J-PARCにおけるΞハイパー核分光実験の早期実現に関する検討

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2010/12/02 @ KEK-WS “Strangeness2010”

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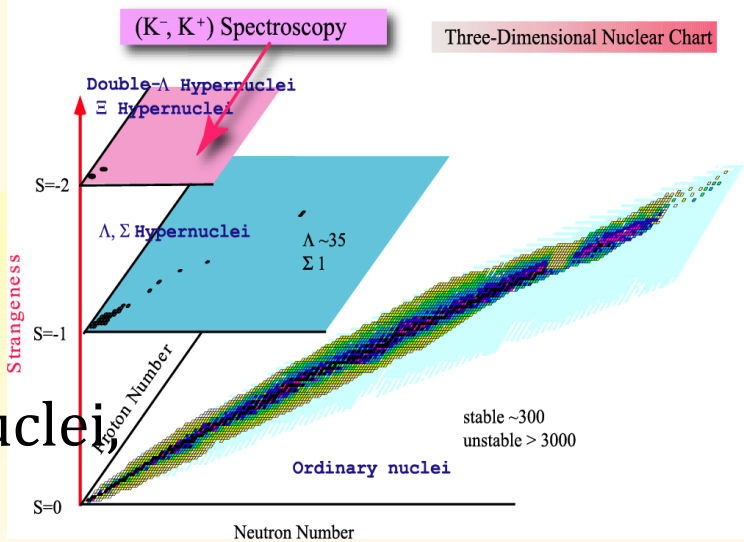
Introduction

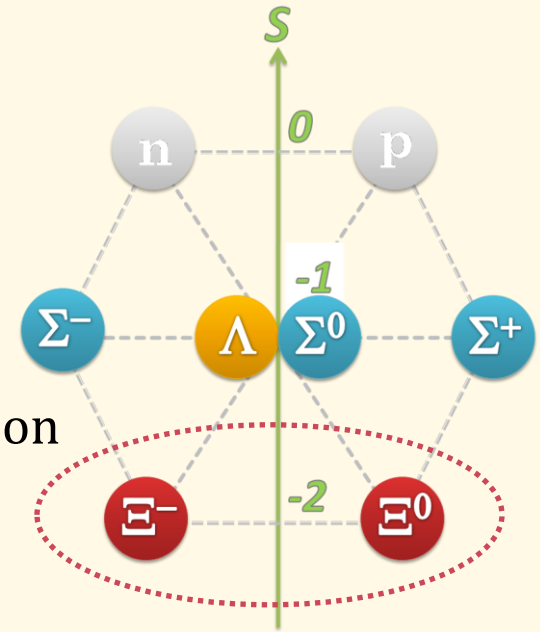


S = -1

- So far, we know Λ-N interaction well extracted from structure of Λ-hypernuclei, including spin component.
  - (π,K) reaction with SKS
  - γ-ray spectroscopy with Hyperball
- successful theoretical understanding.

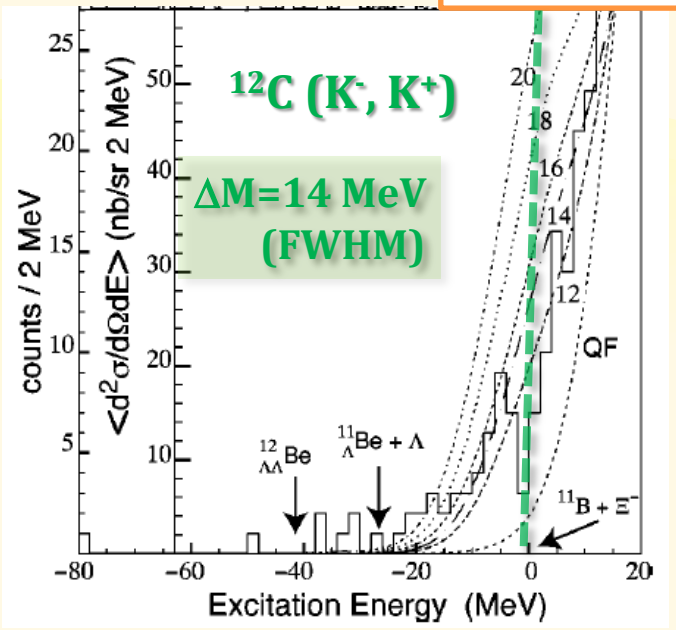
S = -2

- Information is very limited.
  - ΛΛ-hypernuclei => weakly attractive Λ-Λ interaction
    - ex.) NAGARA event : unique ID of species, ${}^{6}_{\Lambda\Lambda}\mathrm{He}$
- Ξ-hypernuclei :
  - No definite evidence for a bound state.
  - There were several experiments using (K^-,K^+) reaction.



Ξ-hypernuclei : previous experiment

BNL-E885



P.Khaustov et al., PRC61(2000)054603

- Previous experiment : BNL-E885
  - not clear evidence of Ξ-hypernuclear bound state.
    - because of limited mass resolution
  - suggest weakly attractive potential of -14 MeV depth.
    - by shape analysis of QF-tail
    - almost unique information on Ξ-hypernuclei up to now

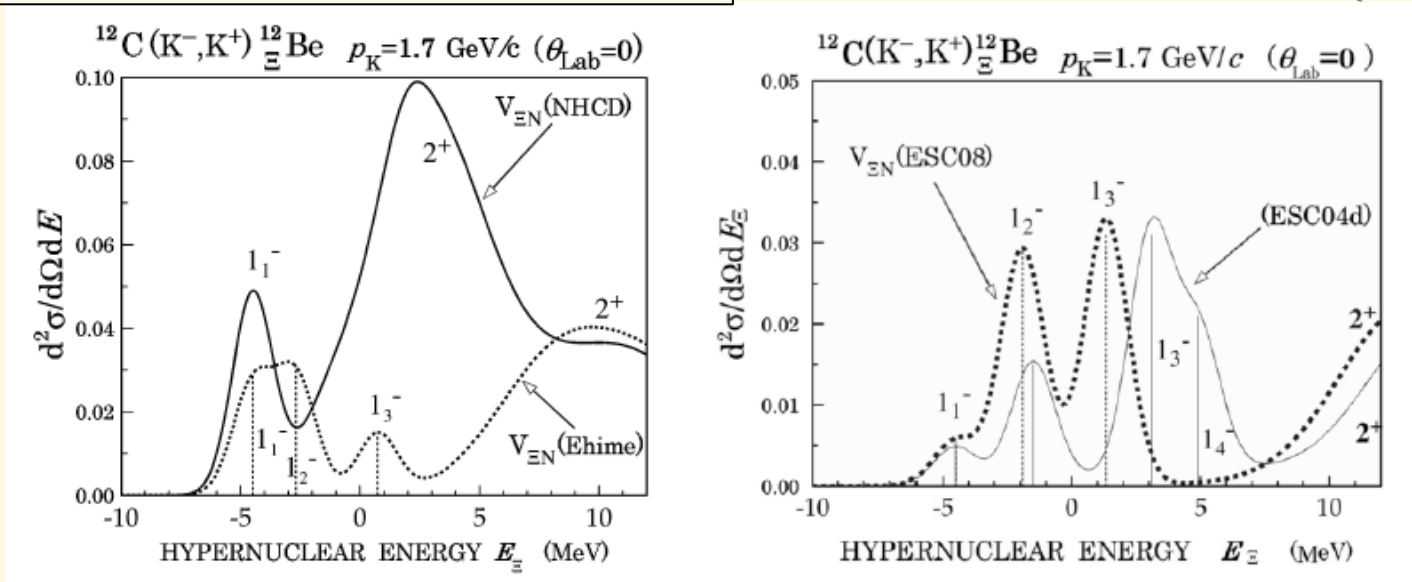
Ξ-hypernuclei : theoretical models

- Various *B*-*B* interaction models exist.
  - Their predictions are quite different for Ξ-N int.

⇐ *Experimental information is strongly awaited.*

DWIA spectra with various int. (*T*=*1*)

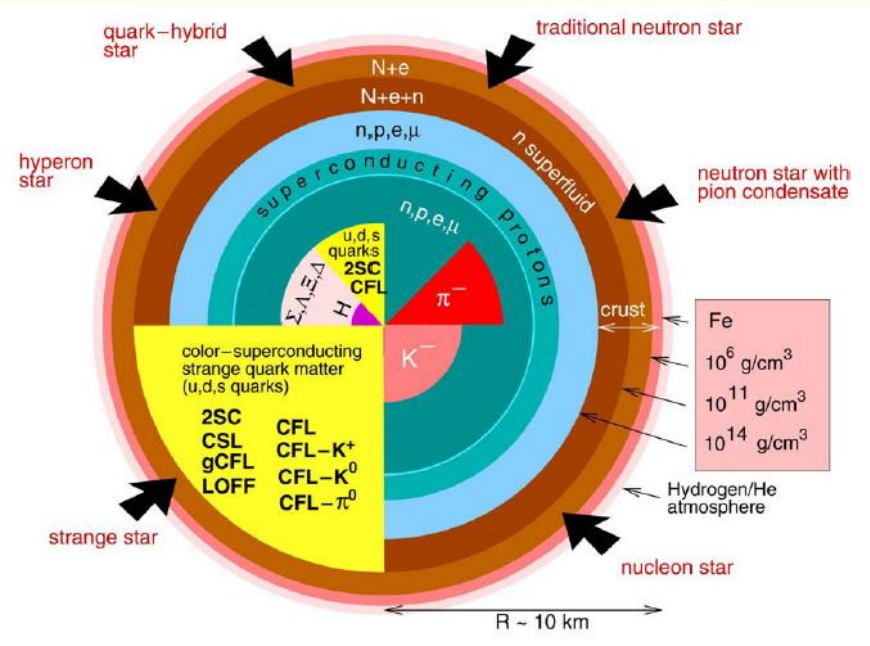
T.Motoba et al., NPA835(2010)223

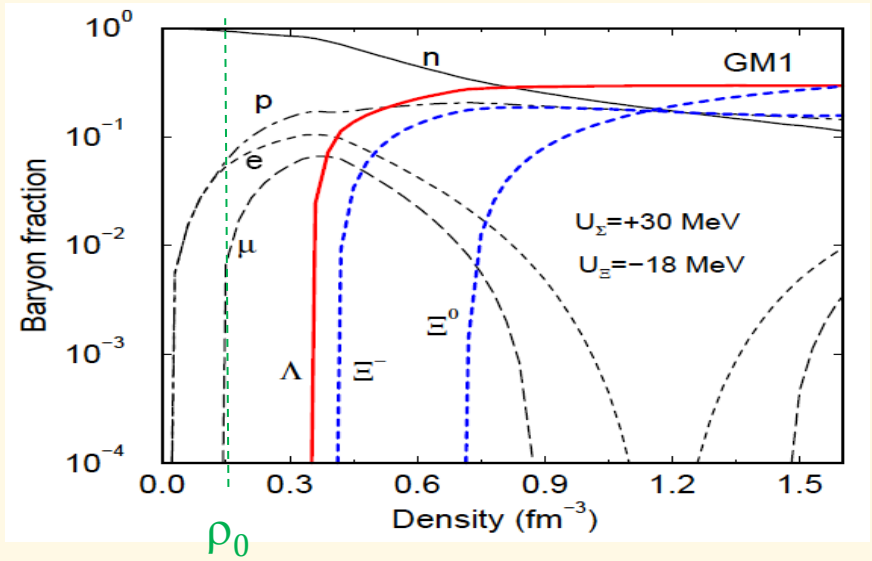


Ξ-hypernuclei : appearance in N.S ?

- Strangeness in dense nuclear matter
  - Inspect into the core of neutron stars
  - Strangeness will take the key role

If Ξ-N is attractive (U_Ξ~-18MeV),
Ξ will appear next to Λ in neutron stars.





F.Waber, PPNP54(2005)193

J.Schaffner-Bielich, NPA804(2008)309

Experiment

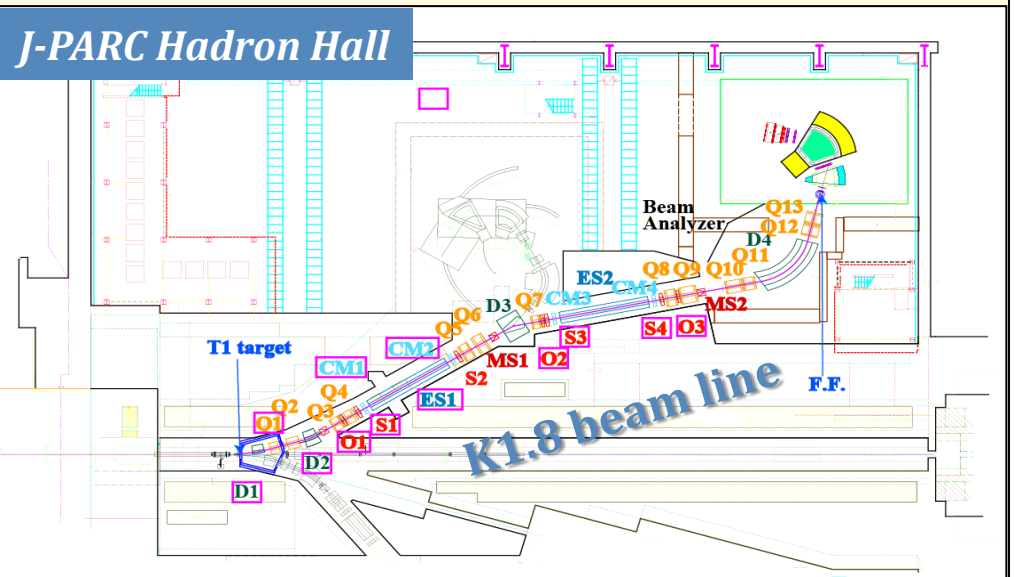
J-PARC E05: Ξ-Hypernuclear Spectroscopy

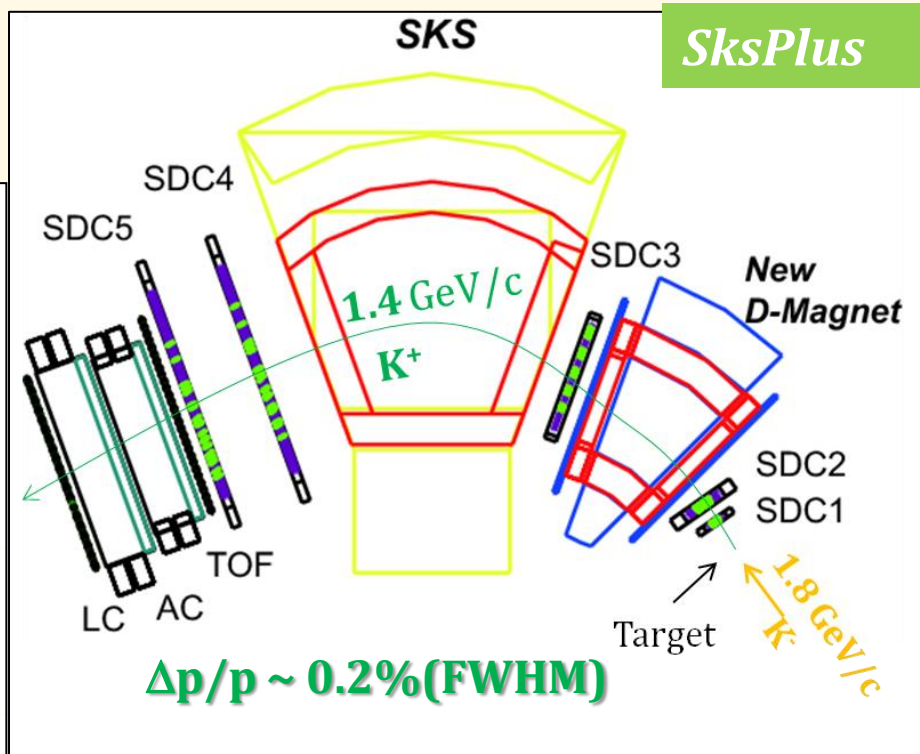
- Spectroscopic study of Ξ-hypernucleus
- using $^{12}C(K^-, K^+)$ reaction ; -> $^{12}_{\Xi}Be$
- Missing mass spectroscopy
  - measure momentum of both incident K^- and outgoing K^+
  - with **high-resolution (~3MeV)** and **enough statistics**
- Only J-PARC can do this experiment. <= 1.4 x 10^6 K^-/spill

- Goal
  - observe peaks of Ξ-hypernuclei for the first time.
  - Binding energy => potential depth (real part)
  - Width => ΞN->ΛΛ conversion width (imaginary part)

Experimental Setup

- **K1.8 beam line + SksPlus**
  - **K^- : 1.8 GeV/c, Beam Spectrometer ($\Delta p/p \sim 10^{-4}$)**
  - **K^+ : 1.3~1.4 GeV/c, SksPlus ($\Delta p/p \sim 2 \times 10^{-3}$)**
    - **New D-mag. is added to obtain stronger mag. field.**
    - **prior momentum resolution than acceptance(40msr)**



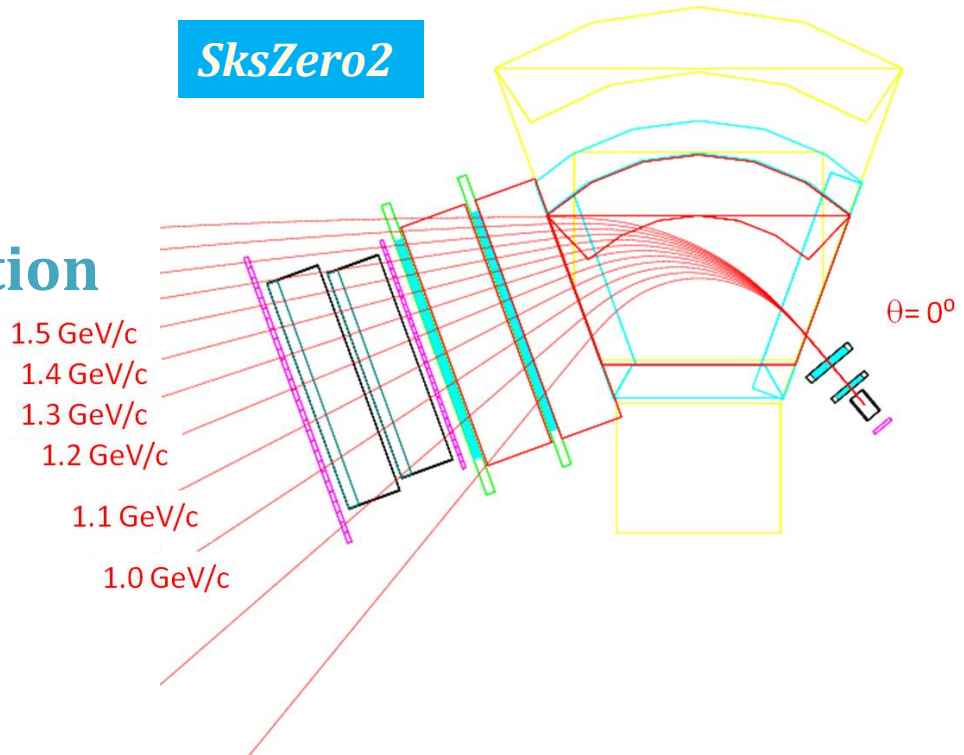


Recent discussion on experimental plan

Setup modification for low intensity beam

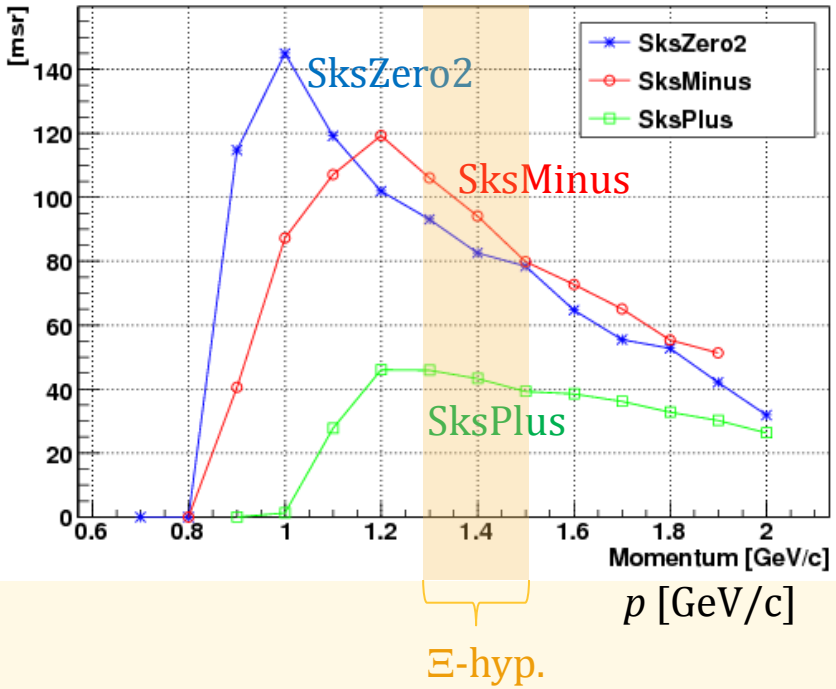
- Accelerator intensity is very limited.
  - **now, ~% of design value (270kW)**
- In original E05 plan, statistics are miserable. => not realistic
- **need more acceptance**

- **modify SKS configuration**
- ***SksZero → SksZero2***
  - only move normal SKS downstream detectors to high-momentum side



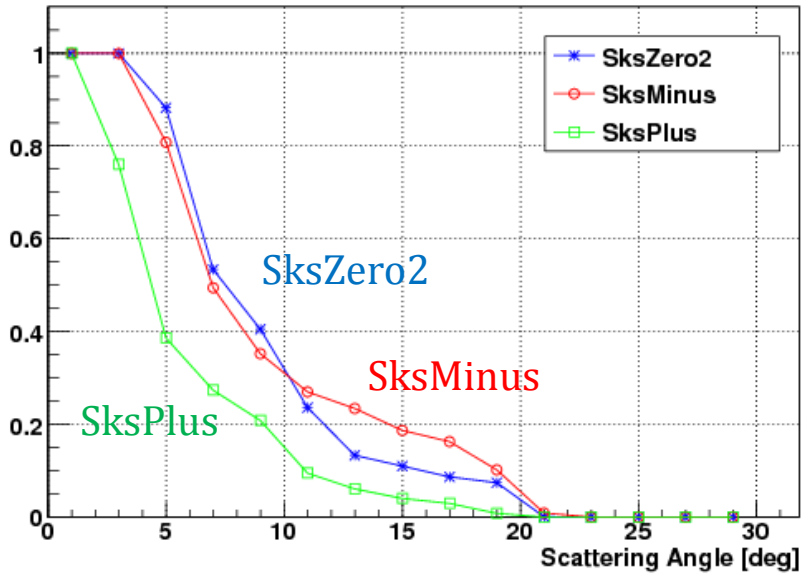
E05 (low intensity beam version) : Acceptance

Momentum Acceptance



Angular Acceptance

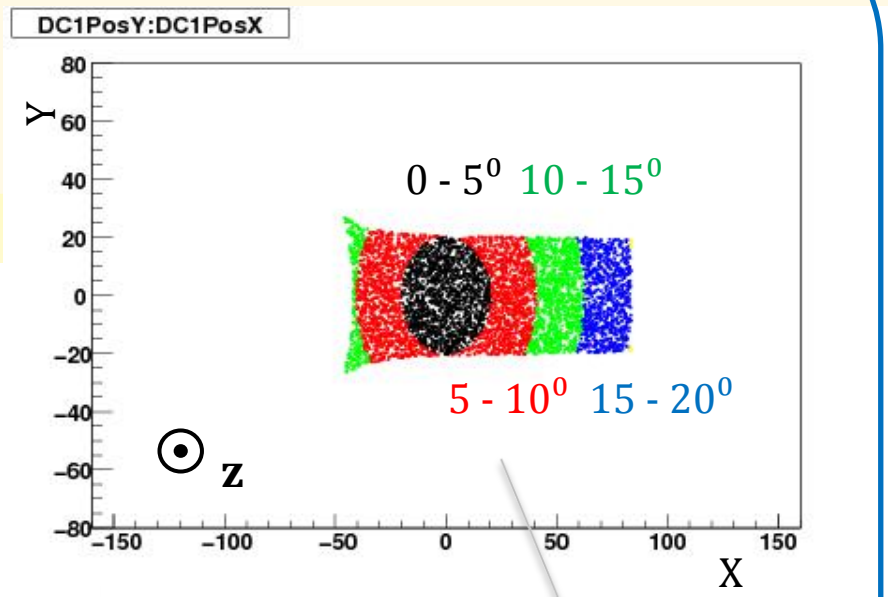
p = 1.3 GeV/c

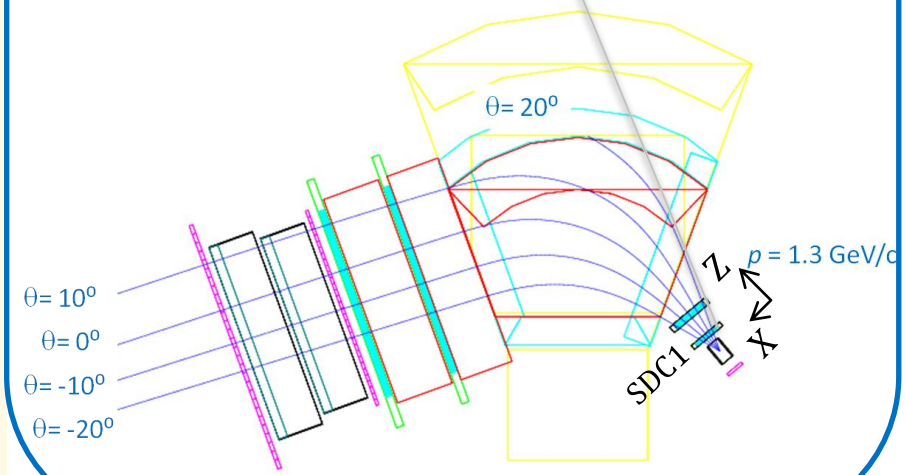


- Acceptance is larger.
  - SksZero2 > SksPlus
    80 msr 40 msr @1.4GeV/c
- 100%-coverage angle
  - SksZero2 < 5°
  - SksPlus < 3°

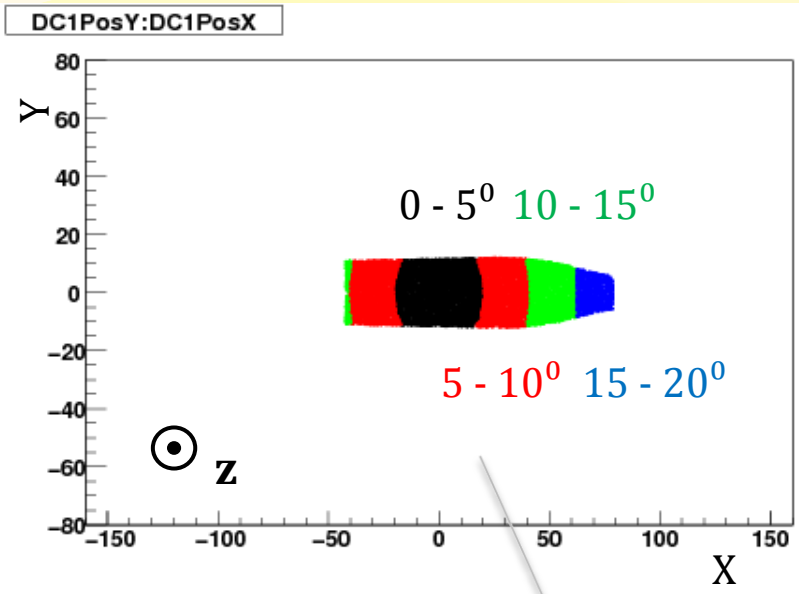
Triggered scattering particle profile @ SDC1

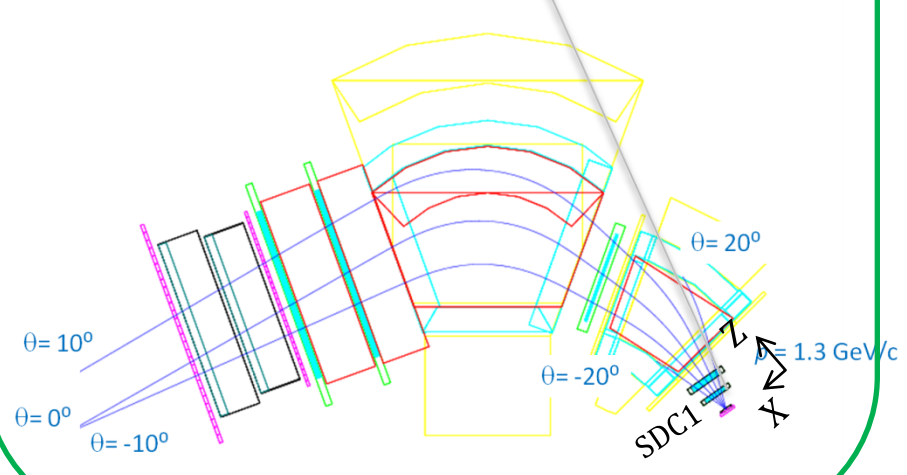
SksZero2





SksPlus

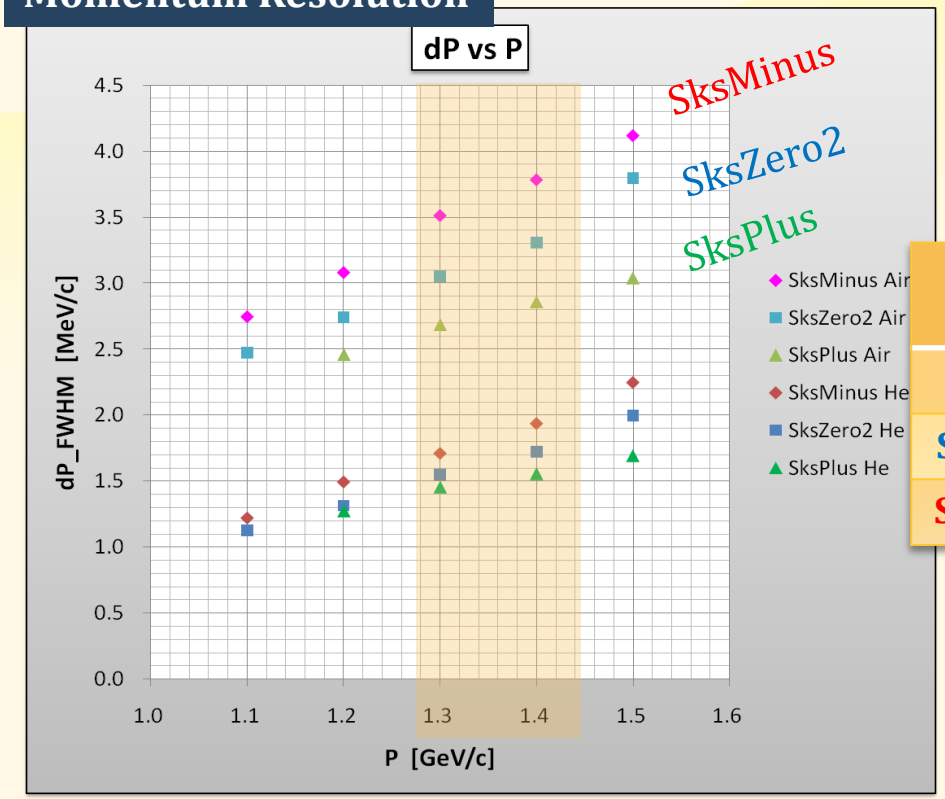




can increase vertical angular acceptance.

E05 (low intensity beam version) : Resolution

Momentum Resolution



$K^- + {}^{12}C \rightarrow K^+ + X$

Missing Mass Resolution

in FWHM

	Δp [MeV/c]	Δp/p [%]	ΔM [MeV]
SksPlus	2.86	0.20	**3.3**
SksZero2	3.31	0.24	**3.7**
SksMinus	3.78	0.27	**4.0**

ΔE_{strag}=2MeV is included.
(5.4g/cm^2 ^{12}C target)

- Δp/p = SksZero2: 0.24 % , SksPlus: 0.20 %
- ΔM = SksZero2: **3.7 MeV** , SksPlus: 3.3 MeV
- *Resolution is just a little worse, but **acceptable level**.*

Yield Estimation (E05 original)

- $Y(^{12}_{\Xi}Be) = N_{beam} \times N_{target} \times d\sigma/d\Omega \times \Delta\Omega \times f_{decay} \times f_{analysis}$

  $= 1.4\times10^{6}[/spill] \times 2.4\times10^{4}[spill/day] \times 5.4 \times 6.02\times10^{-7}/12[/\mu b]$

  $\times 0.06[\mu b/sr] \times 0.04[sr] \times 0.5 \times 0.7$

  $= 7.6$ events/day

  ~ 230 events/month

Yield Estimation (30kW, w/SksZero2)

- $Y(^{12}_{\Xi}Be) = N_{beam} \times N_{target} \times d\sigma/d\Omega \times \Delta\Omega \times f_{decay} \times f_{analysis}$

  $= 1.4\times10^{6}$[/spill] x 2.4×10^{4}[spill/day] x 5.4 x $6.02\times10^{-7}/12$[/μb]

  30/270 x 5/3

  x 0.06[μb/sr] x ~~0.04~~[sr] x 0.5 x 0.7

  0.08 (in case of Pt T1-target)

  = ~~7.6~~ events/day

  2.8

  ~ ~~230~~ events/month

  84

We can take ~80/month statistics at 30kW as the first step of E05.

Now planning….

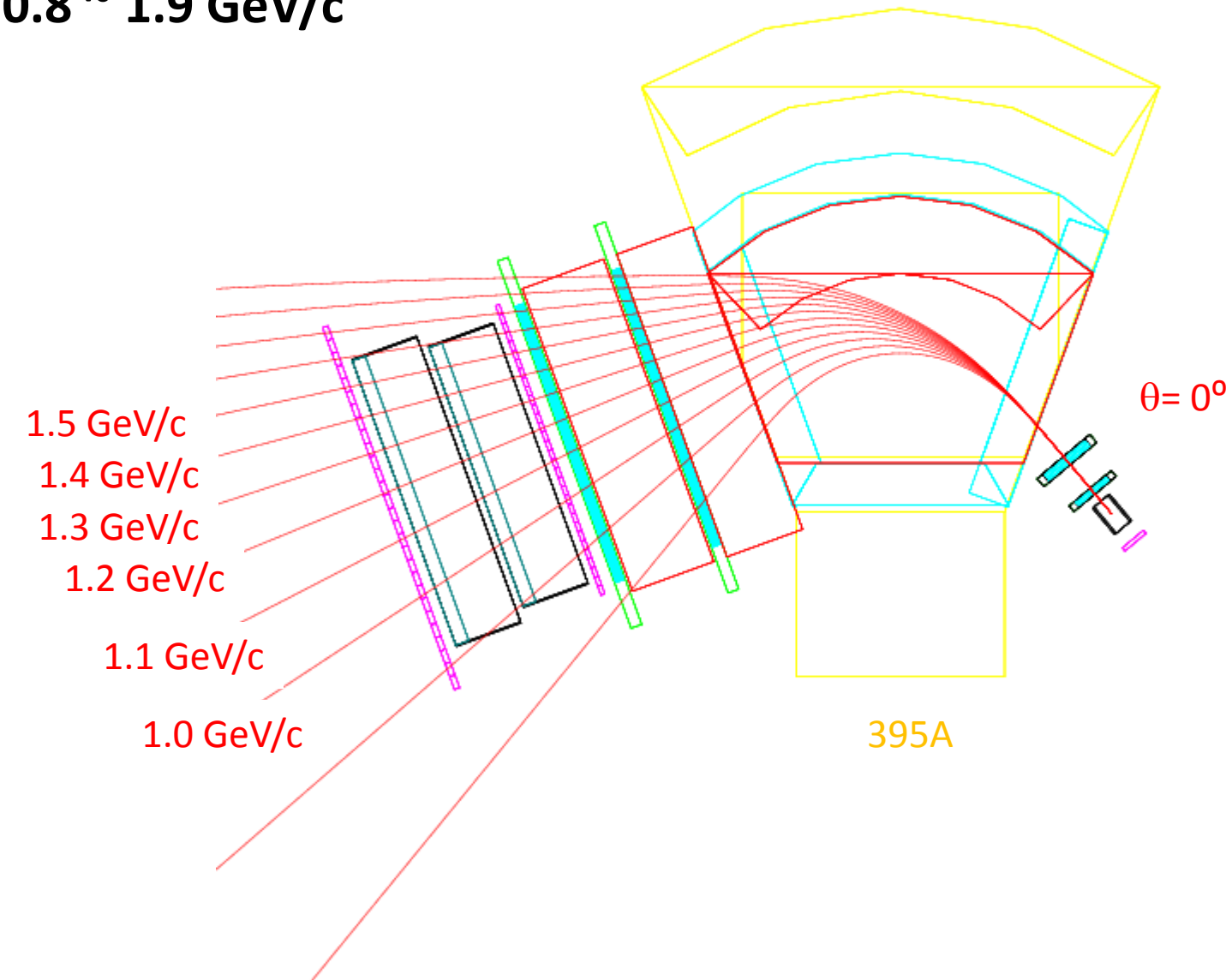
Summary

- J-PARC E05 is planed to observe Ξ-hypernuclei via (K^-,K^+) missing mass spectroscopy.
- It provides essential information to S=-2.
- Ξ-N interaction are extracted from B and Γ.
- Resolution and statistics are important at the experimental point of view.
- We are preparing modified experimental plan for low intensity version. Larger acceptance and acceptable resolution are achieved.
- We want to start exp. at 30kW as the first step.

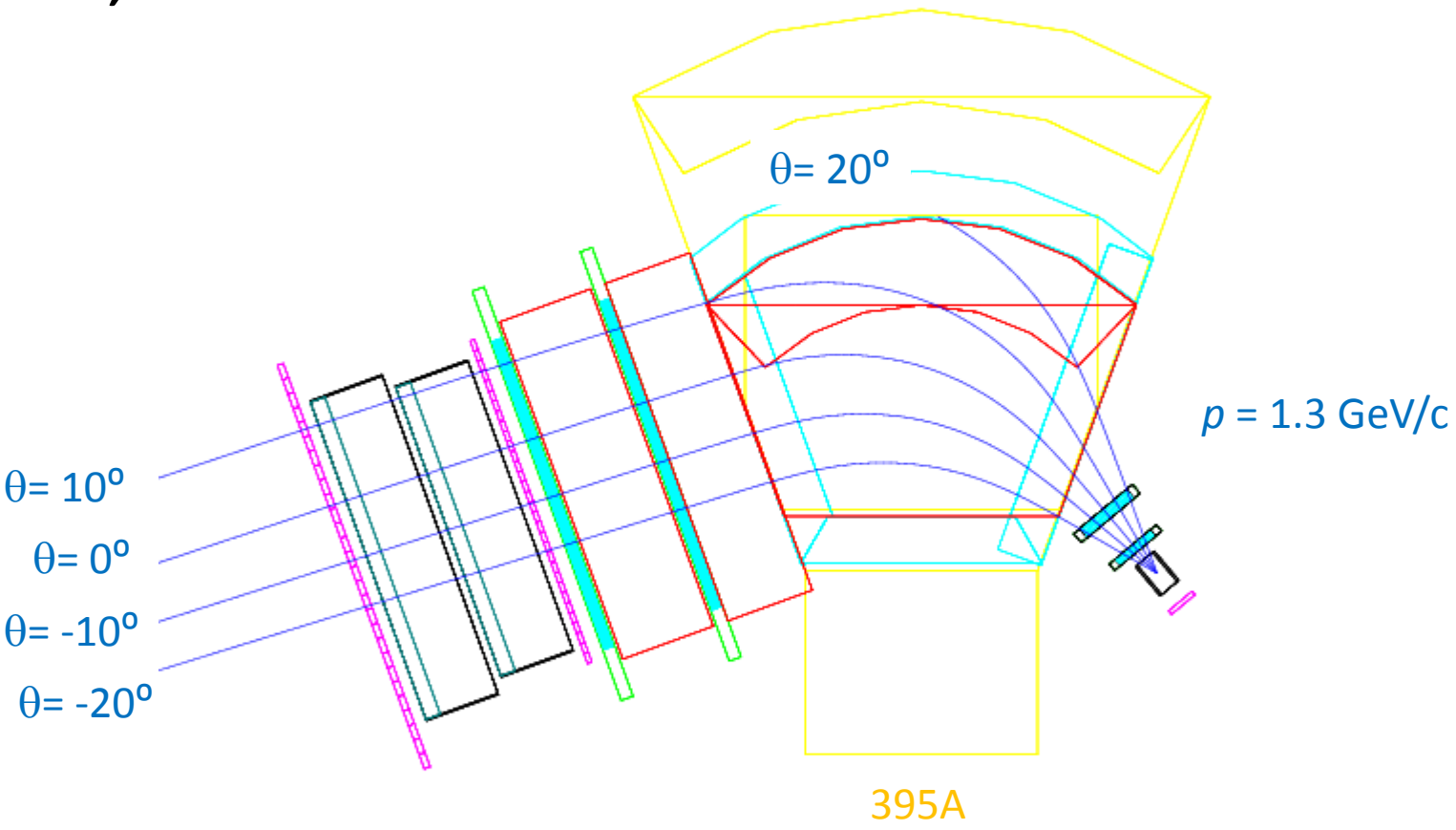
BACKUP

SksZero2 Track @θ=0°, 395A

p **= 0.8 ~ 1.9 GeV/c**

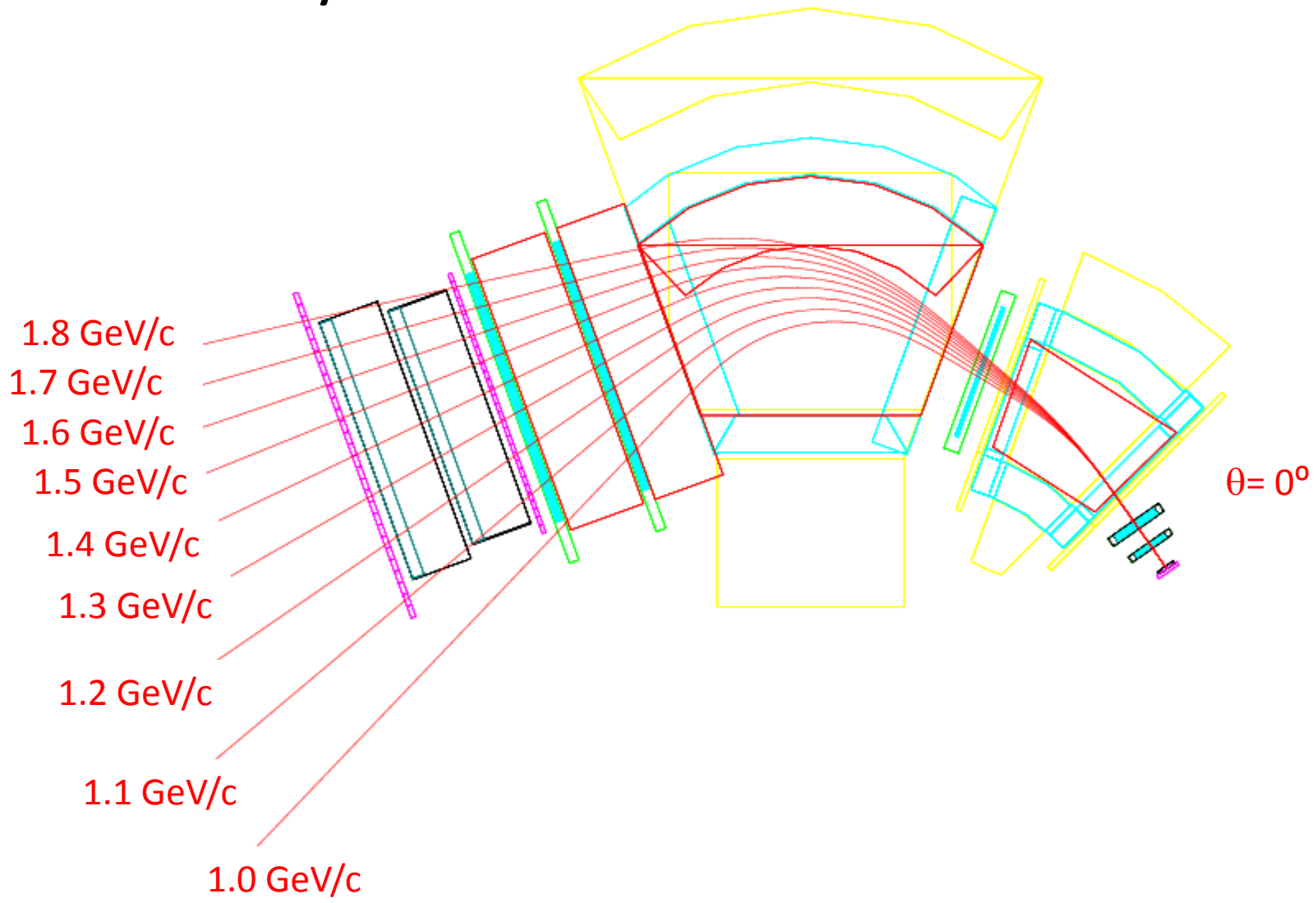


SksZero2 Track @*p*=1.3 GeV/c, 395A
θ = 0°, ±10°, ±20°

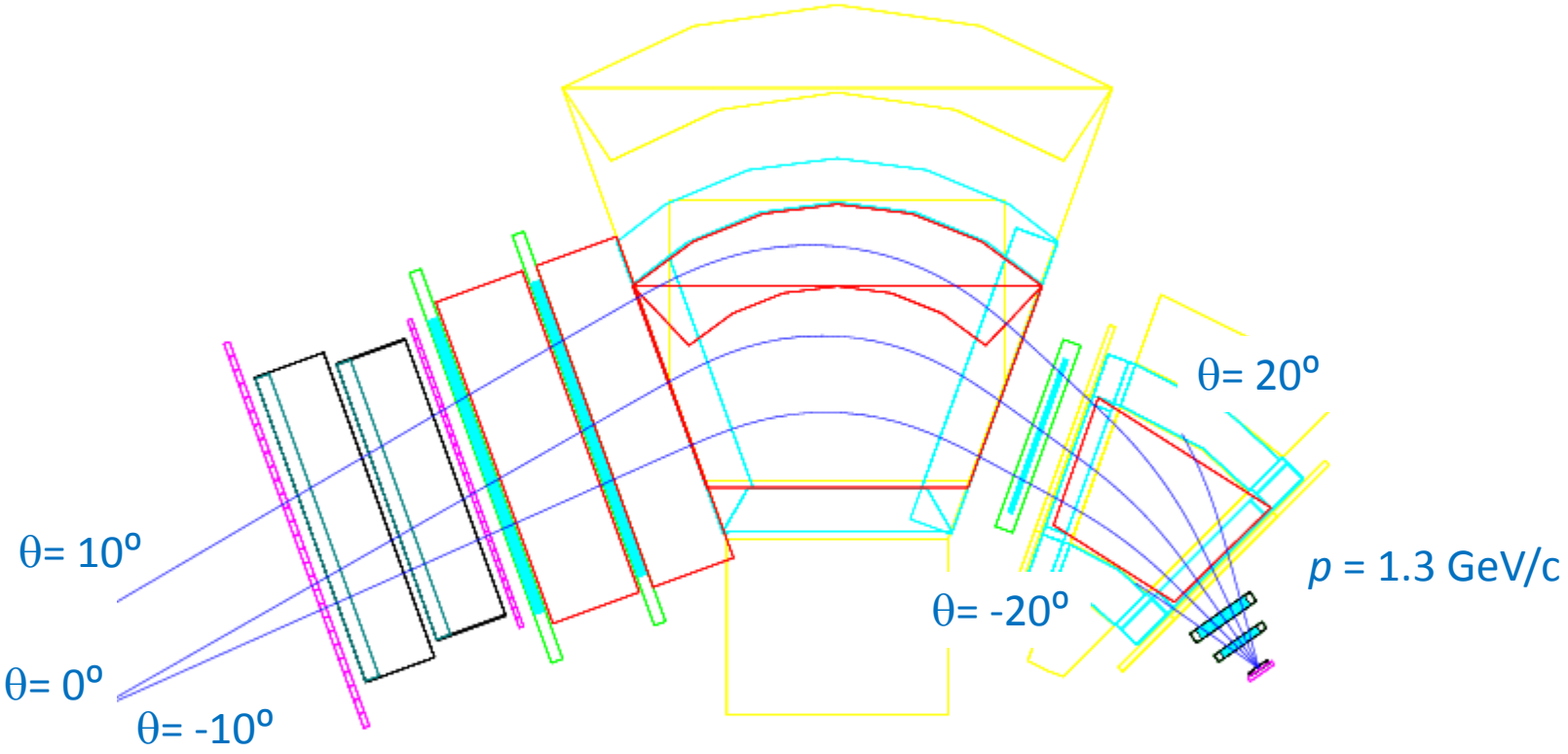


SksPlus Track @θ=0°

p **= 1.0 ~ 1.8 GeV/c**

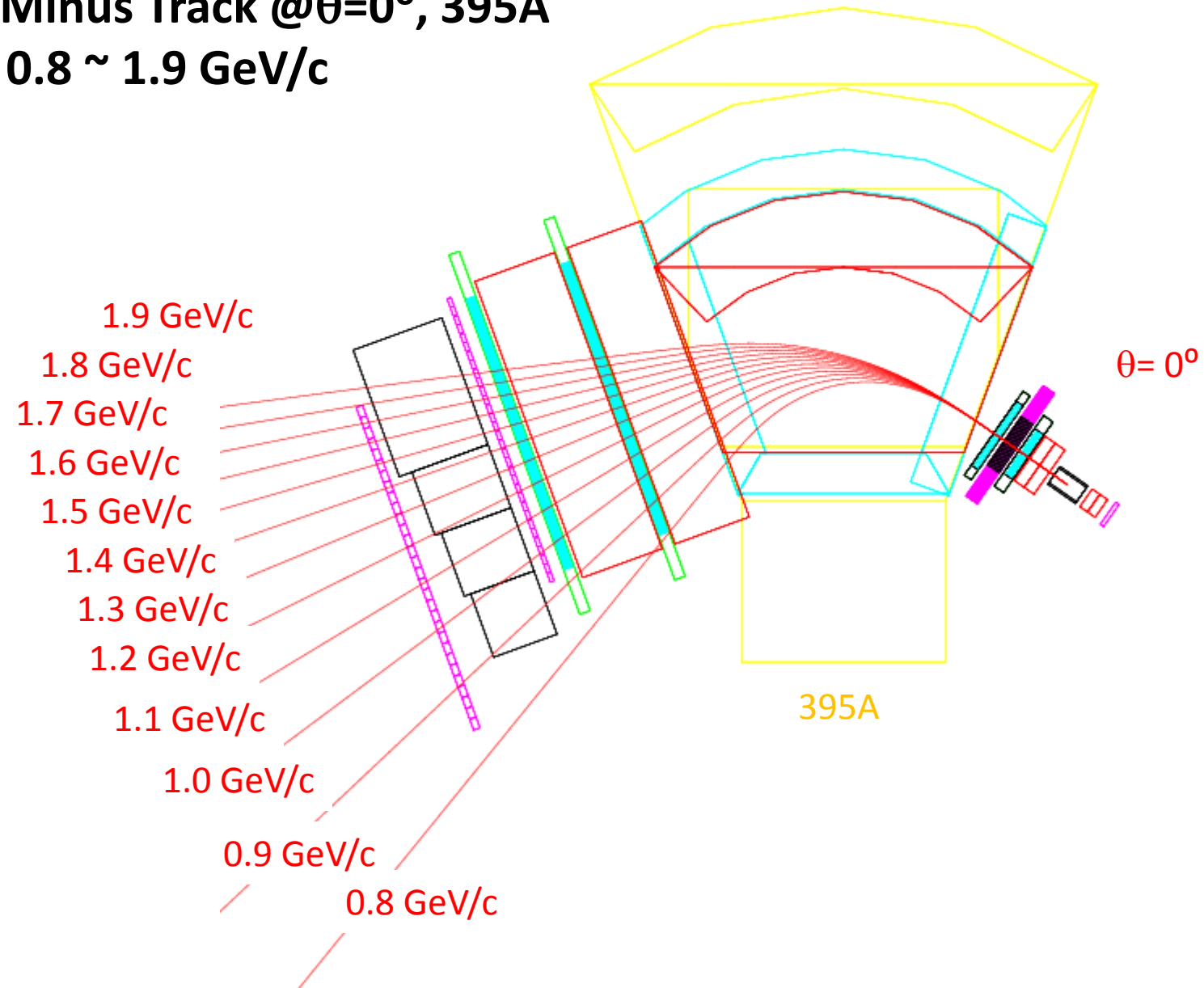


SksPlus Track @*p*=1.3 GeV/c
θ = 0°, ±10°, ±20°

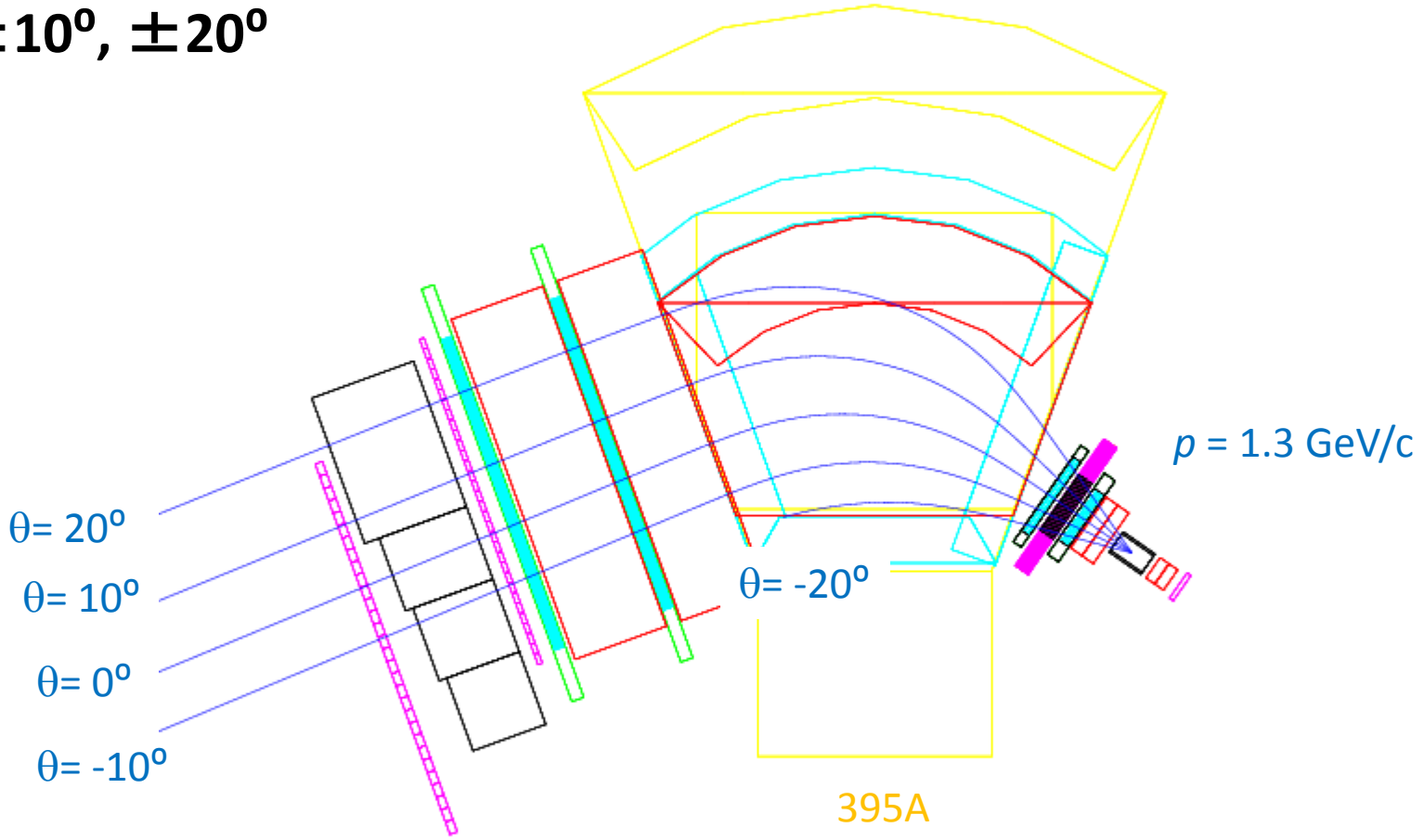


SksMinus Track @θ=0°, 395A

p **= 0.8 ~ 1.9 GeV/c**

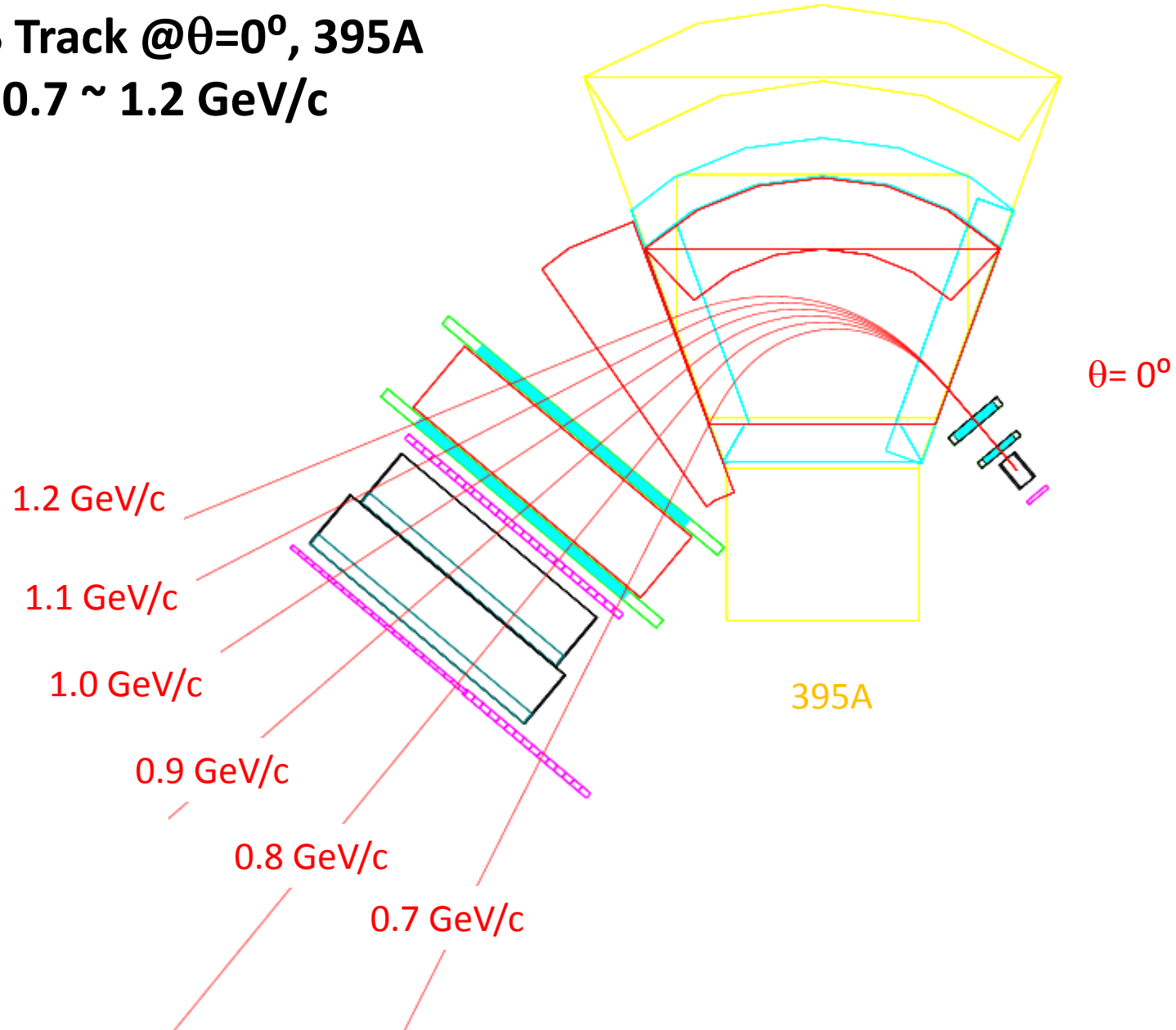


SksMinus Track @*p*=1.3 GeV/c, 395A
θ = 0°, ±10°, ±20°

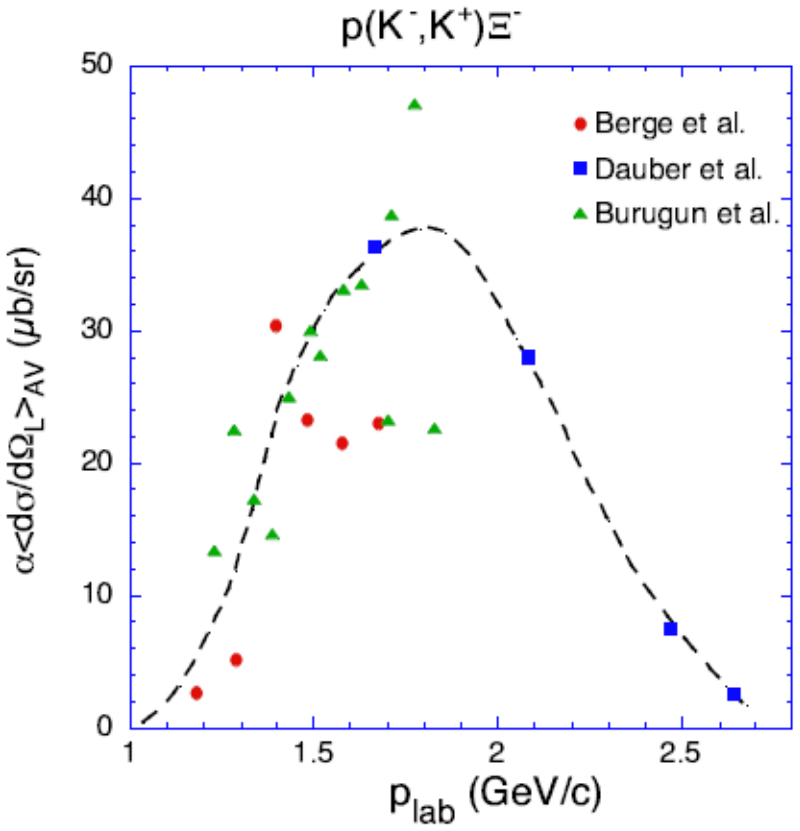


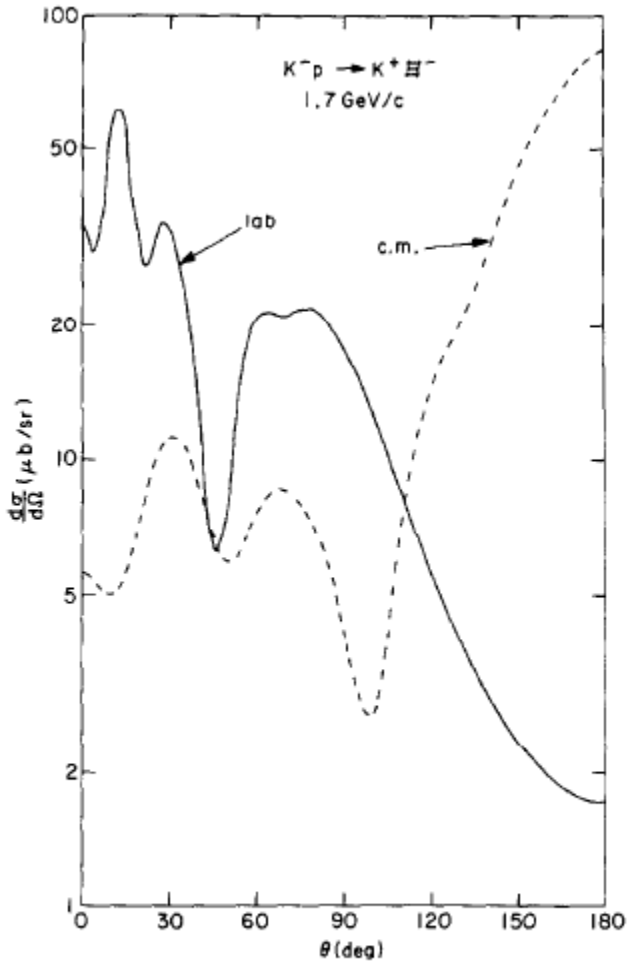
SKS Track @θ=0°, 395A

p **= 0.7 ~ 1.2 GeV/c**



Cross Section





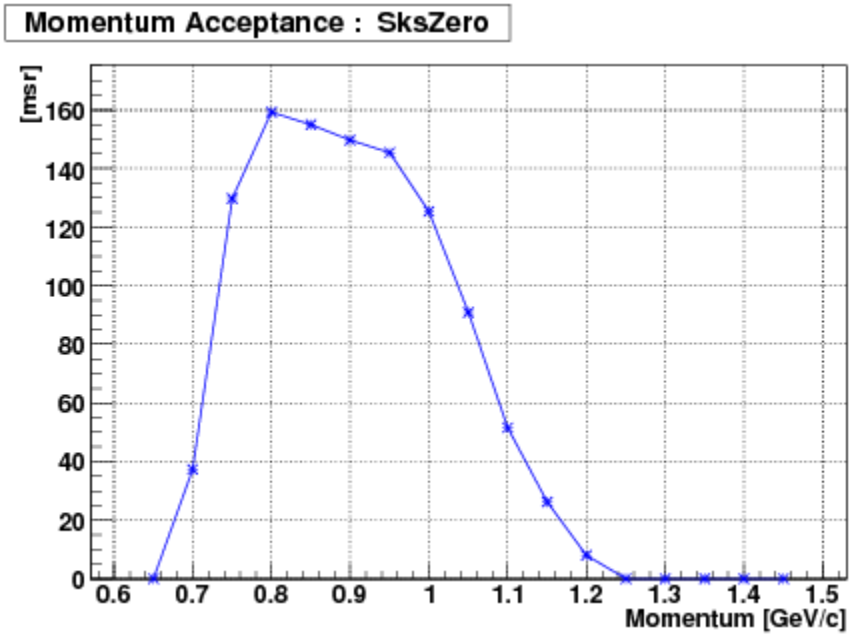
C.B.Dover & A.Gal
Ann. of Phys. 146(1983)309

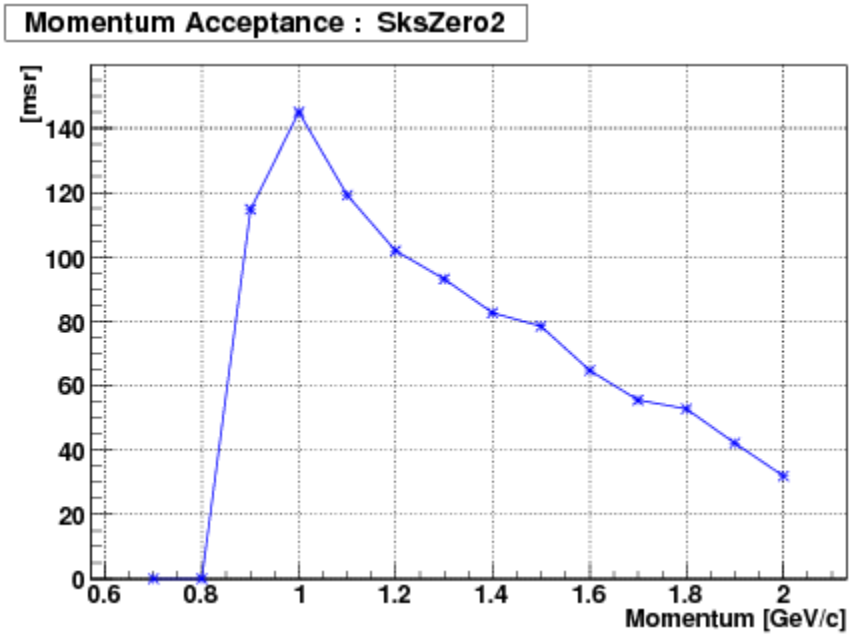
FIG. 4. Angular distributions for the $K^- p \to K^+ \Xi^-$ reaction at 1.7 GeV/c in the center-of-mass dashed line) and lab (solid line) systems, from the data of Dauber *et al.* [14].

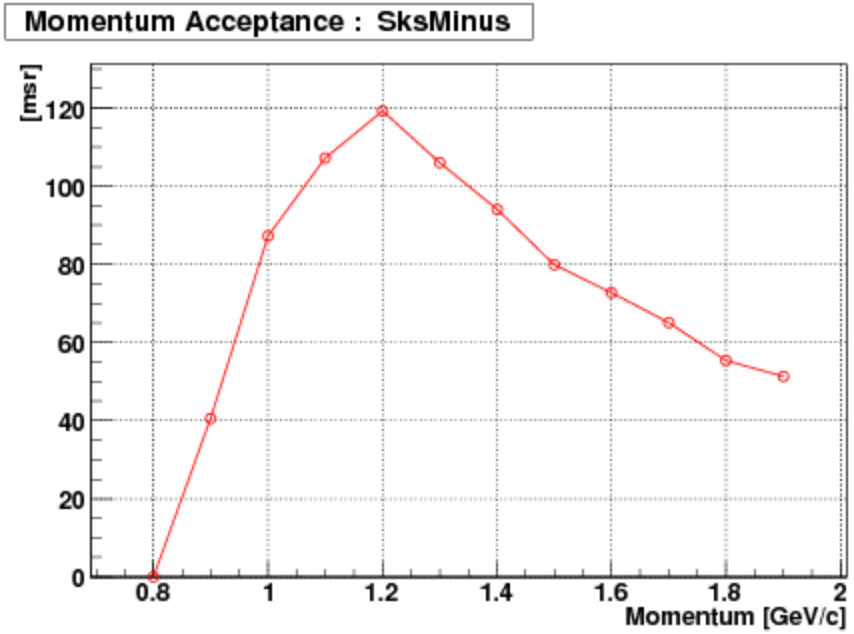
p = 1.65 GeV/c, ^{12}C, $1.7^o < \theta_{lab} < 13.6^o$ average
=> 35 ± 4 μb/sr

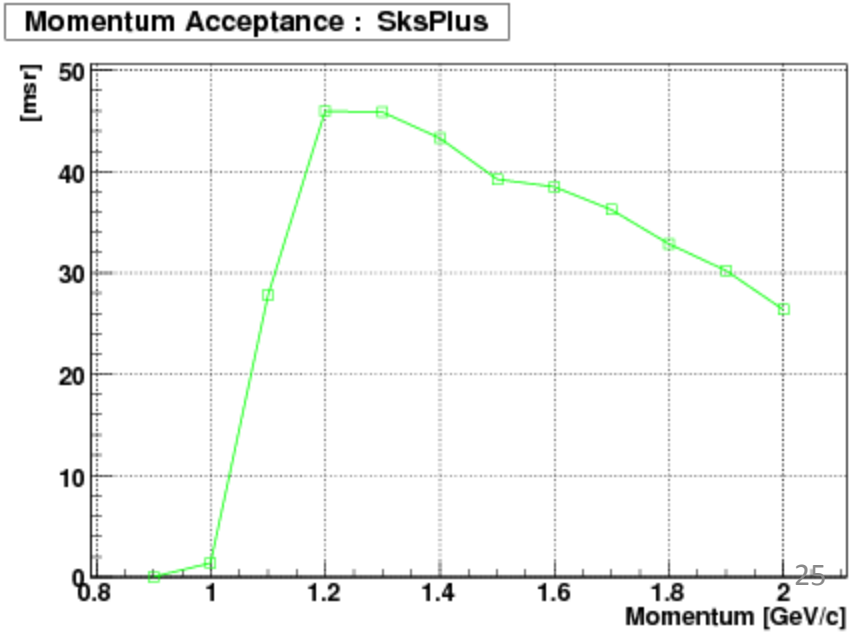
T.Iijima et al., NPA546(1992)588

Momentum Acceptance

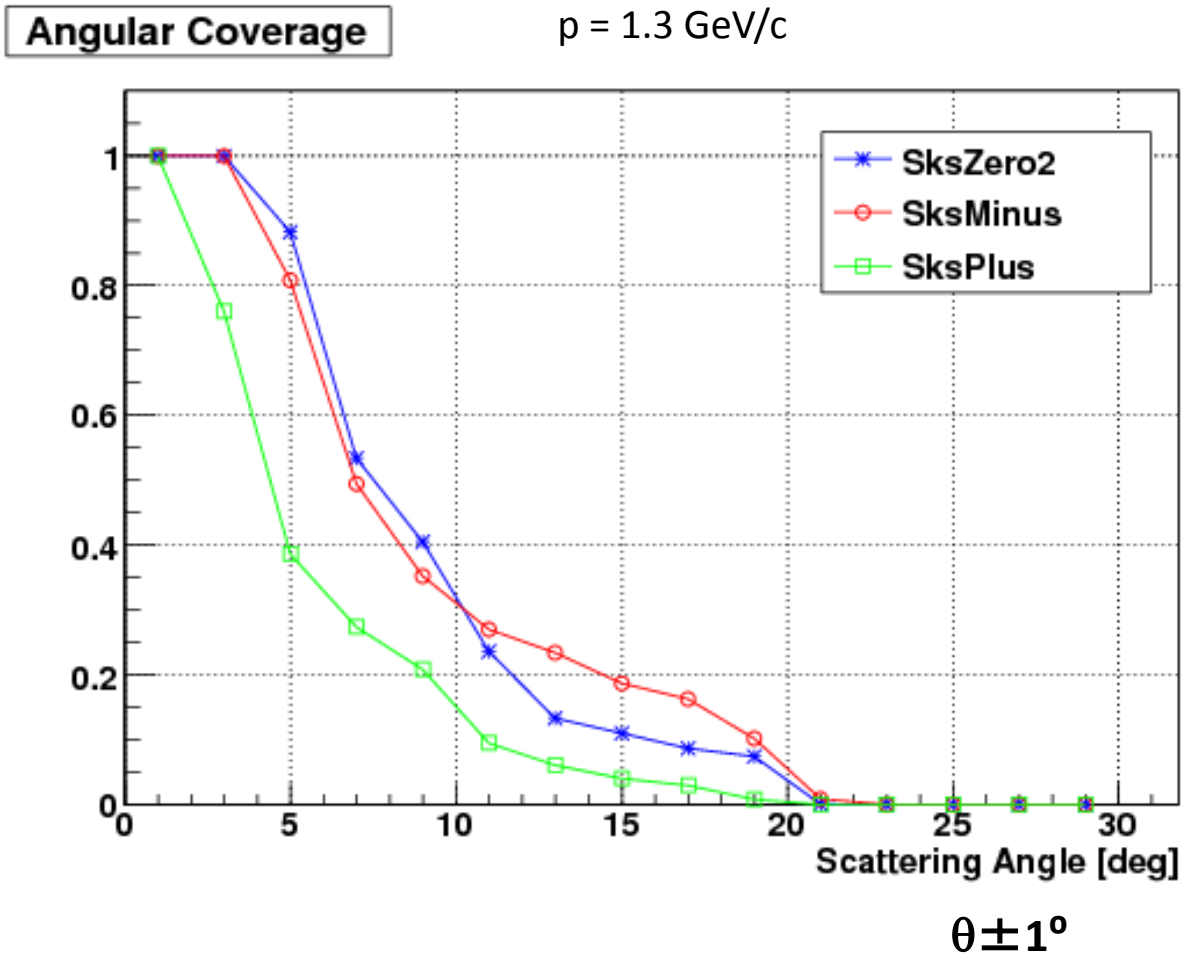








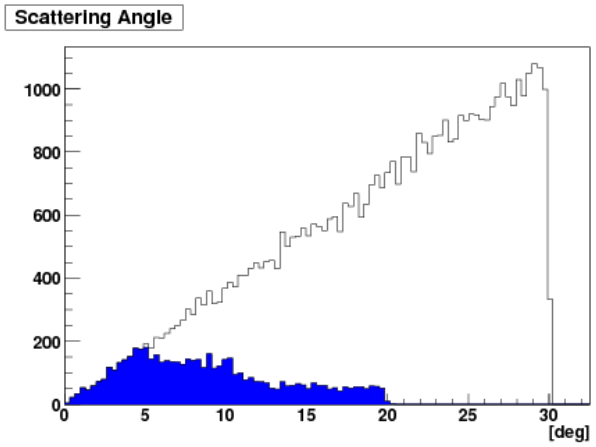
Angular Coverage

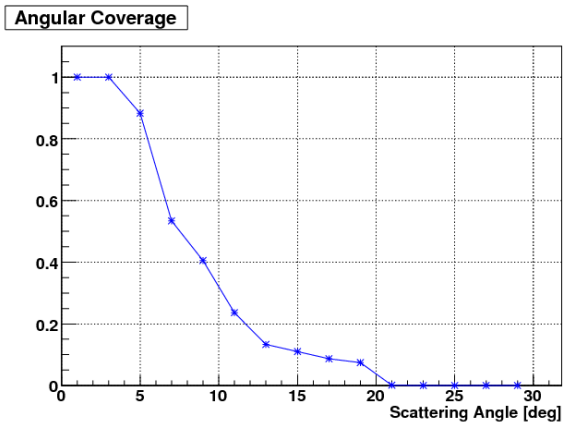


Angular Coverage

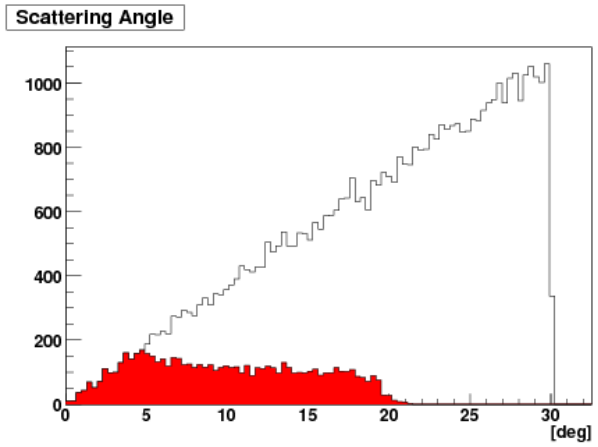
p = 1.3 GeV/c

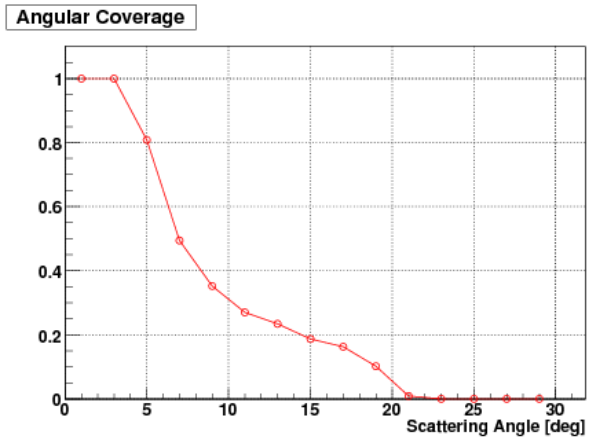
SksZero2



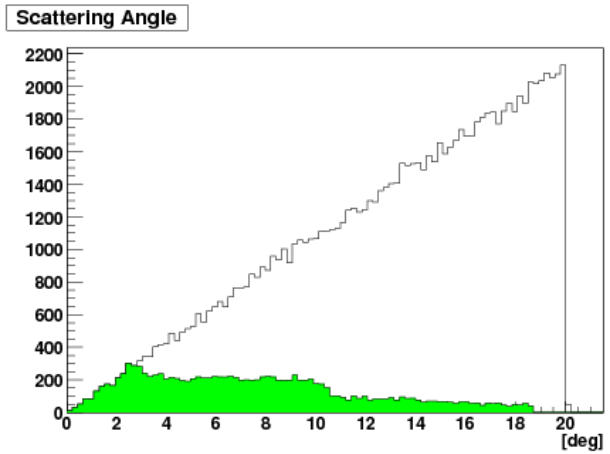


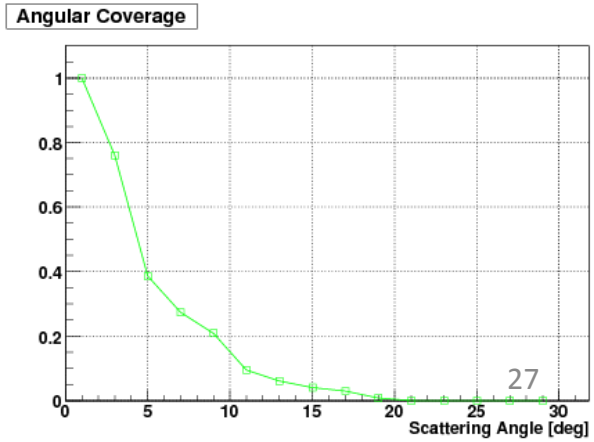
SksMinus



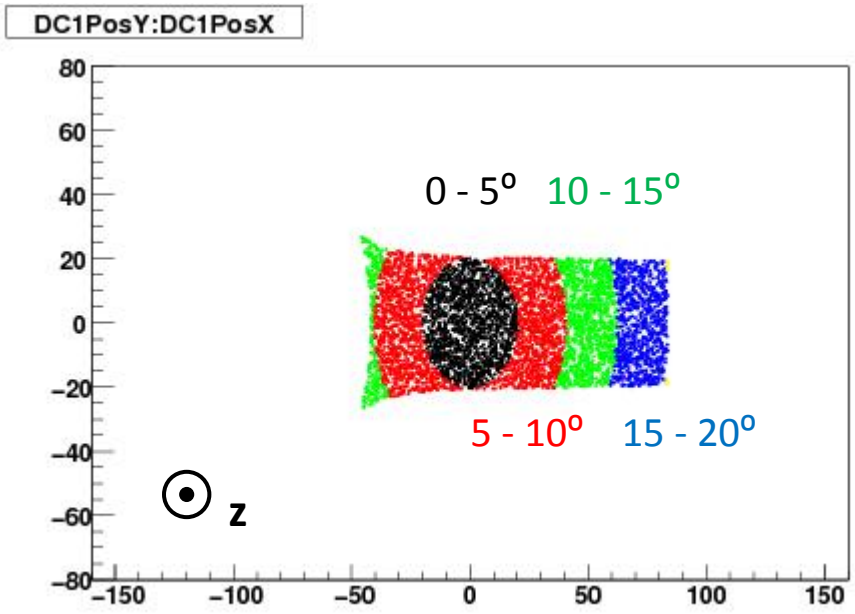


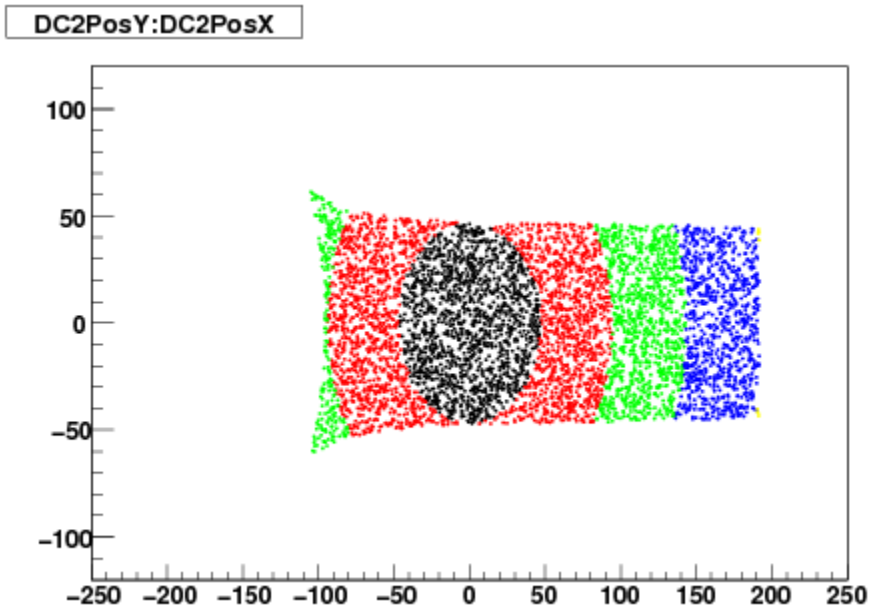
SksPlus

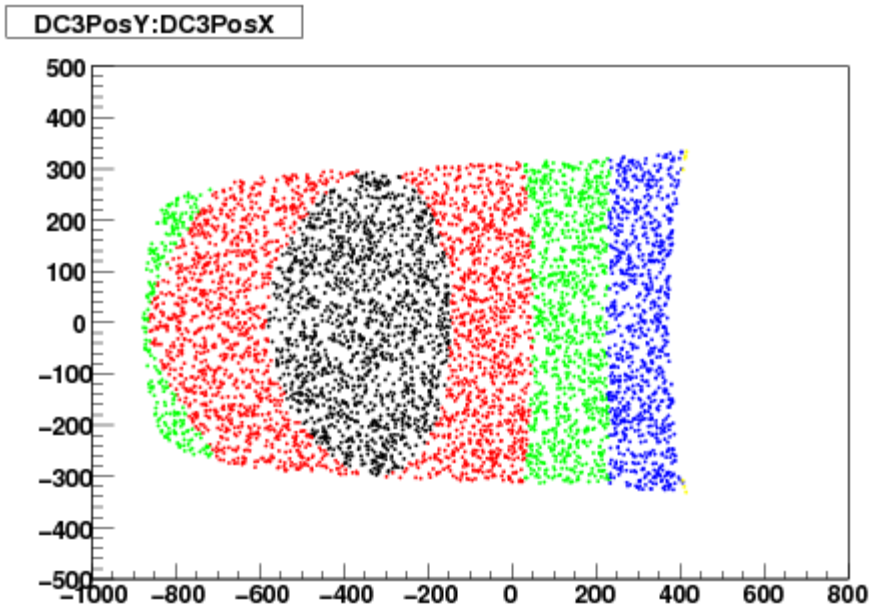


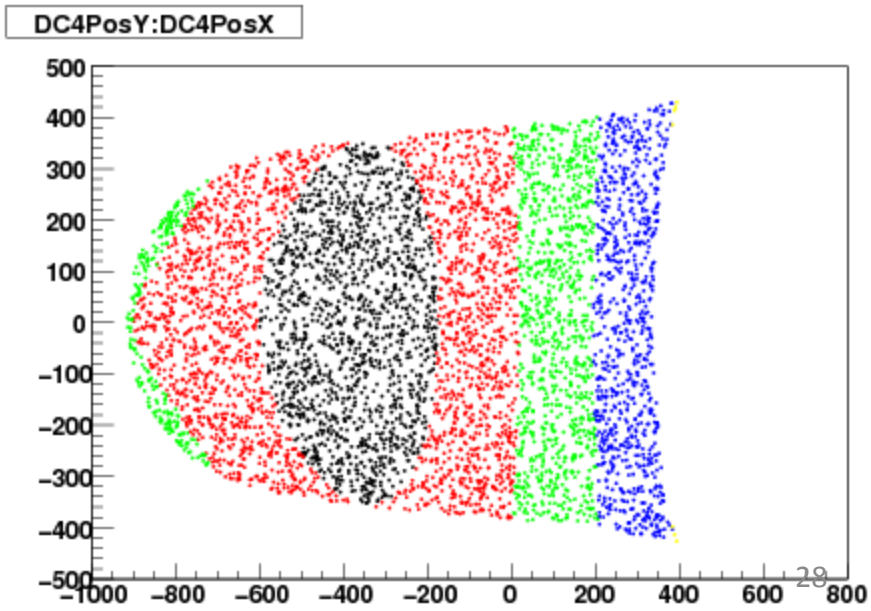


SksZero2 p = 1.3 GeV/c *Triggered scattering particle profile*

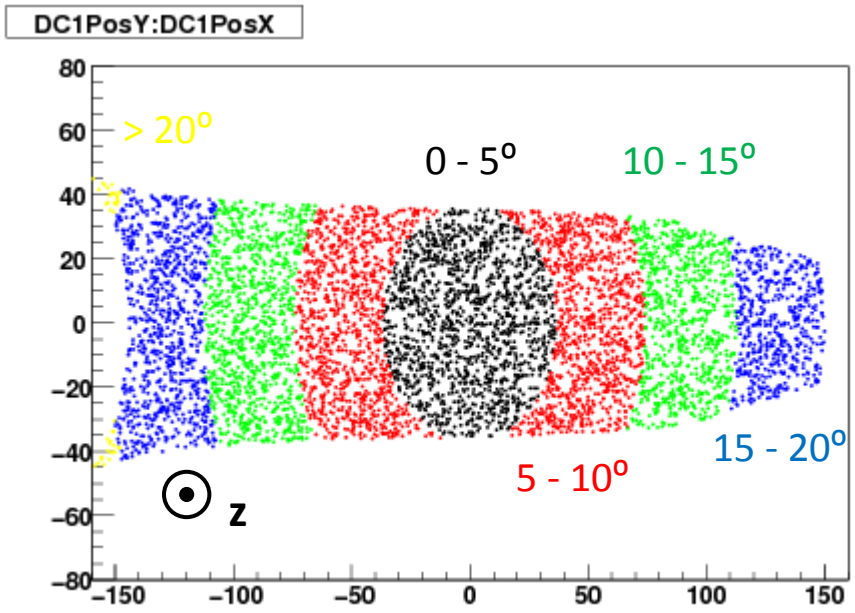


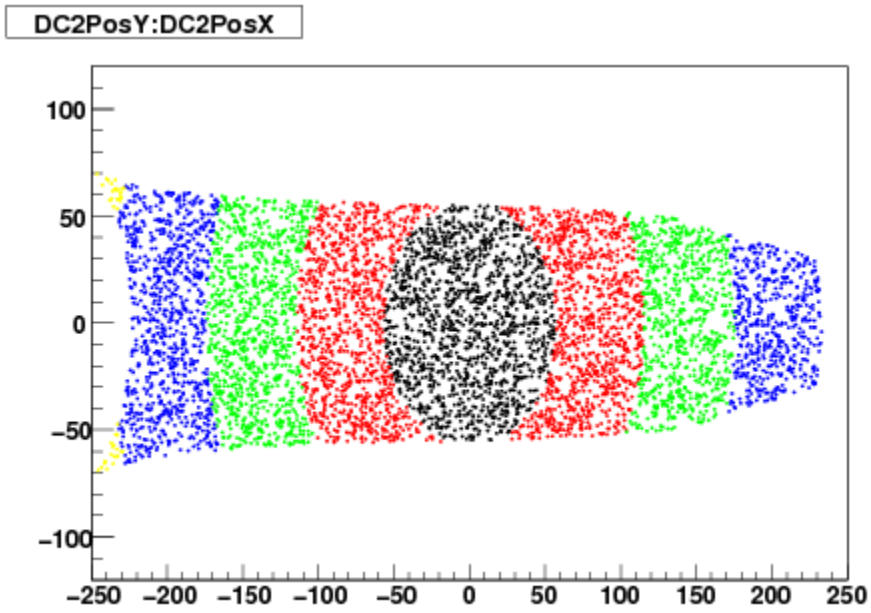


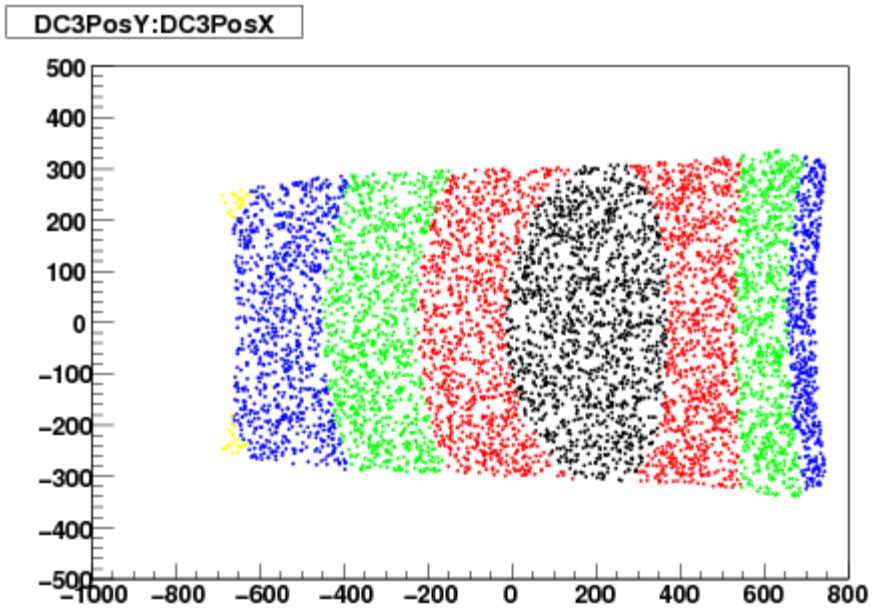


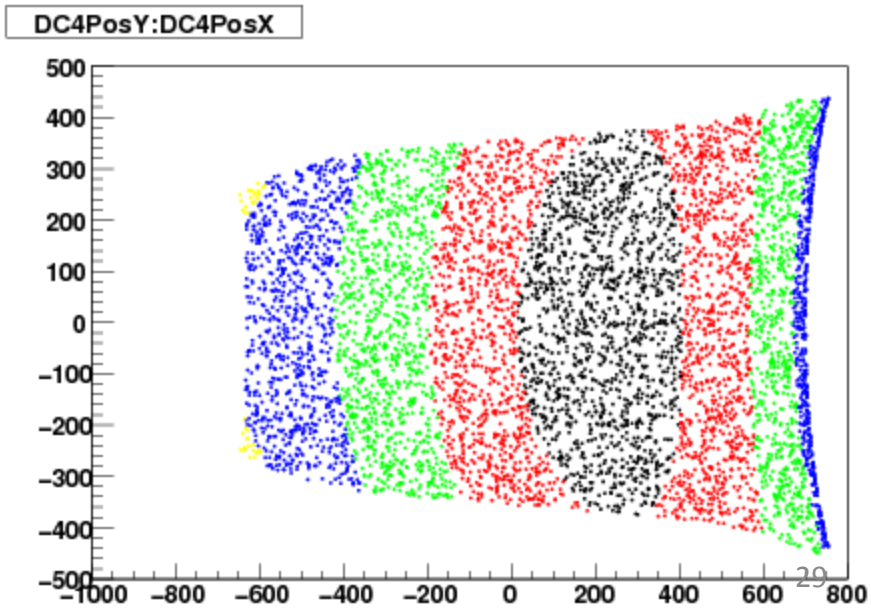


SksMinus p = 1.3 GeV/c *Triggered scattering particle profile*

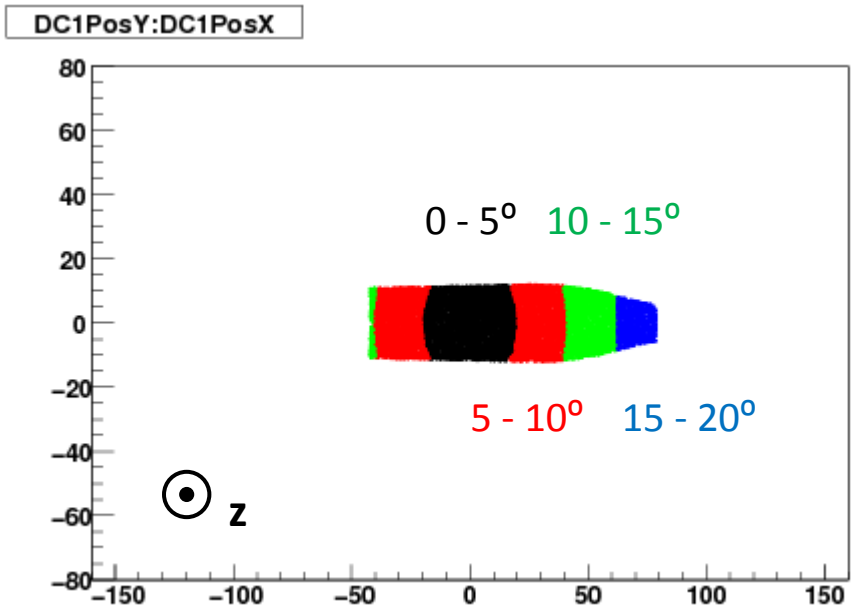


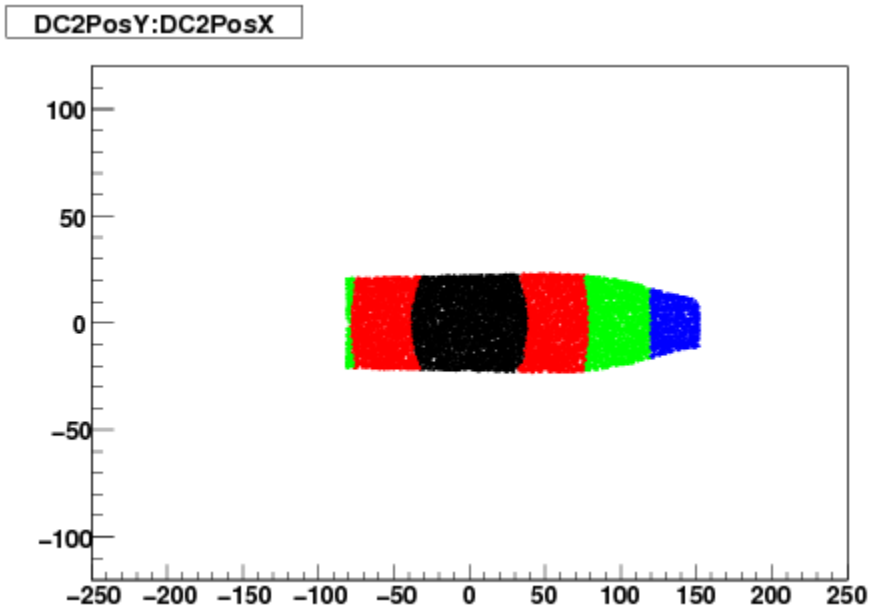


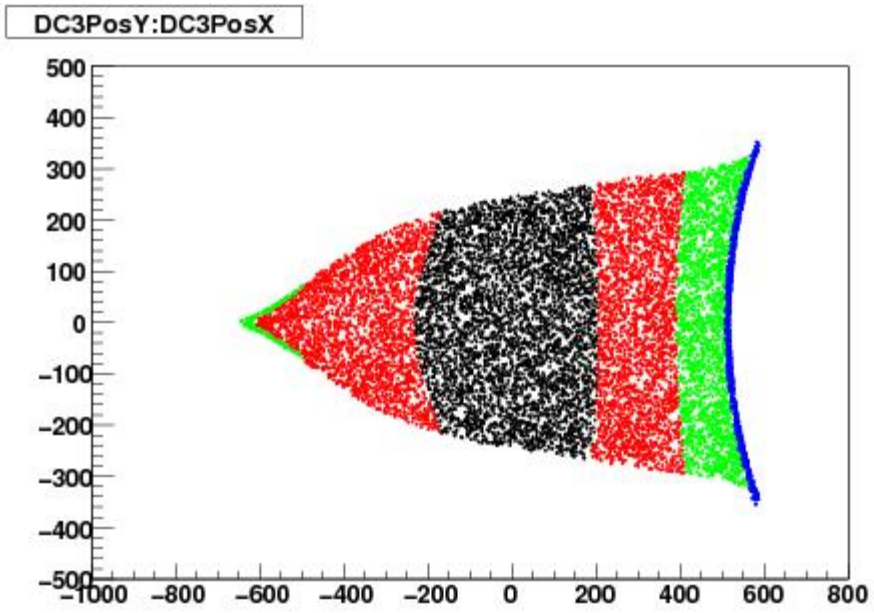


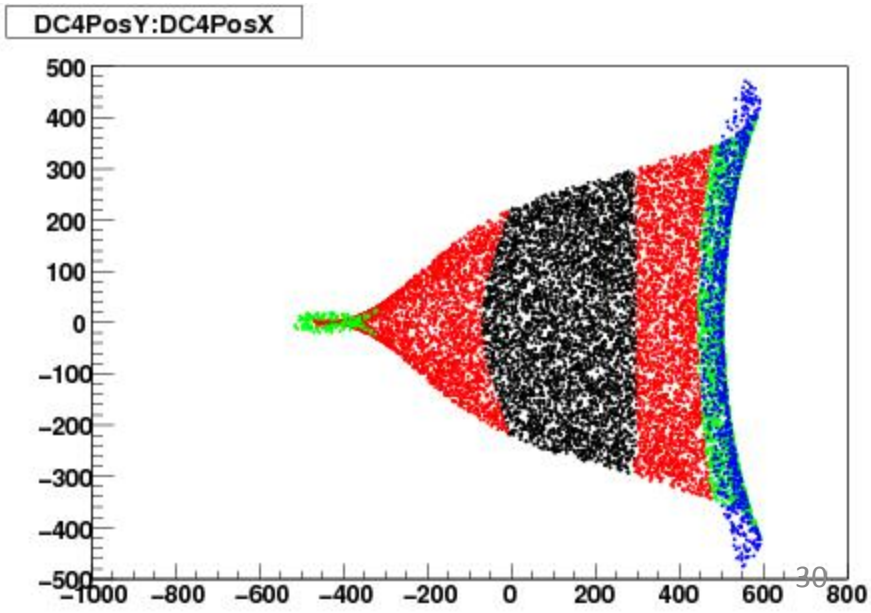


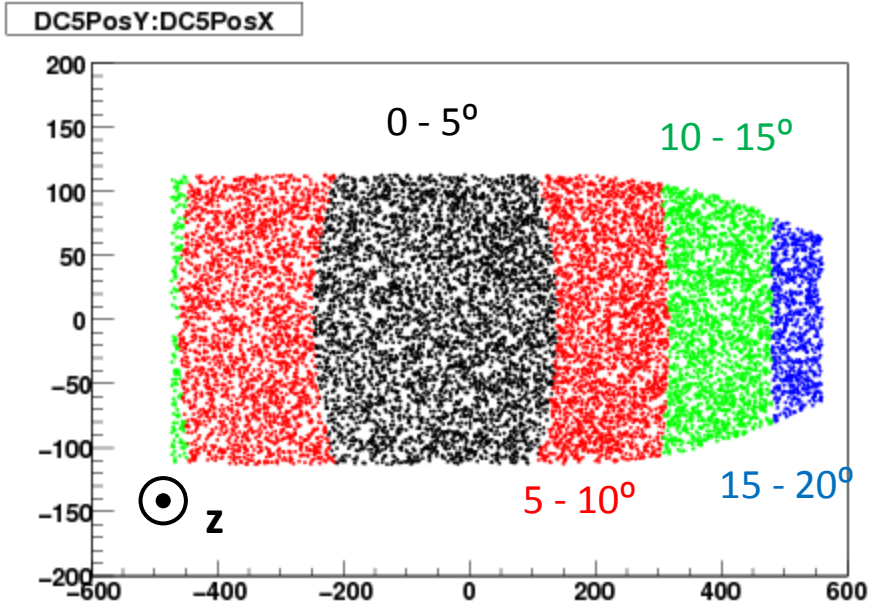
SksPlus p = 1.3 GeV/c *Triggered scattering particle profile*



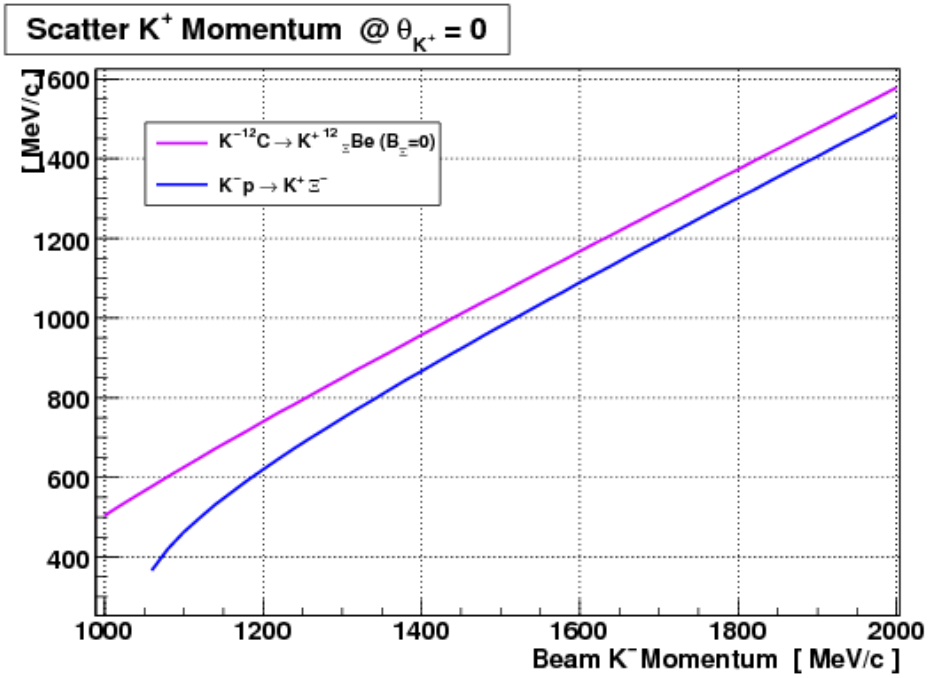




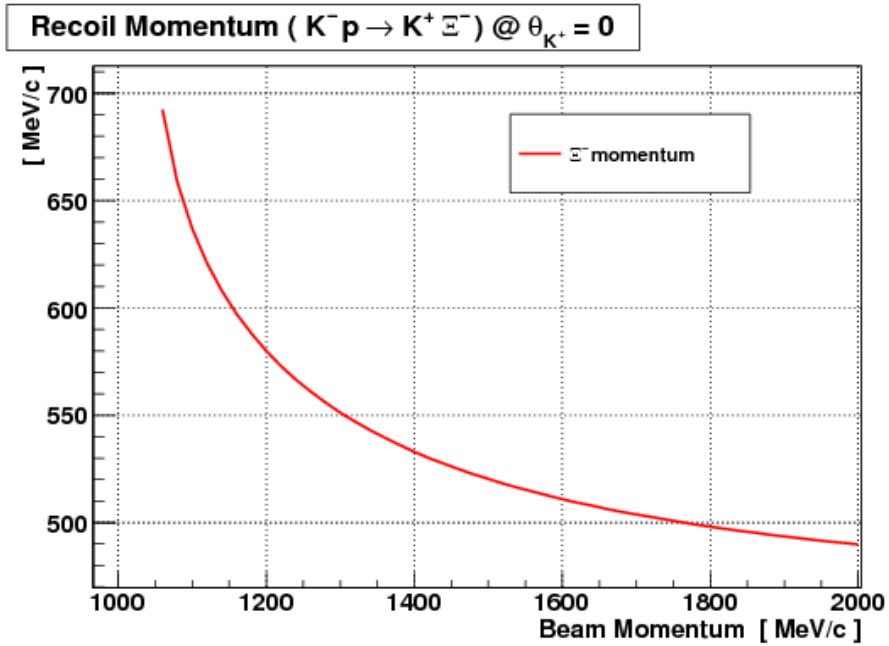



DC5PosY:DC5PosX
0 - 5°
10 - 15°
5 - 10°
15 - 20°
z
200
150
100
50
0
−50
−100
−150
−200
−600
−400
−200
0
200
400
600

Beam momentum vs. Scatter momentum



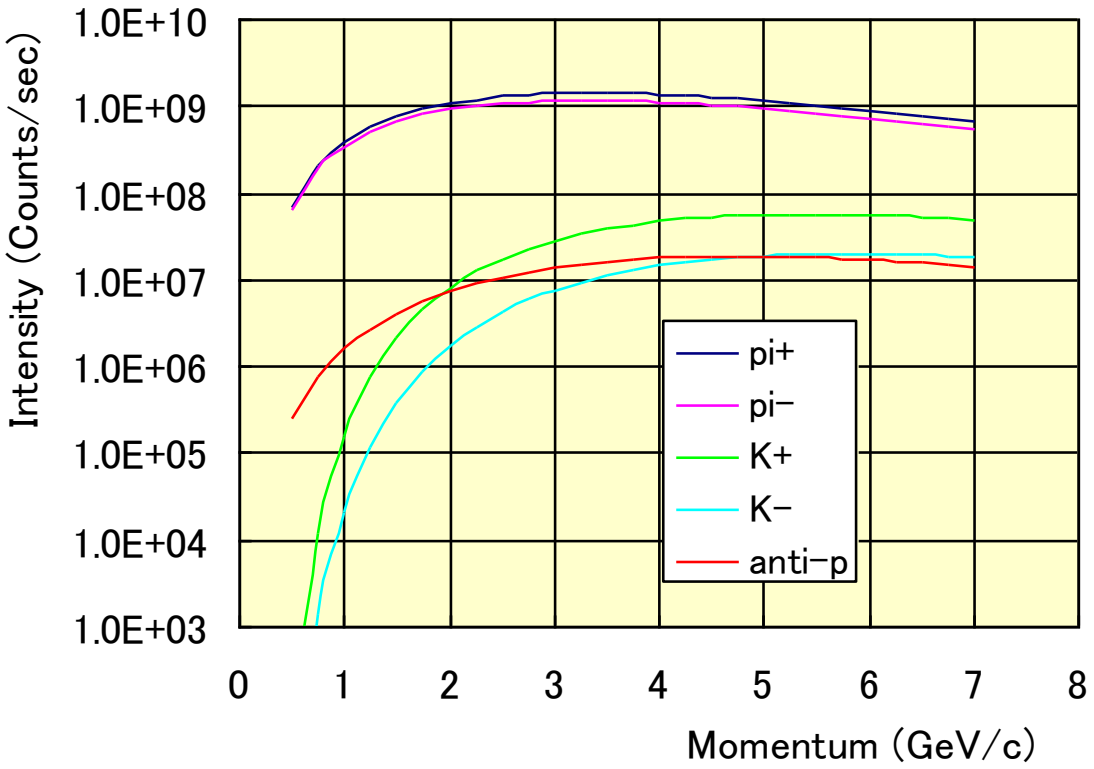
Recoil momentum



- p(K+) ≈ p(K-) – 500MeV/c (for elem. proc.)

Secondary Beam Intensity

50GeV-15μA, Ni-54mm,
BL-Length=50 m,
Acceptance:2msr%

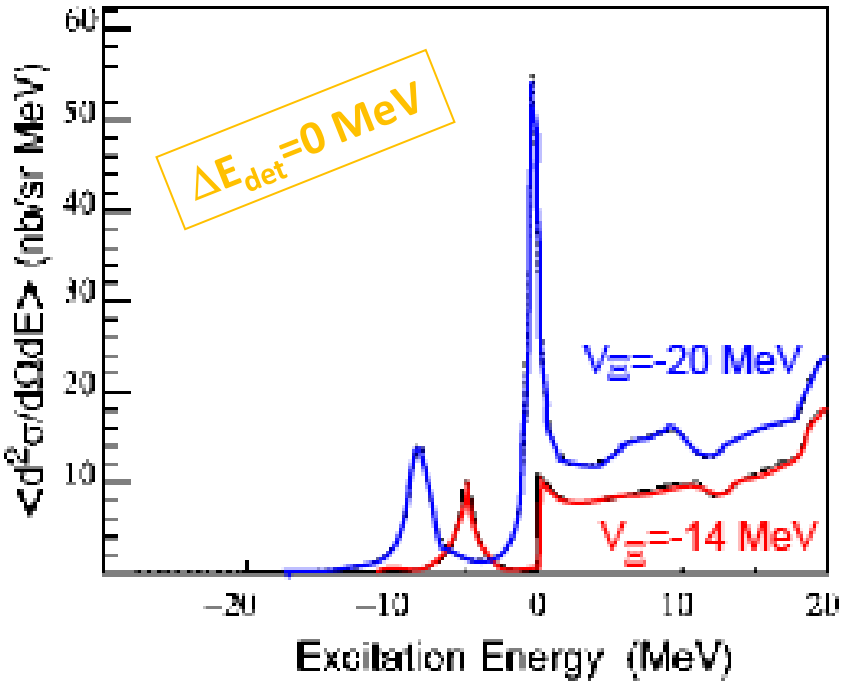


K1.8 (270 kW)の場合

p(K-)	Intensity	
1.8	1.4 x 10^6	<-E05
1.7	1.1 x 10^6	
1.6	0.8 x 10^6	
1.5	0.5 x 10^6	<-E13
1.4	0.2 x 10^6	

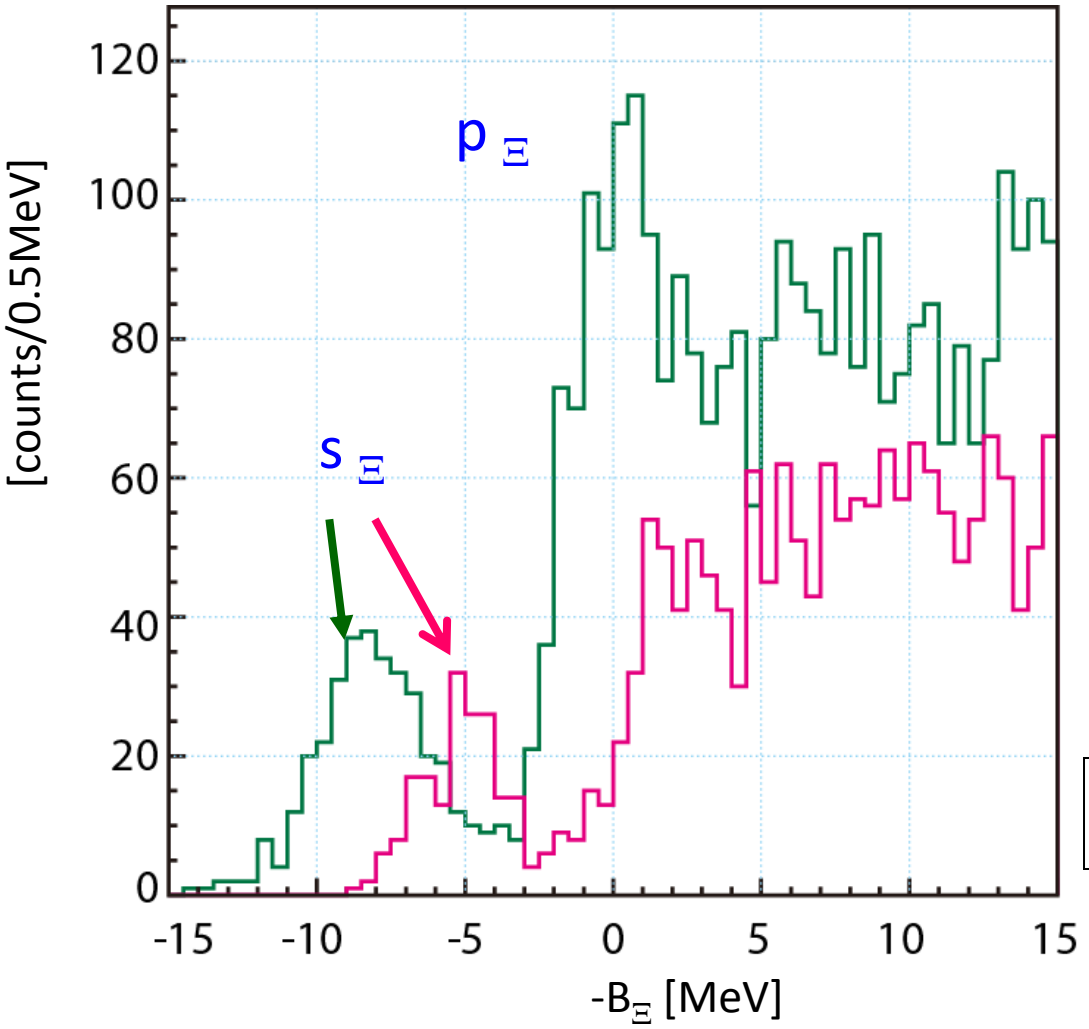
- 図は720kW時でK1.8とも若干ずれるが傾向は変わらないとして表のように見積もる。
- Beam momentumを下げることによるIntensityの減少は比較的大きい。

$^{12}C(K^-,K^+)^{12}{}_{\Xi}Be$ spectra calculated with Woods-Saxon potentials



P.Khaustov et al., PRC61(2000)054603

Expected $^{12}_{\Xi}$Be Spectrum

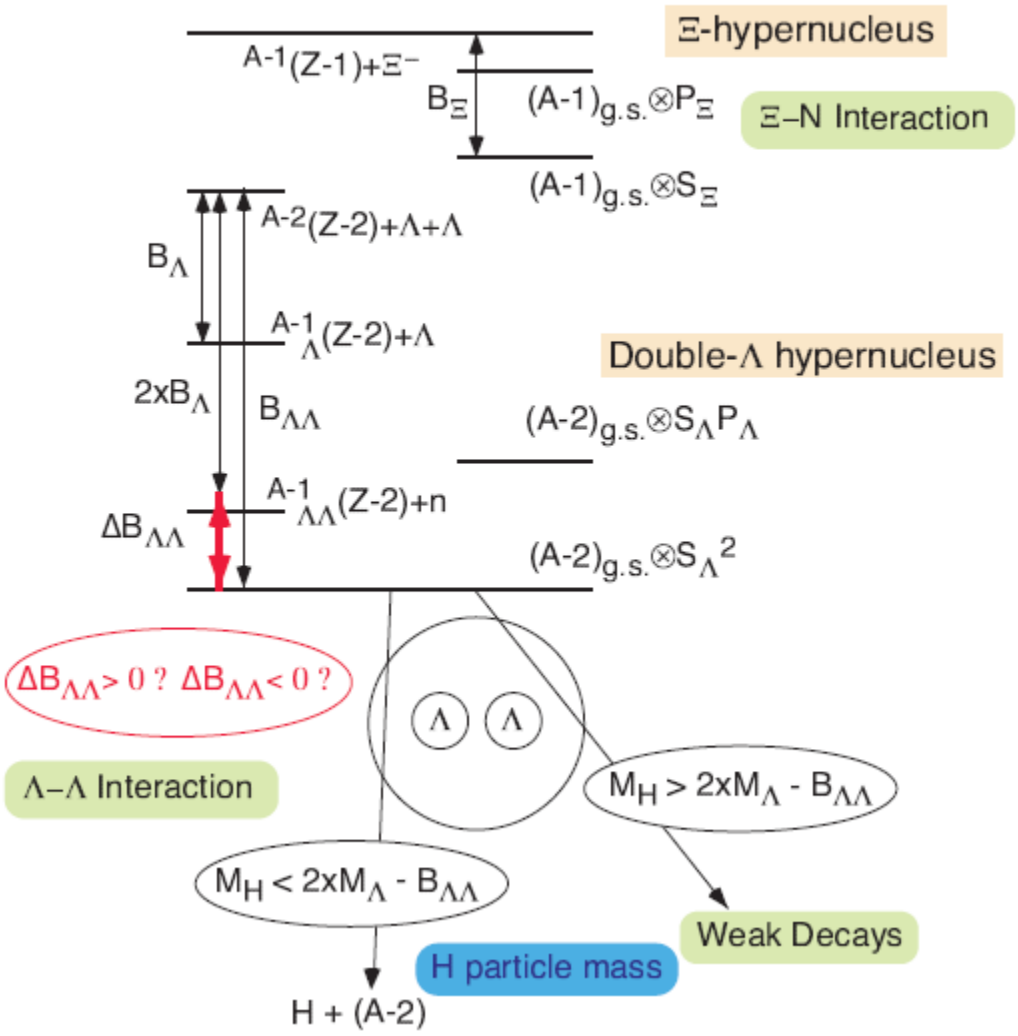


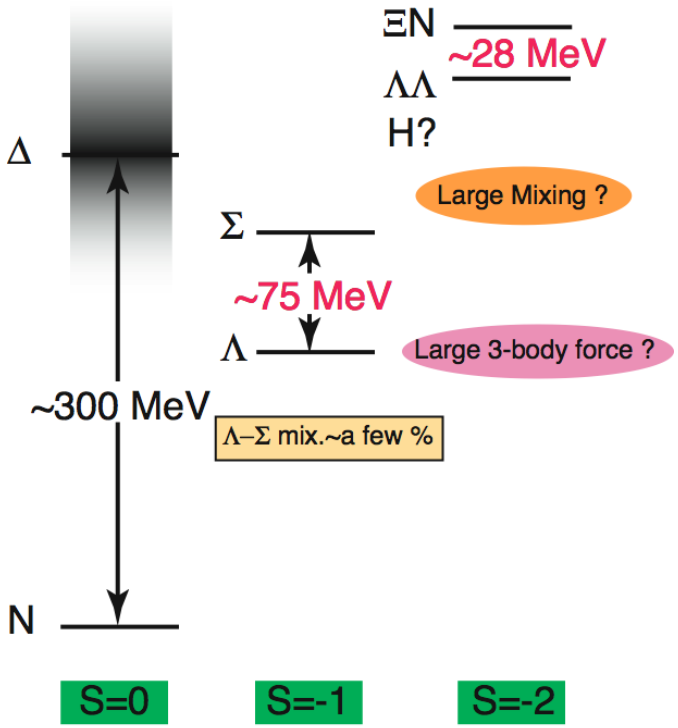
V_{Ξ}= -20MeV

V_{Ξ}= -14MeV

$\Delta E_{meas.}$ = 3 MeV_{FWHM}

Energy Spectrum of S=-2 systems





Missing Mass

$$\begin{aligned} M^2 &= (E_B + m_T - E_S)^2 - (\vec{p}_B - \vec{p}_S)^2 \\ &= m_B^2 + m_S^2 + m_T^2 + 2\left(m_T E_B - m_T E_S - E_B E_S + p_B p_S \cos\theta\right), \end{aligned} \tag{1}$$

Missing Mass Resolution

$$\Delta M^2 = \Delta^2_{Beam} + \Delta^2_{Scatt} + \Delta^2_{\theta} + \Delta E^2_{strag}$$

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

$$\frac{\partial M}{\partial p_B} = \frac{1}{M}[\beta_B(m_T - E_S) + p_S \cos\theta], \tag{3}$$

$$\frac{\partial M}{\partial p_S} = -\frac{1}{M}[\beta_S(m_T + E_B) - p_B \cos\theta], \tag{4}$$

$$\frac{\partial M}{\partial \theta} = -\frac{1}{M} p_B p_S \sin\theta, \tag{5}$$