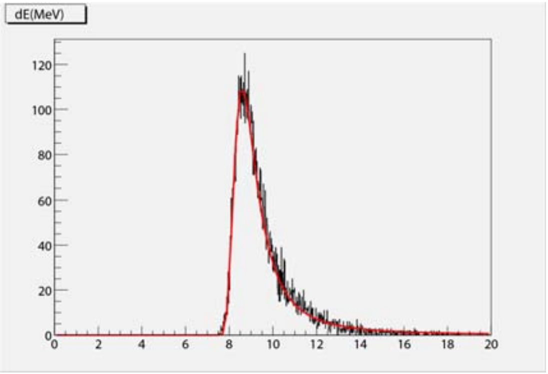
$\Delta\theta$=2mrad

	Δp_B	Δp_S	$\Delta\theta$		$\Delta E_{strag.}$	ΔM
$H(K^-,K^+)\Xi^-$	0.39	1.56	0.30	1.64		
$^{12}C(K^-,K^+)^{12}{}_{\Xi}Be$	0.56	2.26	0.04	2.33	<2.0	<3.07

5.4g/cm^2 Carbon for 1.8GeV/c K^-

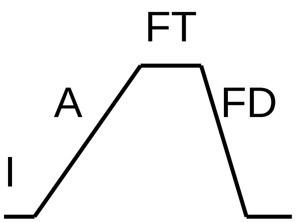
MPV = 8.66MeV, σ=0.33MeV

$\Delta E_{strag.} \sim 1$ MeV ?



Spill Length & Beam Intensity

PS Op. Cycle@30GeV



Injection	0.17s
Acceleraiton	1.39s
Flat-top	0.7s –
Fall down	0.64s
Duration	2.90s –

K^- intensity at K1.8FF

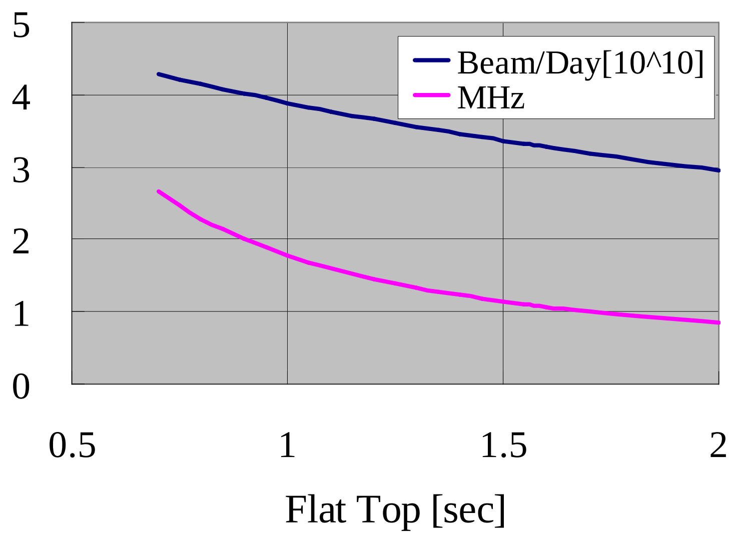
1.6 x 10^6 /spill

(30GeV-9μA)

assumed:

BeamOn time=Flat top -0.1s

90% efficiency



FT 0.7-1.2sec

→ 3.5×10^{10} K^-/day

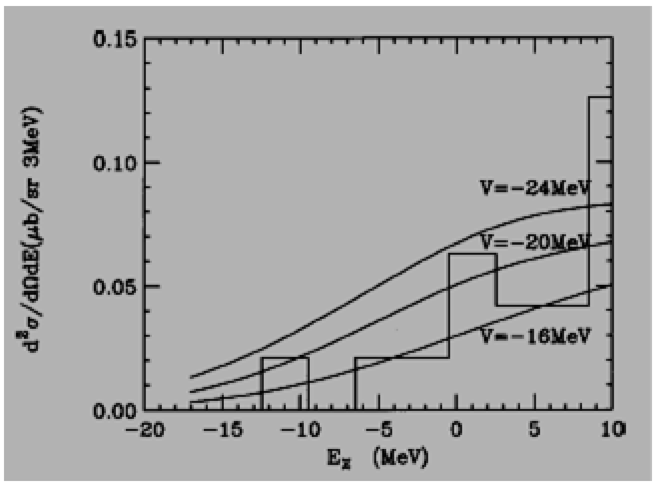
1.5-2.5 MHz@FF

Previous Data on ^{12}C

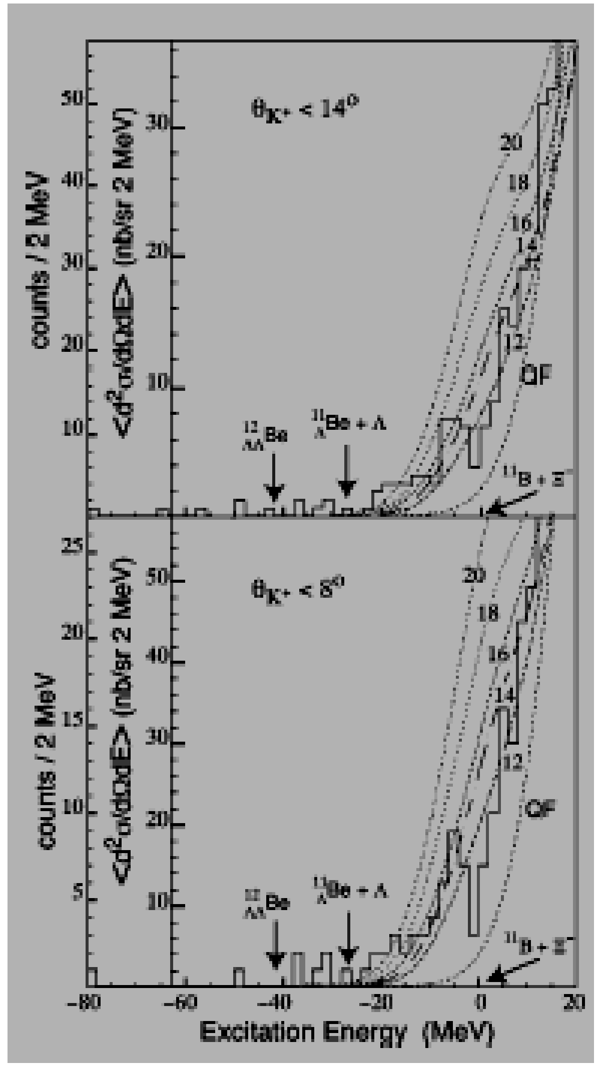
KEK-E224

T.Fukuda et al,
PRC58(1998)1306

$P(K^-)$ = 1.65GeV/c



0.21±0.07 μb/sr E<7 MeV
60 ±45 nb/sr –20<E<0 MeV



AGS-E886

P.Khaustov et al,
PRC61(2000)054603

$P(K^-)$=1.8GeV/c

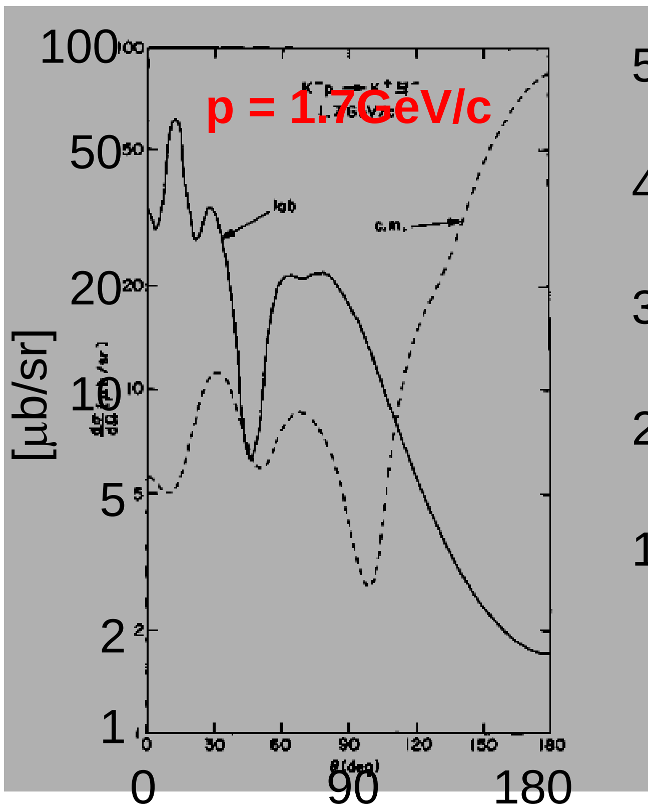
–20 < E < 0 MeV
89±14 nb/sr θ< 8°
42± 5 nb/sr θ<14°

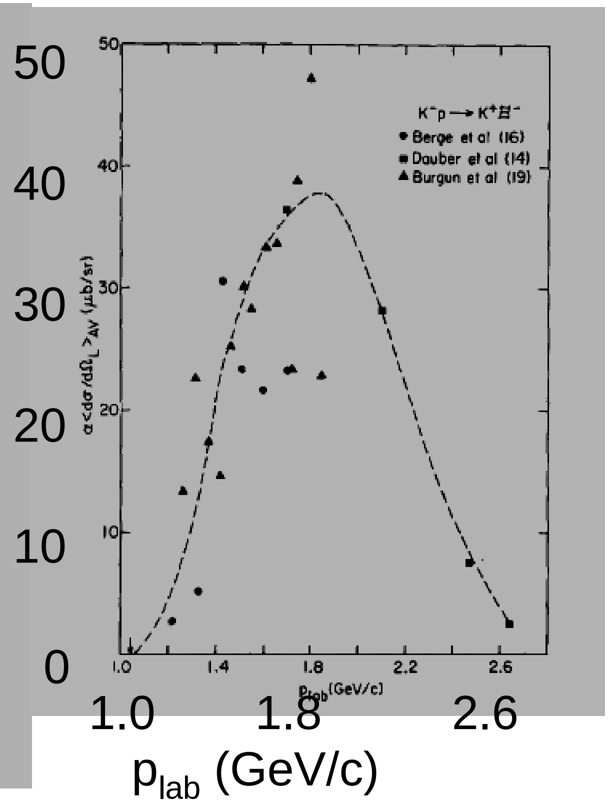
V_Ξ= –14 MeV
Only s-state is bound.

DWIA by Itonaga
92 nb/sr θ< 8°
37 nb/sr θ<14°

p + K⁻ –> K⁺ + Ξ⁻ Reaction

C.B.Dover & A.Gal
Ann. of Phys. 146(1983)309



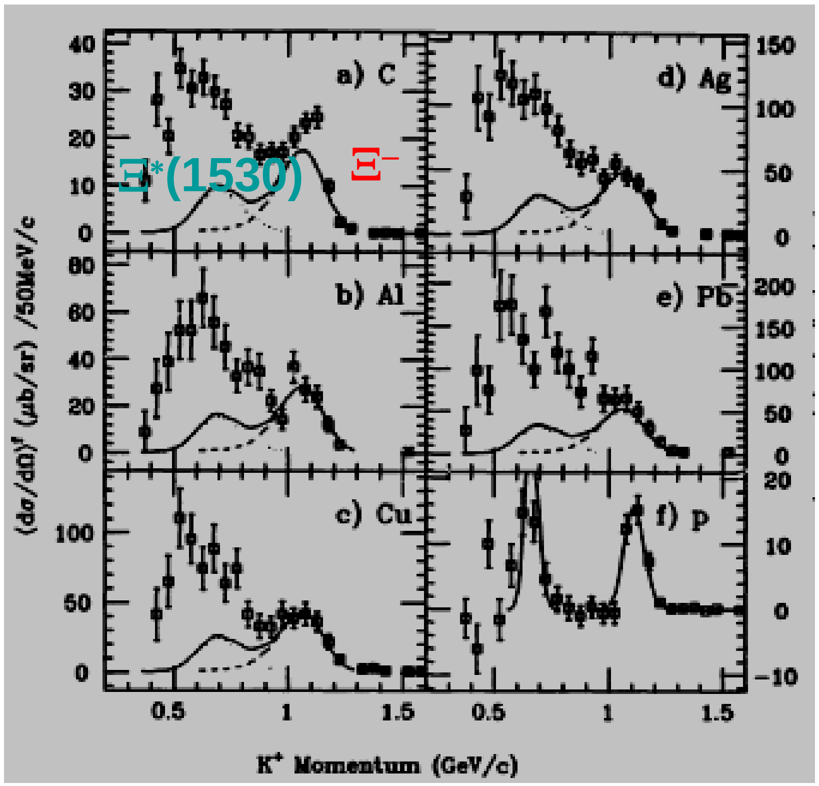


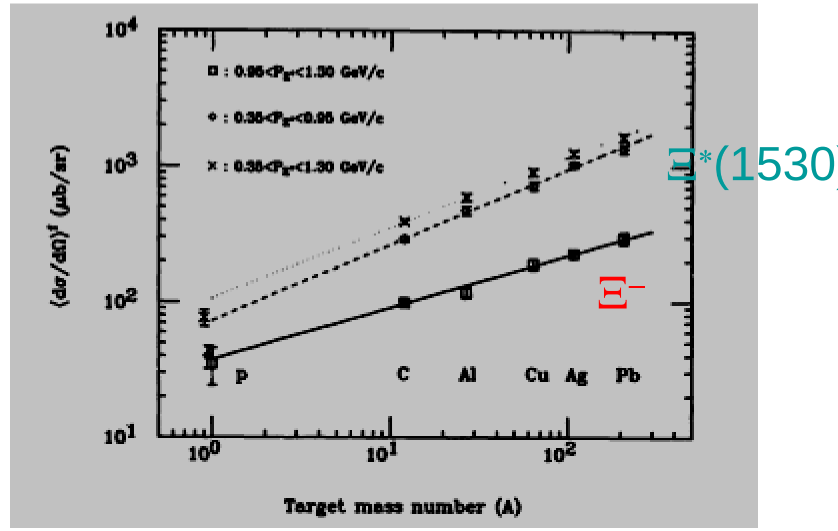
T.Iijima et al.
NPA546(1992)588

p = 1.65 GeV/c
1.7° < θ_{lab} < 13.6°
35±4 μb/sr

p + K^{-} –> K^{+} + Ξ^{-} (Quasi-Free)

T.Iijima et al.
NPA546(1992)588





for Ξ^{-} production

$d\sigma/d\Omega = CA^{\alpha}$

$C = 37 \pm 4\ \mu b/sr$

$\alpha = 0.56 \pm 0.02$

Yield Estimation for $^{12}C(K^-,K^+)^{12}_{\Xi}Be$

5.4 g/cm^2 (3cm) target

N_{tgt}= 5.4 x 6.02x10^{-7}[μb^{-1}] /12

= 2.7 x 10^{-7} [μb^{-1}]

N_{beam} = 3.5 x 10^{10} [/day]

Ω = 0.030

Surv. Rate = 0.5

Ana. Efficiency = 0.5

dσ/dΩ = 0.04 [μb/sr]

N = 2.7x10^{-7} x 3.5x10^{10} x 0.04 x 0.030 x 0.5 x 0.5

= 2.83 [/day]

~ 20 [/week]

~ 85 [/month]

2 months beam time is required at Phase1 beam intenisity.

Yield for $H(K^-,K^+)\Xi^-$

CH_2 target (5 g/cm^2)

$N_H = 5 \times 6.02 \times 10^{-7} \times (2/14)$
$= 4.3 \times 10^{-7}$ [μb^{-1}]
$N_C = 2.15 \times 10^{-7}$ [μb^{-1}]

Liq.-H_2 target (10cm)
$\rho = 0.07$ g/cm^3

$N_H = 0.07 \times 10 \times 6.02 \times 10^{-7} / 1$
$= 4.2 \times 10^{-7}$ [μb^{-1}]

$$N = 4.3 \times 10^{-7} \times 3.5 \times 10^{10} \times 35 \times 0.030 \times 0.5 \times 0.5$$
$$= 3.95 \times 10^{3} \text{ [/day]}$$

Enough Statistics for Spectrometer Calibration

^{3}He Target

From Ishimoto-San’s Information

- Boiling Point 3.19 K [4.215K]
- density@B.P. 0.0589 g/cm^3 [0.125g/cm^3]
- Liquid quantity ~1000cm^3

if 6cmϕ cylinder cell , L=35cm

L=20cm

N_T = 0.0589 x 20 x 6.02x10^{-7} / 3

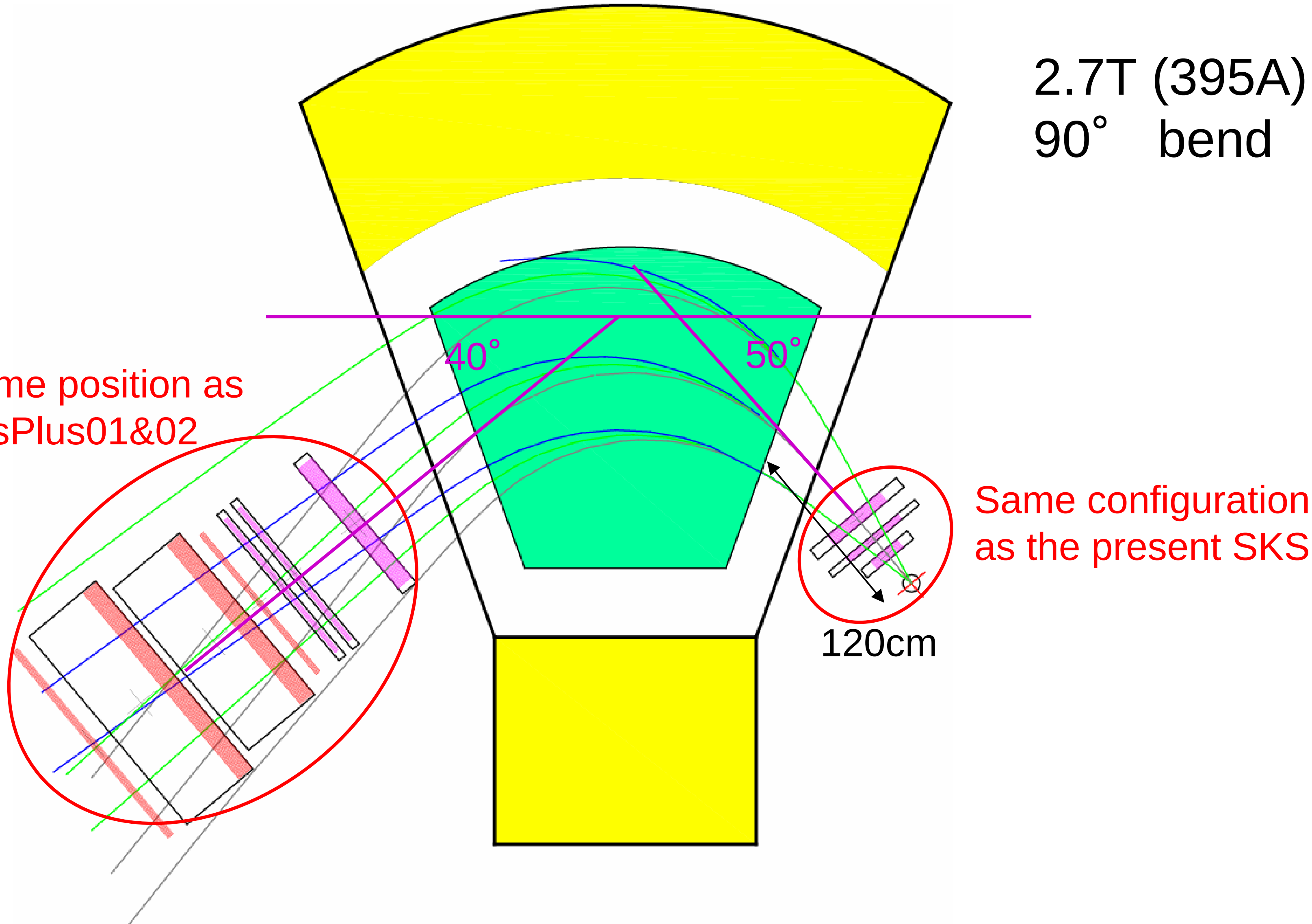
= 2.36x10^{-7} [μb^{-1}]

Target density is same as C case.

Cross Section ?

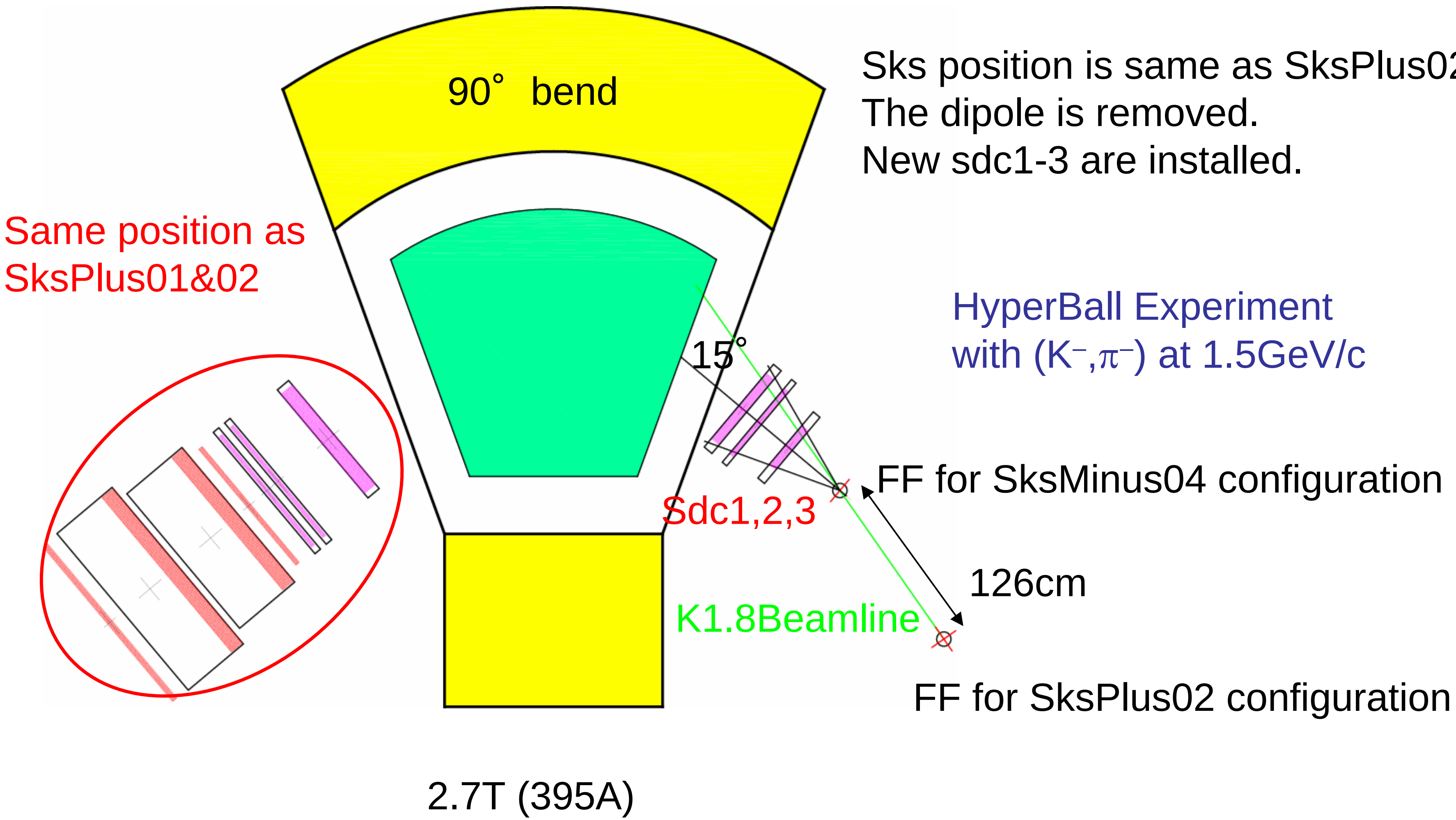
Does bound state exist ?

Sks Single Spectrometer
SksMinus02

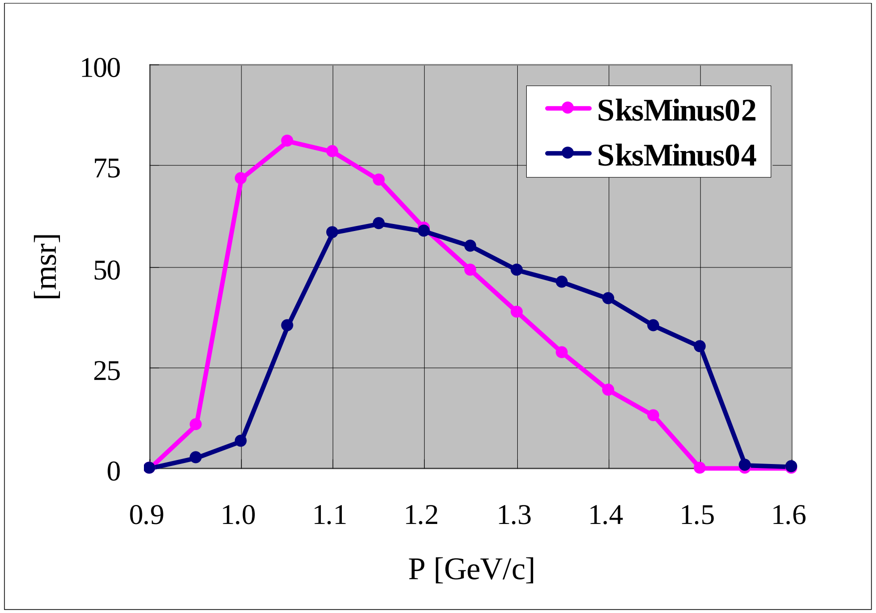


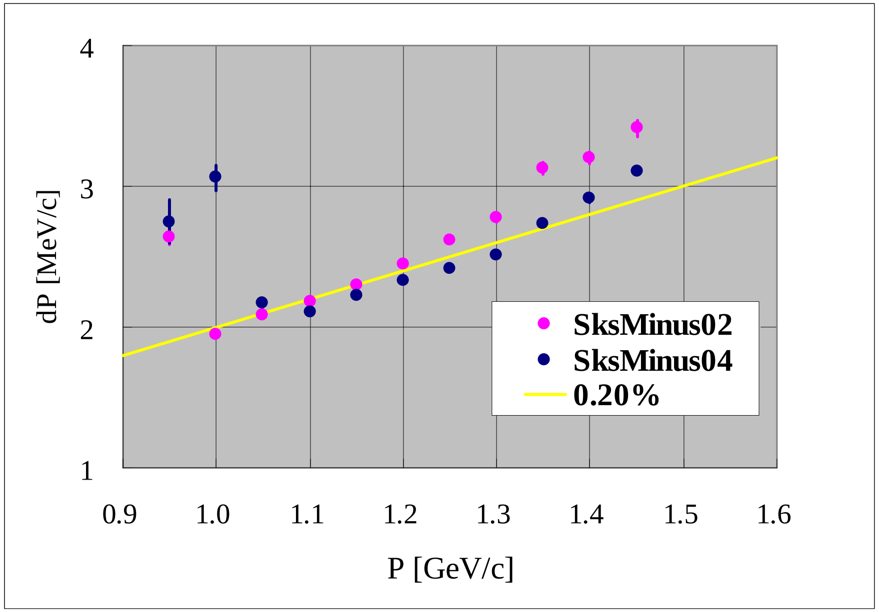
SksMinus04

Sks position is same as SksPlus02.
The dipole is removed.
New sdc1-3 are installed.



Acceptance & Resolution for Sks Single Spectrometers





Comparison between SksPlus02 and SksMinus02

		SksPlus02	SksMinus02
$p(K^-)$	[GeV/c]	1.8	1.65
$p(K^+)$	[GeV/c]	1.15 − 1.45	1.0 − 1.3
Intensity	[/spill]	1.6×10^6	0.8×10^6 *
Solid Angle	[msr]	30	60
Flight Path	[m]	~7	~5
Survival Rate		~0.50	~0.57
ΔM(FWHM)**	[MeV/c^2]		
$^{12}C(K^-,K^+)^{12}_{\Xi}Be$		2.33	3.16
$p(K^-,K^+)\Xi^-$		1.64	2.14

* Naive estimation by Noumi

** without energy loss straggling at the target.

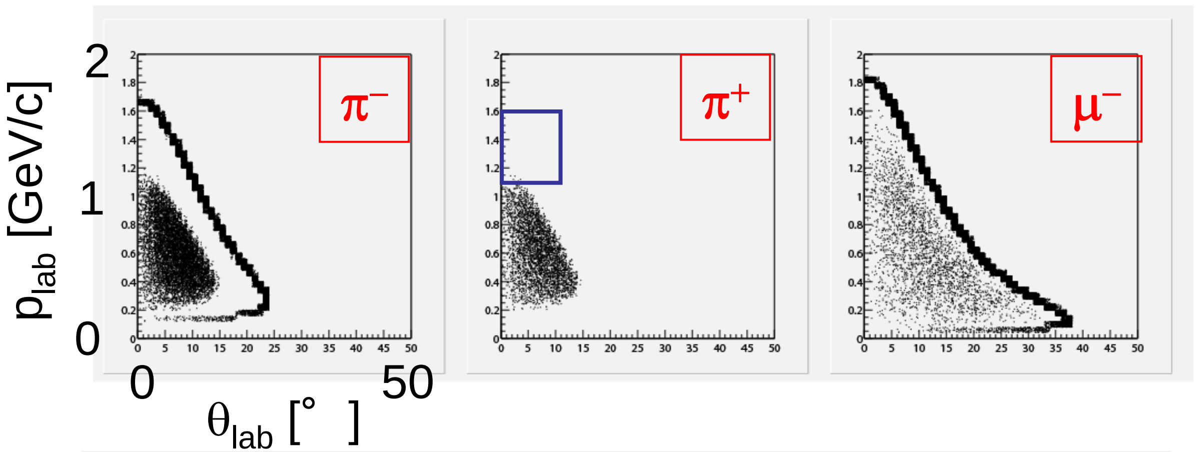
If cross section is same at both incident momenta.

Yield gain is only 10% thanks to the short flight path.

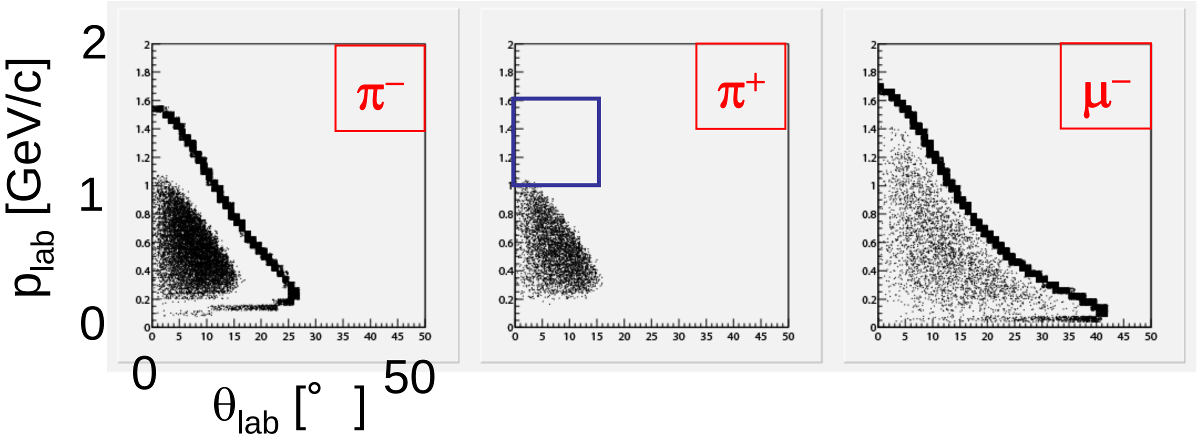
Energy resolution becomes worse.

Backgrounds
–decays–

K^- decays



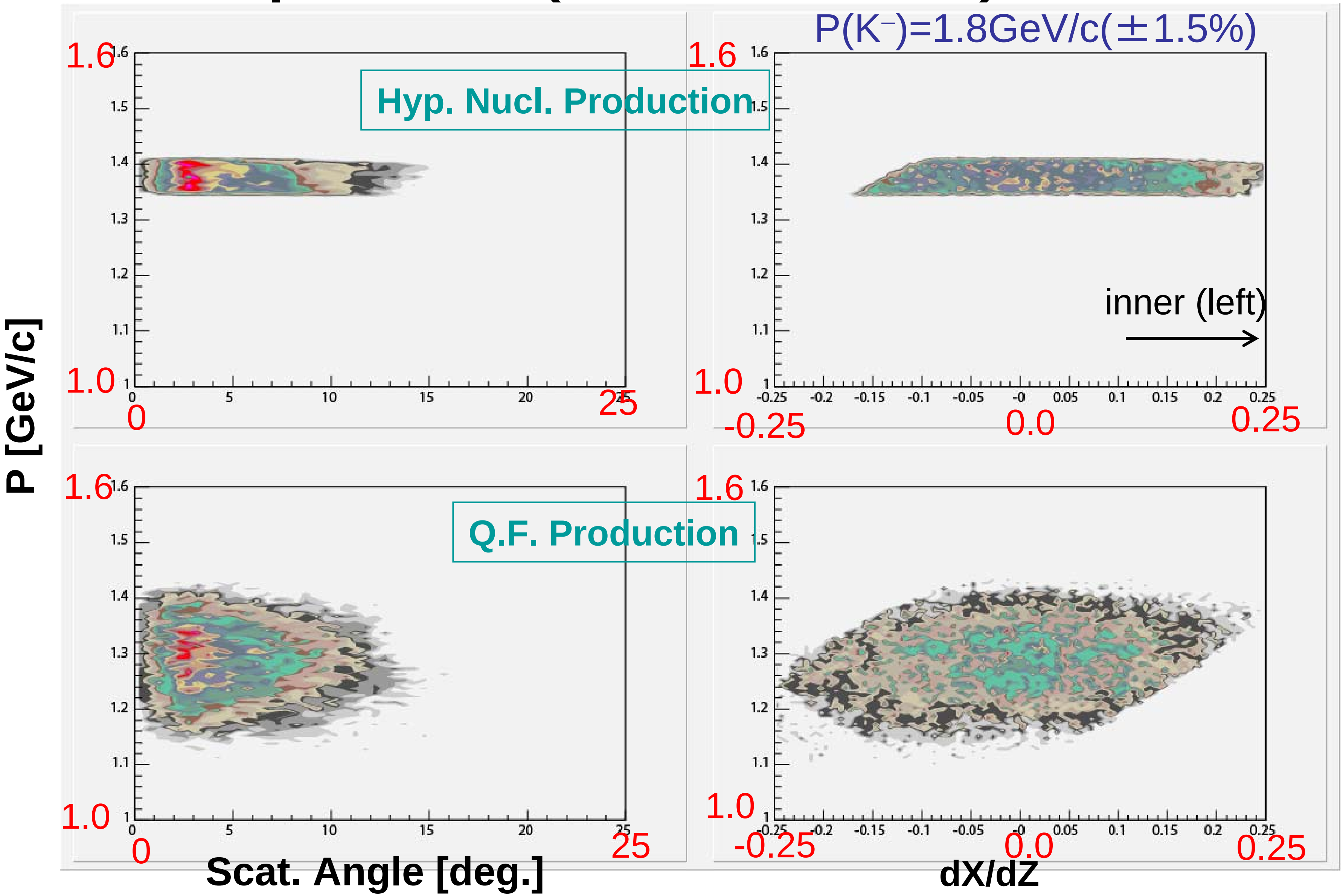
p = 1.8GeV/c



p = 1.65GeV/c

No decay B.G. !!

Acceptance(SksPlus02) More...



Characteristics of (K^-,K^+) reaction

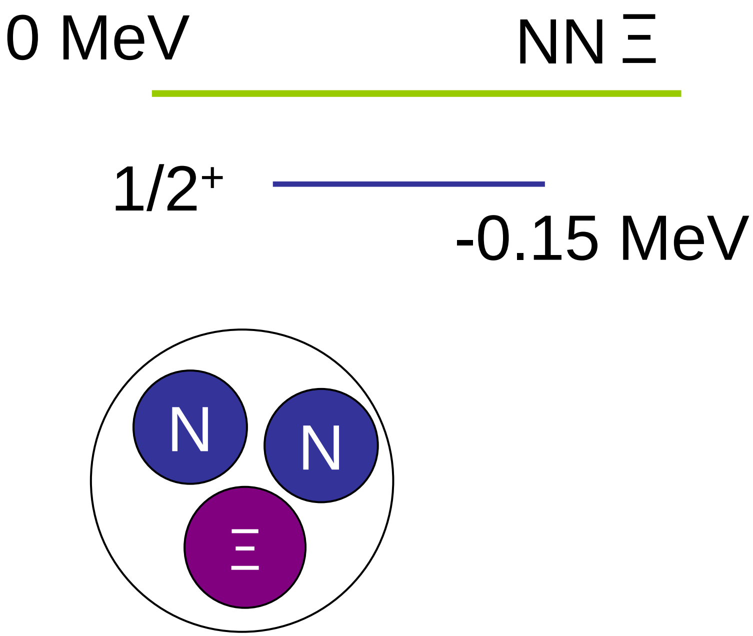
- To convert proton to Ξ^-
- $\Delta I=1$ reaction
  - If target of I=0 is used, I=1 states can be produced.
- Large momentum transfer q~0.5GeV/c
  - spin stretch states
  - smaller S-factor than (π^+,K^+) case of q~0.4GeV/c.

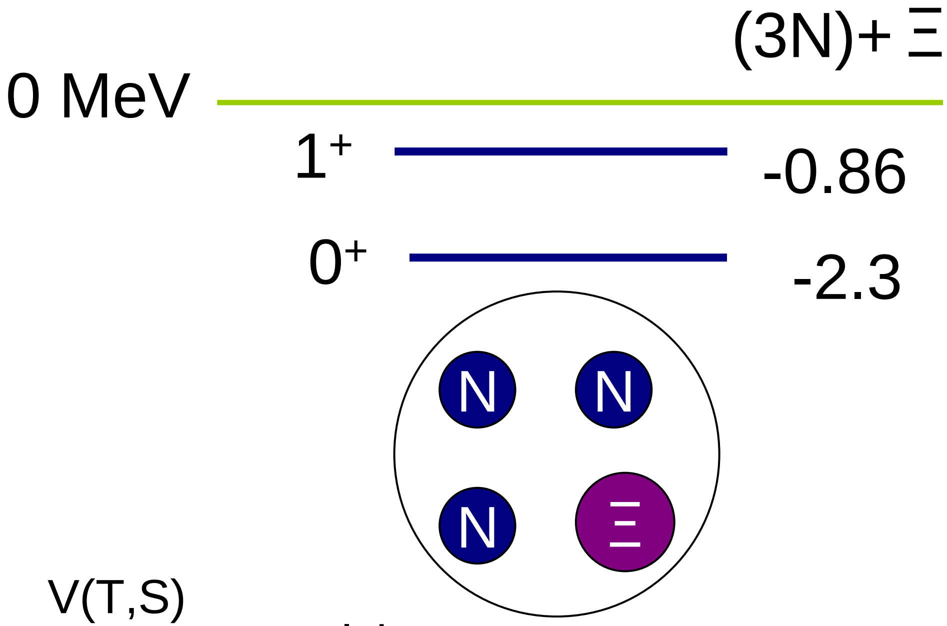
ΞN interaction

- Exp. Information
  - V_{Ξ}= ~–14MeV from $^{12}C(K^{-},K^{+})$
    note that for T=1 state(s)
- ESC04 reproduces V_{Ξ}=–14MeV
  - Strong Isospin dependence
    - T=0 is more atrractive than T=1
- NSC97e and f do not.
  - repulsive

Hiyama's calculation

ESC04





V(T,S)

repulsive

1^+: [12V(1,1)+V(1,0)+10V(0,1)+3V(0,0)]/25

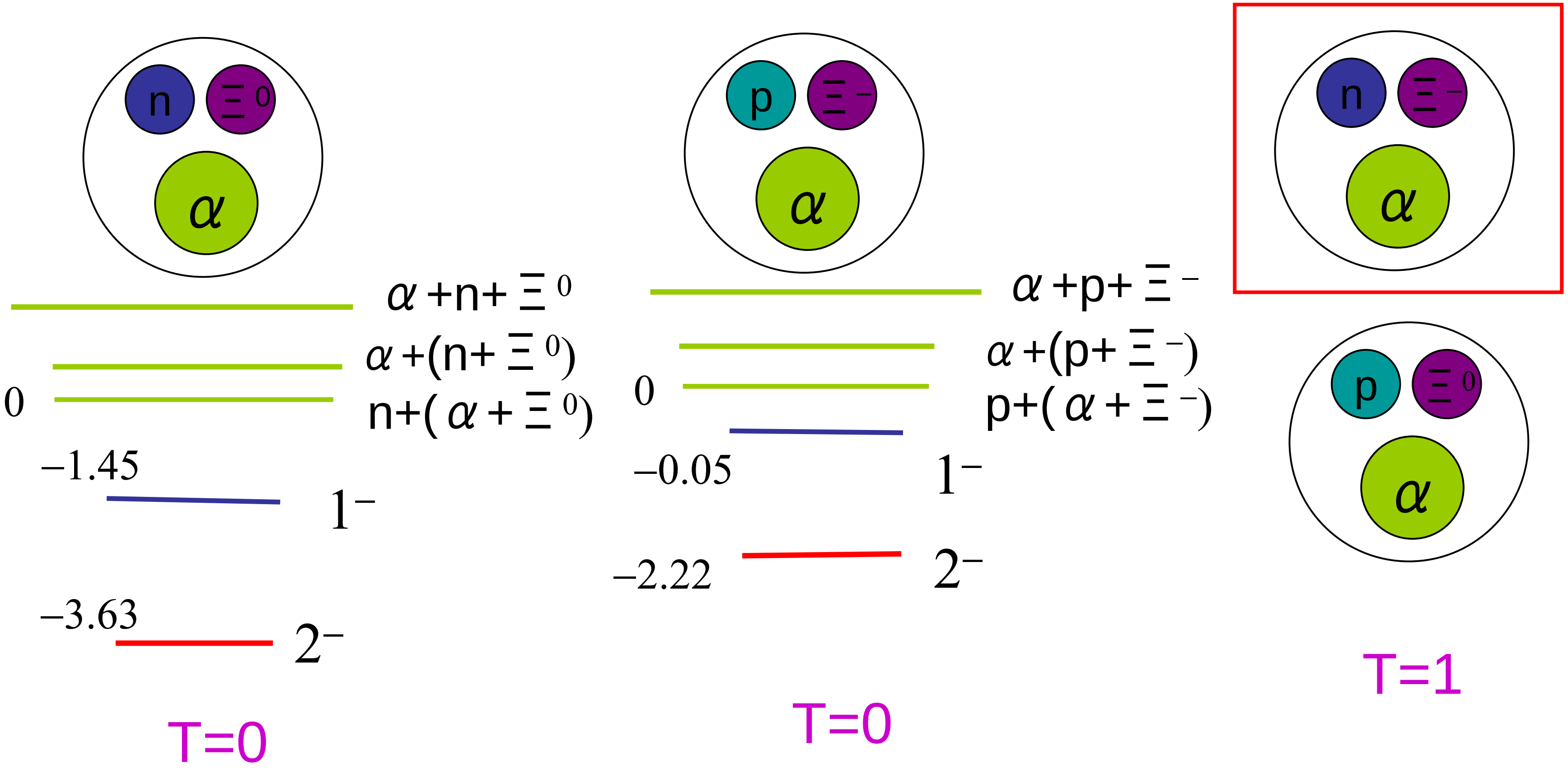
0^+:[V(1,0)+V(0,1)]/2

repulsive

strongly attractive

weakly repulsive

Hiyama's calculation



Hall Rayout (K1.8)