π中間子ビームを用いた K中間子原子核の実験的研究

2015/05/18

Yudai Ichikawa (JAEA)

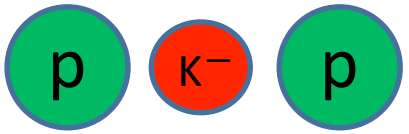
第8回　J-PARC Hadron salon

Contents

- Introduction
  - K^-pp bound state
- J-PARC E27 experiment
  - $d(\pi^+, K^+)$ reaction
  - Experimental set up (K1.8 beam line + SKS + RCA)
  - Coincidence measurement (with RCA)
- Analysis result & Discussion
  - Inclusive analysis
  - Coincidence analysis
- Future plan
- Conclusion

Introduction

K^-pp bound state

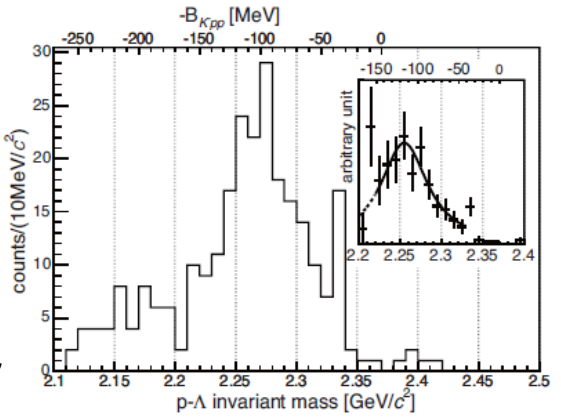


- It is expected to be the simplest kaonic nuclei.
- Total charge:+1, I = ½, $J^P = 0^-$.
- The bound state was expected due to the $\bar{K}N$ strong interaction, which is strong attractive in I = 0.

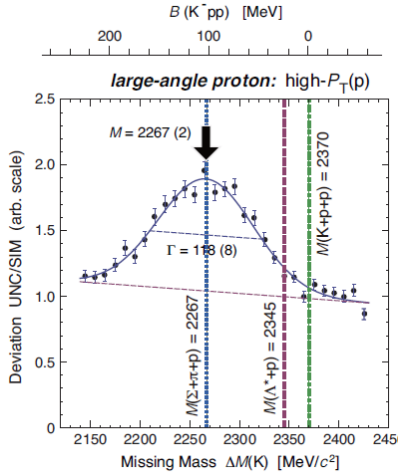
- It has a rich information such as the $\bar{K}N$ strong interaction in sub-threshold region and behavior of $\Lambda(1405)$ in many body system.
- It makes high density (?)

Past experiments for the K^-pp

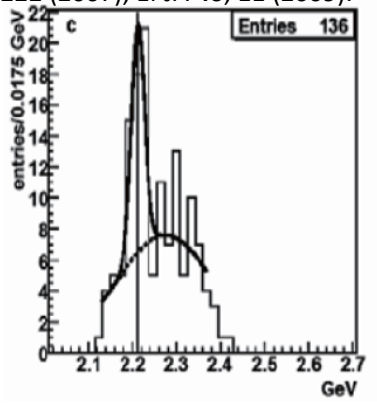
- **FINUDA experiment** M. Agnello *et al.*, PRL **94**, 212303 (2005).
  - Stopped K^- absorption on ^{6,7}Li and ^{12}C.
  - Invariant mass of back-to-back Λp pairs.
  - BE: 115 $^{+6}_{-5}$(stat.)$^{+3}_{-4}$ (syst.)MeV, Γ: 67 $^{+14}_{-11}$(stat.)$^{+2}_{-3}$ (syst.)MeV



- **DISTO experiment** T. Yamazaki *et al.*, PRL **104**, 132502 (2010).
  - $pp \rightarrow K^+\Lambda p$ reaction at T_p=2.85GeV.
  - K^+ missing mass and Λp invariant mass.
  - BE: 103 ±3(stat.) ±5(syst.)MeV, Γ: 118 ±8(stat.) ±10(syst.)MeV



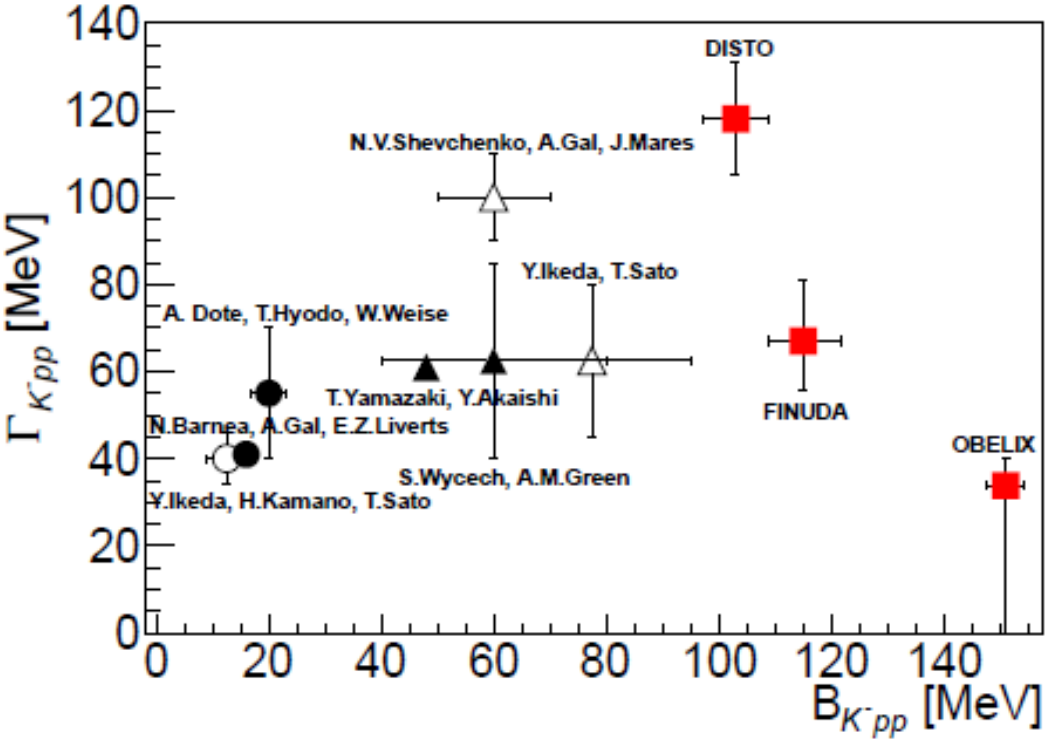
- **OBELIX experiment** G. Bendiscioli *et al.*, NPA **789**, 222 (2007), EPJA **40**, 11 (2009).
  - $\bar{p}$ annihilation reaction on ^{4}He.
  - $(pp\pi^-)$ invariant mass.
  - BE: 151.0 ±3.2(stat.) ±1.2(syst.)MeV,
    Γ: < 33.9 ±6.2 MeV



Comparison BE and Γ of the K^-pp

- Theoretical values of BE and Γ strongly depend on the $\bar{K}N$ interaction and calculation method.
- Theoretical values can't reproduce the experimental ones.
- Experimental values are not consistent with each other.

→ Further experiment is necessary.



Theoretical value	K^{bar}-N interaction	Calculation method
●	Chiral energy dependent	Variation
○	Chiral energy dependent	Faddeev
▲	Energy independent	Variation
△	Energy independent	Faddeev

※ ■ = Experimental value.

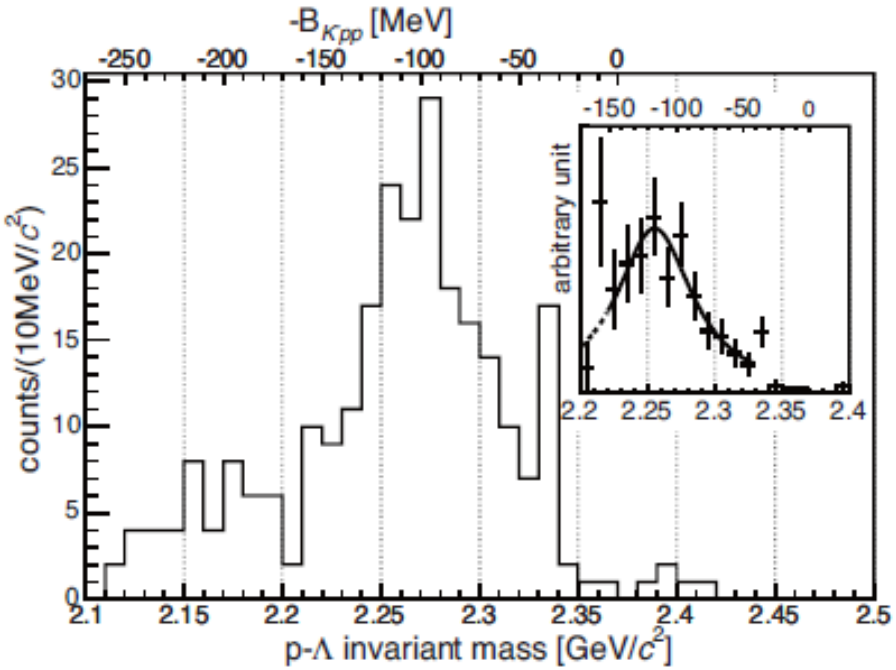
Current situation of the K^-pp

- FINUDA experiment (stopped K^- on $^{6,7}Li$ and ^{12}C)
  - There are theoretical criticism V. Magas, et al., PRC 74, 025206 (2006).
    (FSI of p and Λ + quai-free two nucleon absorption).
  - Reaction mechanism is not clear.
- DISTO experiment ($pp \rightarrow pK^+\Lambda$ at T_p = 2.85 GeV)
  - Ambiguity of the *DEV* spectrum.
    = ambiguity of the background assumption
    ($pK^+\Lambda$ 3 body phase space reaction)

    $pp \rightarrow N^*p$, $N^* \rightarrow K^+\Lambda$
  - It should be an additional background such as N* production.
- OBELIX experiment ($\bar{p}$ annihilation on ^4He)
  - They did not observe Λ peak directly (($pp\pi^-$) invariant mass).
  - Reaction mechanism is not clear. Λpπ threshold cusp (?)

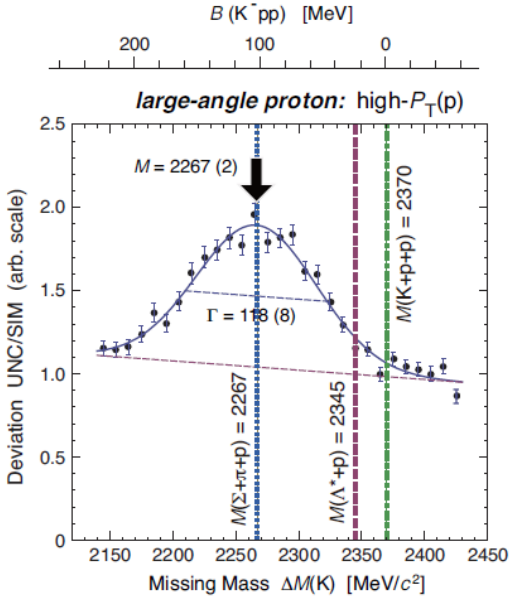
Current situation of the K^-pp

- FINUDA experiment (stopped K^- on $^{6,7}Li$ and ^{12}C)
  - There are theoretical criticism V. Magas, et al., PRC 74, 025206 (2006).
    (FSI of p and Λ + quai-free two nucleon absorption).
  - Reaction mechanism is not clear.
- DISTO experiment ($pp \rightarrow pK^+\Lambda$ at T_p = 2.85 GeV)
  - Ambigu
    = ambig
    ($pK^+\Lambda$ 3
  - It shoul s N* production.
- OBELIX e n ^4He)
  - They dic invariant mass).
  - Reactio hold cusp (?)



$pp \rightarrow N^*p$
$\hookrightarrow K^+\Lambda$

Current [illegible] of the K^-pp



- FINUDA expe[illegible] d K^- on $^{6,7}Li$ and ^{12}C)
  - There are theo[illegible] lagas, et al., PRC 74, 025206 (2006).
    (FSI of p and Λ [illegible] cleon absorption).
  - Reaction mech[illegible]
- DISTO experiment ($pp \rightarrow pK^+\Lambda$ at T_p = 2.85 GeV)
  - Ambiguity of the *DEV* spectrum.
    = ambiguity of the background assumption
    ($pK^+\Lambda$ 3 body phase space reaction)
  - It should be an additional background such as N* production.

$pp \rightarrow N^*p$
$\hookrightarrow K^+\Lambda$

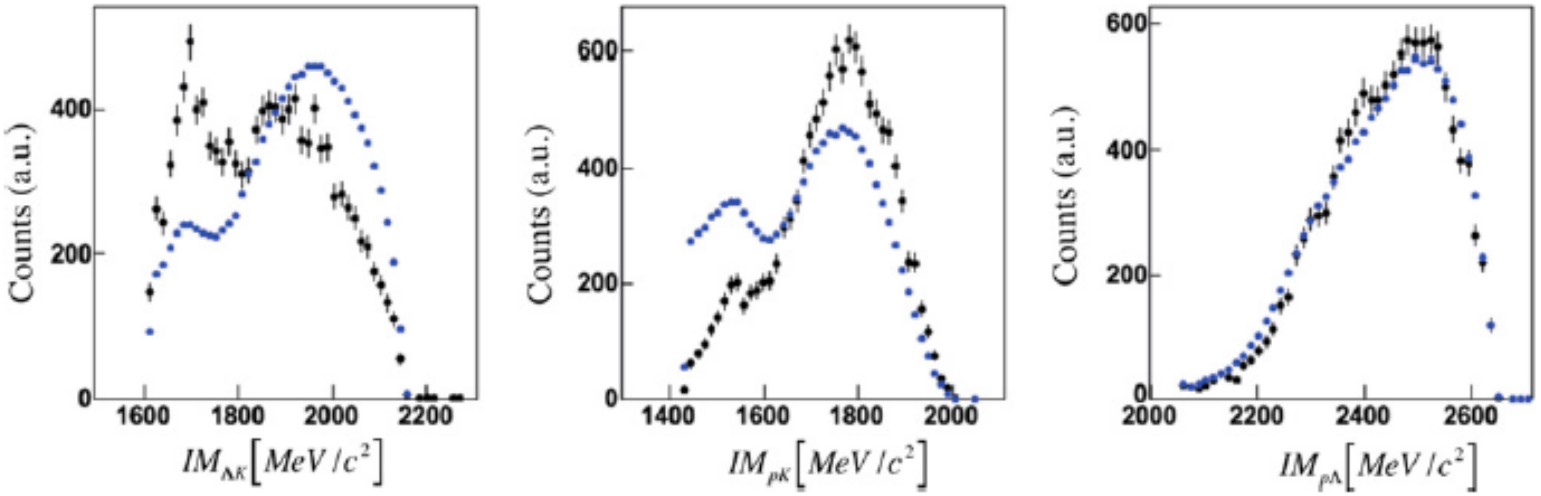
- OBELIX experiment ($\bar{p}$ annihilation on ^4He)
  - They did not observe Λ peak directly (($pp\pi^-$) invariant mass).
  - Reaction mechanism is not clear. Λpπ threshold cusp (?)

HADES data ($pp \rightarrow pK^+\Lambda$ at T_p = 3.5 GeV)

L. Fabbietti *et al.*, NPA 914, 60 (2013).

+ data

- 3body phase space

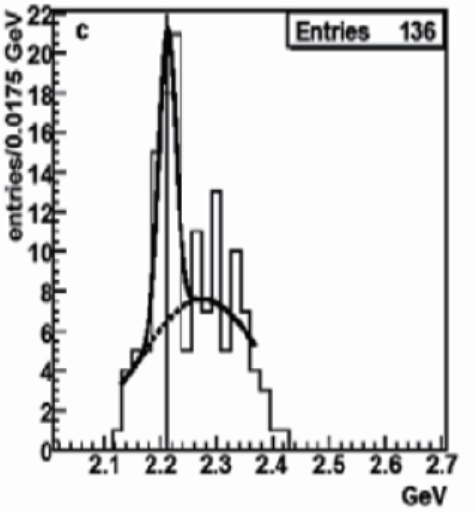


- DISTO experiment ($pp \rightarrow pK^+\Lambda$ at T_p = 2.85 GeV)
  - Ambiguity of the *DEV* spectrum.
    = ambiguity of the background assumption
    ($pK^+\Lambda$ 3 body phase space reaction)
  - It should be an additional background such as N* production.

$pp \rightarrow N^*p$
$\hookrightarrow K^+\Lambda$

- OBELIX experiment ($\bar{p}$ annihilation on ^{4}He)
  - They did not observe Λ peak directly (($pp\pi^-$) invariant mass).
  - Reaction mechanism is not clear. $\Lambda p\pi$ threshold cusp (?)

Curr



- FINUDA d ^{12}C)
  - There a
    (FSI of p
  - Reactio
- DISTO experiment (pp GeV)
  - Ambiguity of the *DEV* spec
    = ambiguity of the backgro →N*p ↳K⁺Λ
    (pK⁺Λ 3 body phase space
  - It should be an additional duction.

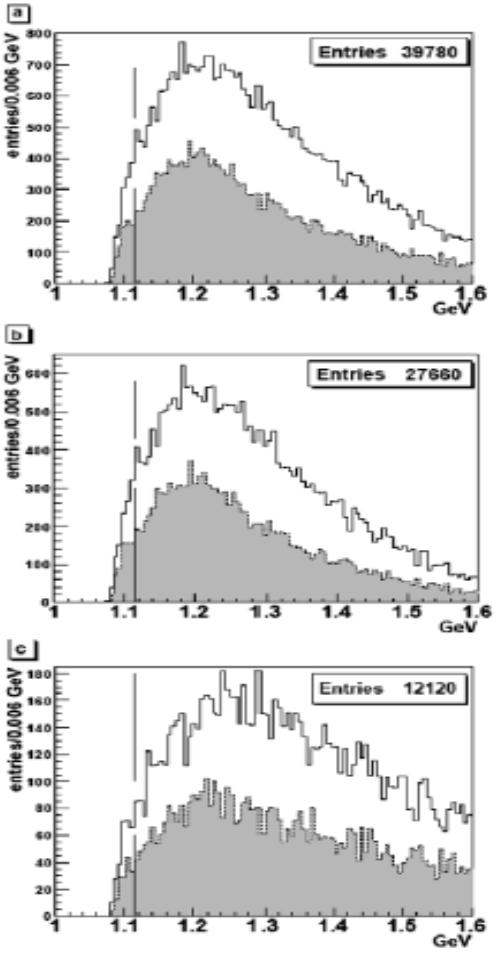


Fig. 3. 5 prongs. $p\pi^-$ IM distribution for all the events (a), for the events in the C region (b) and in A + B region (c). The grey histograms are the experimental phase-space–like $p\pi^+$ distributions. The vertical lines indicate the Λ mass, 1115 MeV.

- OBELIX experiment ($\bar{p}$ annihilation on ^{4}He)
  - They did not observe Λ peak directly ((ppπ⁻) invariant mass).
  - Reaction mechanism is not clear. Λpπ threshold cusp (?)

Requirement of the new experiment

- Target
  - It is better to use lighter target to reduce FSI.
- Reaction
  - We should know the reaction mechanism.
  - Background reaction should be controlled.
- Measurement
  - Exclusive or semi-exclusive measurement is important for the sensitivity of the K^-pp.

Contents

- Introduction
  - K^-pp bound state
- J-PARC E27 experiment
  - $d(\pi^+, K^+)$ reaction
  - Experimental set up (K1.8 beam line + SKS + RCA)
  - Coincidence measurement (with RCA)
- Analysis result & Discussion
  - Inclusive analysis
  - Coincidence analysis
- Future plan
- Conclusion

J-PARC E27 experiment

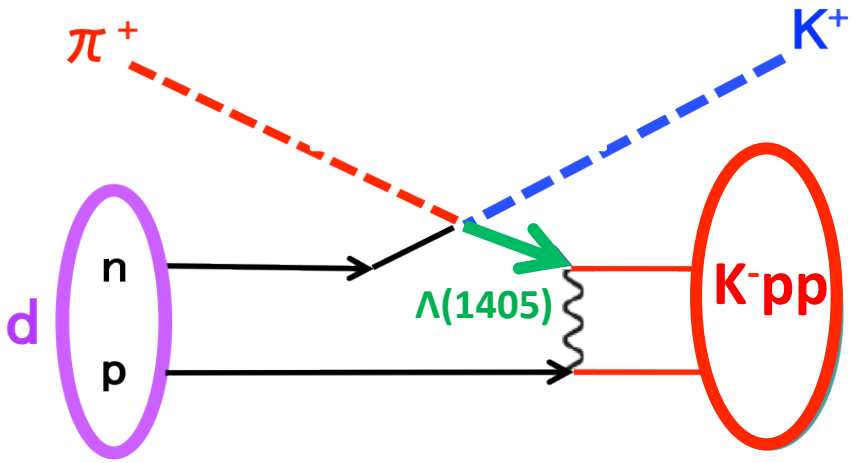
d(π^+, K^+) reaction

- K^-pp is expected to be produced as a Λ(1405) doorway.
- Main background is quasi-free hyperon (Λ, $\Sigma^{+/0}$) and hyperon resonance (Λ(1405), $\Sigma(1385)^{+/0}$) production.
  - Elementary cross sections were measured. (bubble chamber)

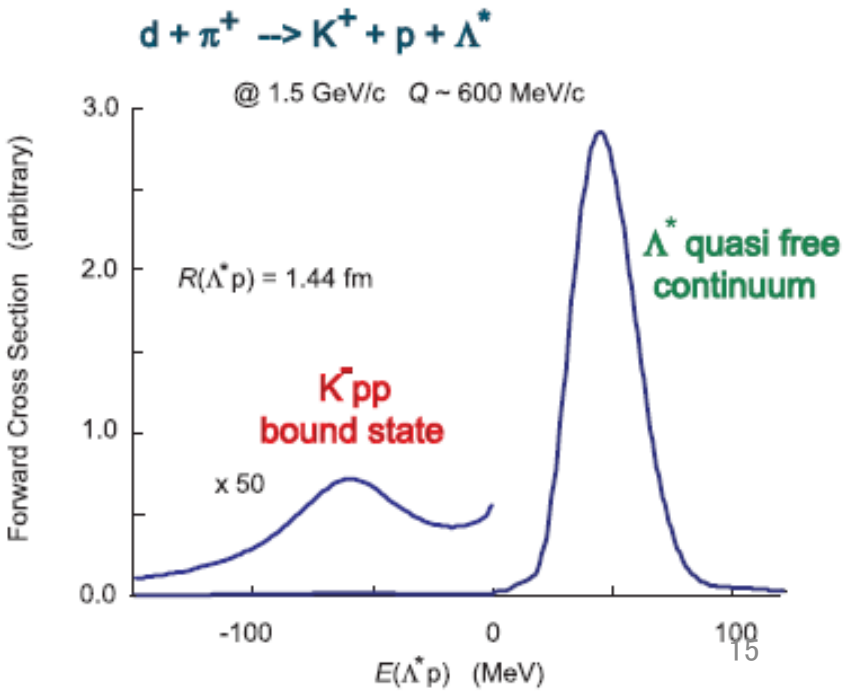
$\pi^+ + n \rightarrow \Lambda(1405) + K^+$

$\Lambda(1405) + p \rightarrow K^-pp$

(→quasi free Λ(1405))



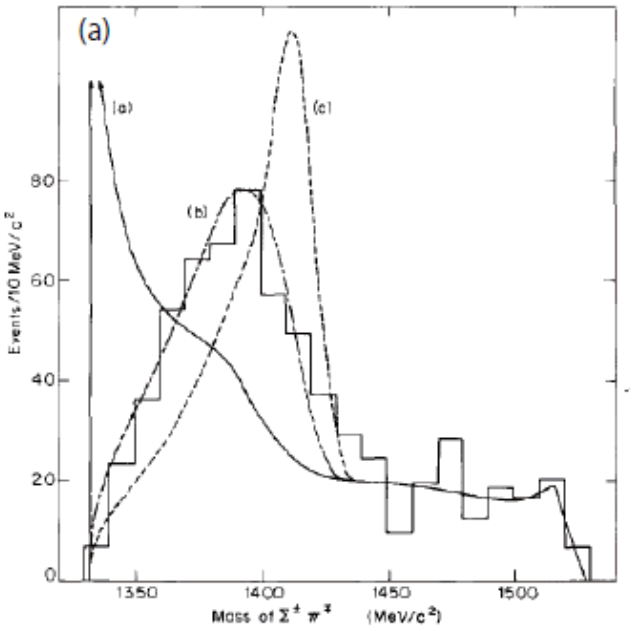
Y. Akaishi and T. Yamazaki, PRC **76**, 045201 (2007).



Λ(1405) elementary cross section

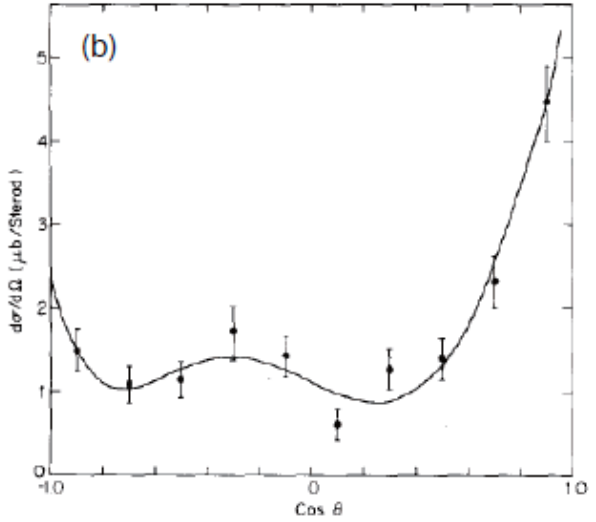
- $\pi^- p \rightarrow K^0 \Lambda(1405)$ reaction was measured by using hydrogen bubble chamber at 1.69 GeV/c.
  ($\pi^+ n \rightarrow K^+ \Lambda(1405)$ cross section should be same assuming the isospin symmetry. We know the elementary cross section of Λ(1405).)

Invariant mass of $\Sigma^{\pm}\pi^{\mp}$

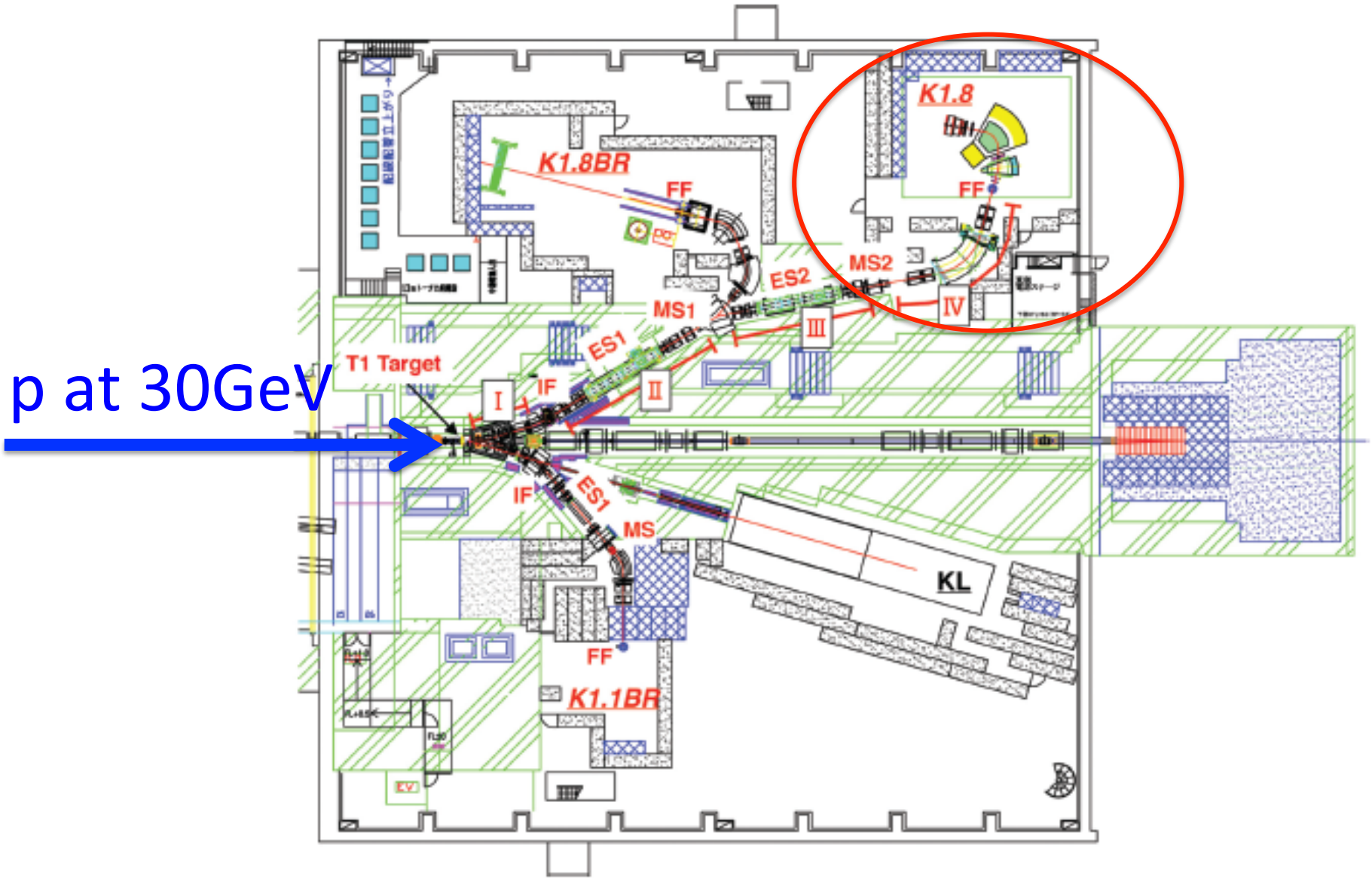


D.W. Thomas et al., NP **B56**, 15 (1973).

Angular distribution



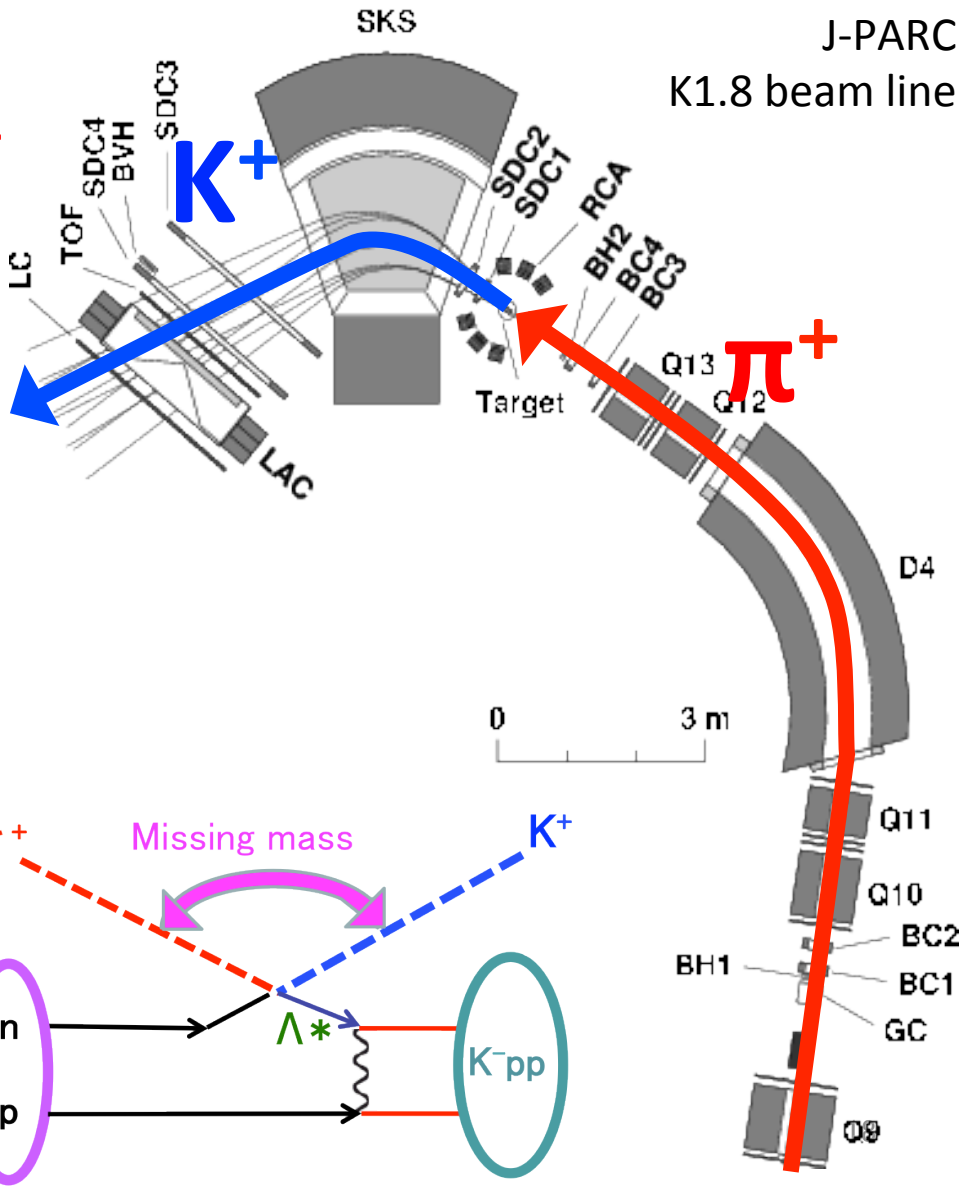
J-PARC Hadron Hall



Experimental setup

[d(π^+, K^+) reaction at p_π = 1.69 GeV/c]

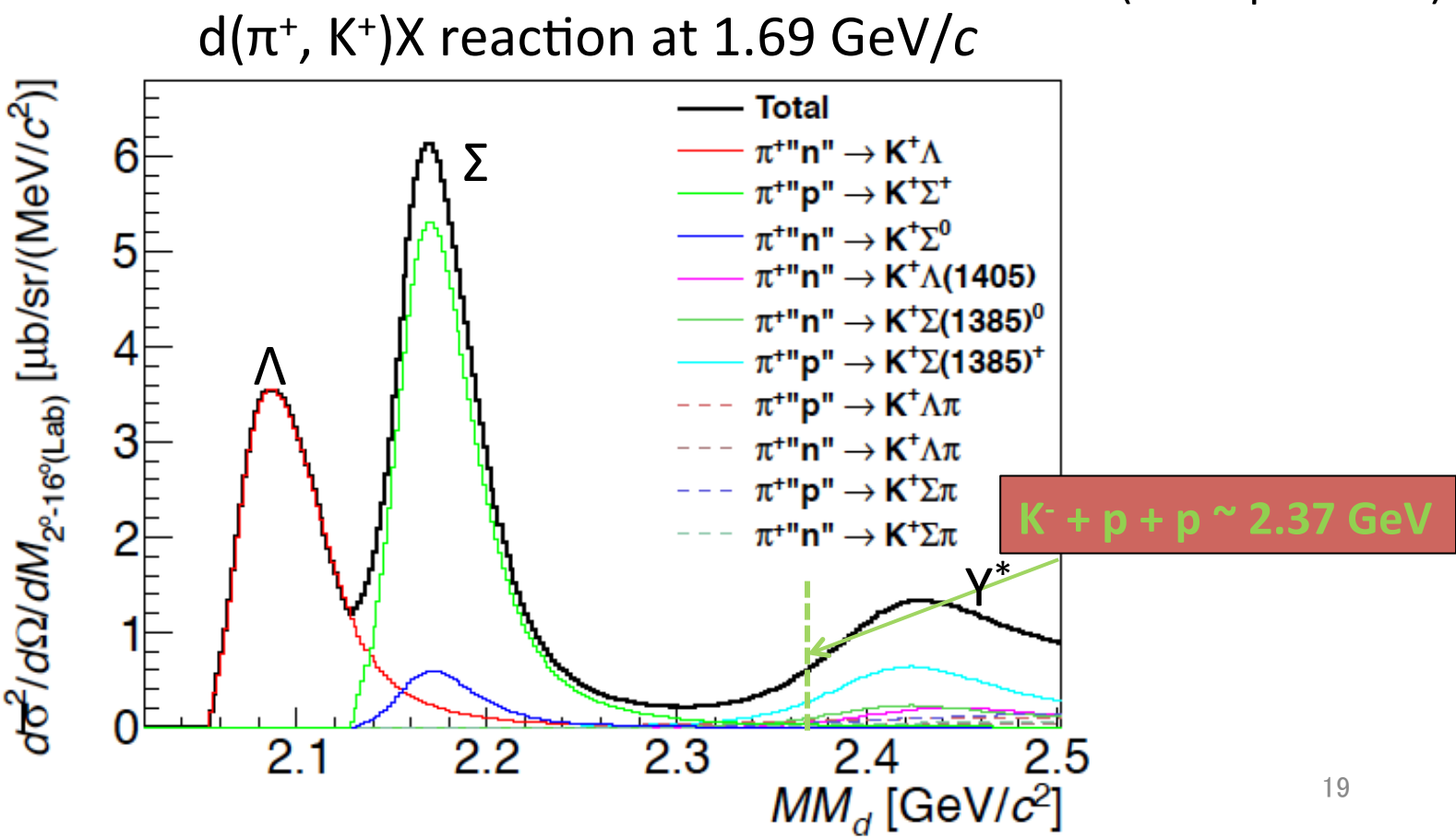
- K1.8 beam line spectrometer
  - 1.69 GeV/c π^+ beam
  - $\Delta p/p \sim 2\times10^{-3}$
- SKS spectrometer
  - 0.8 – 1.3 GeV/c for K^+
  - $\Delta p/p \sim 2\times10^{-3}$
  - $\Delta\Omega \sim 100$ msr
- Target
  - Liquid deuterium



Simulated inclusive missing-mass spectrum

- There are many quasi-free $Y^{(*)}$ productions (background).
  - Estimated using the elementary cross sections of the $\pi^+p \rightarrow K^+X$ and $\pi^-p \rightarrow K^0X$ (for $\pi^+n \rightarrow K^+X$) reactions with deuteron wave-function.

(Bonn potential)



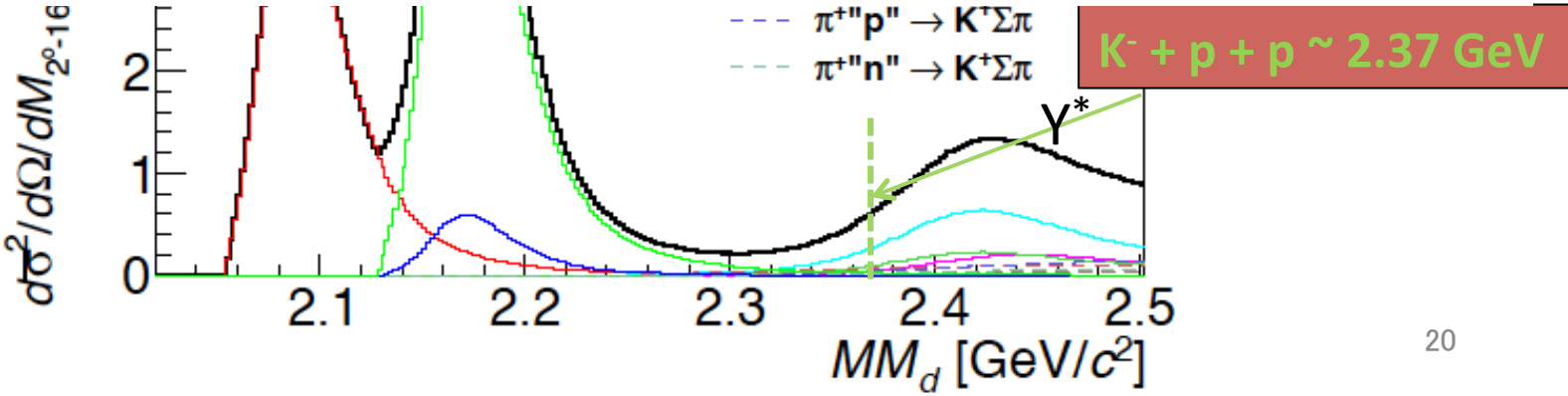
Simulated inclusive missing-mass spectrum

- There are many quasi-free $Y^{(*)}$ productions (background).
  - Estimated using the elementary cross sections of the $\pi^+p \rightarrow K^+X$ and $\pi^-p \rightarrow K^0X$ (for $\pi^+n \rightarrow K^+X$) reactions with deuteron wave-function.

(Bonn potential)

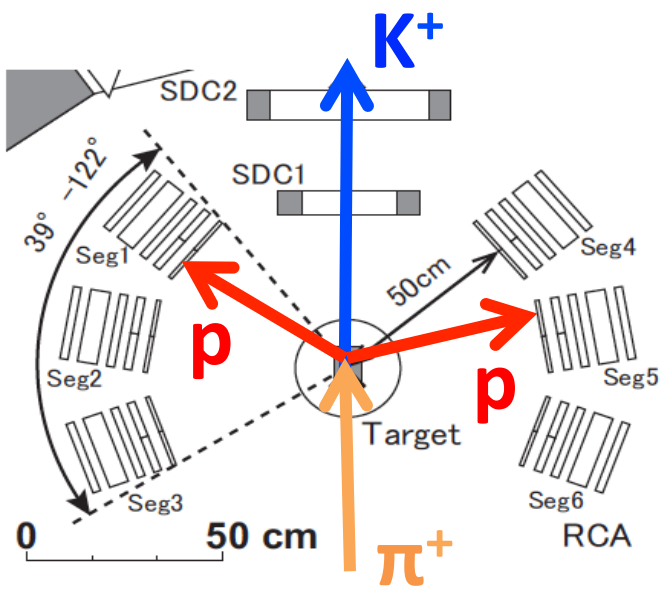
K^-pp signal will be hidden by quasi-free processes at inclusive spectrum.

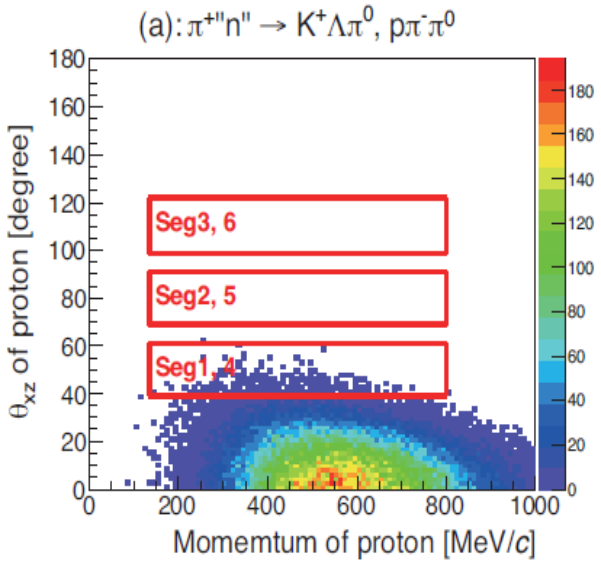
→ Coincidence measurement.

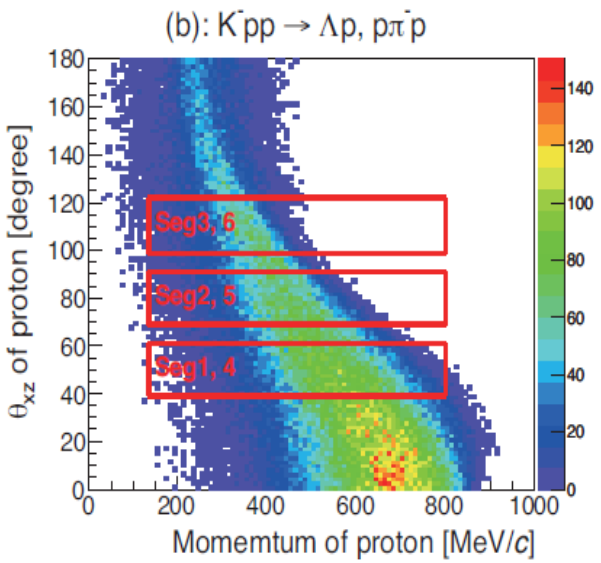


Range counter array (RCA) for the coincidence measurement

- RCA is installed to measure the proton from the K^-pp.
  - $K^-pp \rightarrow \Lambda p \rightarrow p\pi^- p$; $K^-pp \rightarrow \Sigma^0 p \rightarrow p\pi^- \gamma p$; $K^-pp \rightarrow Y p\pi \rightarrow p\pi p$+(etc.)
- We suppress the QF background by tagging a proton.
  - ☆ Seg2 and 5 are free from QF background.
- More strongly suppress by tagging two protons.

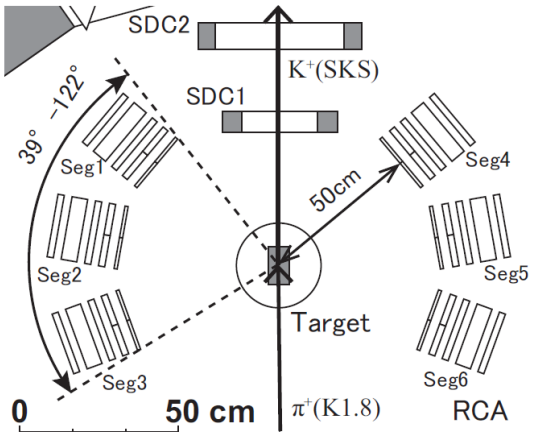


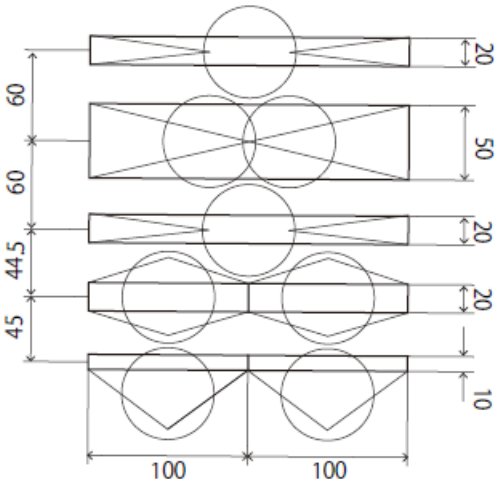


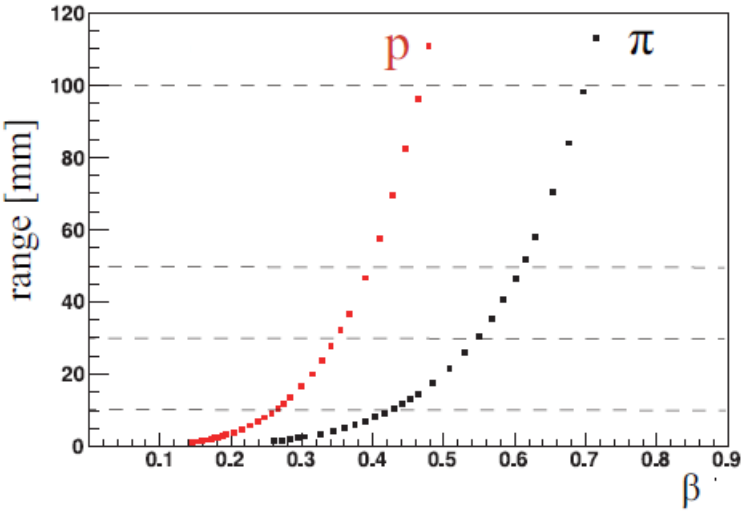


Range counter array (RCA)

- 6units
- 5layers (1+2+2+5+2 cm) of plastic scintillator.
- TOF: 50 cm, θ_{xz}: 39°- 122°
- Momentum acceptance of proton: 135 - 800 MeV/*c*
- Geometrical coverage: ~26%







Requirement of the new experiment

- Target
  - It is better to use lighter target to reduce FSI.

E27 ⇒ We use the liquid deuterium target.

- Reaction
  - We should know the reaction mechanism.

E27 ⇒ The K^-pp is expected to be produced as a $\Lambda(1405)$ doorway.

  - Background reaction should be controlled.

E27 ⇒ The main BG is quasi-free hyperon (resonance) productions.

- Measurement
  - Exclusive or semi-exclusive measurement is important for the sensitivity of K^-pp.

E27 ⇒We carried out the coincidence experiment with RCA.

Beam time in June 2012.

- Beam time allocated for E27 experiment
  - From 9th June to 1st July.

Reaction	Target	Thickness [g/cm^2]	P_{beam} [GeV/c]	Beam intensity [pion/spill]	N_{beam}
$d(\pi^+, K^+)$	LD_2	1.99	1.69	3.0-3.3$\times 10^6$	3.3×10^{11}
$p(\pi^+, K^+)$	LH_2	0.85	1.69	3.0×10^6	7.6×10^9
$p(\pi^+, K^+)\Sigma^+$	LH_2	0.85	1.58	3.0×10^6	1.2×10^9
beam-through	none	–	0.9	$\sim 10^4$	$\sim 10^5$

Contents

- Introduction
  - K^-pp bound state
- J-PARC E27 experiment
  - $d(\pi^+, K^+)$ reaction
  - Experimental set up (K1.8 beam line + SKS + RCA)
  - Coincidence measurement (with RCA)
- Analysis result & Discussion
  - Inclusive analysis
  - Coincidence analysis
- Future plan
- Conclusion

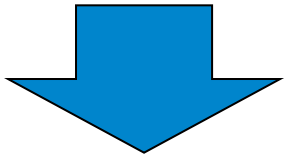
Analysis result
&
Discussion

Spectrometer performance (Calibration)
$p(\pi^+, K^+)\Sigma^+$ at 1.58 GeV/c

K^+ momentum is almost same as the $d(\pi^+, K^+)K^-pp$ reaction.

- Missing mass resolution of Σ^+

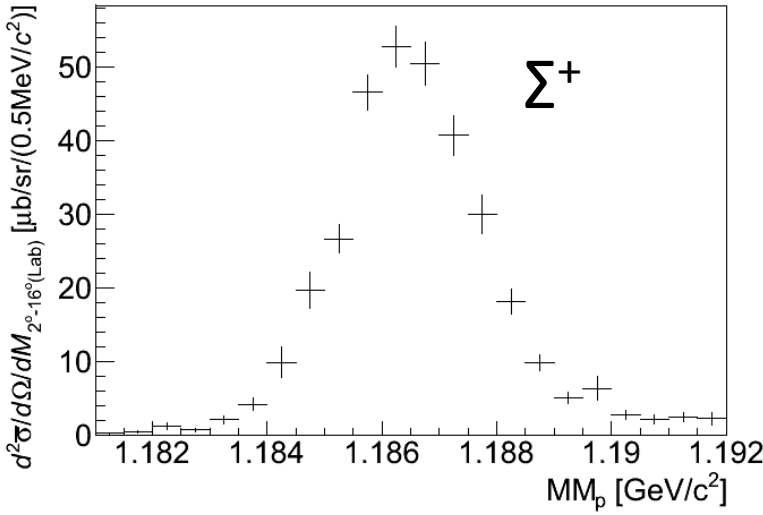
  $\Delta M = 2.8 \pm 0.1$ MeV/c^2(FWHM)

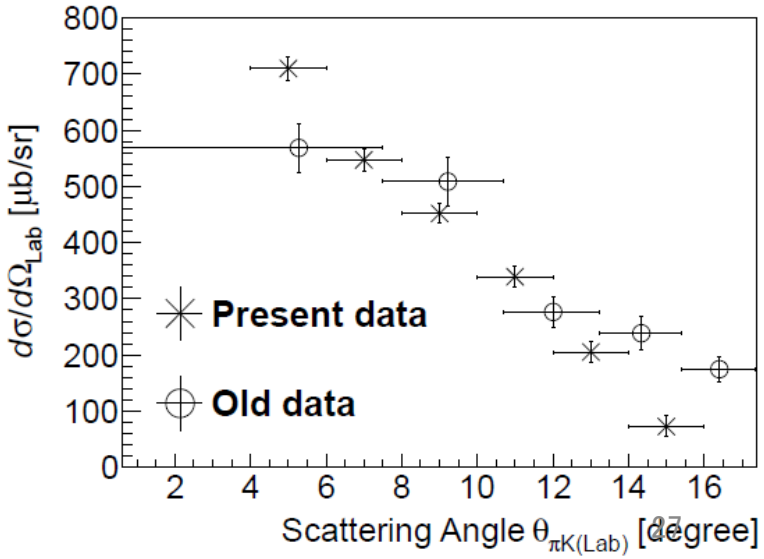


- Missing mass resolution of the

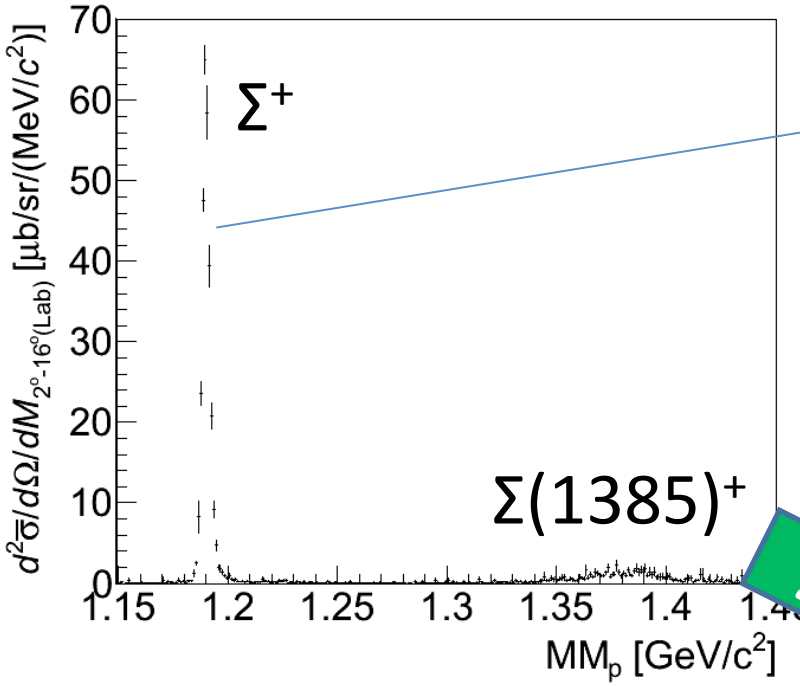
  $d(\pi^+, K^+)K^-pp$ reaction

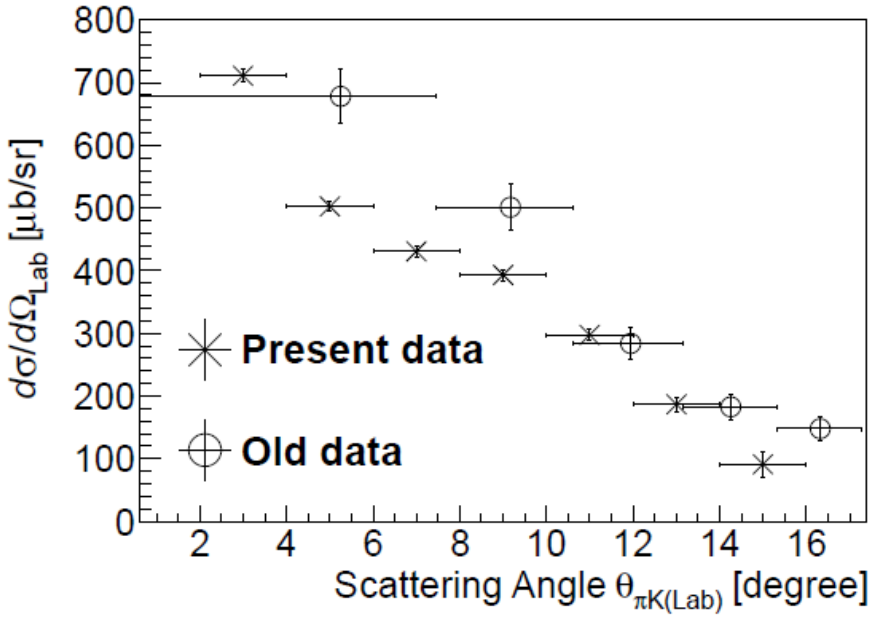
  $\Delta M = 2.7 \pm 0.1$ MeV/c^2(FWHM)



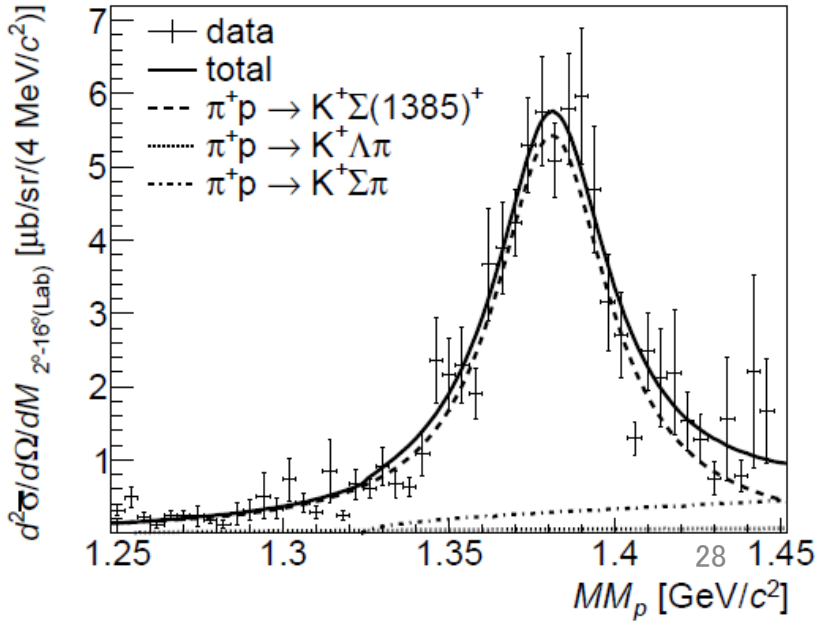


$p(\pi^+, K^+)\Sigma^+$ at 1.69 GeV/c





Zoom



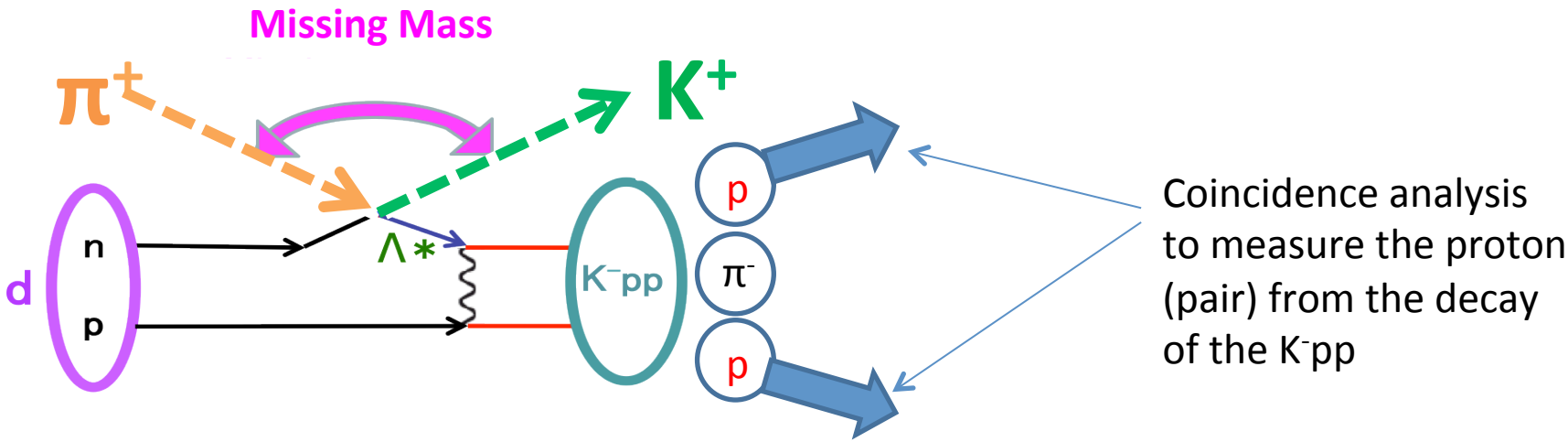
Data:

$M = 1381.1 \pm 3.6$ MeV/c^2

$\Gamma = 42 \pm 13$ MeV

PDG: $M = 1382.8 \pm 0.35$ MeV/c^2,

$\Gamma = 36.1 \pm 0.7$ MeV

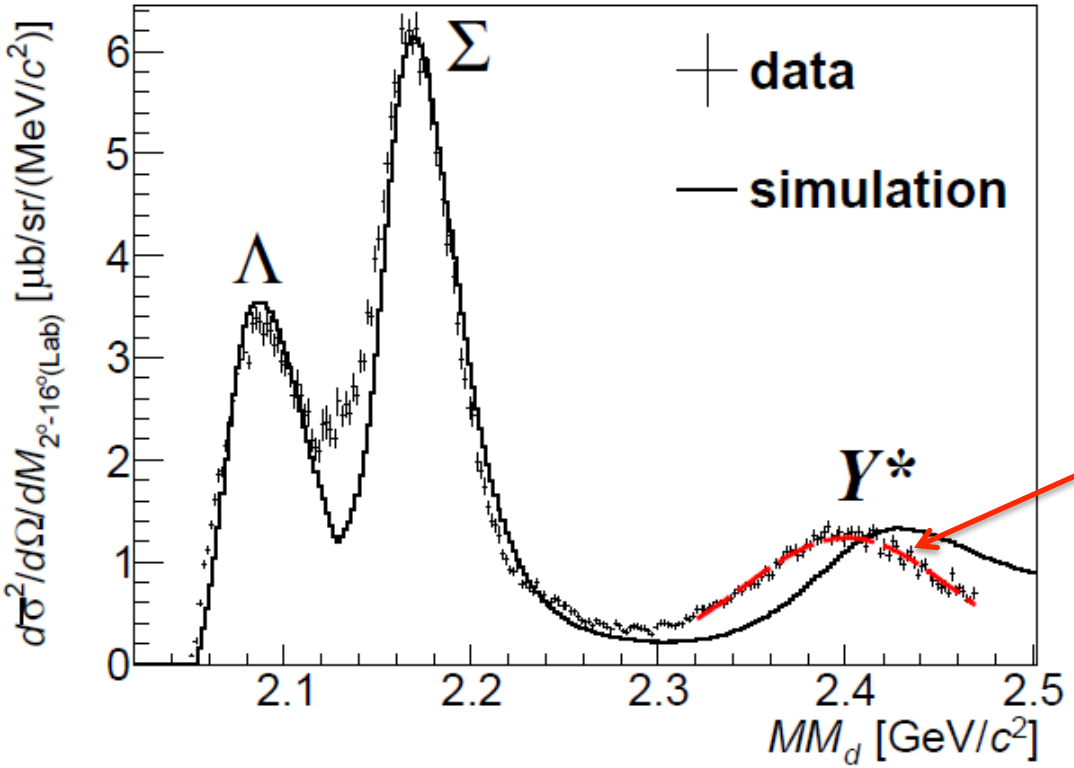


Analysis of E27 experiment

- Inclusive analysis
  - We only use the information of the π+, K+ momenta to search the K-pp.
  - In this analysis, there are large background (quasi-free).
- Coincidence analysis
  - We additionally measure the proton (pair) from the decay of the K-pp.

d(π^+, K^+) at 1.69 GeV/*c* (Inclusive spectrum)

- It is difficult to identify the K^-pp from the inclusive spectrum due to the QF hyperon (Y^*) productions.
- An overall structure of the spectrum is well reproduced expect for two distinct differences.
  - ΣN cusp (~2.13 GeV/c^2) and Y^* peak position.

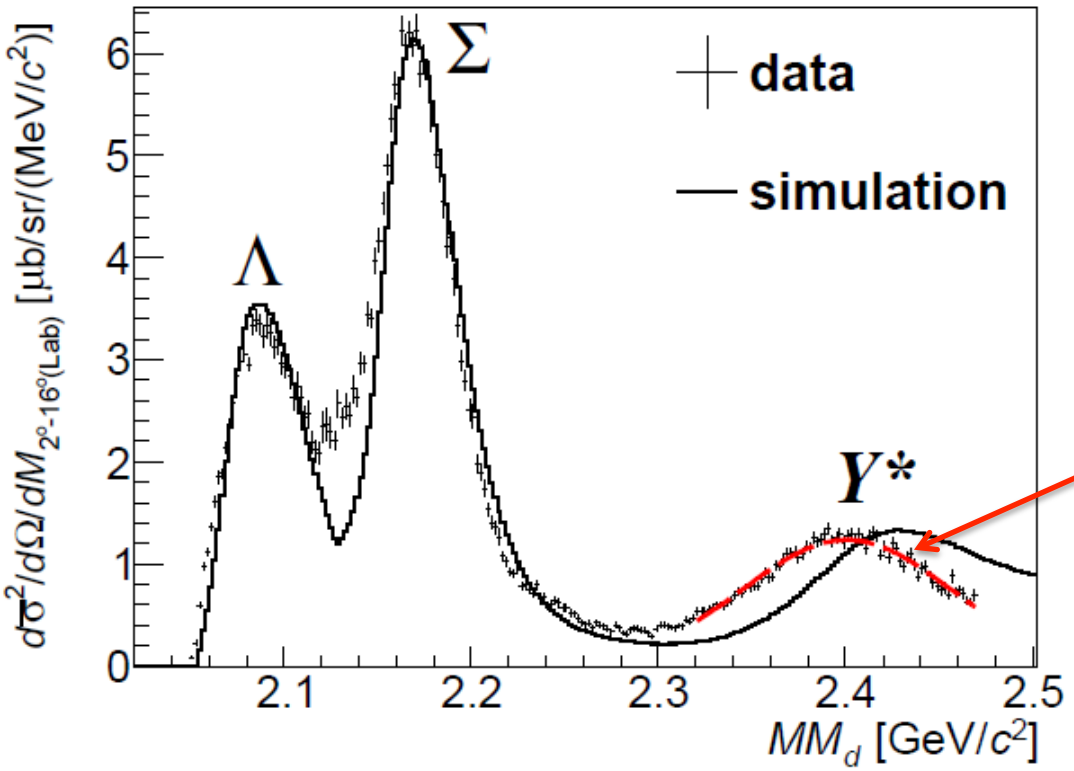


d(π^+, K^+) at 1.69 GeV/*c* (Inclusive spectrum)

*Y** peak; data = 2400.6 ± 0.5(stat.) ± 0.6(syst.) MeV/c^2

sim = 2433.0 $^{+2.8}_{-1.6}$ (syst.) MeV/c^2

``shift" = −32.4 ± 0.5(stat.) $^{+2.9}_{-1.7}$ (syst.) MeV/c^2

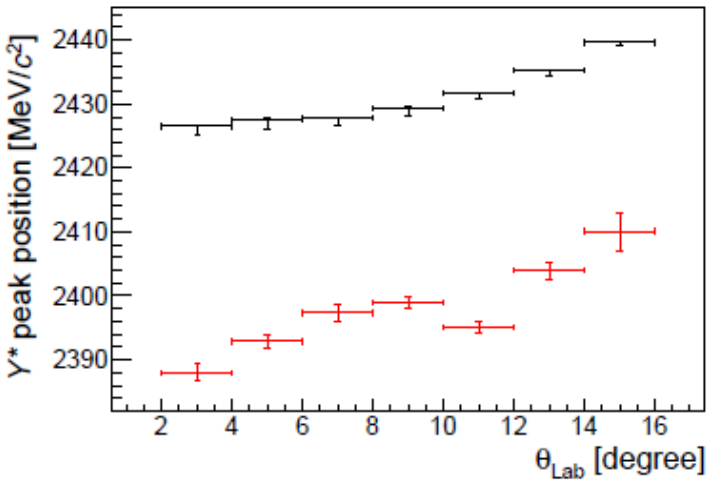


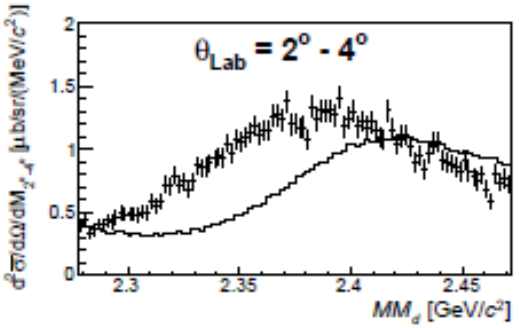
$\theta_{\pi K}$ dependence (+data, —sim)

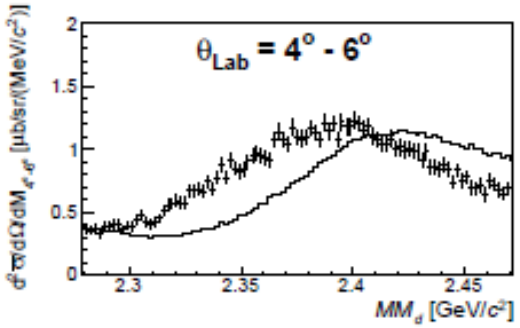
*Y** peak positions are shifted to the low mass side for all scattering angles.

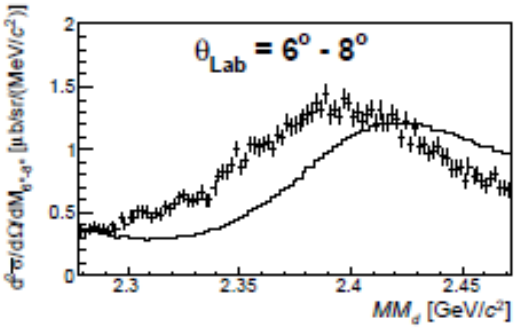
< Peak position >

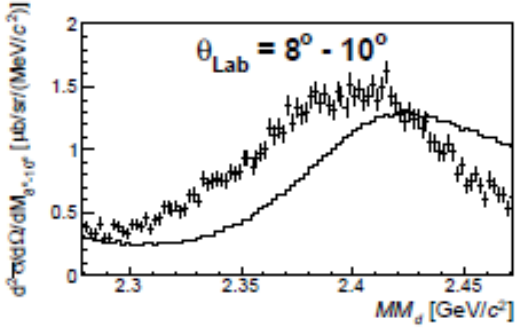
+ data
+ simulation

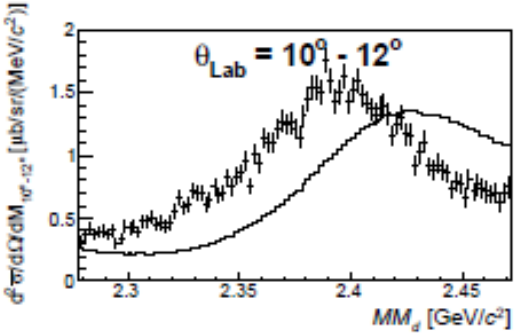


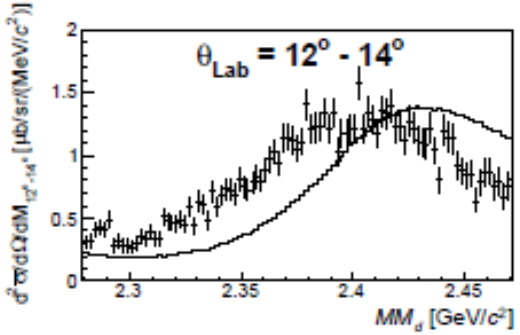


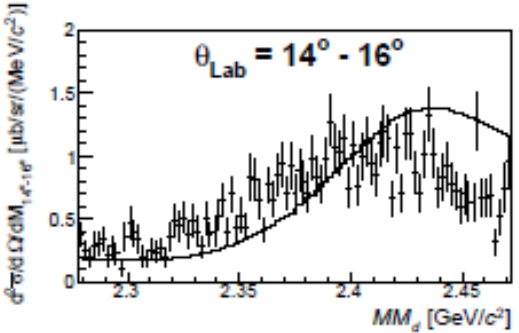


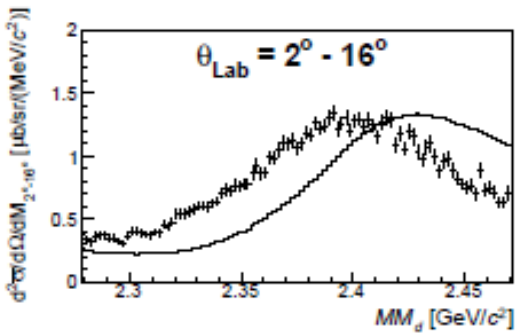










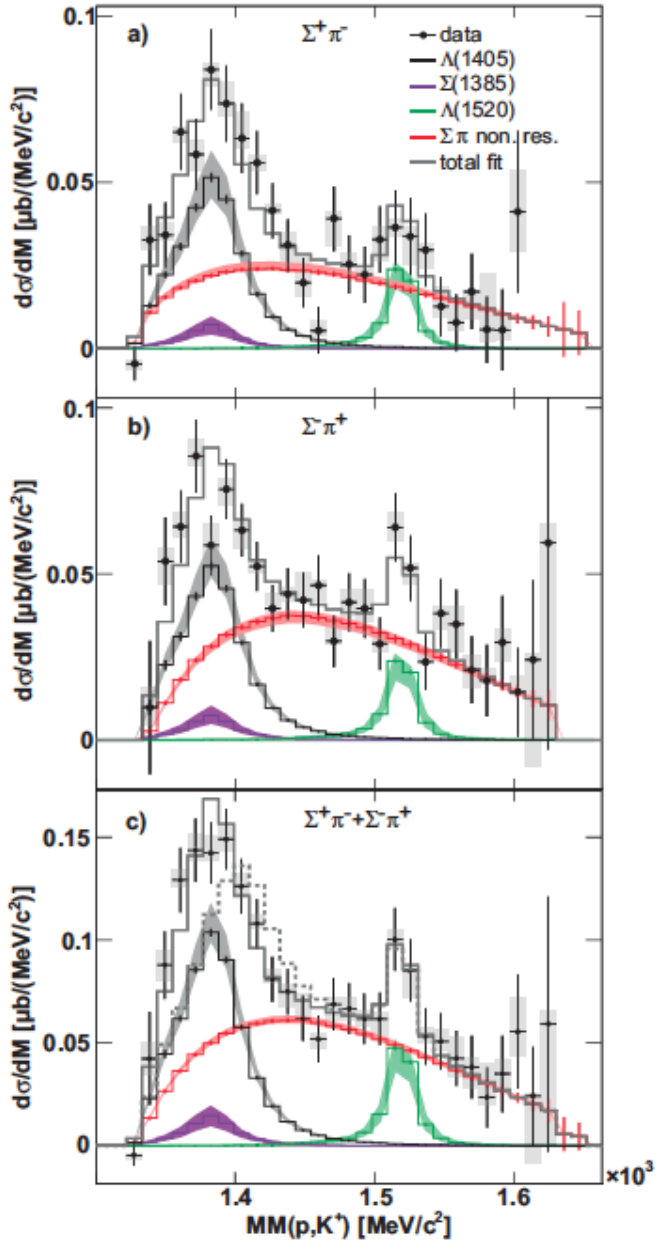


HADES experiment for Λ(1405)

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^{\pm} + \pi^{\mp}$$
$$\hookrightarrow \pi^{\pm} + n.$$

The peak position of Λ(1405) is shifted to low-mass side.

M = 1385 MeV/c^2,
Γ = 50 MeV
S-wave Breit Wigner function



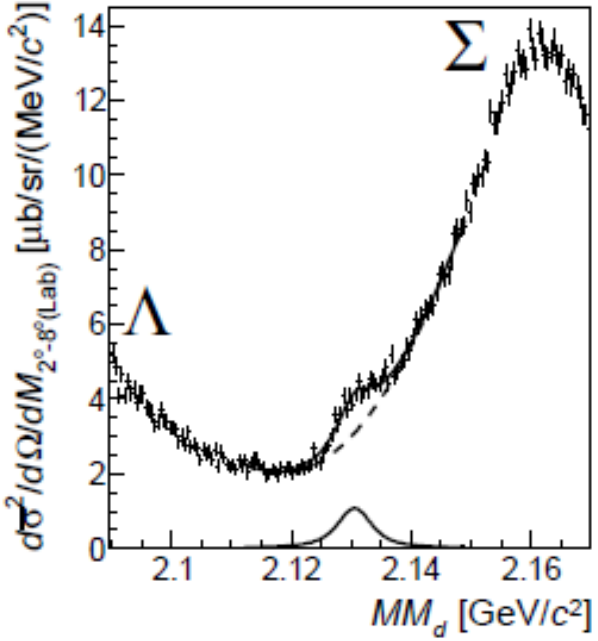
ΣN cusp (Inclusive spectrum)

- A cusp at ΣN threshold is prominent in the forward angle.
  - M_0 = 2130.5 ± 0.4 (stat.) ± 0.9 (syst.) [MeV/c^2]
  - Γ = $5.3^{+1.4}_{-1.2}$ (stat.) $^{+0.6}_{-0.3}$ (syst.) [MeV]
  - dσ/dΩ = 10.7 ± 1.7 μb/sr

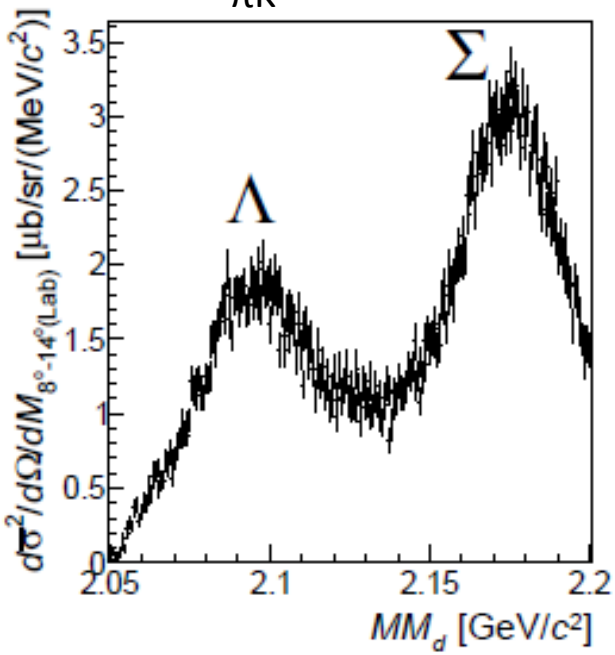
$M(\Sigma^0) + M(p)$
= 2.1309 GeV/c^2

$M(\Sigma^+) + M(n)$
= 2.1289 GeV/c^2

$< \theta_{\pi K} = 2^\circ - 8^\circ >$



$< \theta_{\pi K} = 8^\circ - 14^\circ >$



H. Machner *et al.*, NPA **901**, 65 (2013).

Previous measurement (ΣN cusp)

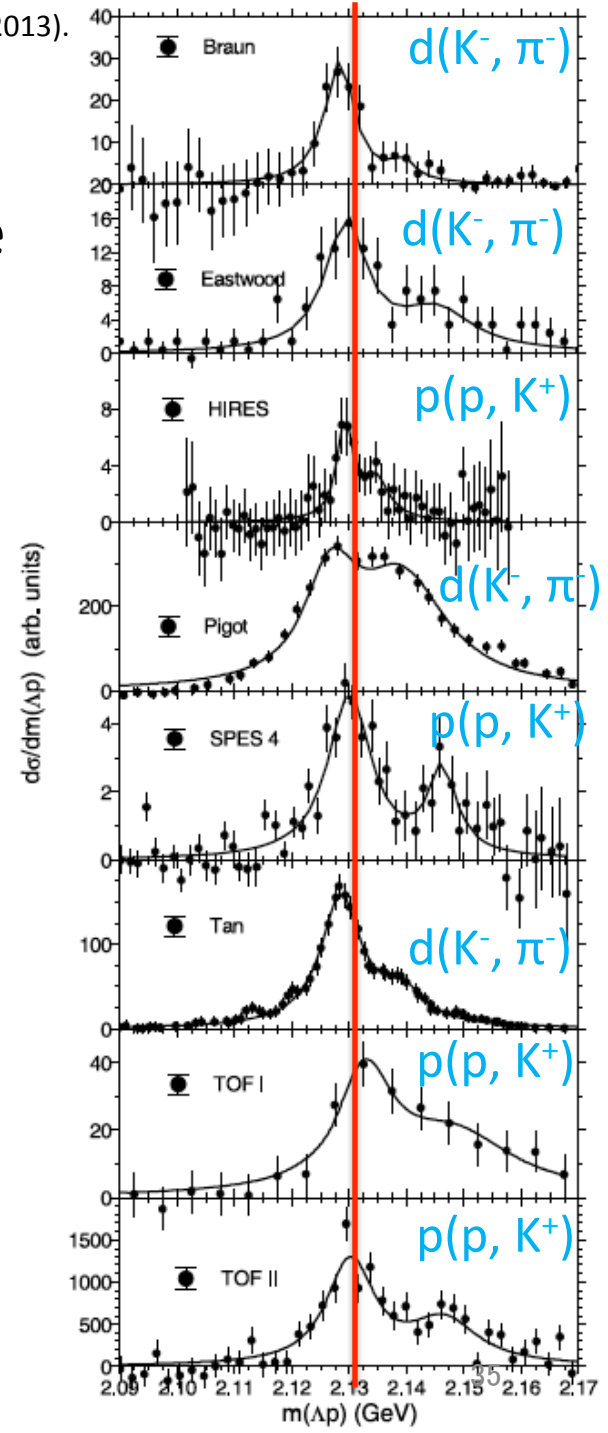
- The ΣN cusp structure was observed in the $d(K^-, \pi^-)$, $d(\pi^+, K^+)$ and $p(p, K^+)$ reaction.
  - In the $d(K^-, \pi^-)$ and $d(\pi^+, K^+)$ reaction

$$K^- + (NN)_d \rightarrow (K^- N) + N \qquad \text{R.H. Dalitz and B.W. Downs, PR } \mathbf{111}\text{, 967 (1958).}$$

$$\downarrow$$

$$(\pi^- + \Sigma) + N \rightarrow \pi^- + (\Sigma + N) \rightarrow \pi^- + \Lambda + p$$

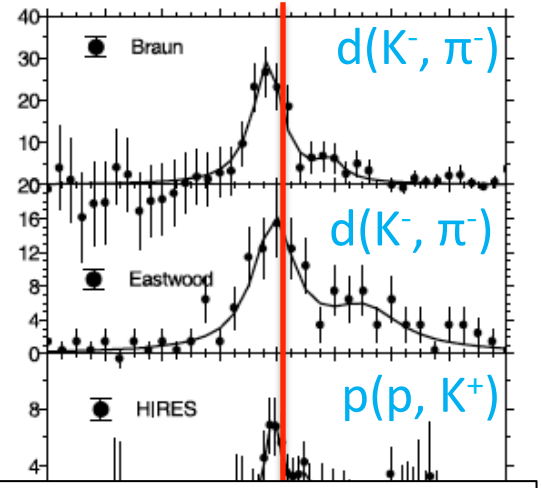
  - In the $p(p, K^+)$ reaction, reaction mechanism is not clear.
- There was no experiment to observe the ΣN cusp in the inclusive spectrum in the $d(K^-, \pi^-)$ and $d(\pi^+, K^+)$ reactions.
  - We can directly compare the inclusive spectrum with the theoretical spectrum.
  - Our MM resolution (3.2 MeV) is better than previous measurement.



H. Machner *et al.*, NPA **901**, 65 (2013).

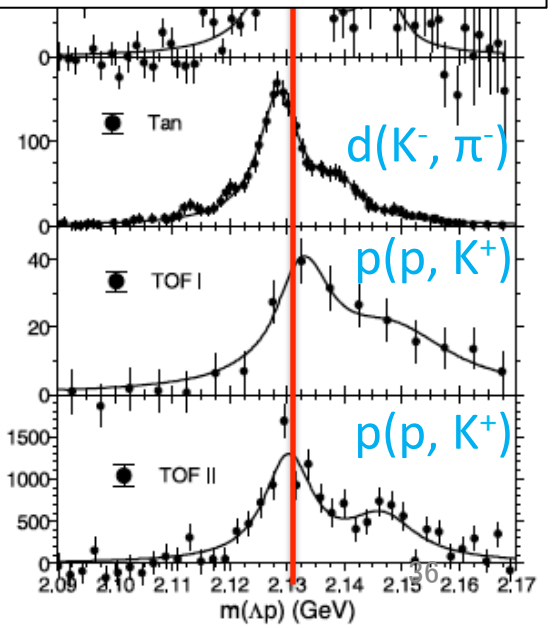
Previous measurement (ΣN cusp)

- The ΣN cusp structure was observed in the $d(K^-, \pi^-)$, $d(\pi^+, K^+)$ and $p(p, K^+)$ reaction.
  - In the $d(K^-, \pi^-)$ and $d(\pi^+, K^+)$ reaction



Further detailed theoretical studies including the present data would reveal the information on the ΣN-ΛN coupling strength and pole position.

- There was no experiment to observe the ΣN cusp in the inclusive spectrum in the $d(K^-, \pi^-)$ and $d(\pi^+, K^+)$ reactions.
  - We can directly compare the inclusive spectrum with the theoretical spectrum.
  - Our MM resolution (3.2 MeV) is better than previous measurement.



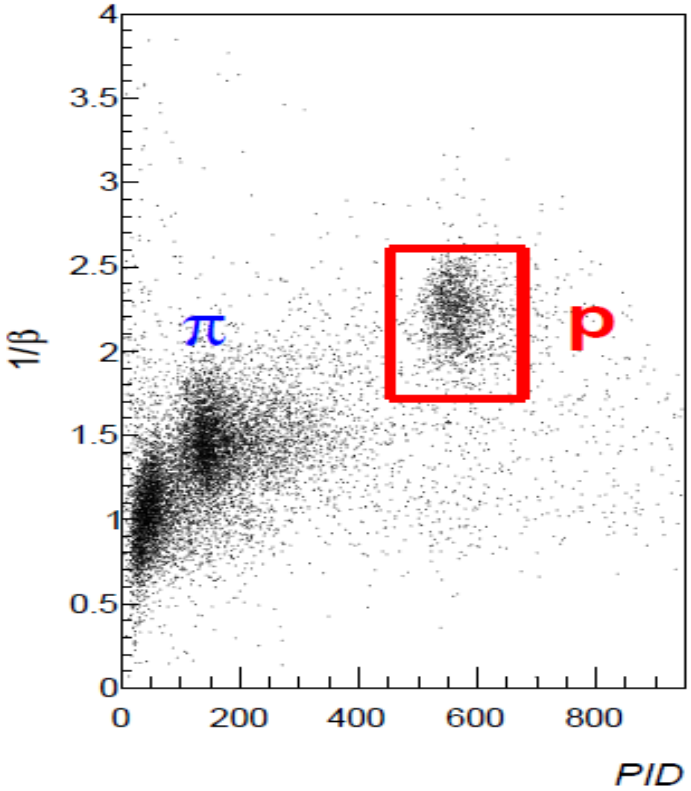
Coincidence analysis

Particle identification (PID) of the RCA

- Emitted proton is selected by RCA.

Information – Stopping layer (range), 1/β, PID parameter

< Stopping layer = 4 >



[PID parameter]

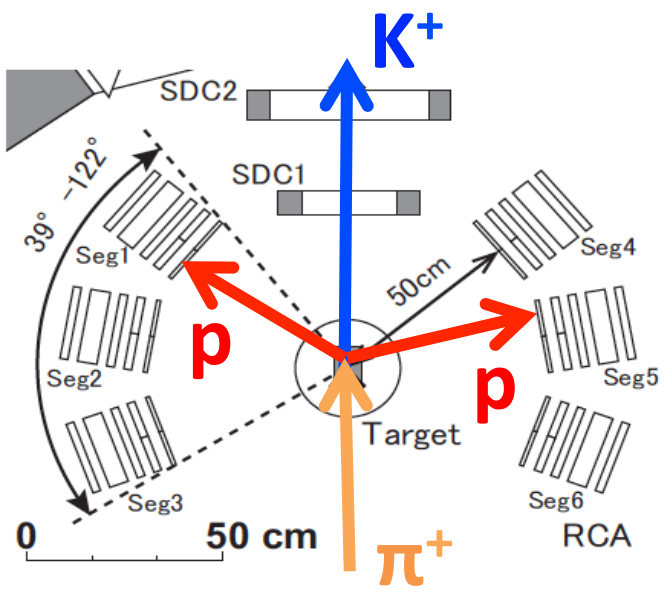
PID $\equiv ((dE_i + dE_{i-1})^{\alpha} - dE_i^{\alpha}) \times \cos\theta$

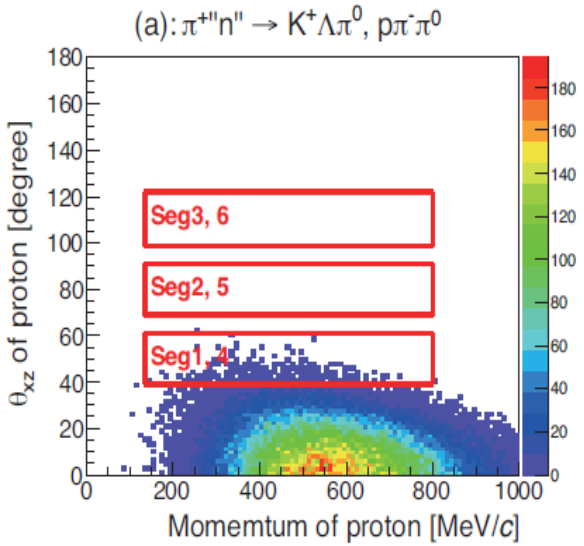
- i: stopping layer
- α (parameter) ~ 1.75
- θ is incident angle for RCA.

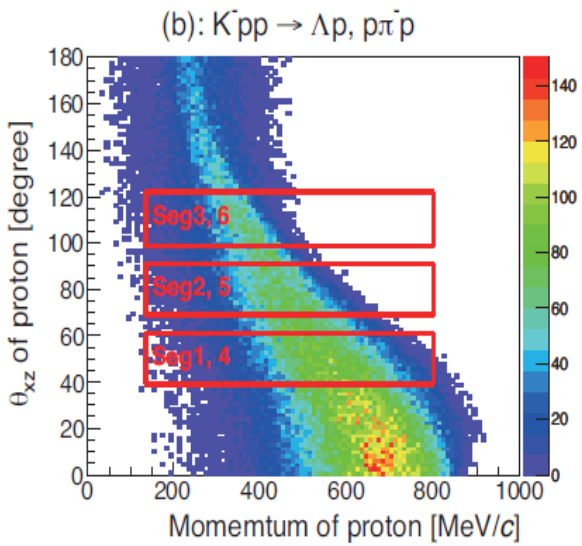
※PID parameter corresponds to the range of the previous layer of the stopping one.

Range counter array(RCA) for the coincidence measurement

- RCA is installed to measure the proton from the K^-pp.
  - $K^-pp \rightarrow \Lambda p \rightarrow p\pi^- p$; $K^-pp \rightarrow \Sigma^0 p \rightarrow p\pi^- \gamma p$; $K^-pp \rightarrow Y p\pi \rightarrow p\pi p$+(etc.)
- We suppress the QF background by tagging a proton.
  - ☆ Seg2 and 5 are free from QF background.
- More strongly suppress by tagging two protons.





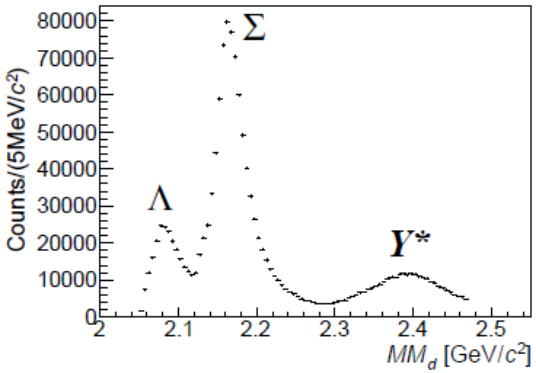


One-proton coincidence analysis

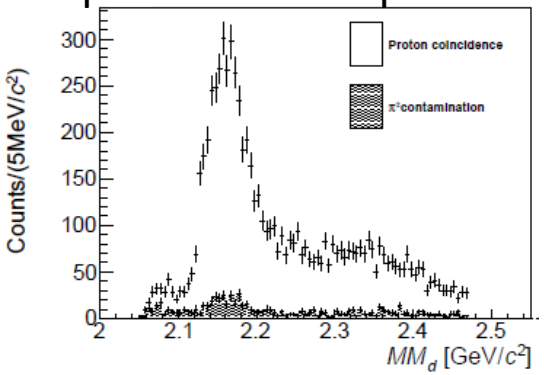
- Seg2 and 5 (RCA) are almost free from the QF backgrounds.
- Excess (~2.13 GeV/c^2) is clearly observed. (ΣN cusp & conversion)
- Broad enhancement (~2.3 GeV/c^2) is observed.

(``K-pp''-like structure)

< Inclusive spectrum >

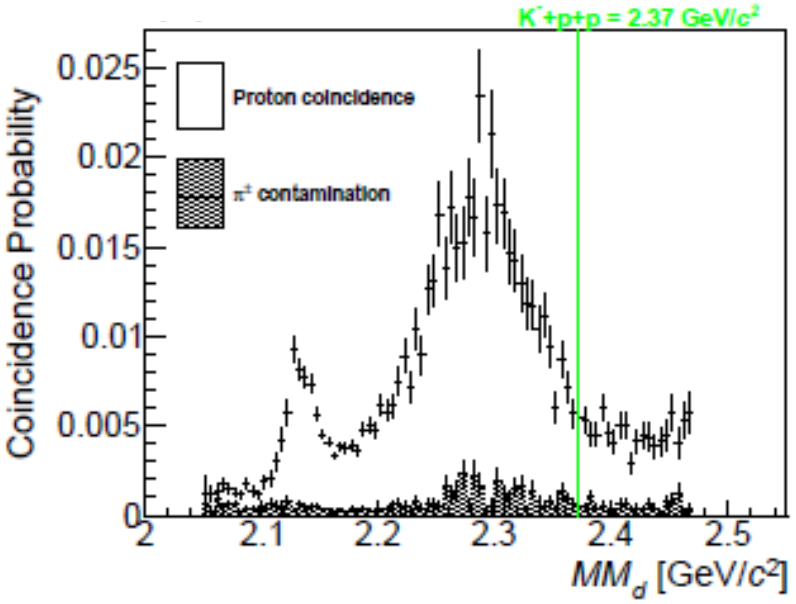


< 1p coincidence spectrum >



1p coin / Inclusive

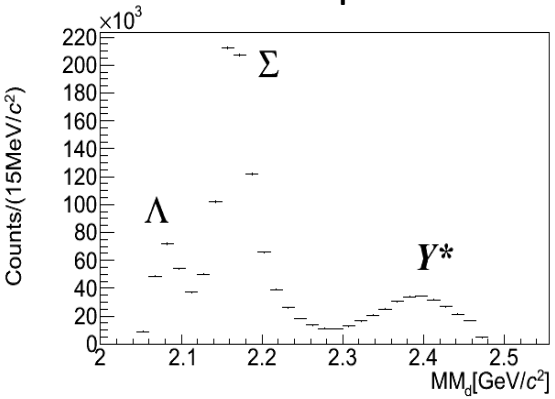
< 1p coincidence probability >



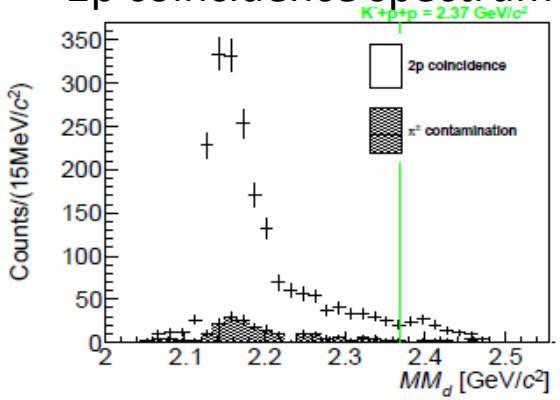
Two-proton coincidence analysis

- 2 proton coincidence spectra show the same tendency as 1 proton coincidence spectra.
  - Excess (~2.13 GeV/c^2, ΣN cusp and conversion) and Broad enhancement (~2.3 GeV/c^2, ``K$^-$pp''-like structure) .

< Inclusive spectrum >

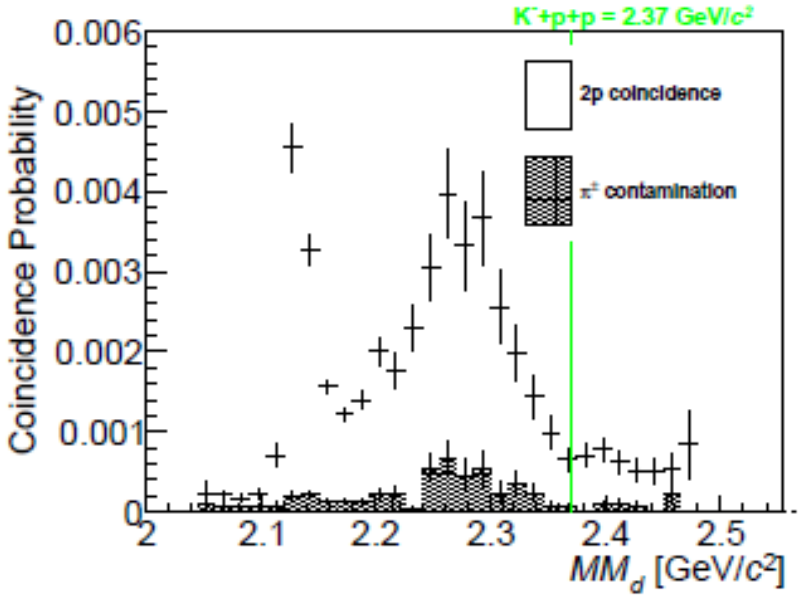


< 2p coincidence spectrum >

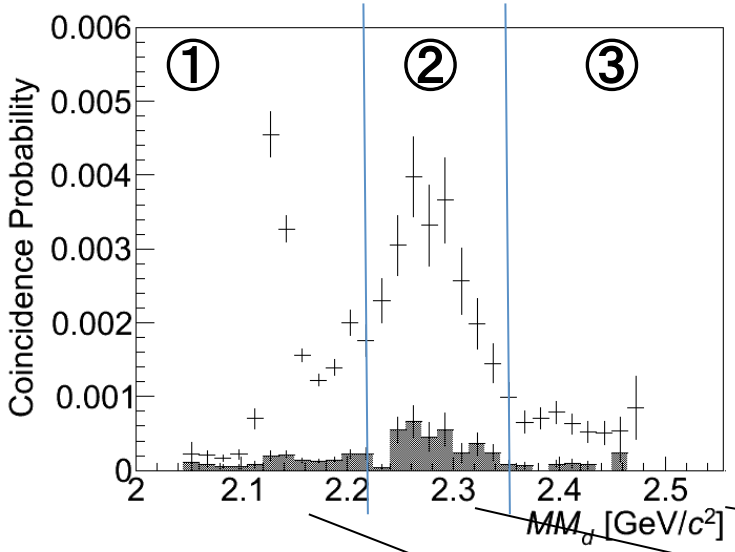


2p coin / Inclusive

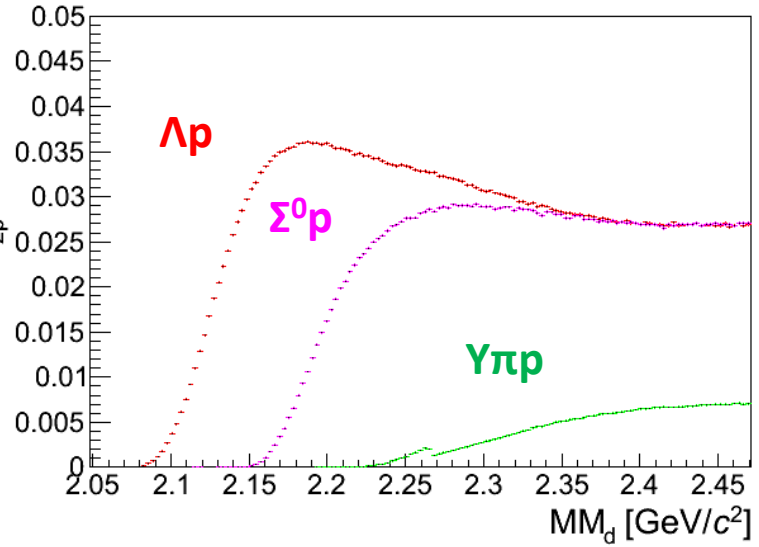
< 2p coincidence probability >



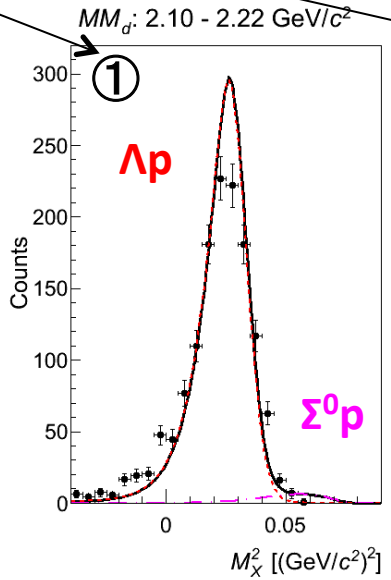
Identification of final states in two-proton coincidence

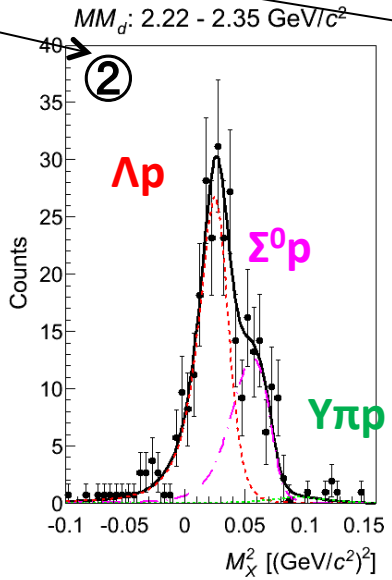


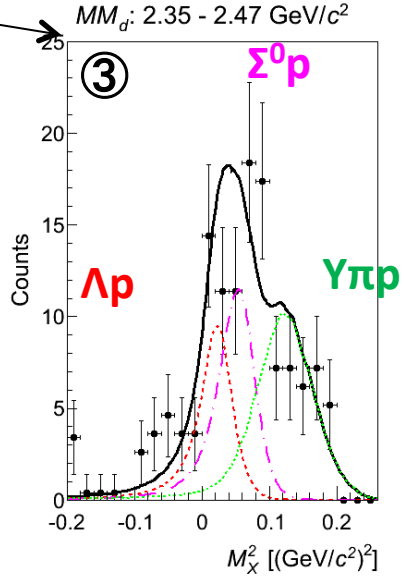
To detect
states sho
$< \pi^+ d \longrightarrow$
We constr
spectra of
X = π [Λ



＋ Data
— X = π (FS: Λp)
— X = πγ (FS: Σ^0p)
— X = 2π(γ) (FS: Yπp)
— Sum





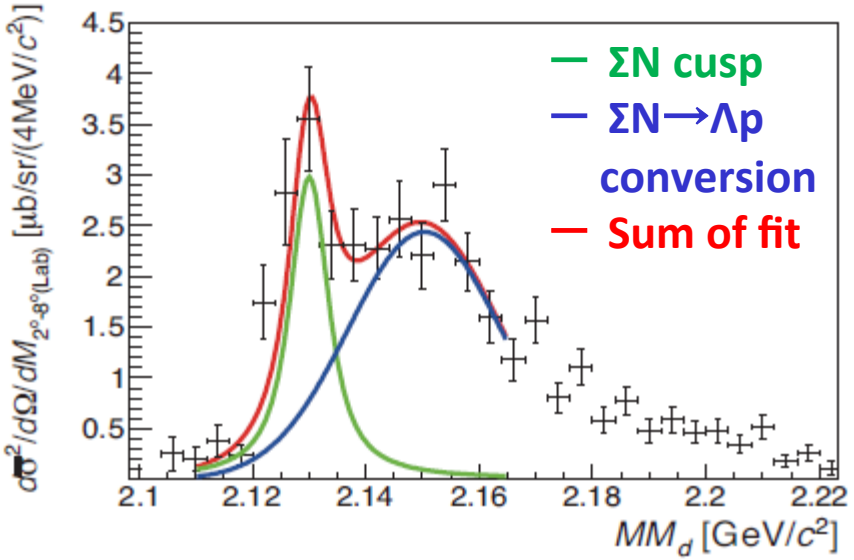


ΣN cusp (two-proton coincidence)

- The ΣN cusp structure is also observed in the 2p spectrum (Λp) for the forward scattering angle (2˚-8˚).
- The peak position, width and cross section are consistent with the inclusive one.

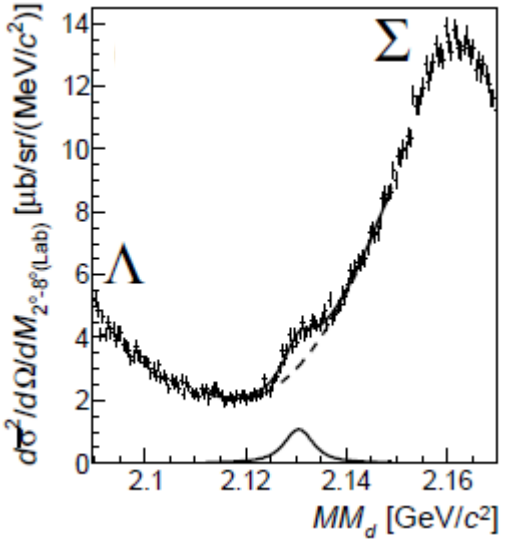
< 2p coincidence result>

$\pi^+ d \rightarrow K^+ W$, $W \rightarrow \Lambda p$



<Inclusive analysis result>

$$\begin{cases} M0 = 2130.5 \pm 0.4(stat) \pm 0.9(sys)[MeV/c^2] \\ \Gamma = 5.3^{+1.4}_{-1.2}(stat)^{+0.6}_{-0.3}(sys)[MeV] \\ d\bar{\sigma}/d\Omega = 10.7 \pm 1.7\ \mu\mathrm{b/sr} \end{cases}$$



``K⁻pp''-like structure(coincidence)

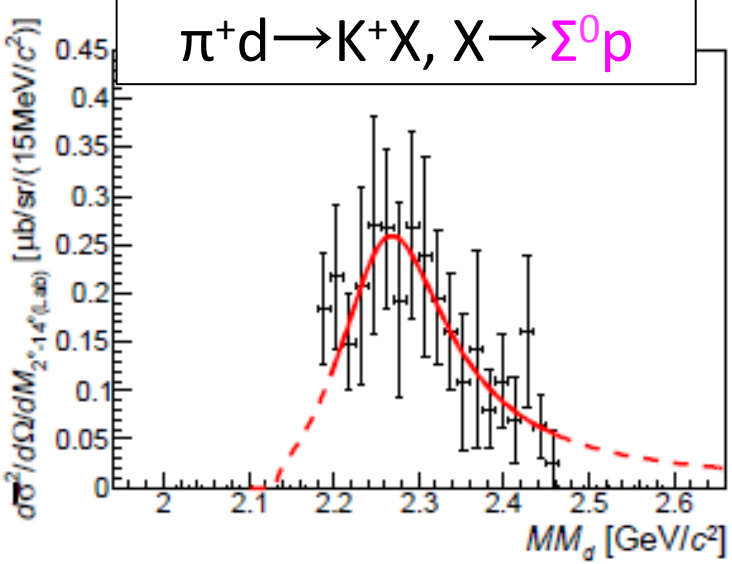
- Broad enhancement ~2.28 GeV/c^2 has been observed in the **$\Sigma^0 p$** spectrum.
  - Mass: $2275\ ^{+17}_{-18}\ (\mathrm{stat.})\ ^{+21}_{-30}\ (\mathrm{syst.})\ \mathrm{MeV}/c^2$ (BE: $95\ ^{+18}_{-17}\ (\mathrm{stat.})\ ^{+30}_{-21}\ (\mathrm{syst.})\ \mathrm{MeV}$)
  - Width: $162\ ^{+87}_{-45}\ (\mathrm{stat.})\ ^{+66}_{-78}\ (\mathrm{syst.})\ \mathrm{MeV}$
  - $d\sigma/d\Omega_{``K^-pp''\to\Sigma^0 p} = 3.0 \pm 0.3\ (\mathrm{stat.})\ ^{+0.7}_{-1.1}\ (\mathrm{syst.})\ \mu\mathrm{b/sr}$

T. Sekihara, D. Jido and Y. Kanada-En'yo, PRC **79**, 062201(R) (2009).

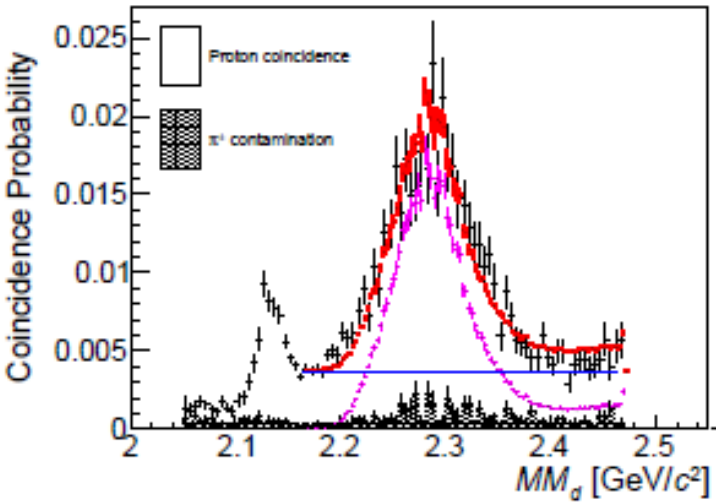
  - $\Gamma_{\Lambda p}/\Gamma_{\Sigma^0 p} = 0.92\ ^{+0.16}_{-0.14}\ (\mathrm{stat.})\ ^{+0.60}_{-0.42}\ (\mathrm{syst.})$. [Theoretical value: ~1.2]

<2proton coincidence analysis>

$\pi^+ d \to K^+ X$, $X \to \Sigma^0 p$



<1 proton coincidence probability>



Discussion on the ``K^-pp''-like structure 1

- Obtained mass (BE ~ 100 MeV) and broad width are not inconsistent with the FINUDA and DISTO values.
  - Theoretical calculation for the K^-pp is difficult to reproduce such a deep binding energy about 100 MeV.
  - The other possibilities?
    - A dibaryon as $\pi\Lambda N - \pi\Sigma N$ bound states? H. Garcilazo and A. Gal, NPA **897**, 167 (2013).

      (It should not decay to the Λp mode because of $I = 3/2$.)
    - Λ^*N bound state? T. Uchino *et al.*, NPA **868**, 53 (2011).
    - A lower $\pi\Sigma N$ pole of the K^-pp? A. Dote, T. Inoue and T. Myo, PTEP 2015 4, 043D02 (2015).

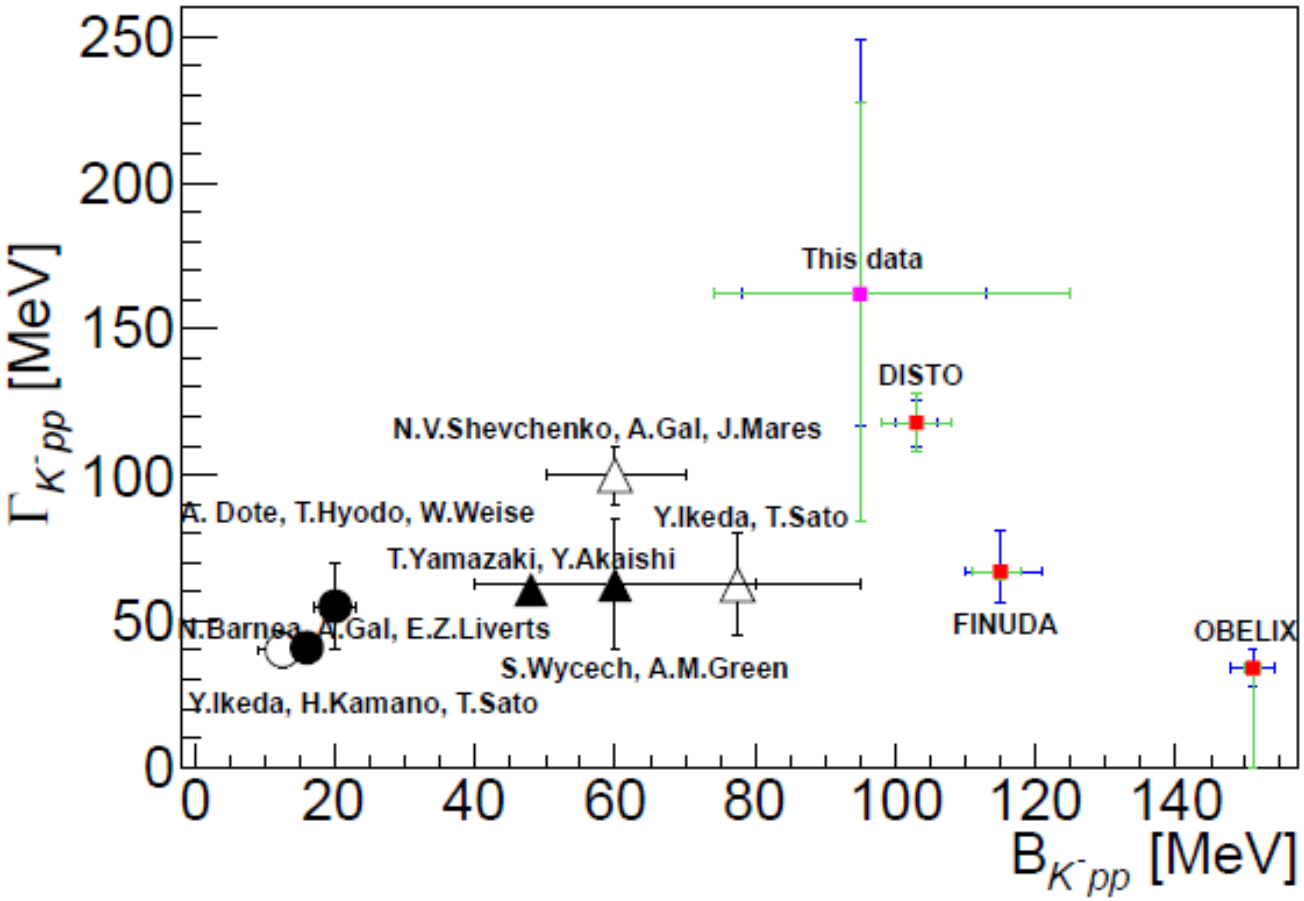
      (The K^-pp might have the double pole structure like $\Lambda(1405)$.)

- Partial restoration of chiral symmetry on the $\overline{K}N$ interaction?

S. Maeda, Y. Akaishi and T. Yamazaki, Proc. Jpn. B **89**, 418 (2013).

Discussion on the ``K⁻pp''-like structure 1

- Obtained mass (BE ~ 100 MeV) and broad width are not inconsistent with the FINUDA and DISTO values.
  - Th
    re
  - Th
    - 0 MeV.
    - , NPA **897**, 167 (2013).
    - /2.)
    - NPA **868**, 53 (2011).
    - 015 4, 043D02 (2015).
    - Λ(1405).)
    - raction?
    - on. B **89**, 418 (2013).

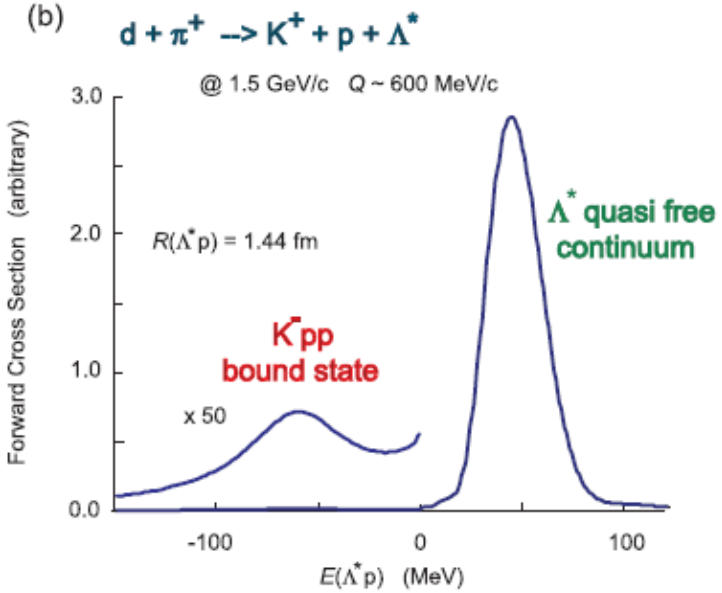


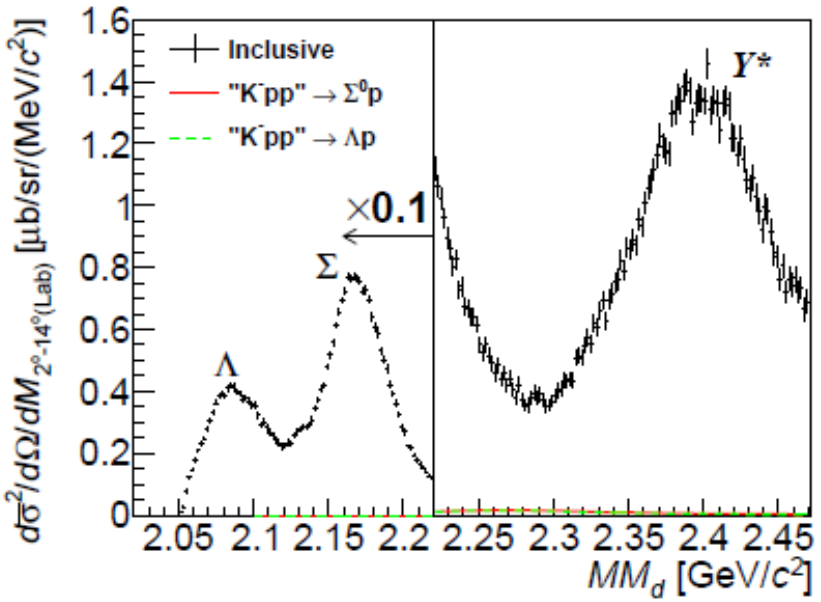
Discussion on the ``K$^-$pp''-like structure 2

- Sticking probability of the Λ(1405) (Elementary: 36.9 μb/sr)
  - $(d\sigma/d\Omega_{``K^-pp''\to\Sigma^0 p})/(d\sigma/d\Omega_{\Lambda(1405)})$ = 8.2 %
  - $(d\sigma/d\Omega_{``K^-pp''\to\Lambda p})/(d\sigma/d\Omega_{\Lambda(1405)})$ = 6.0 %
  - $(d\sigma/d\Omega_{``K^-pp'')}/(d\sigma/d\Omega_{\Lambda(1405)}) \gtrsim$ 14.2 % (for the Y^*: $\gtrsim$ 3.1 %)
  - Theoretical value is about 1%.

Incorrect assumption of the Λ(1405) doorway (?) and/or the other possibilities (?)

Y. Akaishi and T. Yamazaki, PRC **76**, 045201 (2007).

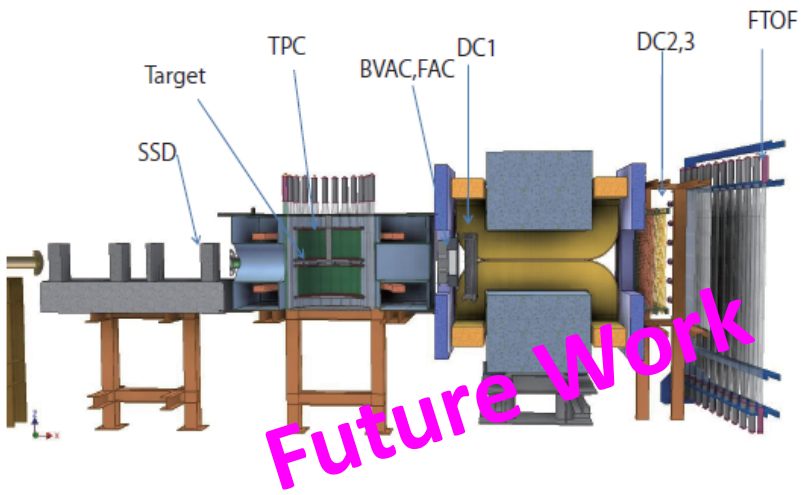


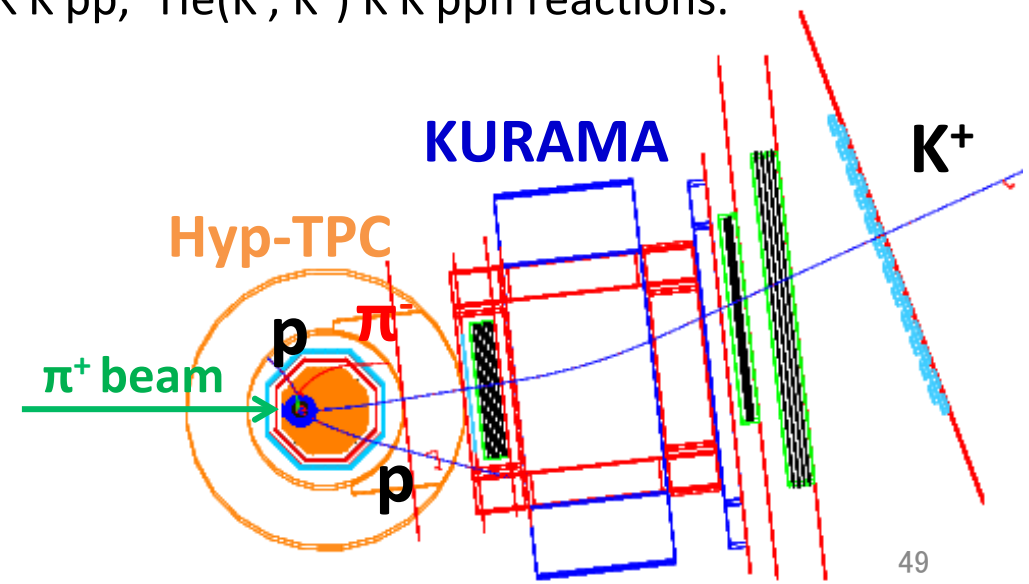


Future plan

To confirm the “K-pp”-like structure

- Further experiment is planed by using **Hyp-TPC** + KURAMA Spectrometer and same reaction (d(π^+, K^+) reaction).
  - E27 experiment = RCA + SKS spectrometer
  - RCA → **Hyp-TPC**（Improve to the large acceptance!! (About 4 times larger)!!）
  - SKS → KURAMA（Improve to the large acceptance (About 2 times larger)!!）
  - In the further experiment, we carried out the perfect experiment to detect all particles in high statistic and determine the spin and parity of the K^-pp-like structure!!
  - We are going to search further kaonic nucleus by using this detector system with $^3He(\pi^+,K^+)K^-ppp$, $d(K^-,K^0)K^-K^-pp$, $^3He(K^-, K^+)K^-K^-ppn$ reactions.





Conclusion

- The K^-pp bound state are not well explored, yet. We have searched for the K^-pp bound state using the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c.
- We have measured the inclusive missing-mass spectrum at 1.69 GeV/*c* in high statistic and energy resolution for the first time.
- The overall structure is well reproduced with a simple quasi-free picture except for two peculiar deviations.
  - The centroid of the broad bump structure in Y^* region was shifted to low mass side, by -32.4 ± 0.5 (stat.) $^{+2.9}_{-1.7}$ (syst.) MeV/c^2.
  - We observed the ΣN cusp in the inclusive spectrum for the first time in this reaction.
- We have observed a mass distribution of the ``$K^-pp$''-like structure in the $\pi^+d \rightarrow K^+$``K^-pp'', ``K^-pp''$\rightarrow \Sigma^0 p$ mode in two-proton coincidence .
  - Mass: $2275\ ^{+17}_{-18}$ (stat.) $^{+21}_{-30}$ (syst.) MeV/c^2 (BE: $95\ ^{+18}_{-17}$ (stat.) $^{+30}_{-21}$ (syst.) MeV)
  - Width: $162\ ^{+87}_{-45}$ (stat.) $^{+66}_{-78}$ (syst.) MeV