Analysis status of $d(K^{-}, N)$"$\pi\Sigma$"
at J-PARC K1.8BR beam line

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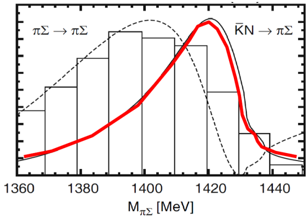
Content

Nature of $\Lambda(1405)$

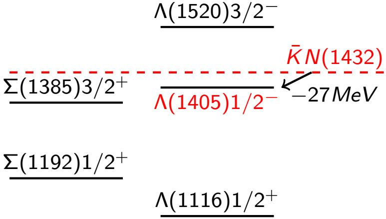
$\Lambda(1405)$

- $I(J^P) = 0\left(\frac{1}{2}^-\right)$
- $mass = 1405.1^{+1.3}_{-1.0} MeV$
- $\Gamma = 50.5 \pm 2.0 MeV$

C. Patrignani et al.(PDG), Chin. Phys. C, 40, 100001 (2016).



D. jido et el. Nucl Phys A725(2003), 181



$\Lambda(1520)3/2^-$

$\bar{K}N(1432)$

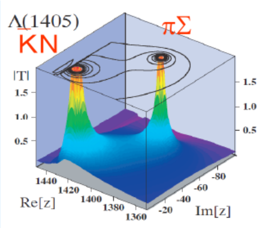
$\Sigma(1385)3/2^+$

$\Lambda(1405)1/2^-$

$-27MeV$

$\Sigma(1192)1/2^+$

$\Lambda(1116)1/2^+$

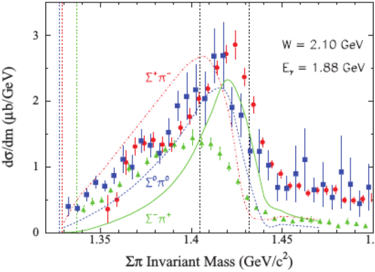


ChU model, T. Hyodo

Recent experimental studies

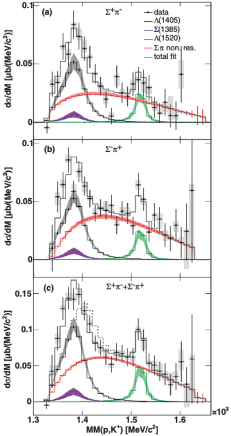
- p/γ induced experiments
  How these spectra couple to the $\bar{K}N$ pole or the $\pi\Sigma$ pole is still controversial.

$\gamma p \to K^+\pi^-\Sigma^+, K^+\pi^0\Sigma^0, K^+\pi^+\Sigma^-$



CLAS collaboration: Phys Rev C87, 035206

$pp \to K^+p\pi^-\Sigma^+, K^+p\pi^+\Sigma^-$

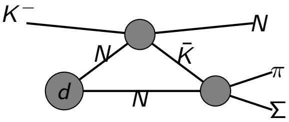


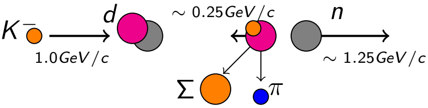
HADES collaboration:
Phys Rev C87, 025201

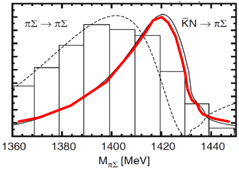
Kaon induced reaction is desired.

$d(K^-, N)$ reaction

- The $d(K^-, N)$ reaction measrued at $\theta_N = 0$ is expected to enhance an **S-wave** $\bar{K}N \to \pi\Sigma$ scattering even **below the $\bar{K}N$ threshold**.



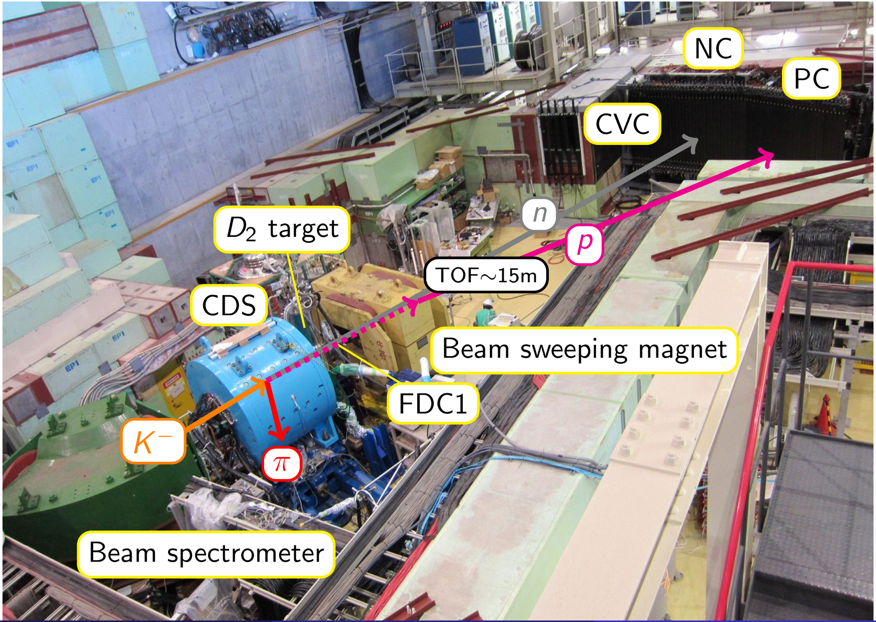




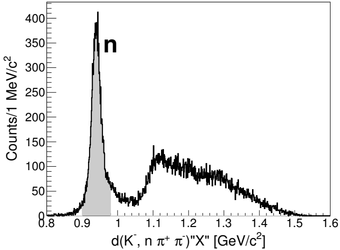
- All final states are identified to decompose the $I = 0$ and the $I = 1$ amplitudes.

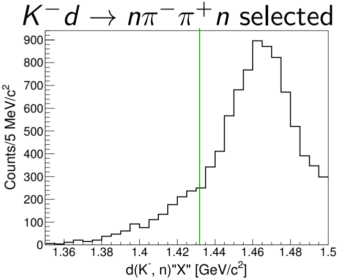
$d(K^-, n)"\pi^\pm\Sigma^\mp"$	I=0,1	Σ(1385) (I=1, P-wave) excepted to be suppressed Λ(1405) (I=0, S-wave) non-resonant (I=1,0) (S, P, D)
$d(K^-, n)"\pi^0\Sigma^0"$	I=0	Λ(1405)(I=0, S-wave), non-resonant (S, P, D)
$d(K^-, p)"\pi^-\Sigma^0"$	I=1	non-resonant (S, P, D) Σ(1385) (P-wave) excepted to be suppressed

The K1.8BR experimental setup



$K^-d \to n\pi^+\pi^-n$ selection



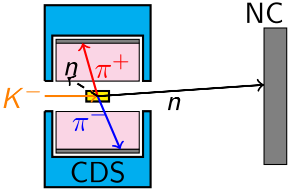

$K^-d \to n\pi^-\pi^+n$ selected

Signal

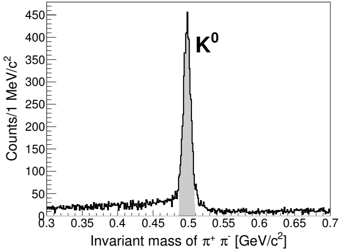
- $K^-d \to \underset{\text{detect}}{n}\ \pi^\pm\ \Sigma^\mp \to \underset{\text{detect}}{n\ \pi^\pm}\pi^\mp \underset{\text{missing}}{n}$

Background

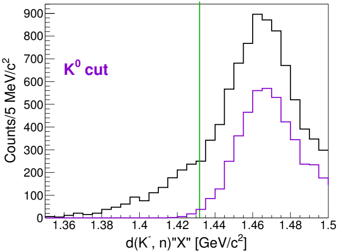
- $K^-d \to \underset{\text{detect}}{n}\ K^0\ \underset{\text{missing}}{n_{spec}}(K^0 \to \pi^+\pi^-)$
- $K^-d \to \pi^\pm\ \Sigma^\mp\ \underset{\text{missing}}{n_{spec}}\ (\Sigma^\pm \to \underset{\text{detect}}{n\ \ \pi^\pm})$



$K^-d \to nK^0n_{spec}$ rejection



$K^-d \to n\pi^-\pi^+n$ selected

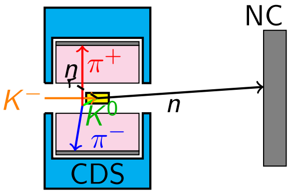


Signal

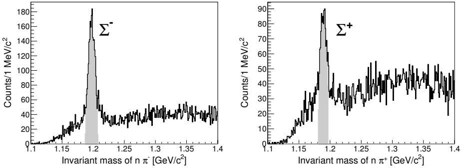
- $K^-d \to \underset{\text{detect}}{n}\ \pi^\pm\Sigma^\mp \to \underset{\text{detect}}{n\ \pi^\pm}\pi^\mp\underset{\text{missing}}{n}$

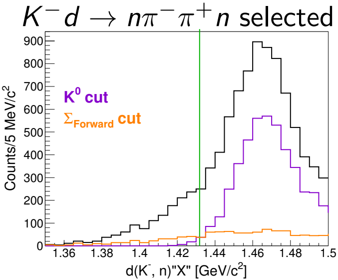
Background

- $K^-d \to \underset{\text{detect}}{n}\ K^0\ \underset{\text{missing}}{n_{spec}}(K^0 \to \pi^+\pi^-)$
- $K^-d \to \pi^\pm\ \Sigma^\mp\ \underset{\text{missing}}{n_{spec}}\ (\Sigma^\pm \to \underset{\text{detect}}{n}\ \ \pi^\pm)$



$K^-d \rightarrow \pi^\pm\Sigma^\mp n_{spec}$ rejection



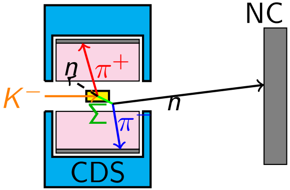


Signal

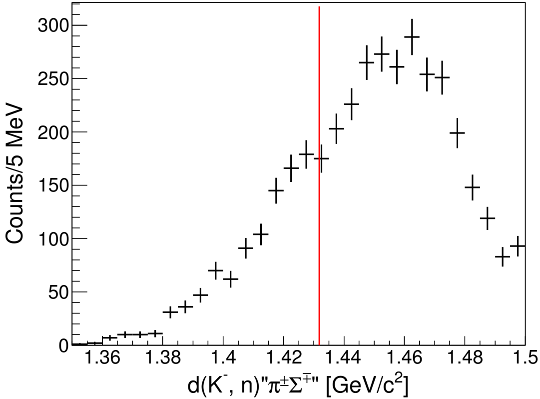
- $K^-d \rightarrow \underset{\text{detect}}{n\ \pi^\pm}\ \Sigma^\mp \rightarrow \underset{\text{detect}}{n\ \pi^\pm}\pi^\mp \underset{\text{missing}}{n}$

Background

- $K^-d \rightarrow \underset{\text{detect}}{n}\ K^0\ \underset{\text{missing}}{n_{spec}}(K^0 \rightarrow \pi^+\pi^-)$
- $K^-d \rightarrow \pi^\pm\ \Sigma^\mp\ \underset{\text{missing}}{n_{spec}}\ (\Sigma^\pm \rightarrow \underset{\text{detect}}{n\ \pi^\pm})$



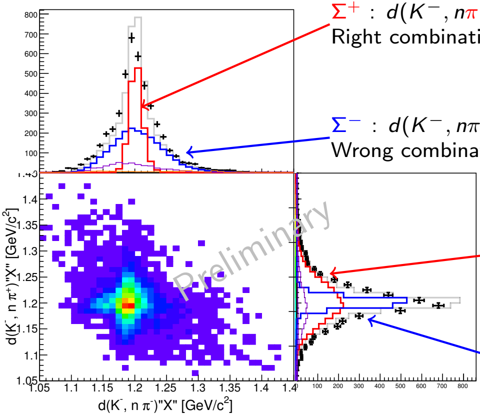
$d(K^-, n)$"$\pi^\pm\Sigma^\mp$" spectrum



K^0 and forward-going Σ are removed.
This spectrum includes both $\pi^+\Sigma^-$ and $\pi^-\Sigma^+$ modes.
→ These modes should be separated.

$\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ identification

Missing mass distributions of $d(K^-, n\pi^\pm)$ are estimated by MC simulations in order to separate the $\Sigma^\mp\pi^\pm$ modes.



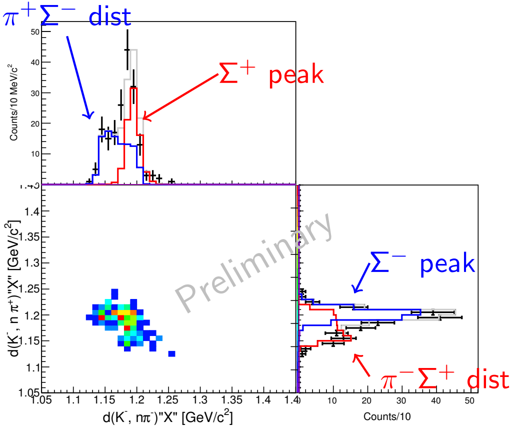
Σ^+ : $d(K^-, n\pi^-)"\pi^+ n"$
Right combination of $n\pi$

Σ^- : $d(K^-, n\pi^-)"\pi^+ n"$
Wrong combination of $n\pi$

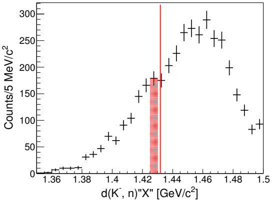
Σ^+ : $d(K^-, n\pi^+)"\pi^- n"$
Wrong combination of $n\pi$

Σ^- : $d(K^-, n\pi^+)"\pi^- n"$
Right combination of $n\pi$

Fitting for $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ separation



Example $d(K^-, n)"X"$
$1.425 \sim 1.430[GeV/c^2]$

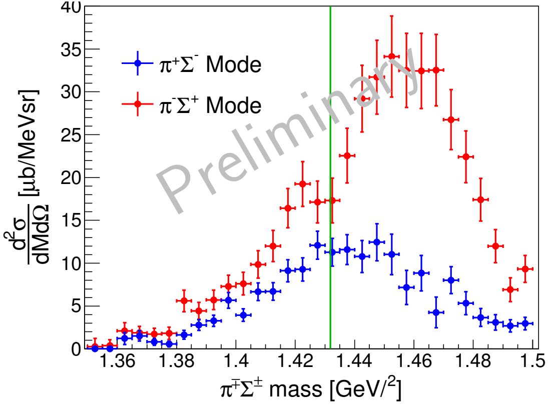


Fittings are done bin by bin
Free parameters

1. Number of $\pi^+\Sigma^-$ events.
2. Number of $\pi^-\Sigma^+$ events.

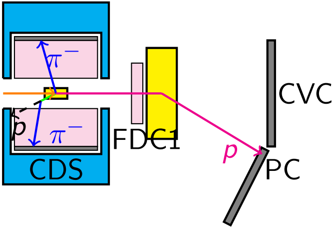
Cross section of $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$

$$(\pi^\pm\Sigma^\mp) \sim \frac{1}{3}|f_{I=0}|^2 + \frac{1}{2}|f_{I=1}|^2 \pm \frac{\sqrt{6}}{3} Re(f_{I=0} f^*_{I=1})$$



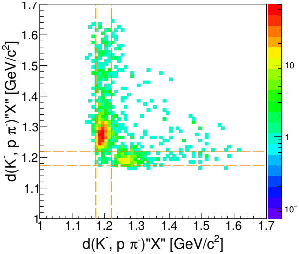
Interference between the $I = 0$ and 1 amplitudes of the $\pi\Sigma$ scattering is observed.

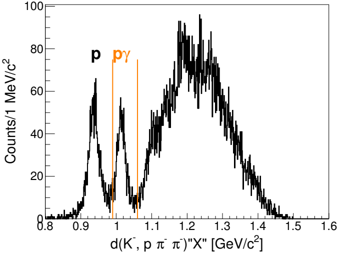
$d(K^-, p)"\pi^-\Sigma^0"$ event selection



$$K^- d \rightarrow p\pi^-\Sigma^0 \rightarrow p\pi^-\Lambda\gamma$$
$$\rightarrow p\pi^-\pi^- p\gamma$$

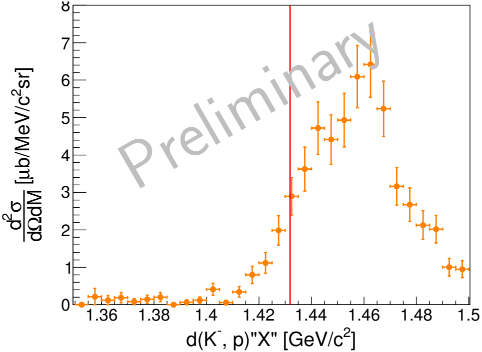
$d(K^-, p\pi^-\pi^-)"p\gamma"$ selected





$d(K^-, p)"\pi^-\Sigma^0"$ mode is clearly idendentified by selecting $d(K^-, p\pi^-\pi^-)"p\gamma"$ and $d(K^-, p\pi^-)"\Sigma^0"$.

Cross section of $d(K^-, p)"\pi^-\Sigma^0"$

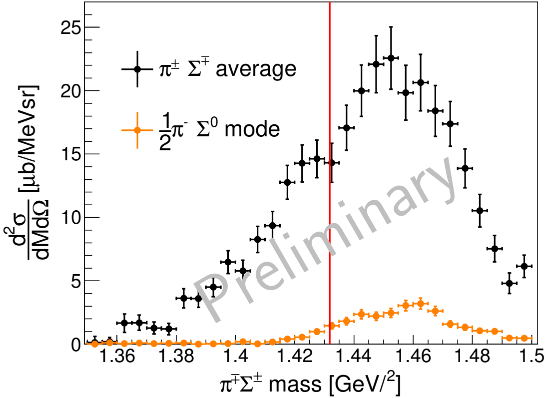


$d(K^-,p)"\pi^-\Sigma^0"$	I=1	non-resonant (S, P, D) Σ(1385) (P-wave) to be supressed

Comparison $\pi^{\pm}\Sigma^{\mp}$ $(I = 0, 1)$ and $\pi^{-}\Sigma^{0}$ $(I = 1)$

$$\frac{1}{2}\left(\pi^{-}\Sigma^{+} + \pi^{+}\Sigma^{-}\right) \sim \frac{1}{3}|f_{I=0}|^2 + \frac{1}{2}|f_{I=1}|^2$$

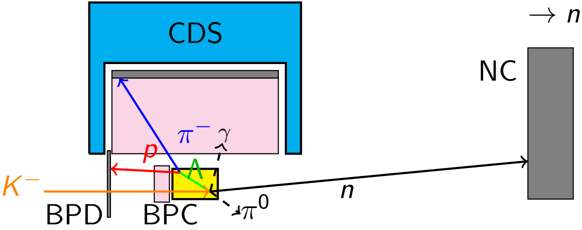
$$\frac{1}{2}\pi^{-}\Sigma^{0} \sim \frac{1}{2}|f_{I=1}|^2$$

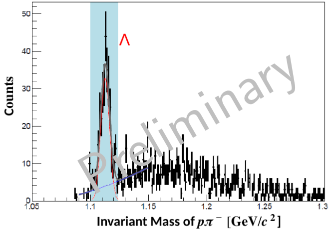


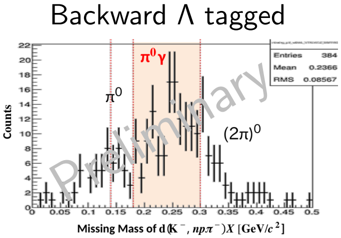
The $I = 0$ amplitude is dominant.

$d(K^-, n)"\pi^0\Sigma^0"\,(I = 0)$ event selection

$$K^- d \rightarrow n\Sigma^0\pi^0 \rightarrow n\Lambda\gamma\pi^0$$
$$\rightarrow np\pi^-\gamma\pi^0$$

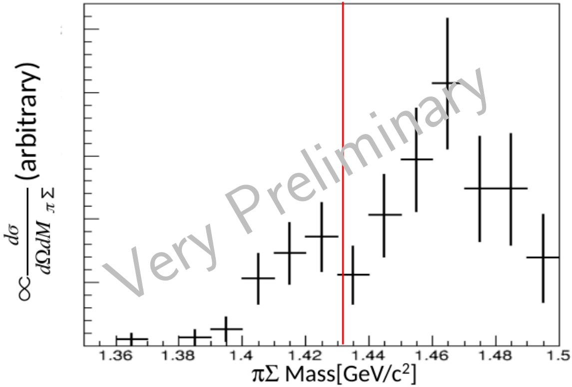





Backward Λ tagged

$d(K^-, n)"\pi^0\Sigma^0"$ mode is clearly identified by selecting Λ and $d(K^-, n\Lambda)"\pi^0\gamma"$.

$d(K^-, n)$"$\pi^0\Sigma^0$"$(I = 0)$ spectram



The $d(K^-, n)$"$\pi^0\Sigma^0$" spectrum is observed, which seems similar to those obtained in the $\pi^\pm\Sigma^\mp$ modes.

Statistics will be increased further in coming beam time in June, 2017.

Summary

- The preliminary result of the E31 1st physics run is presented.
    - $d(K^-, n)"\pi^{\pm}\Sigma^{\mp}"(I = 0, 1)$ spectra is presented.
      The difference of two spectra is observed due to interference of the $I = 0$ and 1 amplitudes.
    - Comparison of $d(K^-, n)"\pi^{\pm}\Sigma^{\mp}"$ and $d(K^-, p)"\pi^{-}\Sigma^{0}"$
      The I=0 amplitude is dominant.
    - $d(K^-, n)"\pi^{0}\Sigma^{0}"(I = 0)$ spectra is presented.
      The $d(K^-, n)"\pi^{0}\Sigma^{0}"$ spectrum is observed.
- The result of the E31 1st physics run will be finalized.
- The E31 2nd physics run will be performed in June, 2017.

The J-PARC E31 Collaboration

S. Ajimura[1], G. Beer[2], M. Bragadireanu[4], P. Buehler[4], L. Busso[5], M. Cargnelli[4], S. Choi[3], C. Curceanu[8], S. Enomoto[14], D. Faso[5], H. Fujioka[13], Y. Fujiwara[12], T. Fukuda[11], C. Guaraldo[8], R. S. Hayano[12], T. Hashimoto[9], T. Hiraiwa[1], M. Iio[14], M. Iliescu[8], K. Inoue[1], N. Ishibashi[7], Y. Ishiguro[13], T. Ishikawa[12], S. Ishimoto[14], T. Ishiwatari[4], K. Itahashi[9], M. Iwai[14], M. Iwasaki[9,10], S. Kawasaki[1], P. Kienle[15], H. Kou[10], Y. Ma[9], J. Marton[4], Y. Matsuda[12], Y. Mizoi[11], O. Morra[5], T. Nagae[13], H. Noumi[1], H. Ohnishi[9], S. Okada[9], H. Outa[9], K. Piscicchia[8], L. Poli Lener[8], A. Romero Vidal[8], Y. Sada[1], A. Sakaguchi[7], F. Sakuma[9], M. Sato[9], M. Sekimoto[14], H. Shi[12], K. Shirotori[1], D. Sirghi[8], F. Sirghi[8], S. Suzuki[14], T. Suzuki[12], H. Tatsuno[8], M. Tokuda[10], D. Tomono[9], A. Toyoda[14], K. Tsukada[16], E. Widmann[4], O. Vazquez Doce[8], T. Yamaga[1], T. Yamazaki[9,12], K. Yoshida[7], H. Yim[3], J. Zmeskal[4] .

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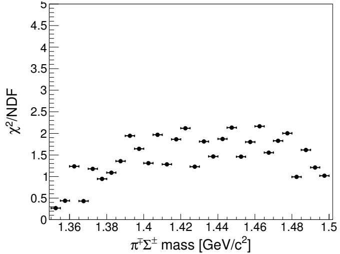
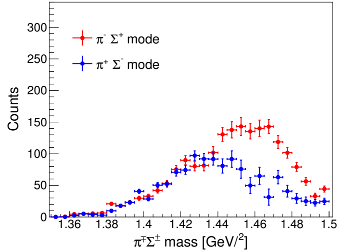
11. *Osaka Electro-Communication University, Japan, 12. University of Tokyo, Japan*
13. *Kyoto University, Japan, 14. High Energy Accelerator Research Organization (KEK), Japan*
15. *Technische Universitat Munchen, Germany, , 16. Tohoku University, Japan*

Back up

Decomposed $\pi^+\Sigma^-$ & $\pi^-\Sigma^+$





bin	$\pi^+\Sigma^-$	$\pi^-\Sigma^+$	χ^2/NDF
1.350:1.355	0.2 ± 0.7	0.0 ± 1.4	$7.20/27 = 0.27$
1.355:1.360	0.6 ± 0.9	0.0 ± 1.4	$13.21/30 = 0.44$
1.360:1.365	4.5 ± 1.0	2.5 ± 1.0	$38.32/31 = 1.24$
1.365:1.370	5.0 ± 1.1	5.0 ± 1.1	$12.98/30 = 0.43$
1.370:1.375	5.6 ± 1.3	3.8 ± 1.4	$37.72/32 = 1.18$
1.375:1.380	6.5 ± 1.5	3.1 ± 1.5	$28.32/30 = 0.94$
1.380:1.385	20.9 ± 2.4	9.9 ± 2.4	$33.76/31 = 1.09$
1.385:1.390	17.8 ± 2.2	17.7 ± 2.2	$43.40/32 = 1.36$
1.390:1.395	23.3 ± 2.6	22.9 ± 2.6	$60.24/31 = 1.94$
1.395:1.400	29.8 ± 3.3	40.7 ± 3.3	$52.60/32 = 1.64$
1.400:1.405	33.0 ± 3.0	28.6 ± 3.0	$41.90/32 = 1.31$
1.405:1.410	42.0 ± 4.1	50.4 ± 4.1	$55.09/28 = 1.97$
1.410:1.415	53.2 ± 4.6	52.2 ± 4.6	$39.78/31 = 1.28$
1.415:1.420	75.3 ± 6.0	70.8 ± 6.0	$67.00/36 = 1.86$
1.420:1.425	89.8 ± 7.0	74.4 ± 7.0	$63.58/30 = 2.12$
1.425:1.430	80.4 ± 7.5	97.1 ± 7.5	$40.59/33 = 1.23$
1.430:1.435	81.5 ± 8.5	91.8 ± 8.5	$56.14/31 = 1.81$
1.435:1.440	101.8 ± 9.7	91.8 ± 9.7	$49.82/34 = 1.47$
1.440:1.445	130.7 ± 11.0	80.9 ± 11.2	$61.76/33 = 1.87$
1.445:1.450	137.8 ± 12.7	91.8 ± 12.9	$72.51/34 = 2.13$
1.450:1.455	143.3 ± 13.9	75.8 ± 14.3	$52.57/36 = 1.46$
1.455:1.460	135.5 ± 11.9	49.7 ± 12.8	$72.02/40 = 1.80$
1.460:1.465	140.1 ± 13.0	64.9 ± 13.8	$84.39/39 = 2.16$
1.465:1.470	143.0 ± 11.4	31.5 ± 12.7	$66.83/43 = 1.55$
1.470:1.475	118.7 ± 9.9	62.9 ± 10.5	$78.59/43 = 1.83$
1.475:1.480	101.6 ± 8.4	40.9 ± 9.3	$86.10/43 = 2.00$
1.480:1.485	79.1 ± 7.0	29.3 ± 7.7	$41.63/42 = 0.99$
1.485:1.490	56.3 ± 6.0	25.1 ± 6.6	$75.95/47 = 1.62$
1.490:1.495	32.9 ± 4.9	22.6 ± 5.1	$61.75/51 = 1.21$
1.495:1.500	44.4 ± 4.7	24.8 ± 5.1	$51.95/51 = 1.02$

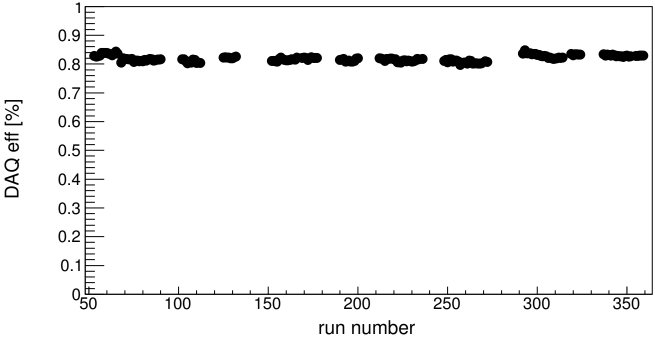
Summarize factor for cross section calculation

	$d(K^-,n)$	$d(K^-,p)$
N_{beam}	$(6.83 \pm 0.085) \times 10^9$	
N_{target}	5.06×10^{23}	
$Eff_{K \otimes CDH1}$	$94.6 \pm 2.1\%$	
$Eff_{K \otimes N/C}$	$99.8 \pm 0.2\%$	$95.5 \pm 2.2\%$
Eff_{DAQ}	$81.7 \pm 1\%$	
Eff_{CDC}	$(97.7 \pm 0.4\%)^{2(ntrack)}$	
$Eff_{Detector}$ (EFF_{NC}/Eff_{FDC1})	$29.2 \pm 1.8\%$	$96.2 \pm 0.7\%$

$$F_{d(K^-,n)} = 0.215 \pm 0.015 \text{ (err: } 7.1\%)$$
$$F_{d(K^-,p)} = 0.682 \pm 0.027 \text{ (err: } 3.9\%)$$

DAQ efficiency

(DAQ efficiency)=(1st trigger accept)/(1st trigger request)



- DAQ efficiency is estimated at 81.7 ± 1%.

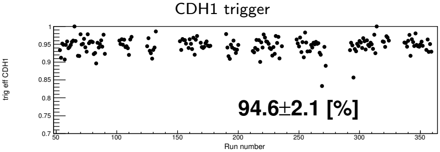
trigger efficiency

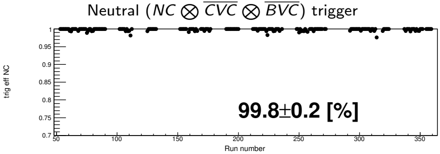
- $d(K^{-},n)$"X" was triggered by $K \bigotimes CDH1 \bigotimes Neutral$

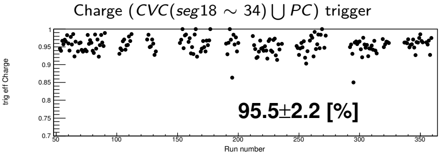
  Neutral$=NC \bigotimes \overline{CVC} \bigotimes \overline{BVC}$
- $d(K^{-},p)$"X" was triggered by $K \bigotimes CDH1 \bigotimes Charge$

  Charge$=CVC(seg18 \sim seg34) \bigcup PC$
- CDH1 and Neutral/Charge efficiency were estimated separately.

Estimation of CDH1 trigger used unbiased Kaon events.
Estimation of Neutral/Charged trigger used unbiased $K \bigotimes CDH1$ events.


CDH1 trigger


Neutral ($NC \bigotimes \overline{CVC} \bigotimes \overline{BVC}$) trigger


Charge ($CVC(seg18 \sim 34) \bigcup PC$) trigger

Reconstructed vertex position

Vertex position was reconstructed by a beam track and a CDC track.

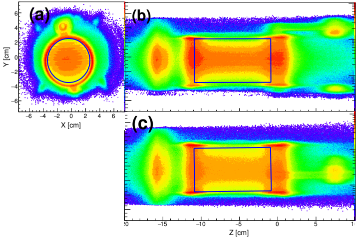


Figure: Vertex position is reconstructed by the beam track and the CDC track.

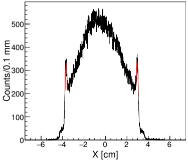


Figure: X position
$Z = -3$cm and $Y = 0$cm

Vertex resolution

- $\sigma_{XY} \sim 1.1mm$ by target cell.
- $\sigma_Z \sim 7.1mm$ by DEF.

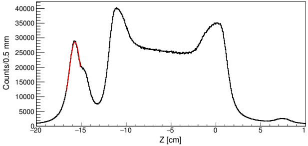


Figure: Z position
$X = 0$cm and $Y = 0$cm

CDS particle identification

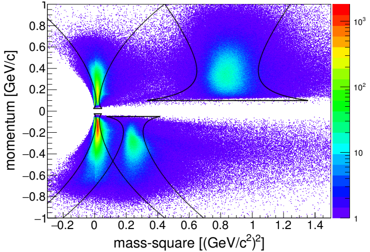


Figure: Lines show PID selection corresponding to 2.5σ.

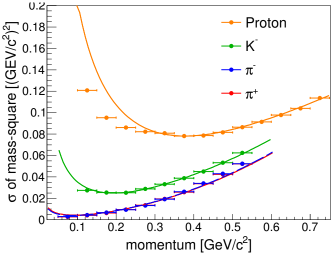


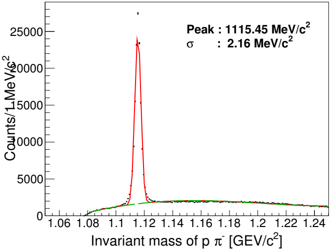
Figure: Lines shows fitting result.

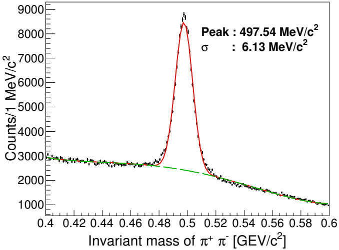
Particle identification function

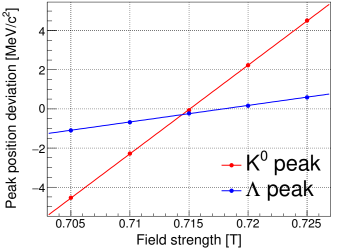
$$\sigma^2_{m^2} = 4m^2p^2C_{angle} + 4m^4\left(1+\frac{m^2}{p^2}\right)C_{multi} + 4p^2(m^2+p^2)C_{TOF}$$

$C_{angl}, C_{multi}, C_{TOF}$: parameter about angle resolution, multiple scattering and TOF resolution.

CDS field

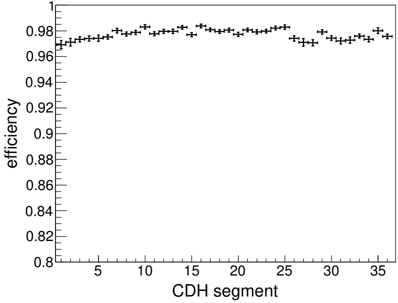






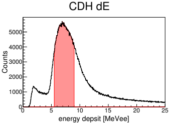
- CDS field was calibrated by peak positions of Λ and K^0.
- CDS field estimated at 715T.

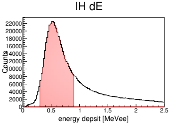
CDC efficiency

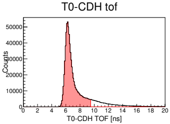


Trigger event

- CDH and IH 1hit
- $|\phi_{CDH} - \phi_{IH}| < 20^\circ$
- MIP like event select

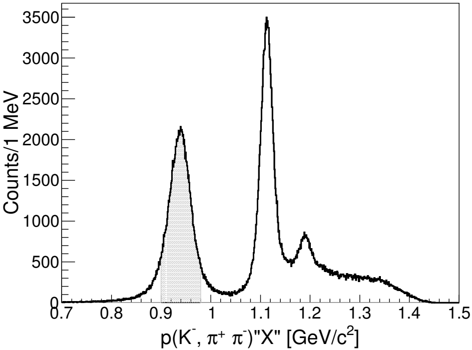






- CDC efficeicncy is estimated at $97.7 \pm 0.4\%$.

$p(K^-, \pi^+\pi^-)"n"$ selection (Run62 H_2 target)



- Gray region represents $p(K^-, \pi^+\pi-)"n"$ selection.

$K^{-}p \to K^{0}n$ selection (Run62 H_2 target)

1. $K^{-}p \to \pi\Sigma$ rejected by 3σ.
2. $K^{0} \to \pi^{+}\pi^{-}$ selection by 2σ.

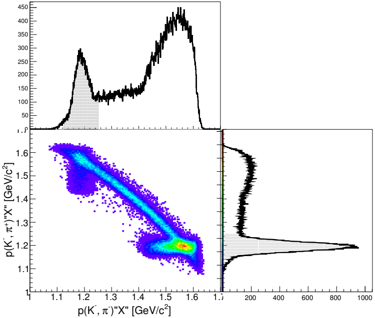


Figure: Scatter plot of $p(K^{-},\pi^{-})"X"$ and $p(K^{-},\pi^{+})"X"$. Gray hatced region represents rejection region.

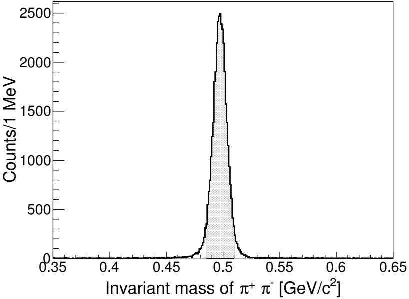
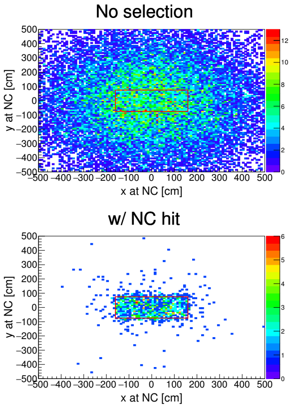
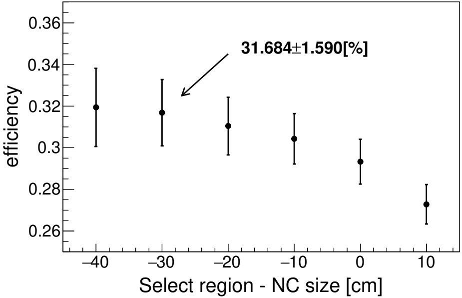


Figure: Invariant mass of $\pi^{+}\pi^{-}$ without $K^{-}p \to \pi^{\pm}\Sigma^{\mp}$.

Instrinsic NC efficiency (Run62 H_2 target)

Trigger event : neutron scatterd toward the NC and CVC/BVC no fire.



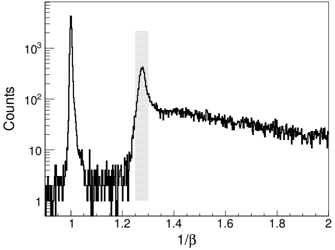


- Efficiency was almost saturate at -30cm.
- NC efficiency was estimated at $31.7 \pm 1.6\%$.

NC over kill (Run69)

Trigger event

- run52∼run59 (Neutral trigger w/o $\overline{CVC}$ and $\overline{BVC}$)
- $1/\beta = 1.25 \sim 1.3$ (Qusi-elastic event).
- NC layer1 no fire to guarantee neutron

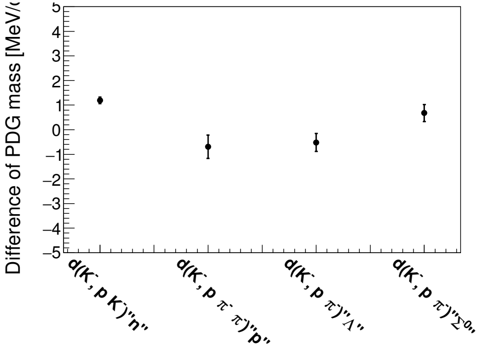


Detector	over kill
CVC fire	1.9 ± 0.2 %
BVC fire	5.9 ± 0.3 %
CVC $\bigcup$ BVC	7.6 ± 0.4 %

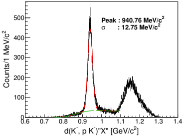
Figure: $1/\beta$ spectrum in run52∼59. NC layer1 was used to veto charged particle.

- $NC \bigotimes \overline{CVC} \bigotimes \overline{BVC}$ efficeincy was estimated at $29.2 \pm 1.8\%$.

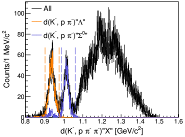
Difference of missing mass from PDG



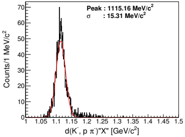
$d(K^-,pK^-)"n"$



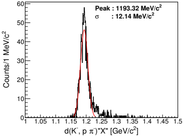
$d(K^-,p\pi^-\pi^-)"p"$



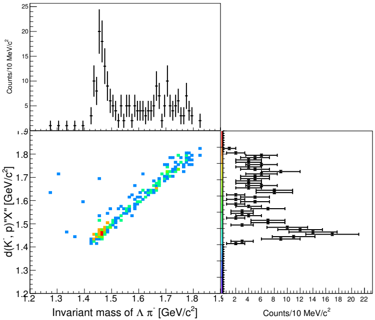
$d(K^-,p\pi^-)"\Lambda"$

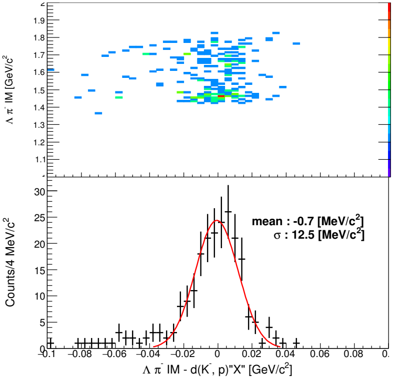


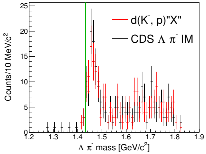
$d(K^-,p\pi^-)"\Sigma^0"$



Consistency of CDS $\Lambda\pi^-$ IM and $d(K^-,p)$"X" MM







$\Lambda\pi^-$ and $d(K^-,p)$"X" is within $1.0 MeV/c^2$.
Difference of $d(K^-,p)$"X" is about $1 MeV/c^2$.