# Spectroscopic study of hyperon resonance below $\overline{K}N$ threshold via the d($K^-$,n) reaction

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# Contents

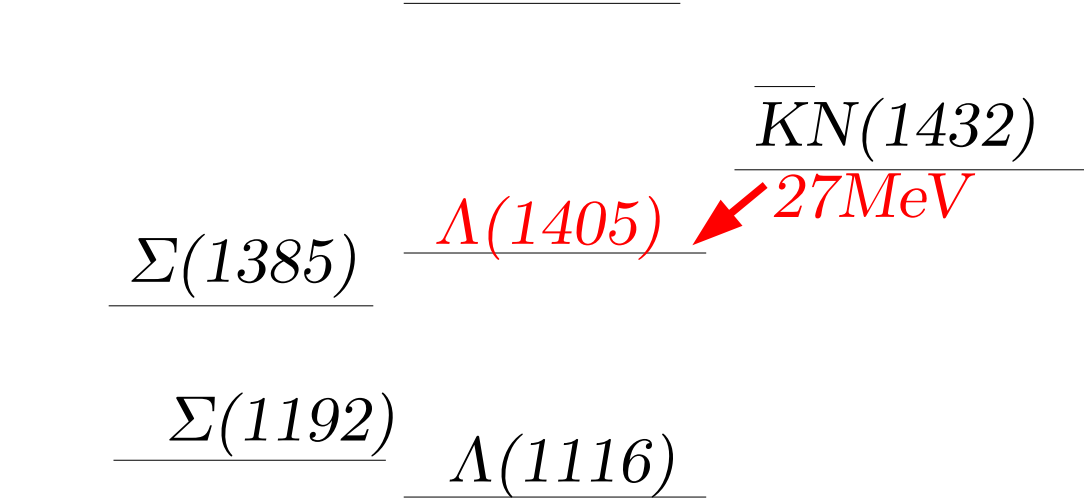
- Introduction
- Experimental setup
- Preliminary results
  - d($K^-$, n)"X" spectrum identified $\pi^{\mp}\Sigma^{\pm}$
  - Cross section ratio of $\pi^-\Sigma^+$ to $\pi^+\Sigma^-$
- Ongoing analysis on $\pi^0\Sigma^0$ and $\pi^0\Lambda$
- Summary

| | Exp. Target | Primary-beam intensity | Secondary-kaon intensity | Duration | Kaons on target (w/ tgt selection) |
|---|---|---|---|---|---|
| **May, 2013 (Run#49c)** | E15 1st $^3$He | 24 kW (30 Tppp, 6s) | 140 k/spill | 88 h | $5.3 \times 10^9$ |
| **Apr-May, 2015 (Run#62)** | calibration $H_2$ | 26.5 kW (33 Tppp, 6s) | 130 k/spill | 73 h | $3.7 \times 10^9$ |
| **Apr-May, 2015 (Run#62)** | calibration $D_2$ | 26.5 kW (33 Tppp, 6s) | 130 k/spill | 53 h | $2.8 \times 10^9$ |
| **Autumn, 2015** | E15 2nd $^3$He | 40 kW (50 Tppp, 6s) | 200k/spill | 26d | $50 \times 10^9$ |

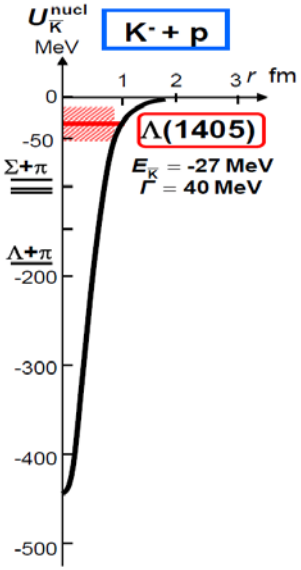
# Introduction

# Λ(1405)

PDG
- I(Jᵖ)=0($\frac{1}{2}^-$)
- mass $1405.1^{+1.3}_{-1.0}$ MeV
- Width = 50.5 ± 2 MeV

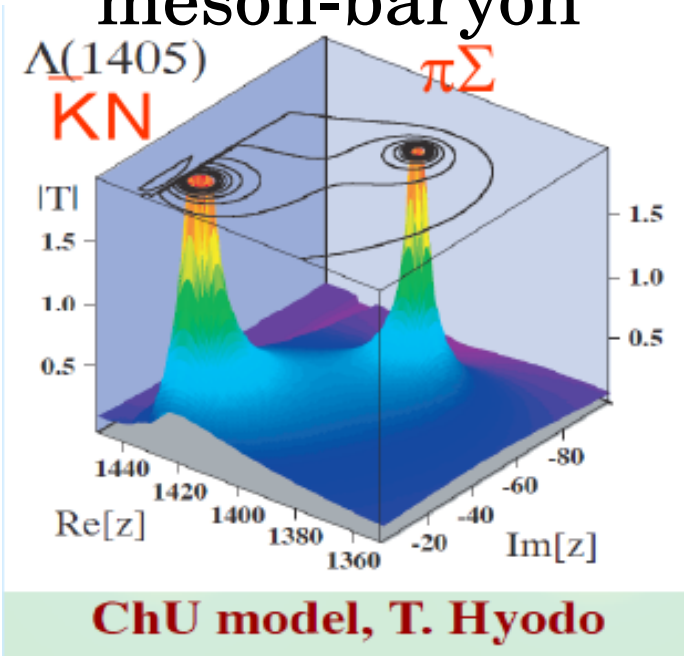



## $\overline{K}N$ bound state




Y.Akaishi & T.Yamazaki
PLB535, 70(2002).

## Two-poles of meson-baryon



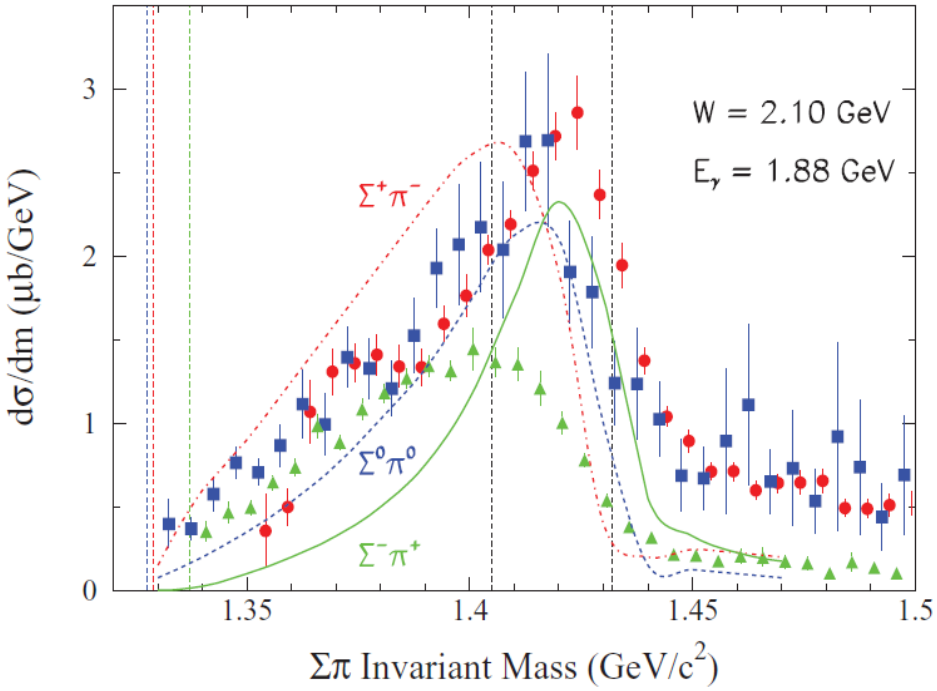

ChU model, T. Hyodo

# Recent experimental study of Λ(1405)

Line shapes of Λ(1405) have been reported.

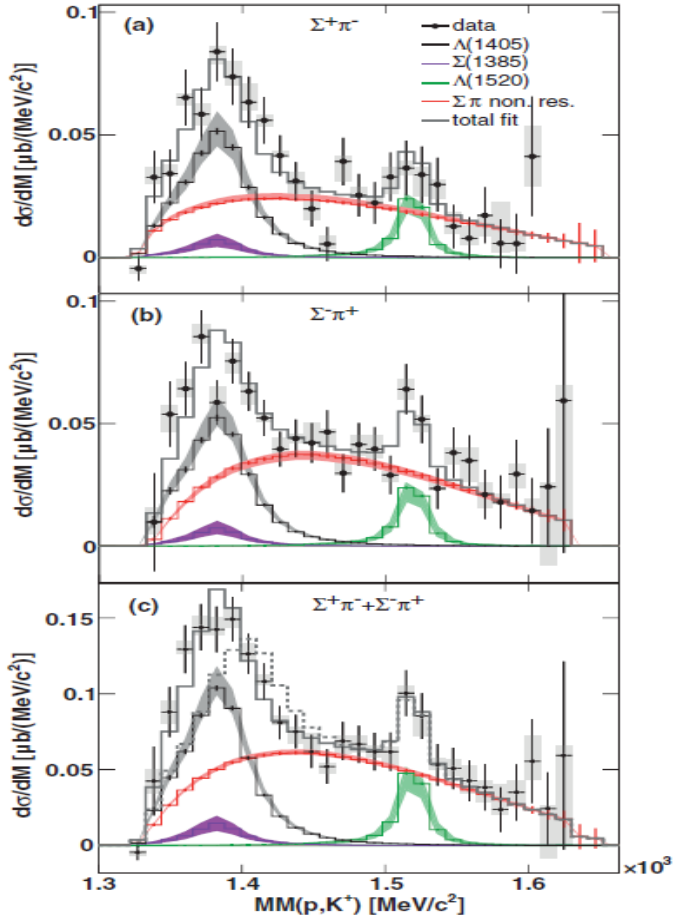
## Photo-production

CLAS collaboration:
PRC87, 035206




## pp collision

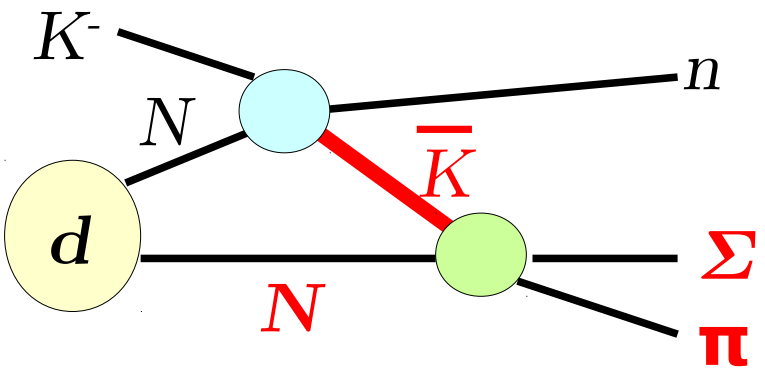
HADES collaboration:
PRC87, 025201




Kaon induced reaction is desired.

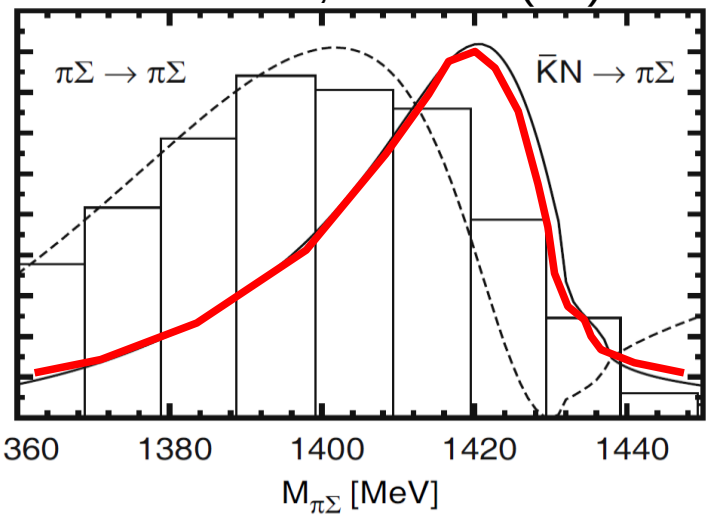
# d(K⁻, n) reaction

- The d(K⁻, n) reaction measured 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.




Chiral Unitary Model

D. Jido et al., NPA725(03)181



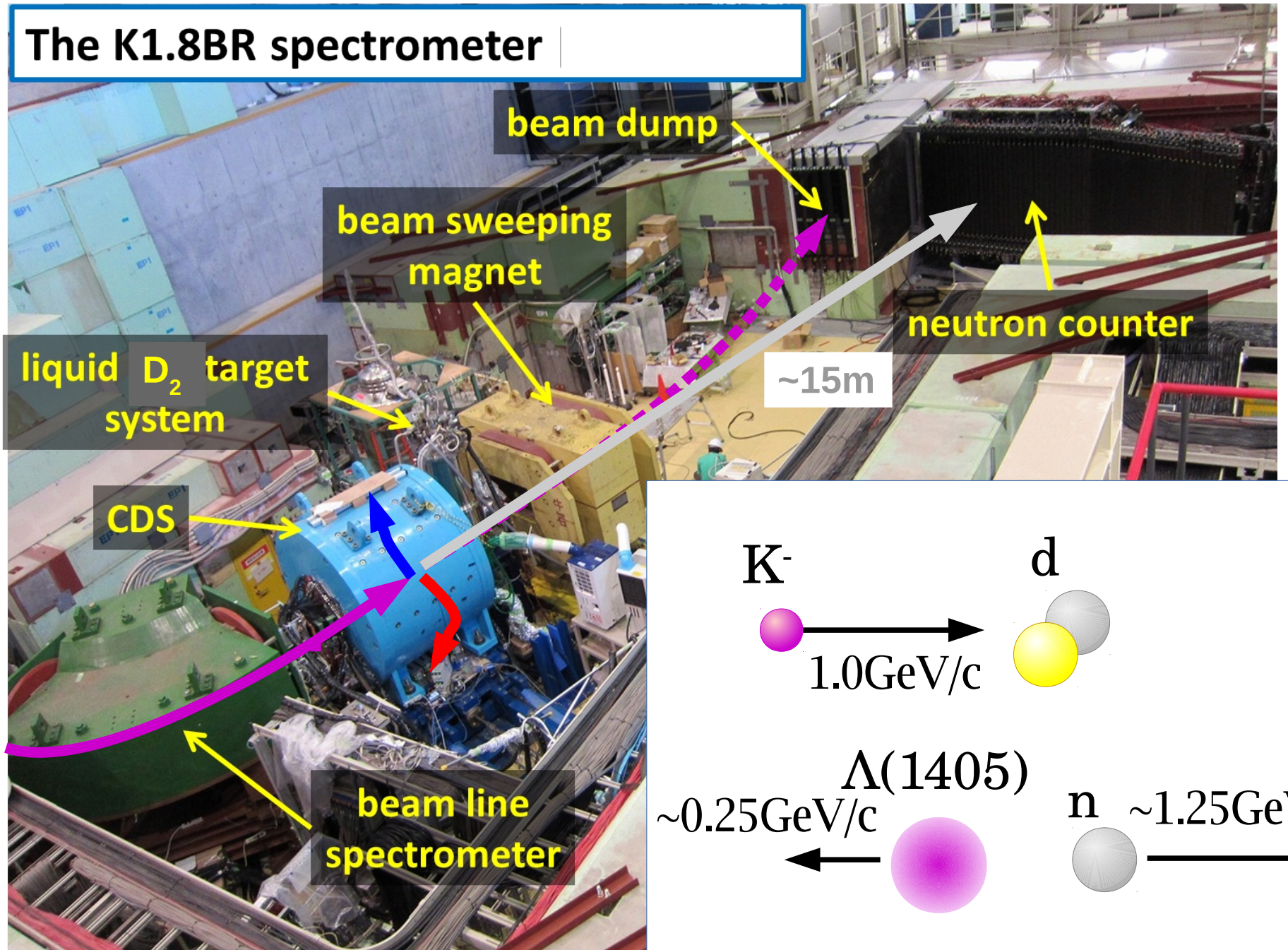

| | | | | |
|---|---|---|---|---|
| $\Lambda(1405)$ | $I=0$ | S-wave | $\pi^-\Sigma^+$, $\pi^+\Sigma^-$, $\pi^0\Sigma^0$ | **Pure I=0** |
| $\Sigma(1385)$ | $I=1$ | P-wave | $\pi^-\Sigma^+$, $\pi^+\Sigma^-$, $\pi^0\Lambda$ | **Pure I=1** |
| Non resonant | $I=0,1$ | S,P,D,... | | |

Identification of all $\pi\Sigma$ & $\pi\Lambda$ mode is necessary to decompose isospin.

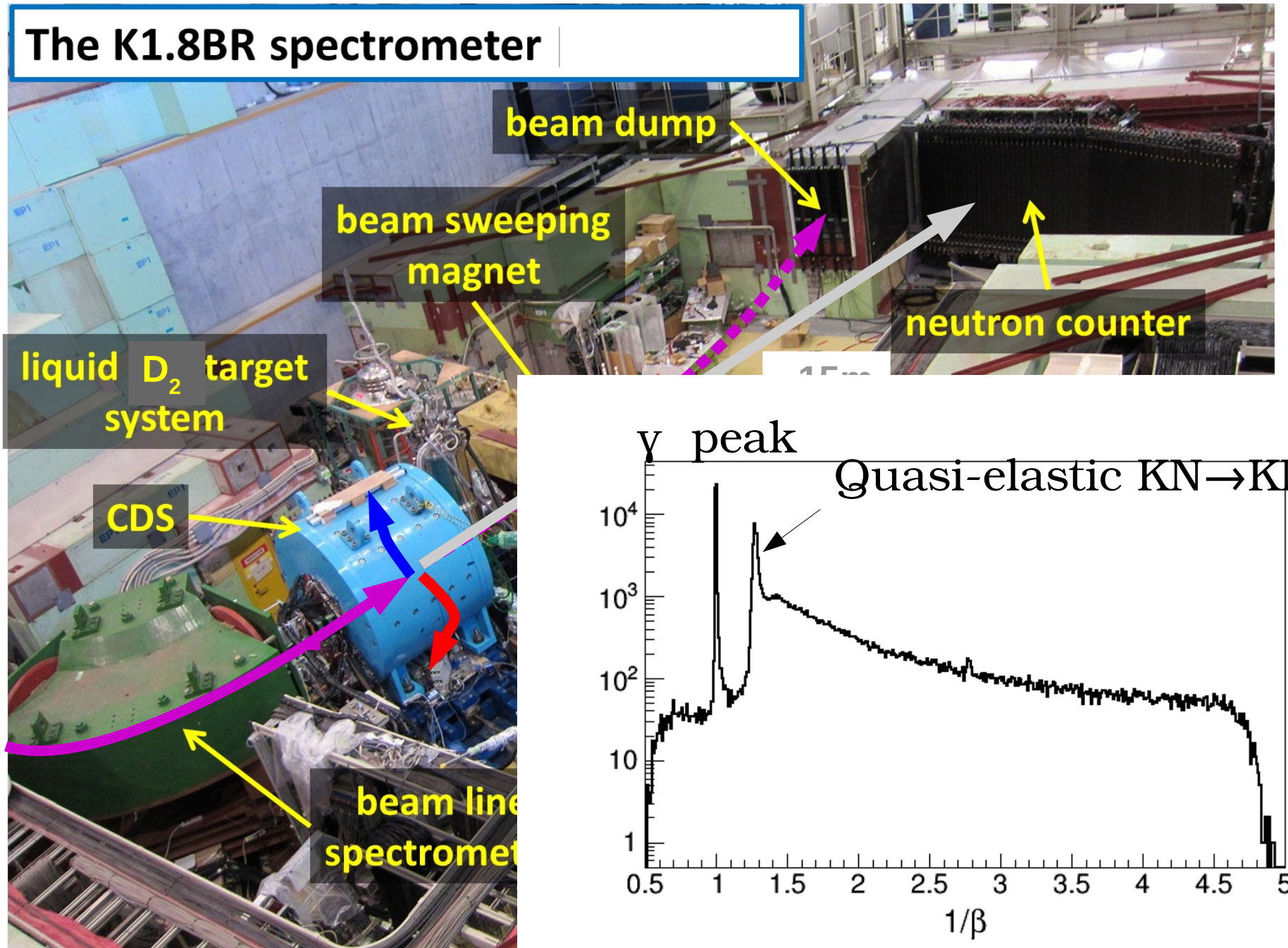
The goal of E31.

# Experimental Setup

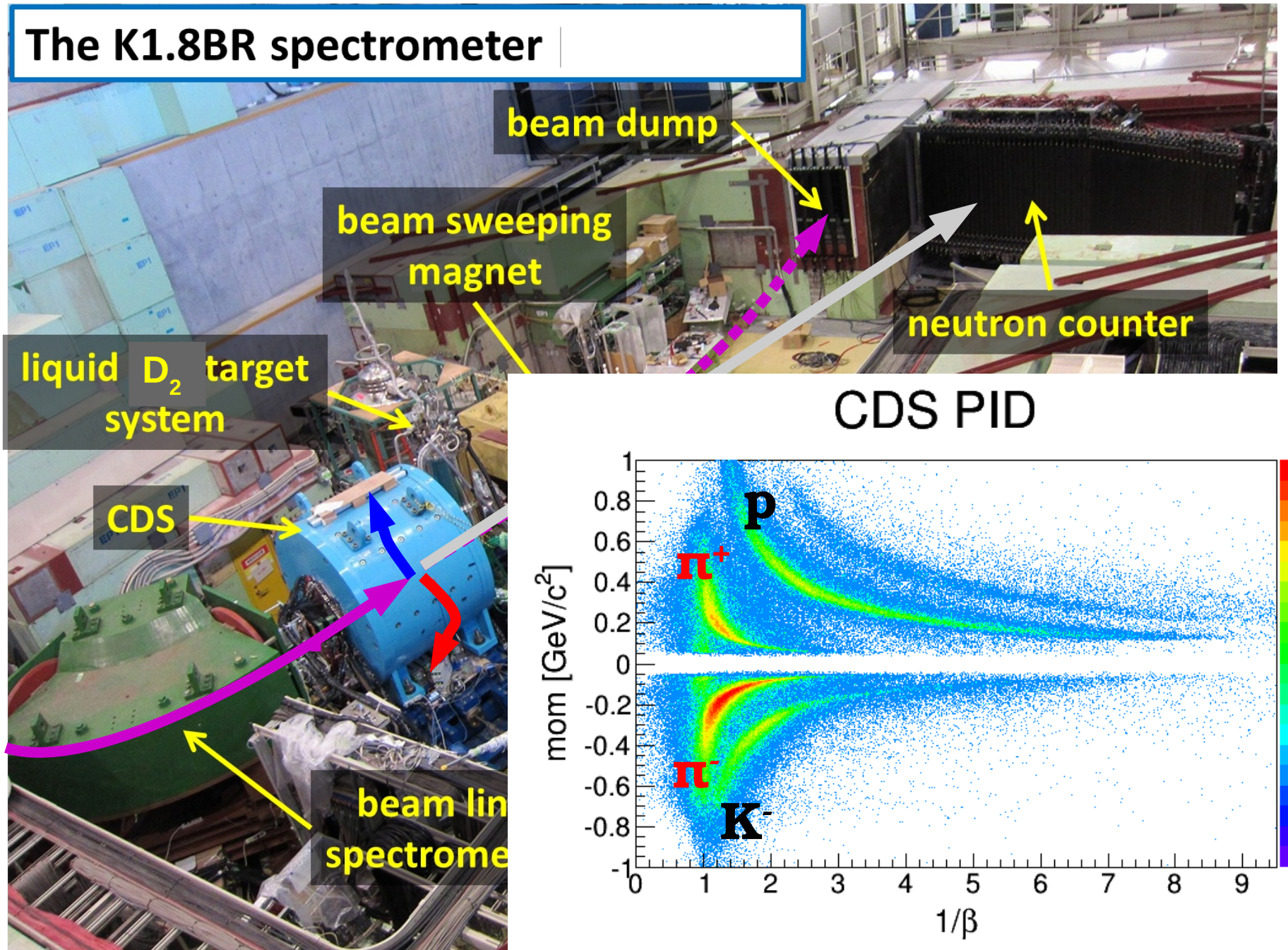
# Experimental Setup



# Experimental Setup

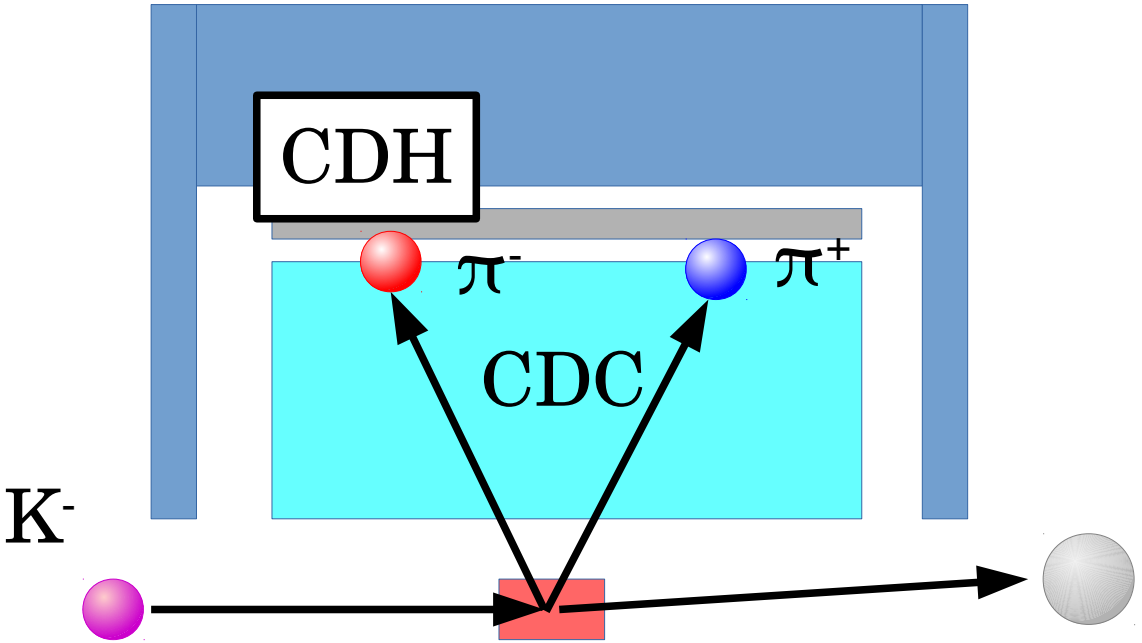


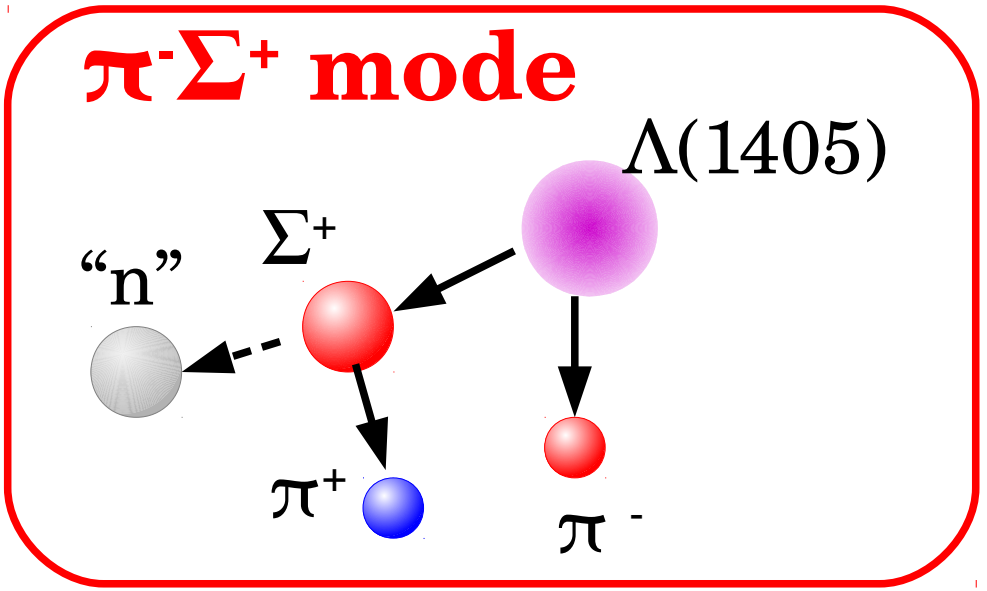
# Experimental Setup

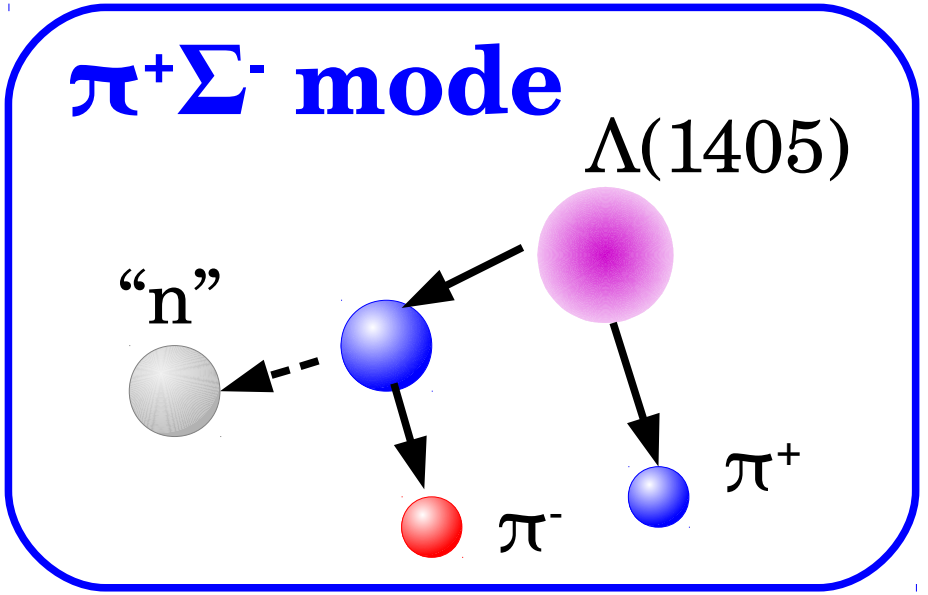


# Analysis on $\pi^{\mp}\Sigma^{\pm}$ mode

# Mode identification $\pi^{\mp}\Sigma^{\pm}$

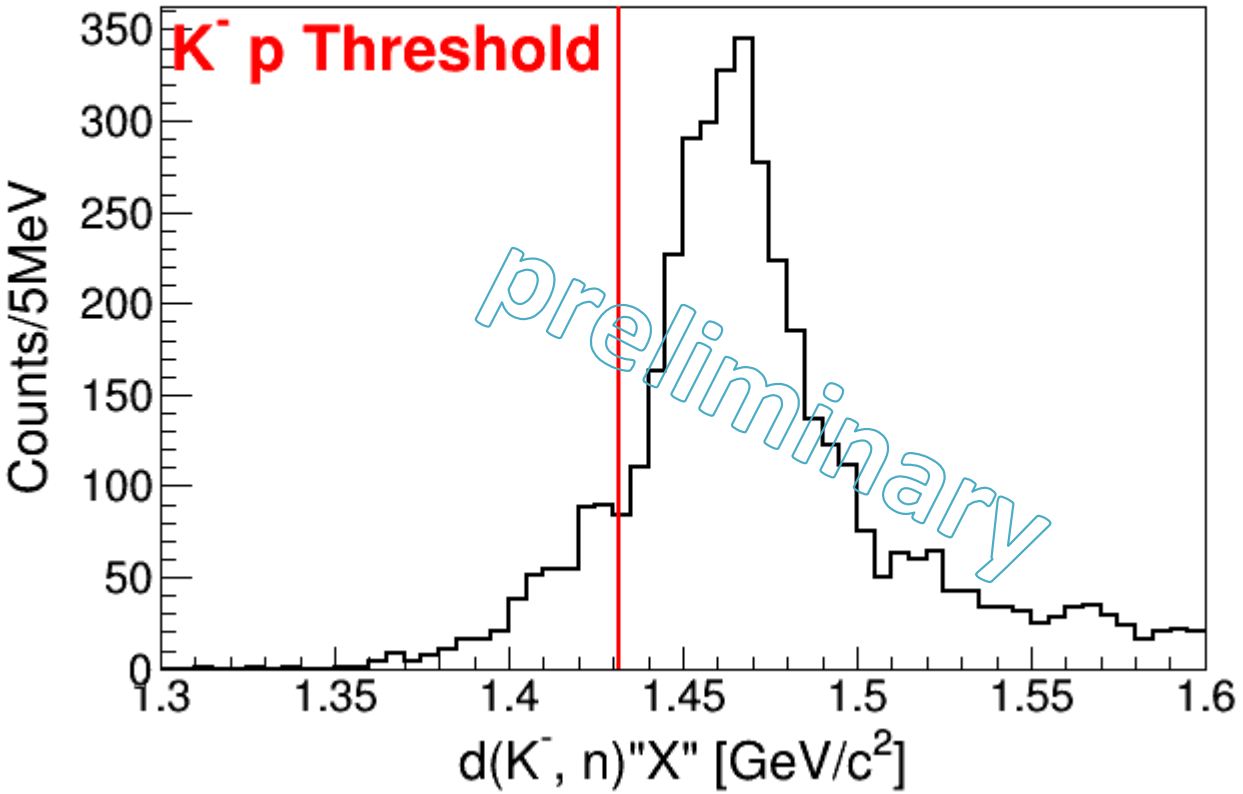


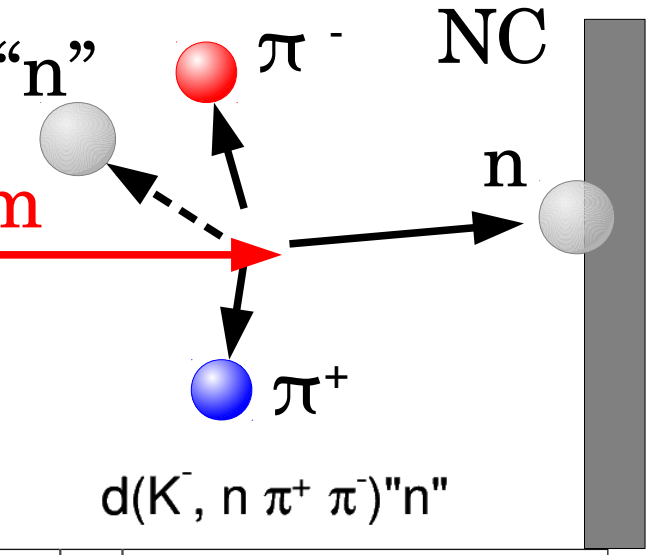



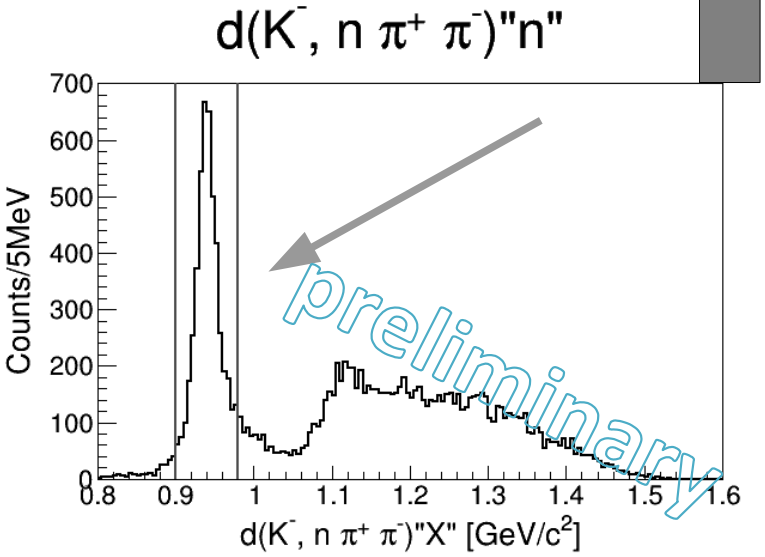




$K^- d \rightarrow n \pi^+ \pi^- n$ events was identified.

# $K^- d \to n \pi^+ \pi^- n$ events




Expected contributions in $K^- d \to n \pi^+ \pi^- n$ events are

Signal : Backward $\Lambda(1405)$ production.

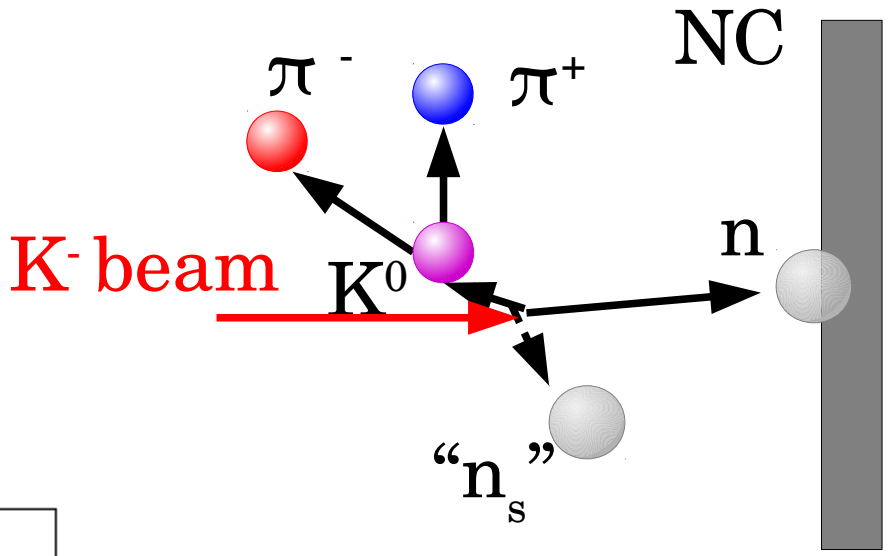
BG processes :

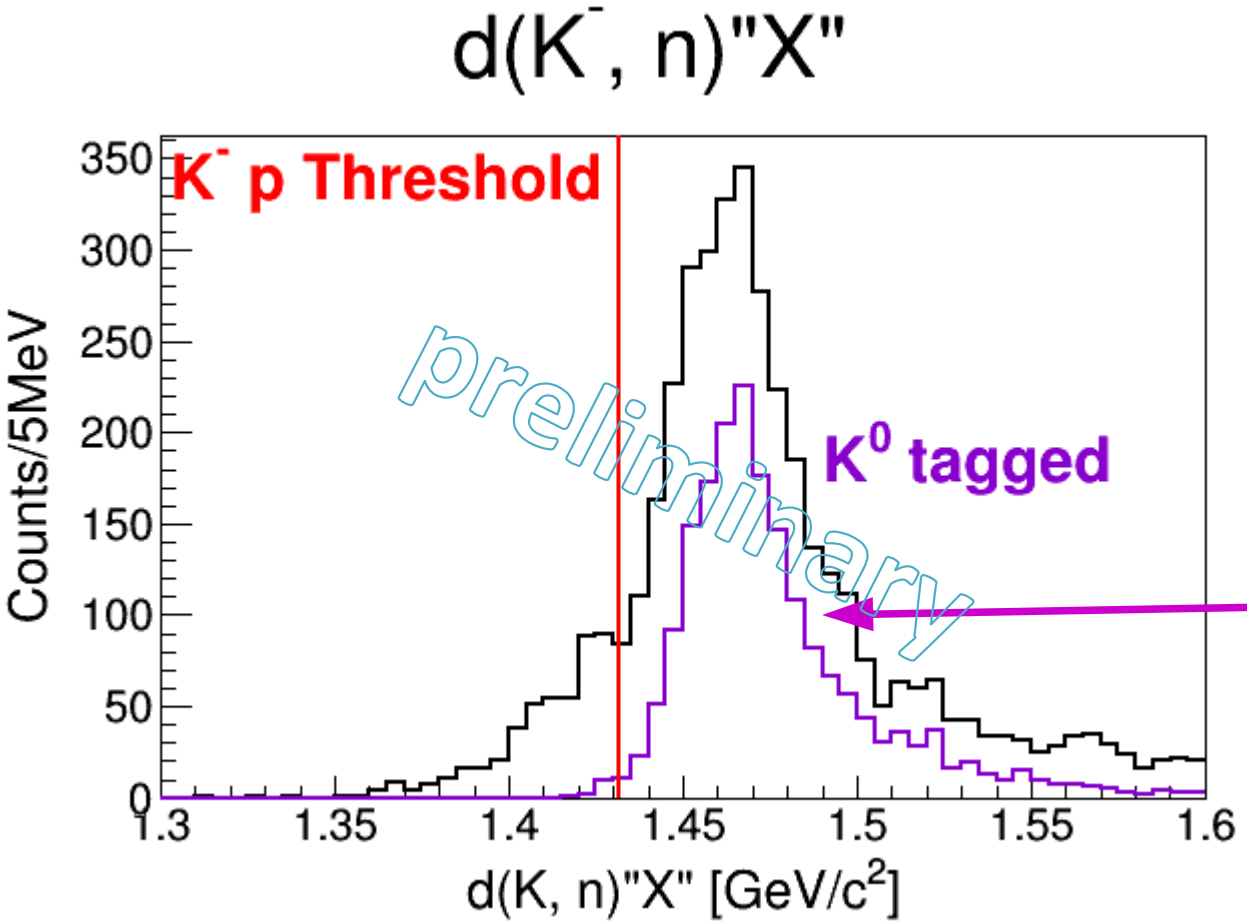
1.) Quasi-free $K^0$ production. ($K^- d \to K^0 n n_S$)

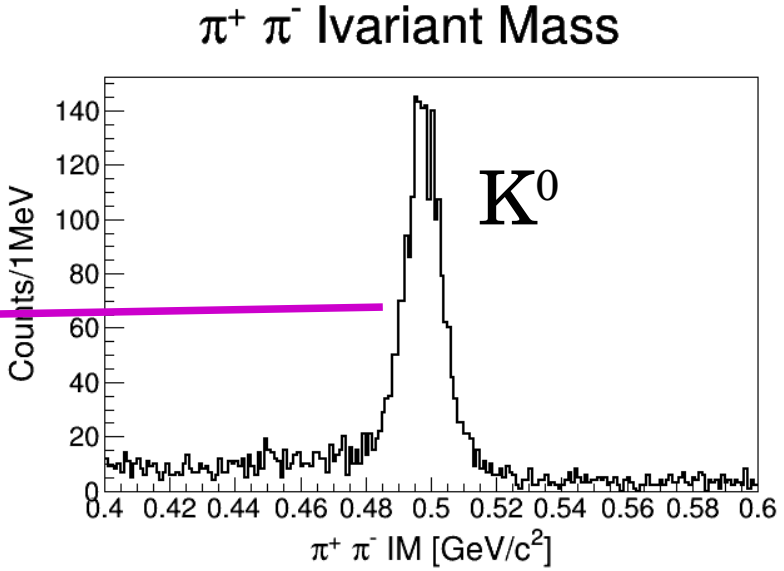
2.) $\Sigma$ production in a forward direction. ($K^- d \to \pi^{\mp}\Sigma^{\pm} n$)

# $K^- d \rightarrow n \pi^+ \pi^- n$ events

## 1.) $K^- d \rightarrow K^0 n n_s$



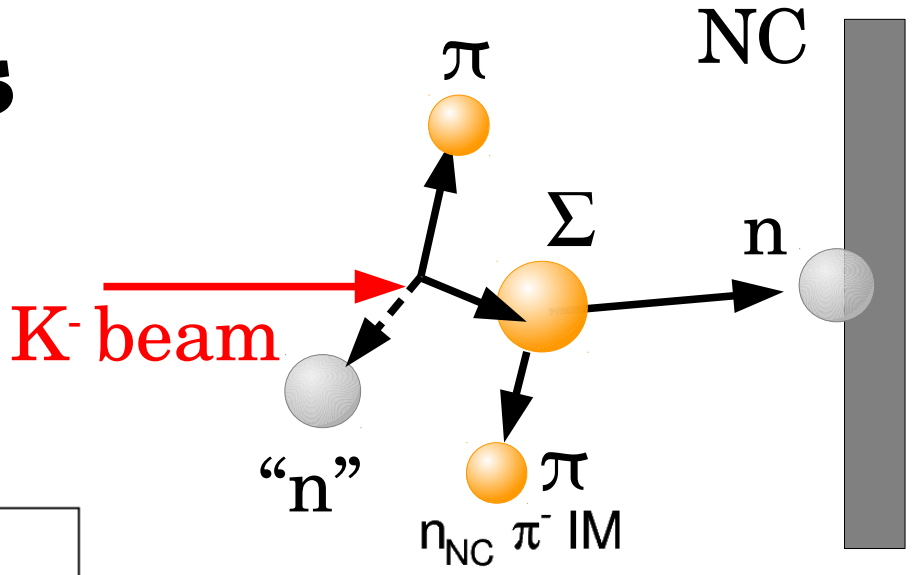



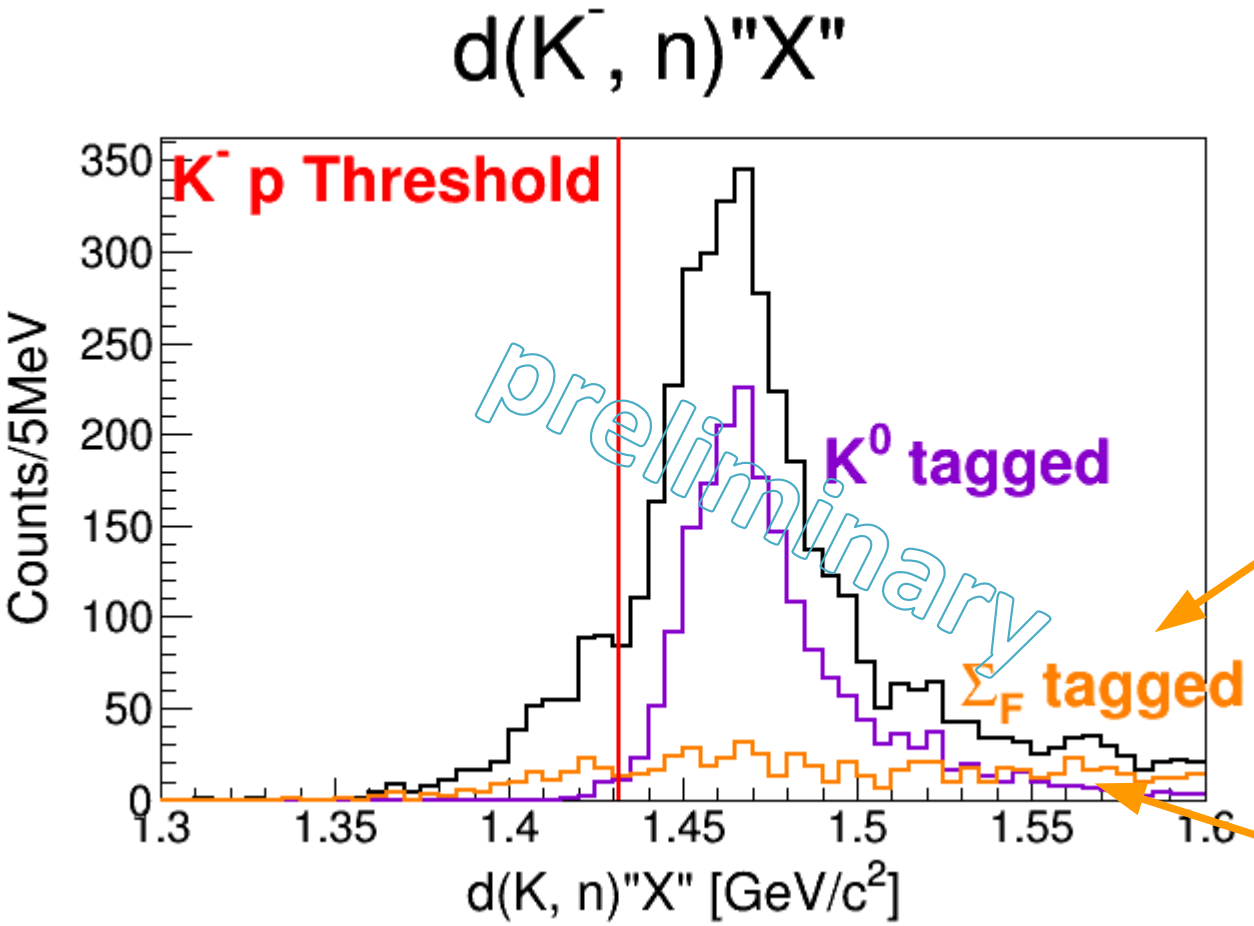



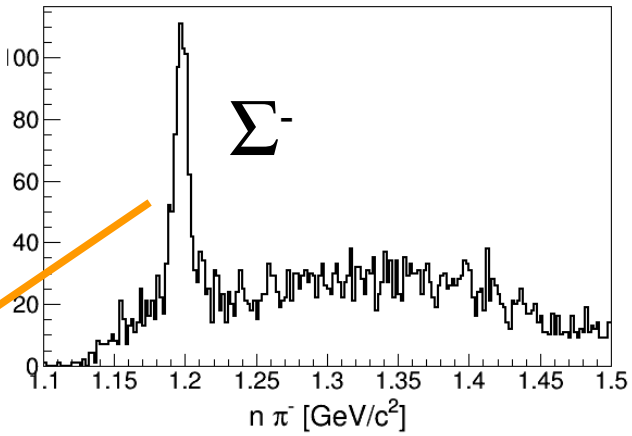
# $K^- d \to n \pi^+ \pi^- n$ events

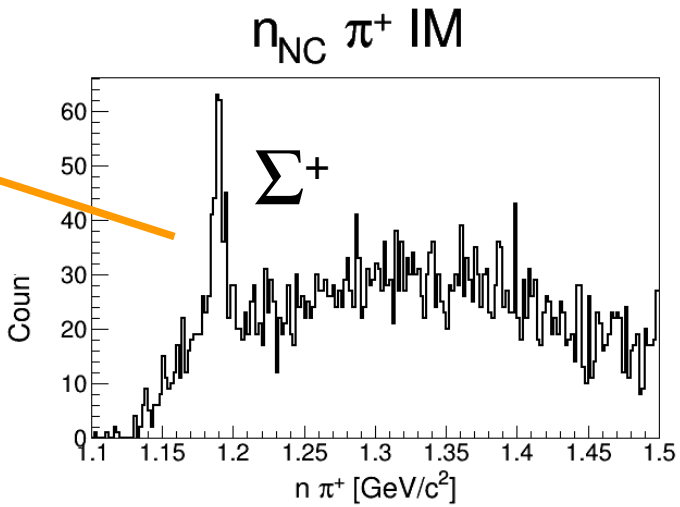
1.) $K^- d \to K^0 n n_s$

2.) $K^- d \to n \pi \Sigma_{Forward}$



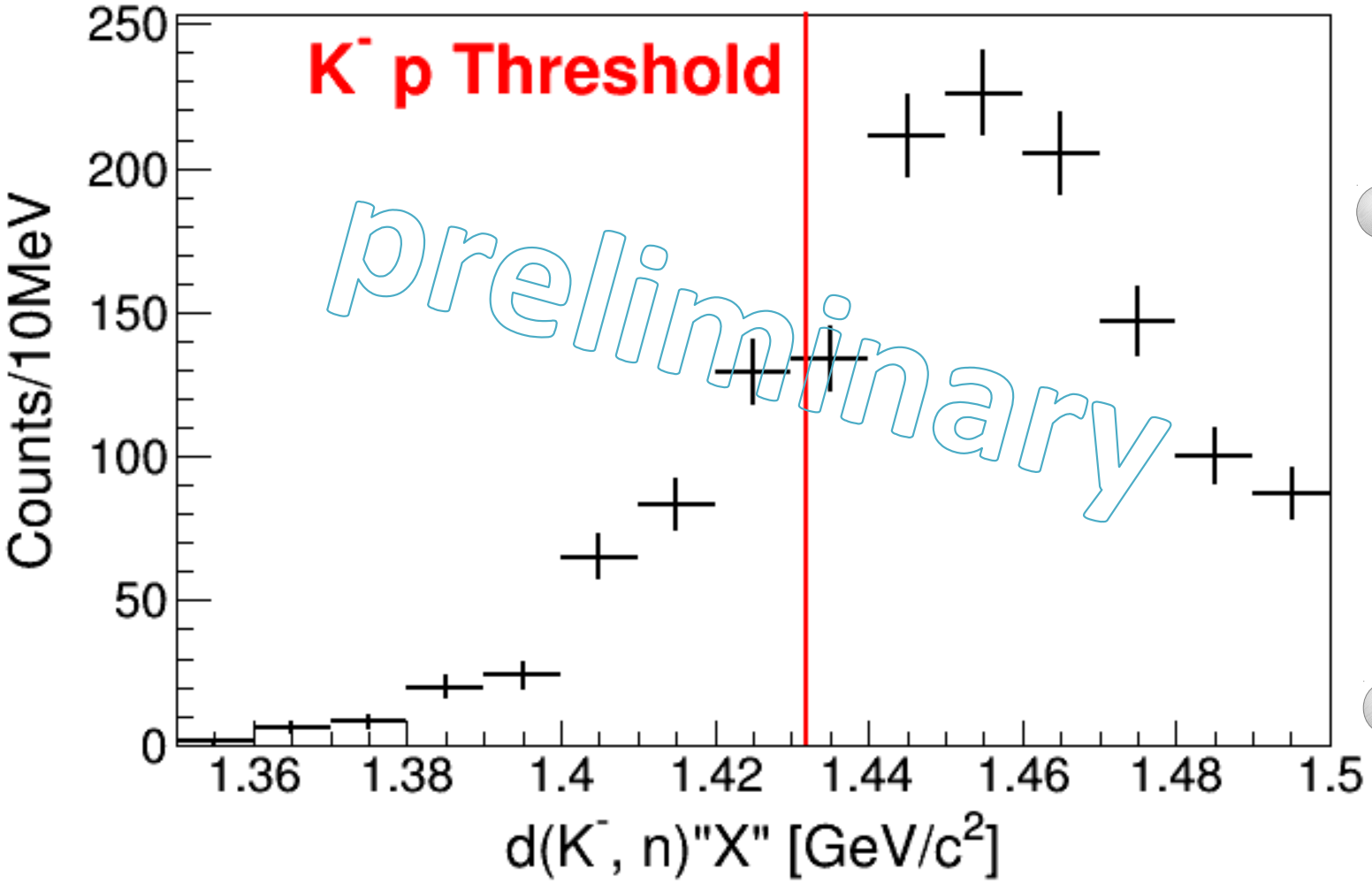



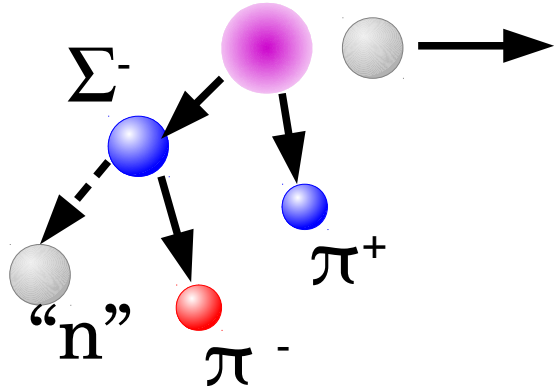




These two contributions are removed.

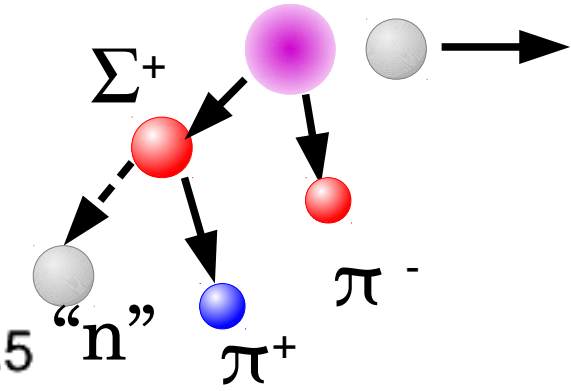
# d(K⁻, n)"$X_{\pi^{\mp}\Sigma^{\pm}}$" Spectrum




$\pi^+\Sigma^-$ mode




$\pi^-\Sigma^+$ mode

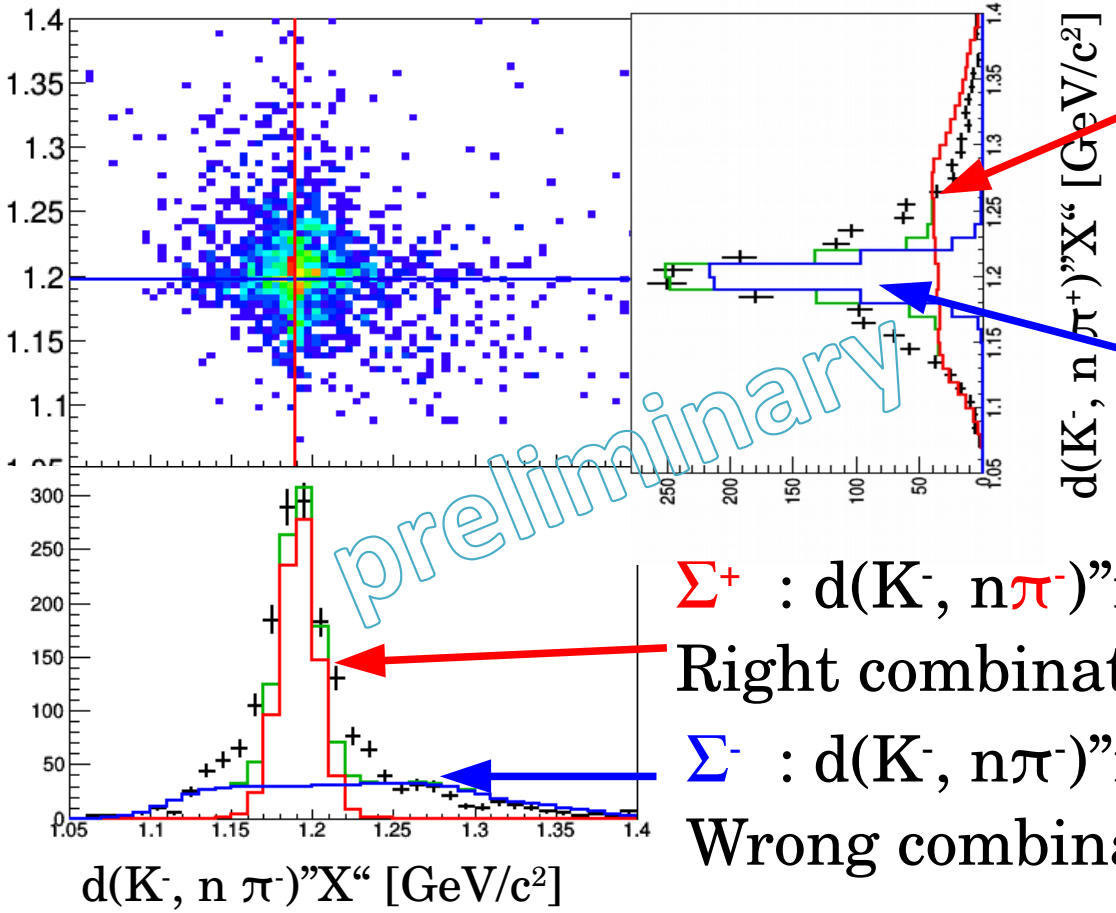



We observed some events below the $\overline{K}N$ threshold

Both $\pi^-\Sigma^+$ mode and $\pi^+\Sigma^-$ mode are included.

To be separated.

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

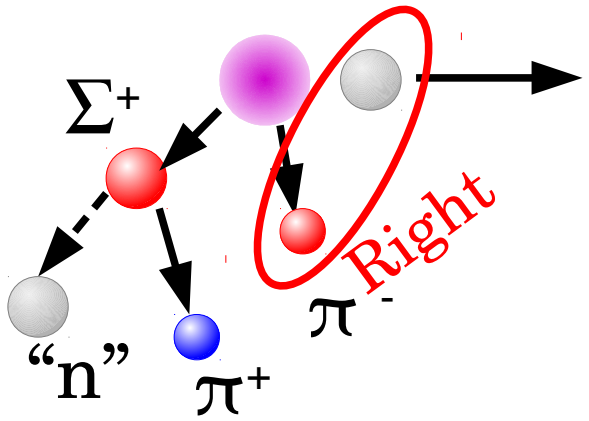



$\Sigma^+$ : d(K$^-$, n$\pi^+$)"$\pi^-$n"
Wrong combination of n$\pi$

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

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

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




Distributions are generated by a MC sim.

Assumption: $K^-d \rightarrow n\Lambda(1405)$ : $\theta_n = 0$ deg.

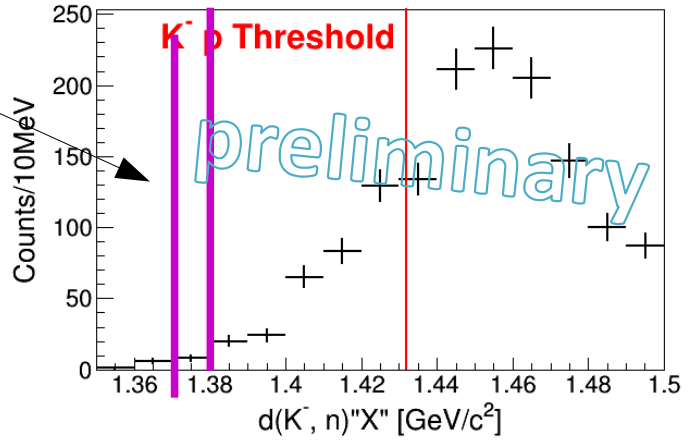
$M_{\Lambda(1405)}$ : Flat distribution (1.34~1.6[MeV/c$^2$])

Distributions depend on the missing mass of the d(K$^-$, n)"$X_{\pi\Sigma}$"

# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

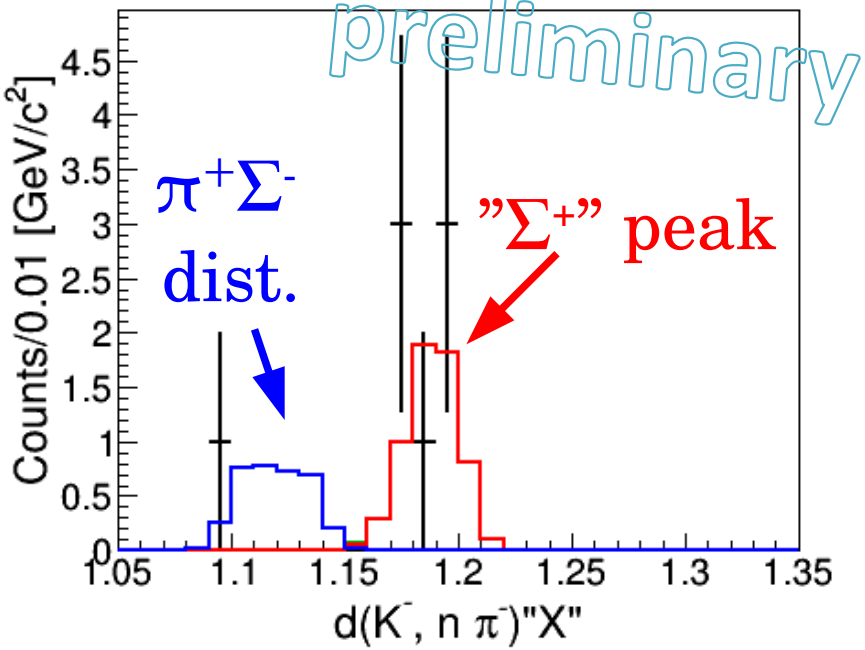
Fittings are done bin-by-bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

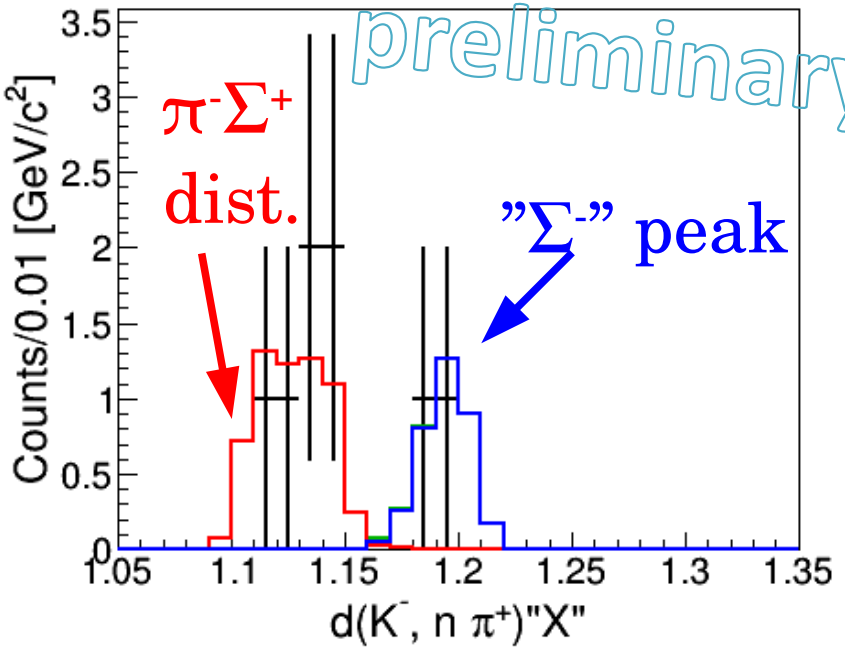



Example : MM=1.37~1.38 [GeV/$c^2$]

d($K^-$, n $\pi^-$)"X"



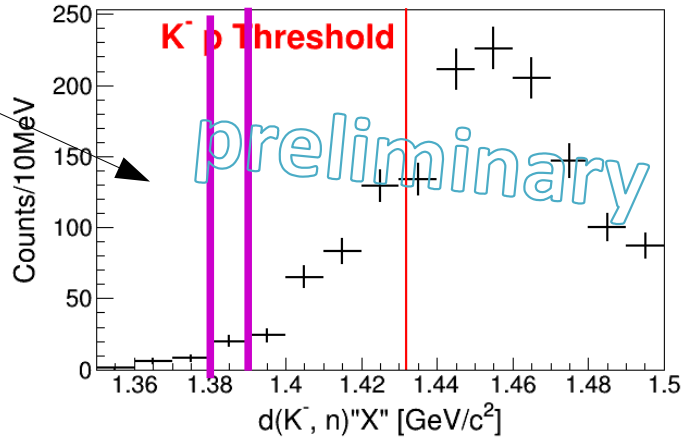

d($K^-$, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

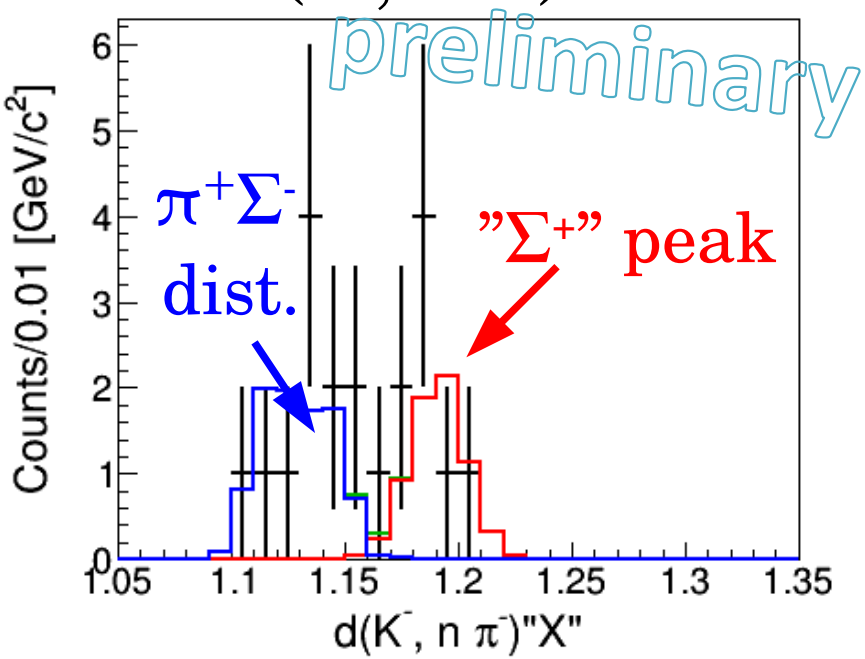
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

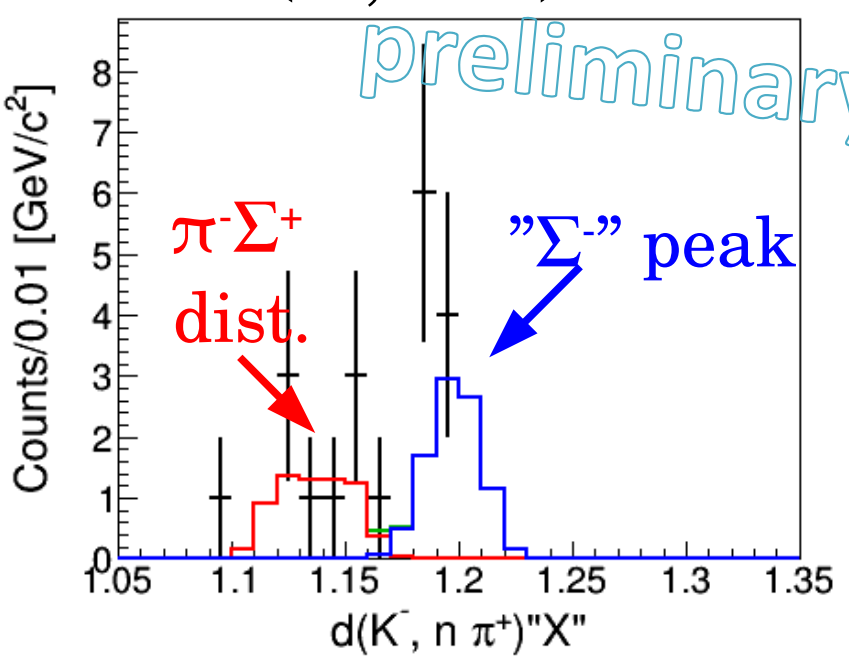



Example : MM=1.38~1.39 [GeV/$c^2$]

d($K^-$, n $\pi^-$)"X"



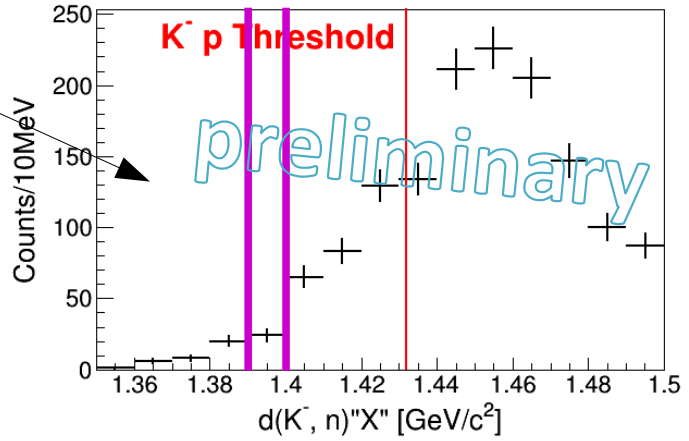

d($K^-$, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

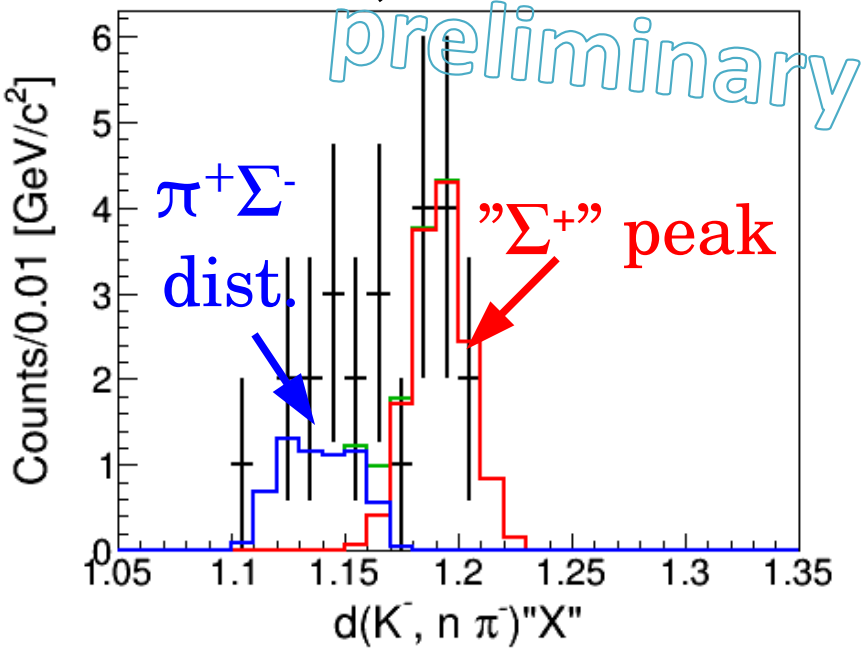
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

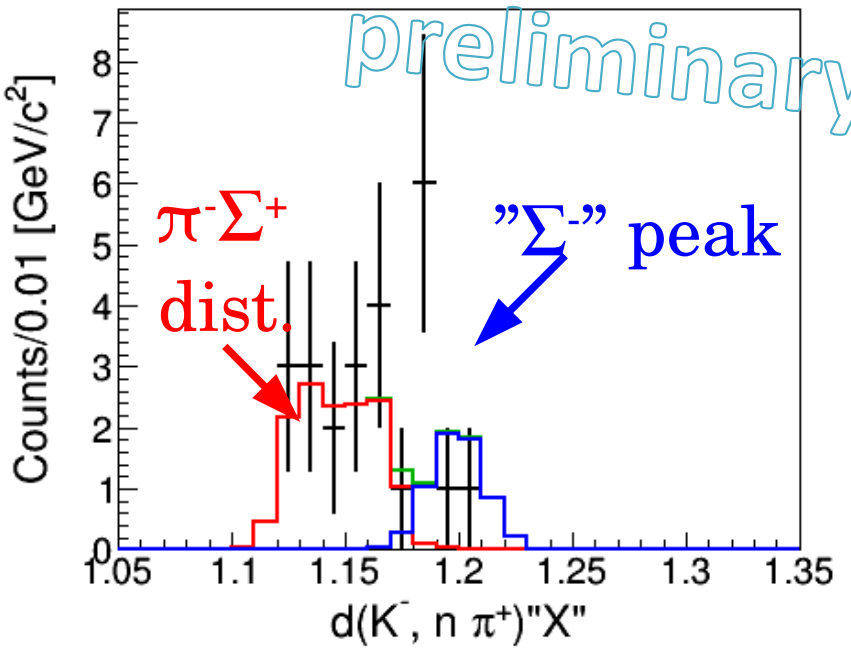



Example : MM=1.39~1.40 [GeV/$c^2$]

d($K^-$, n $\pi^-$)"X"



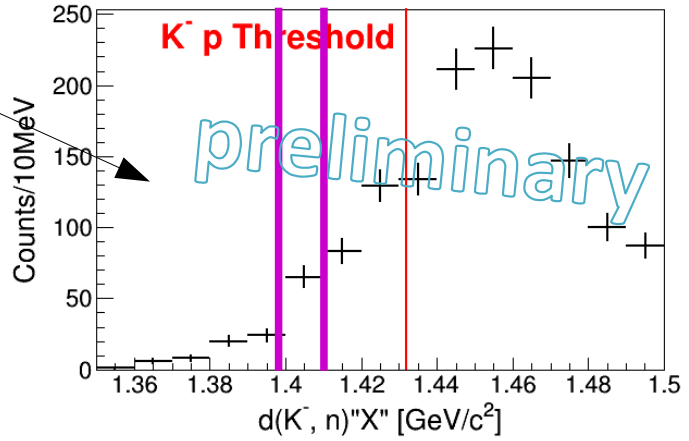

d($K^-$, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

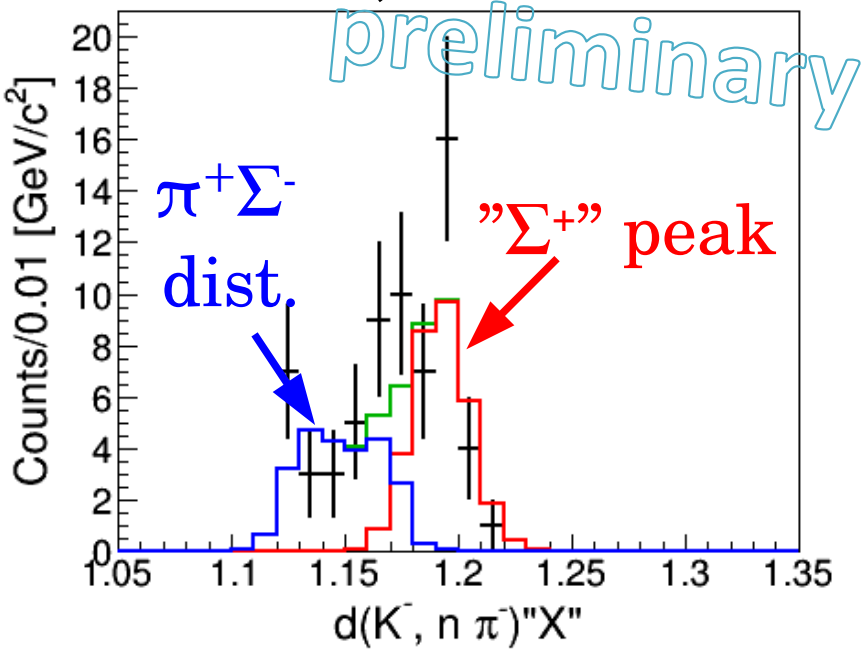
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

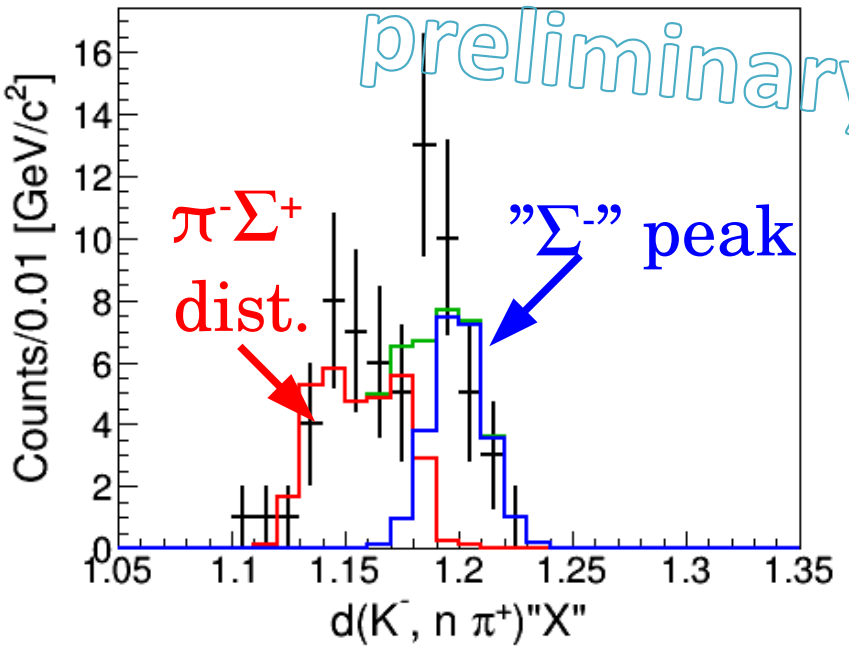



Example : MM=1.40~1.41 [GeV/$c^2$]

d(K⁻, n $\pi^-$)"X"



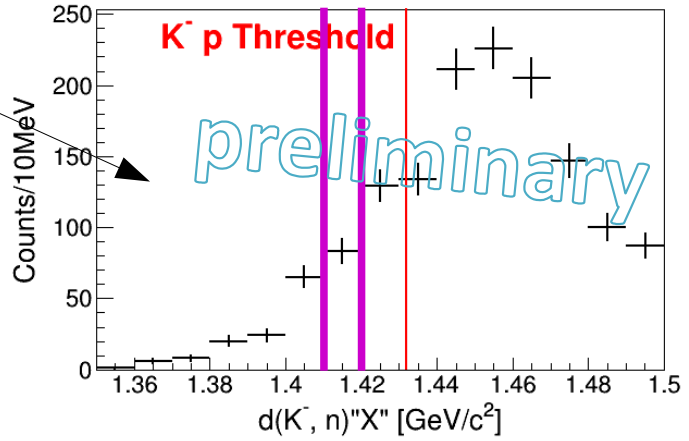

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

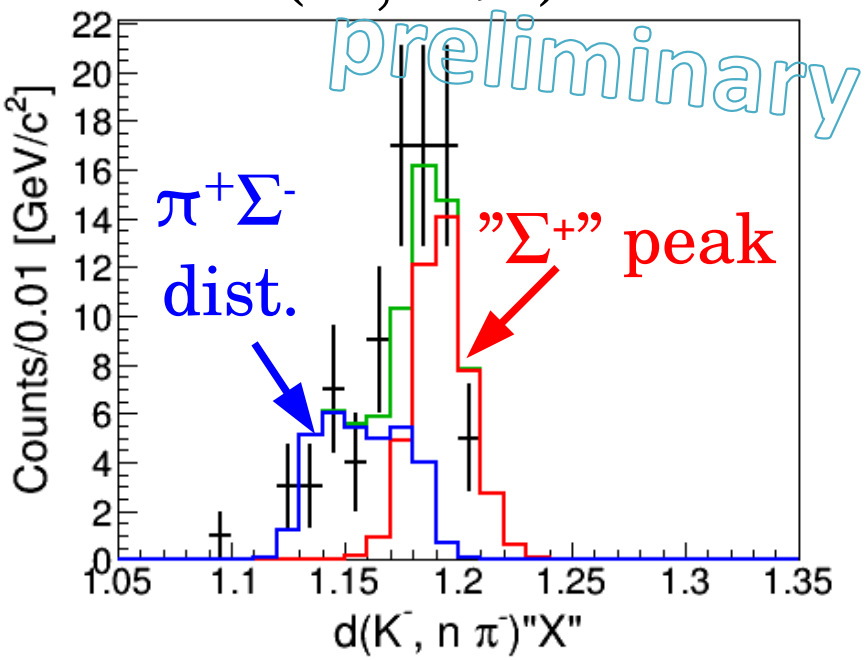
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

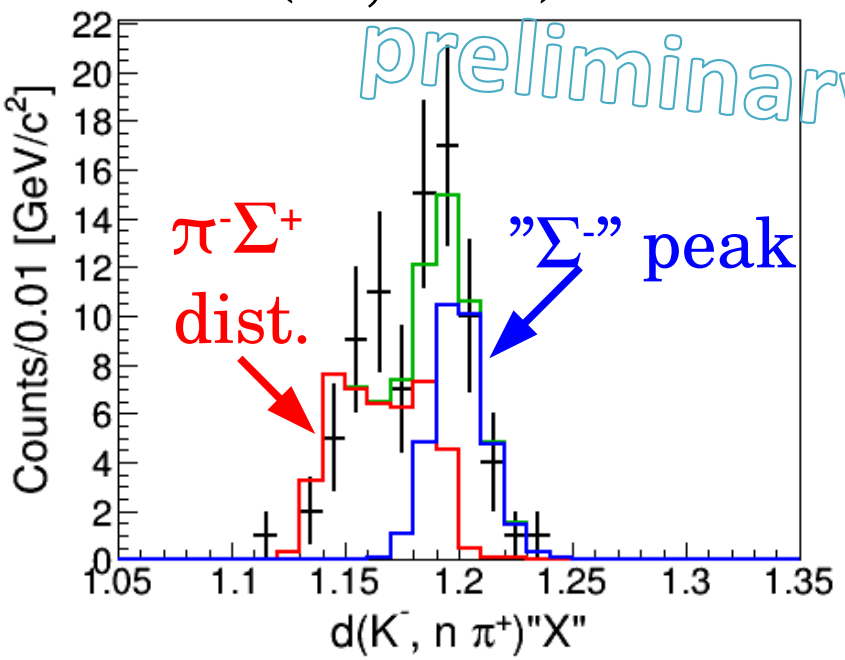



Example : MM=1.41~1.42 [GeV/$c^2$]

d(K⁻, n $\pi^-$)"X"



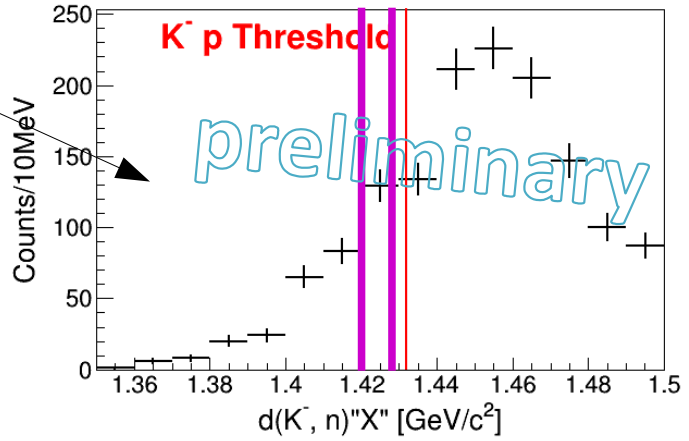

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

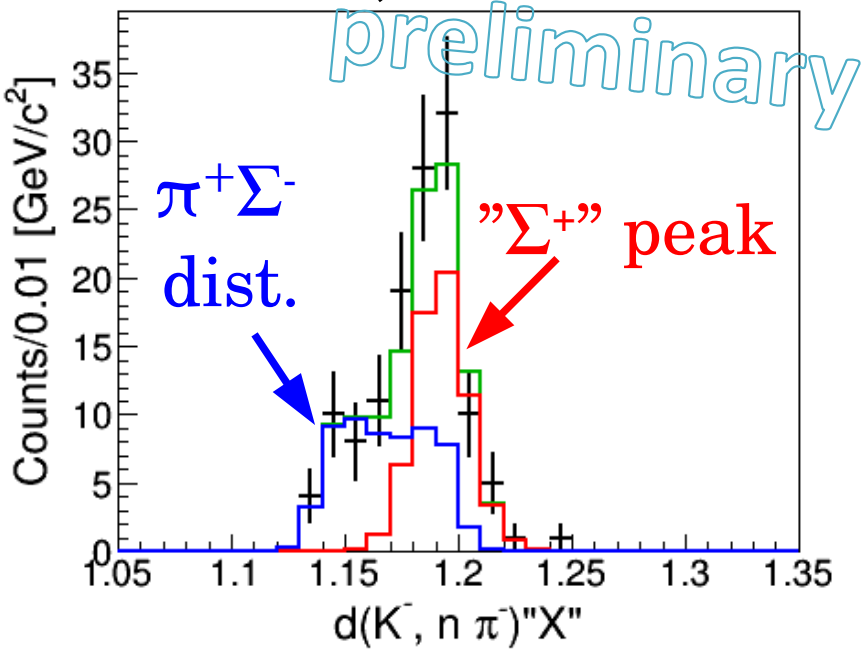
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

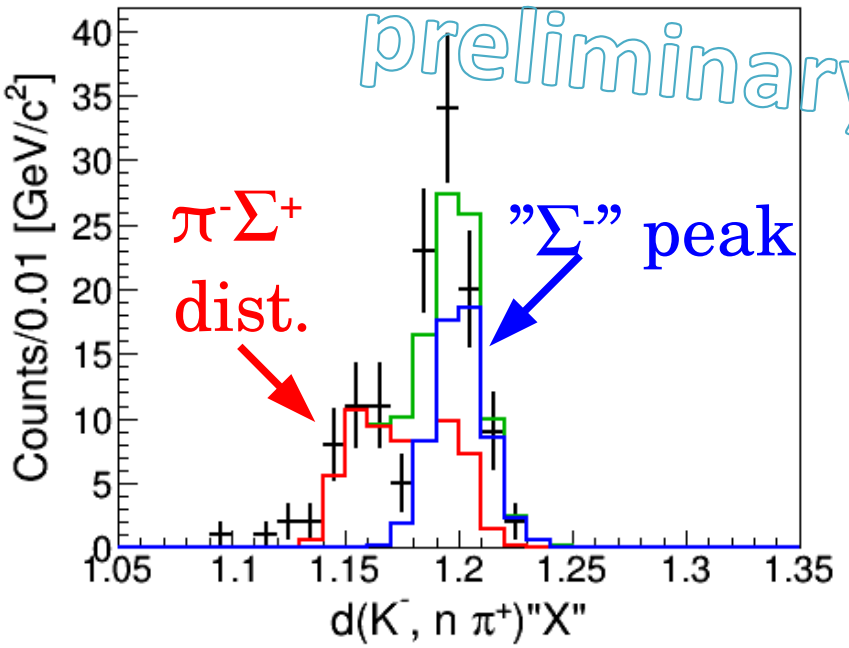



Example : MM=1.42~1.43 [GeV/$c^2$]

d($K^-$, n $\pi^-$)"X"



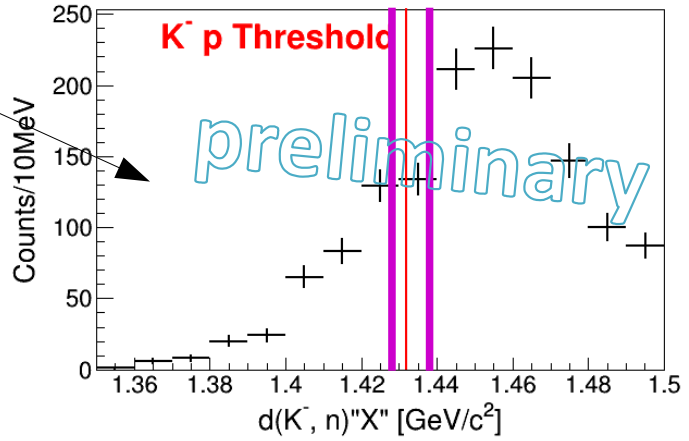

d($K^-$, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

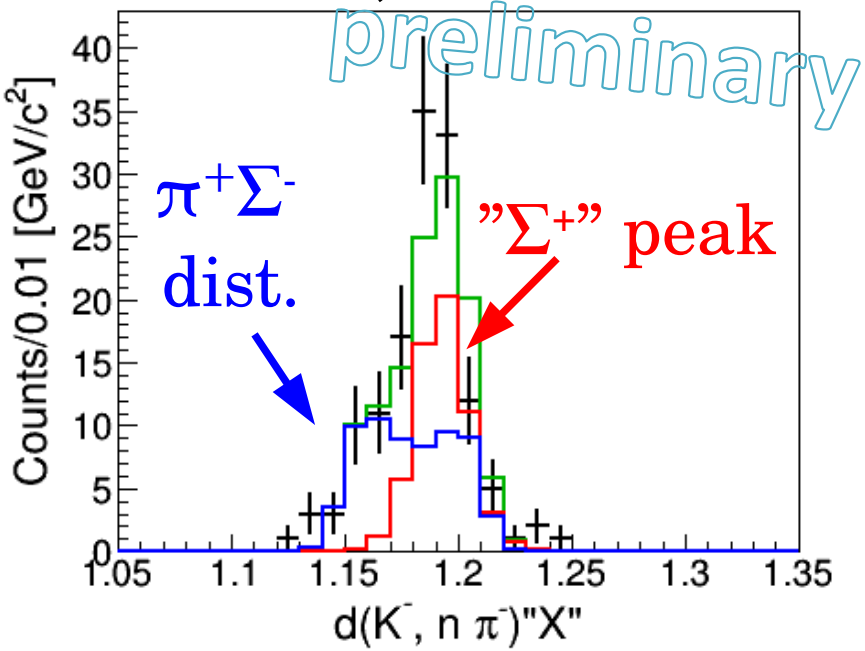
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

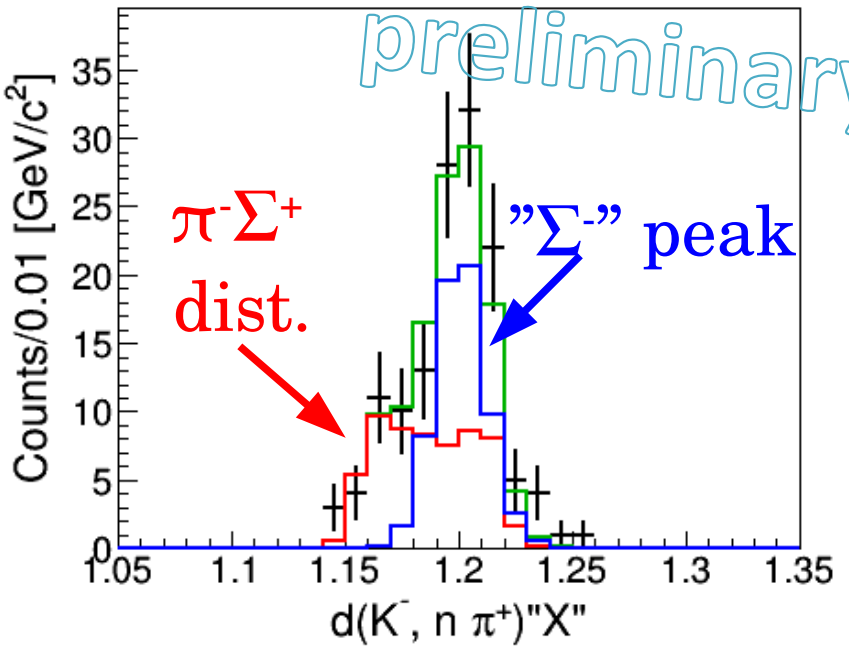



Example : MM=1.43~1.44 [GeV/c²]

d(K⁻, n $\pi^-$)"X"



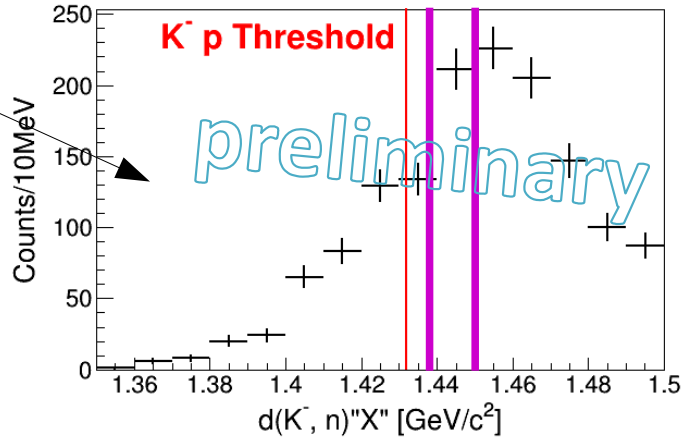

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

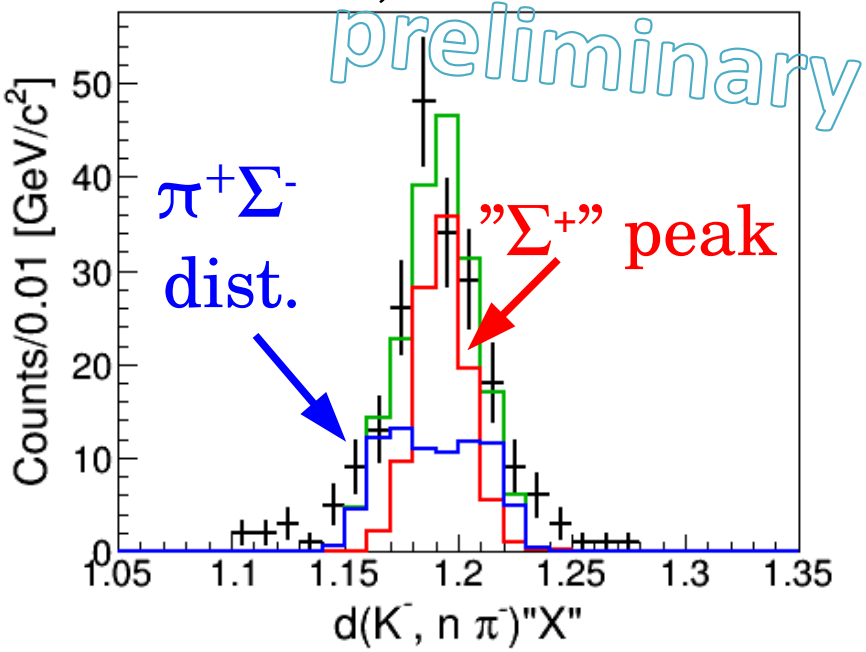
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

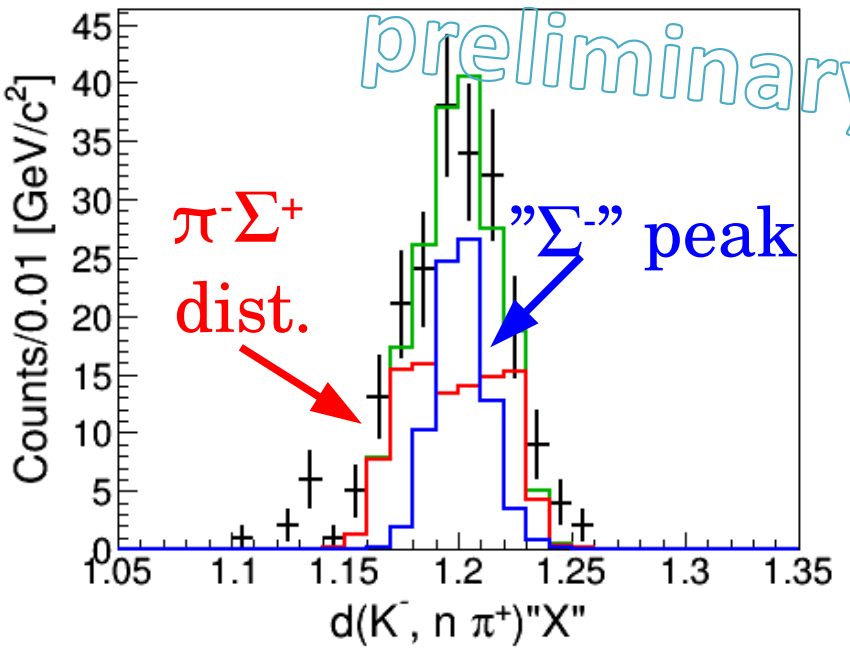



Example : MM=1.44~1.45 [GeV/c²]

d(K⁻, n $\pi^-$)"X"



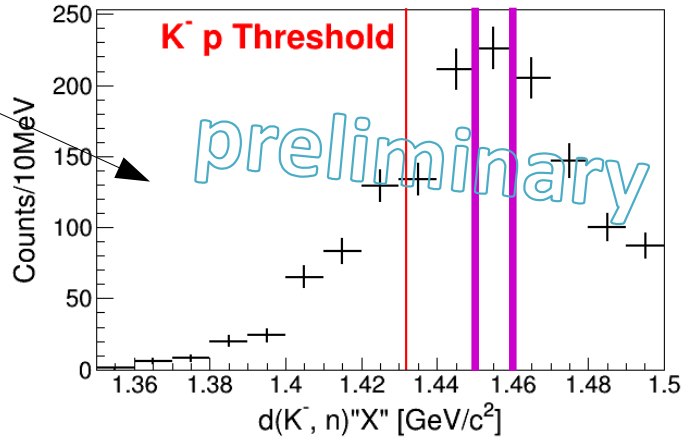

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

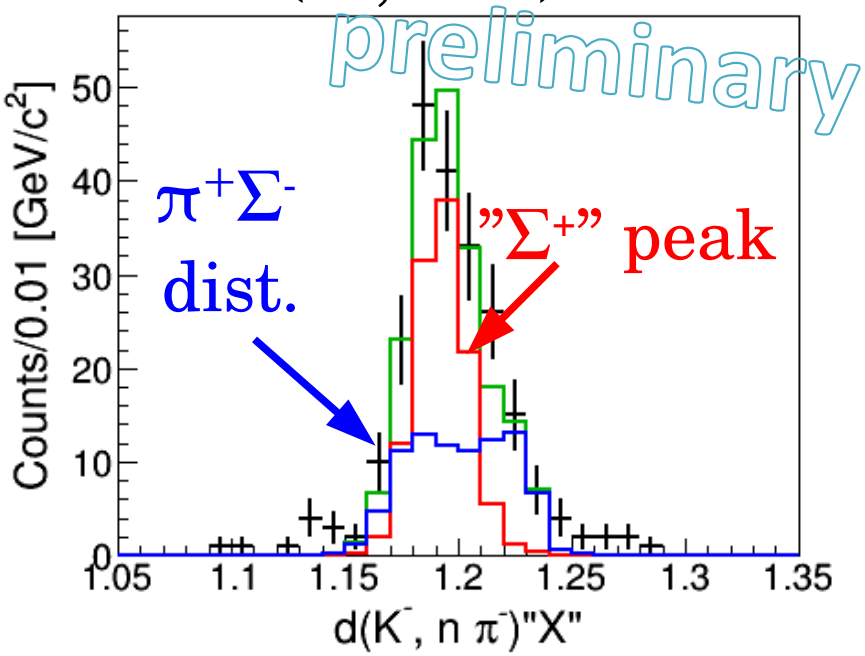
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

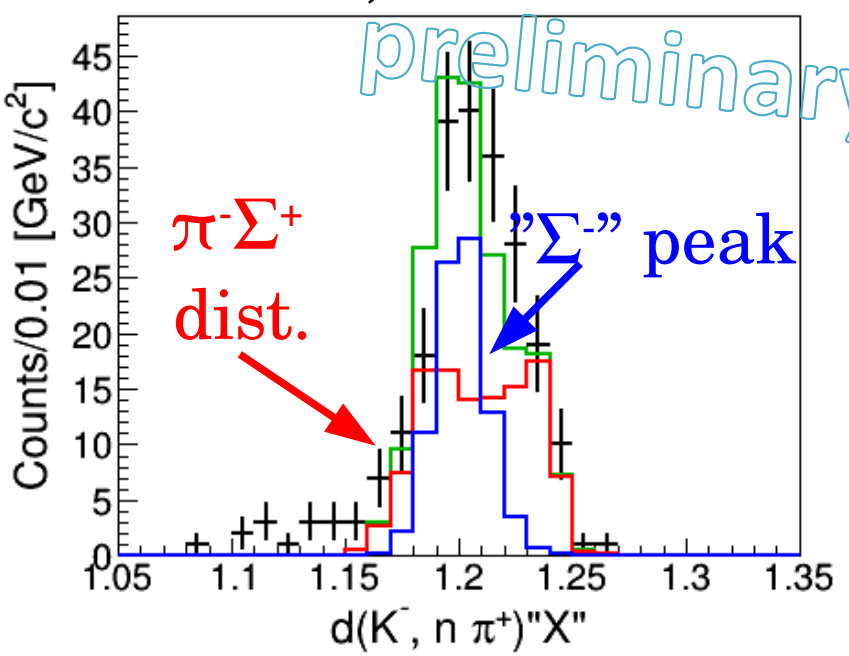



Example : MM=1.45~1.46 [GeV/c²]

d(K⁻, n $\pi^-$)"X"



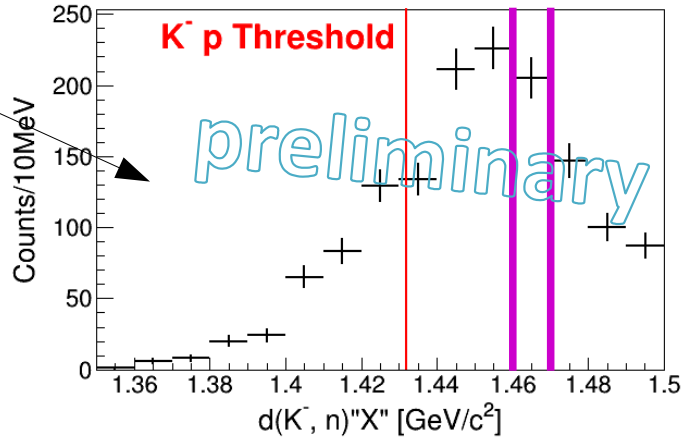

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

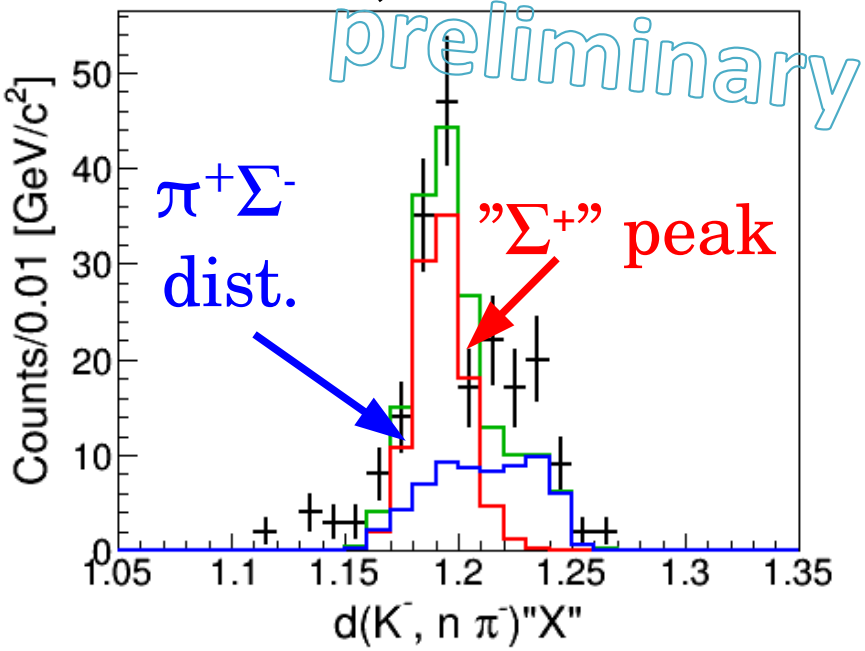
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

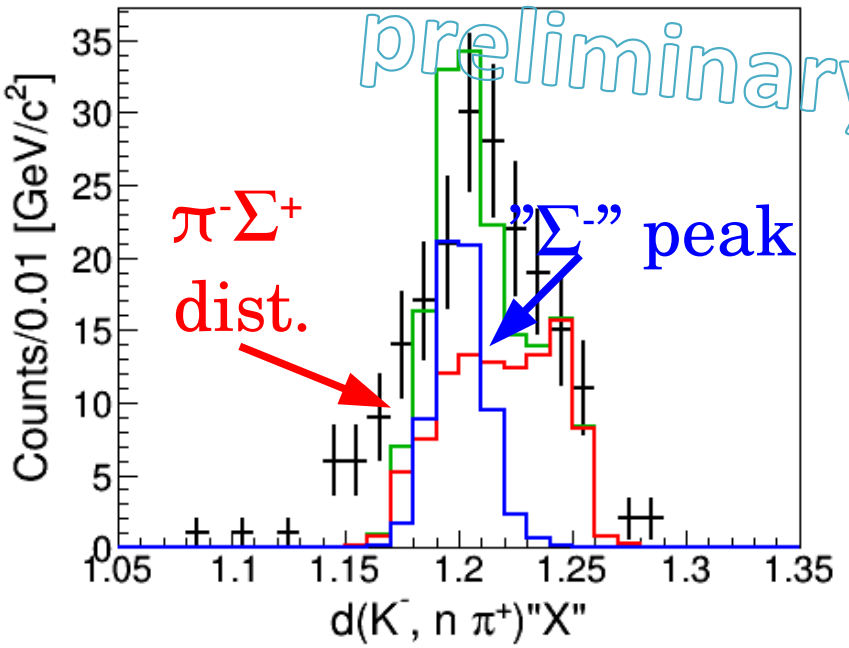



Example : MM=1.46~1.47 [GeV/$c^2$]

d($K^-$, n $\pi^-$)"X"



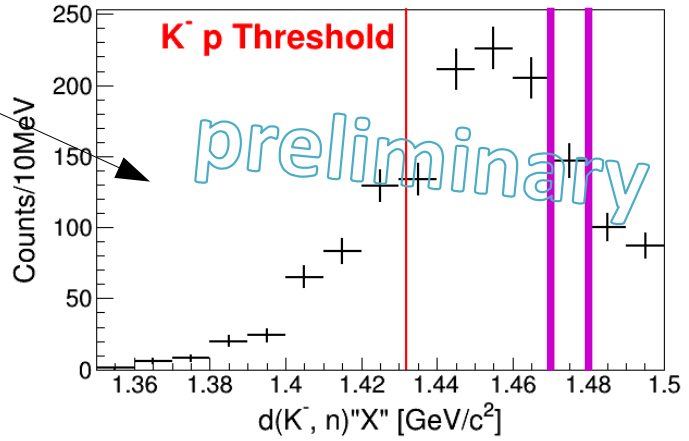

d($K^-$, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

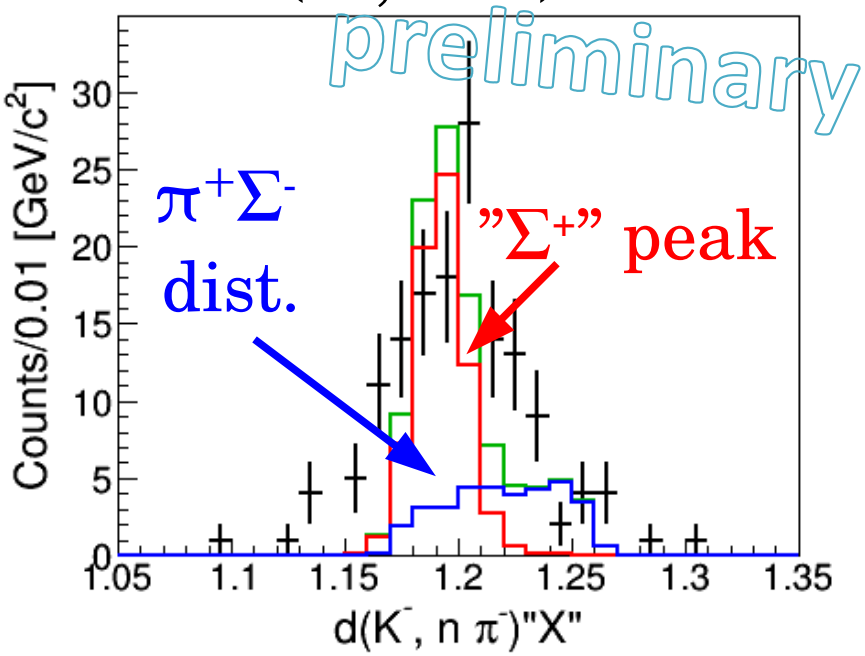
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

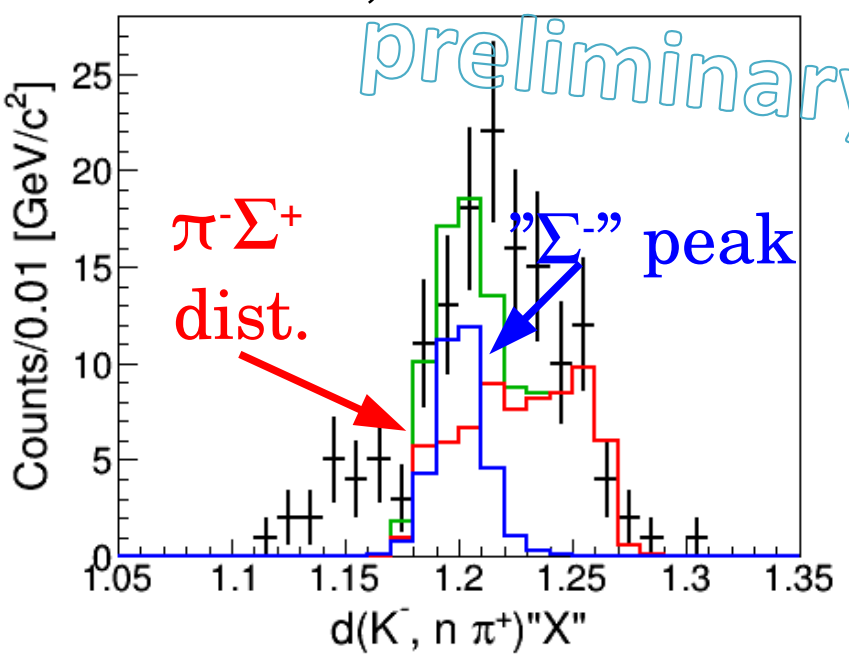



Example : MM=1.47~1.48 [GeV/c²]

d(K⁻, n $\pi^-$)"X"



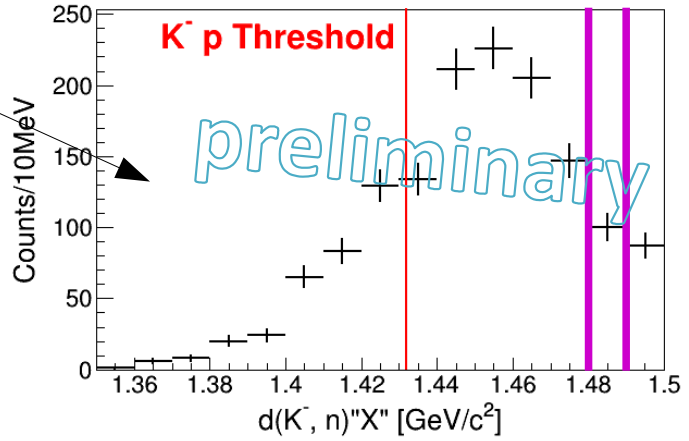

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

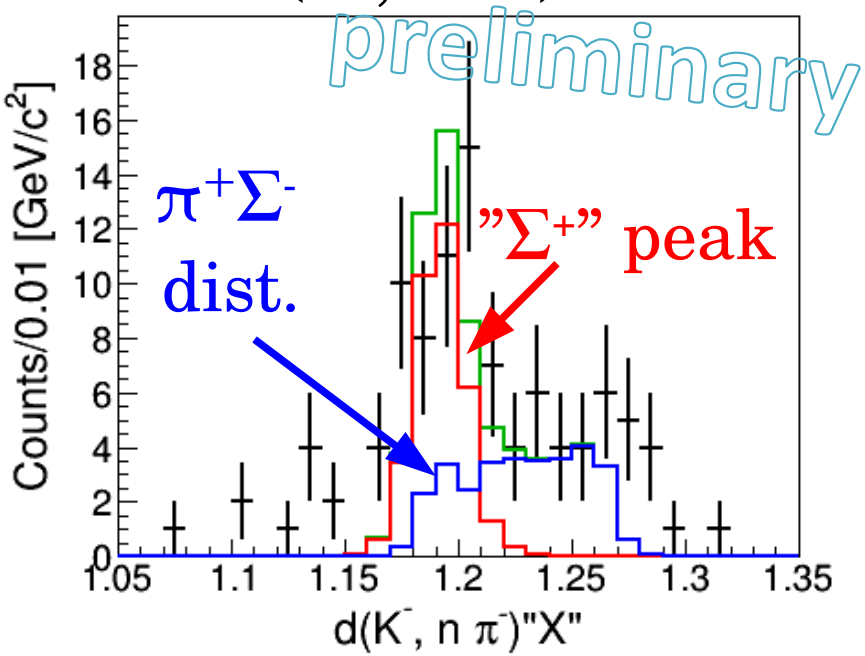
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

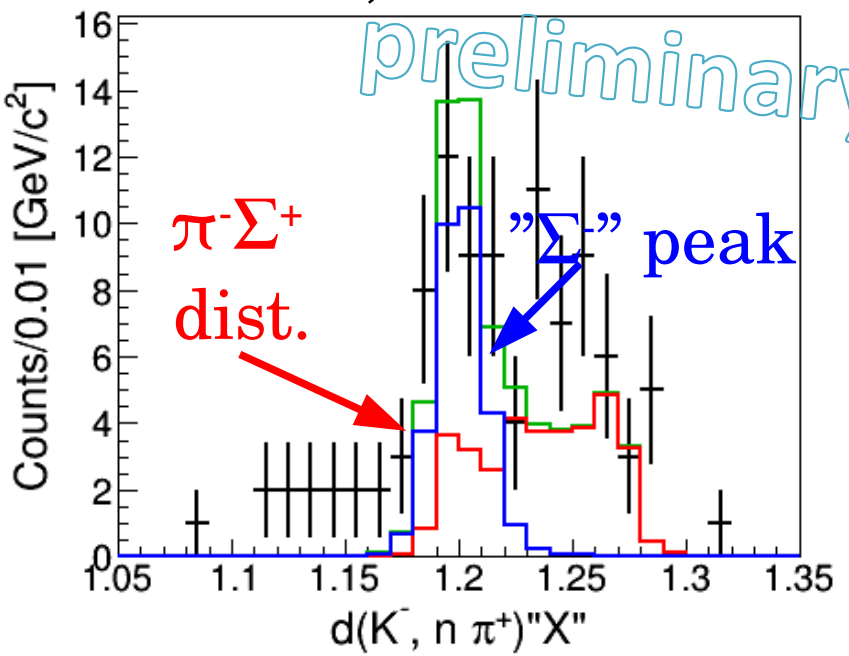



Example : MM=1.48~1.49 [GeV/c²]

d(K⁻, n $\pi^-$)"X"



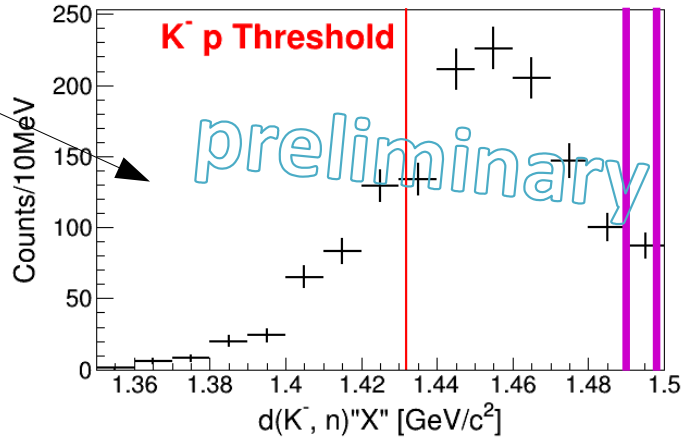

d(K⁻, n $\pi^+$)"X"



# Fitting for $\pi^-\Sigma^+$/$\pi^+\Sigma^-$ mode separation

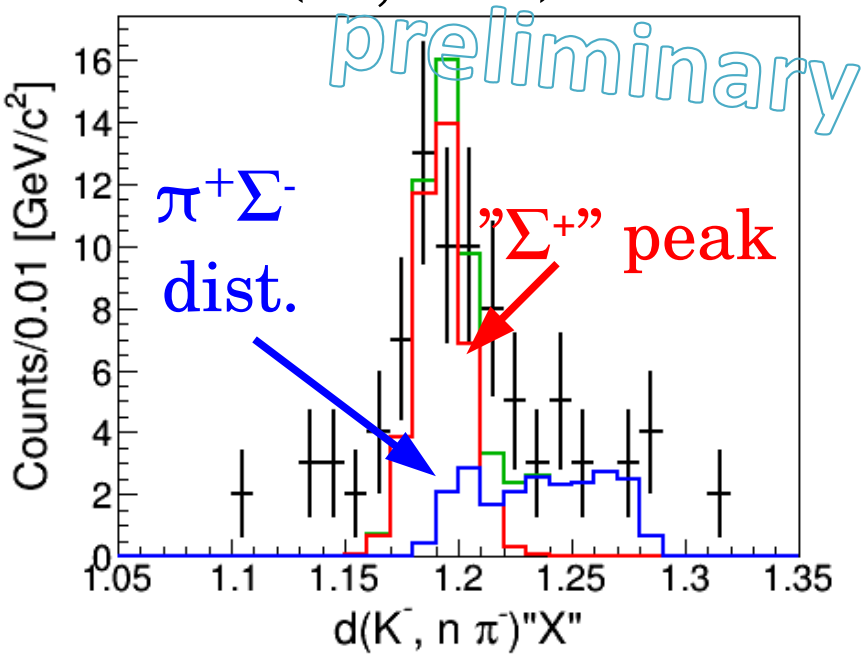
Fittings are done bin by bin.

Two free parameters
1.) Number of $\pi^-\Sigma^+$ events
2.) Number of $\pi^+\Sigma^-$ events

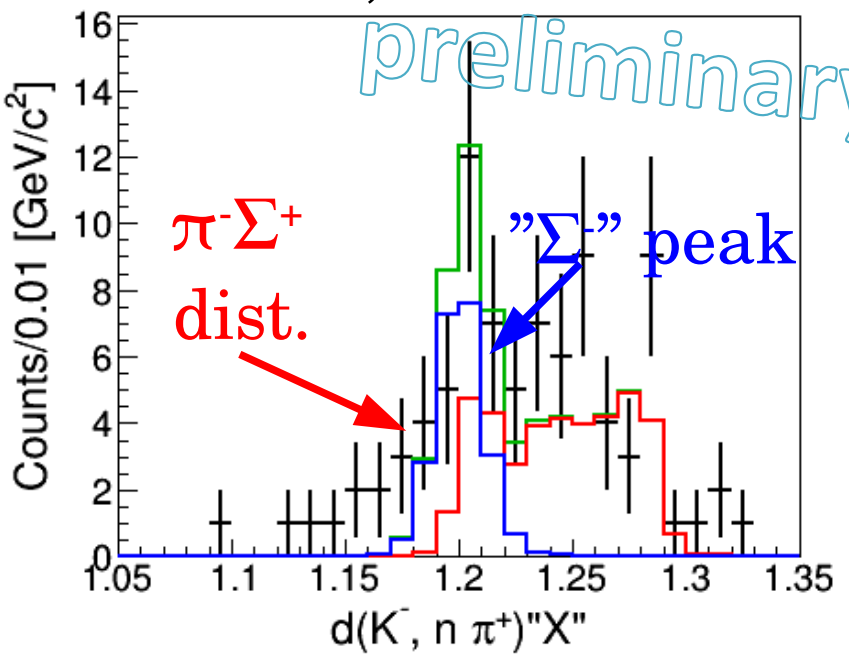



Example : MM=1.49~1.50 [GeV/c²]

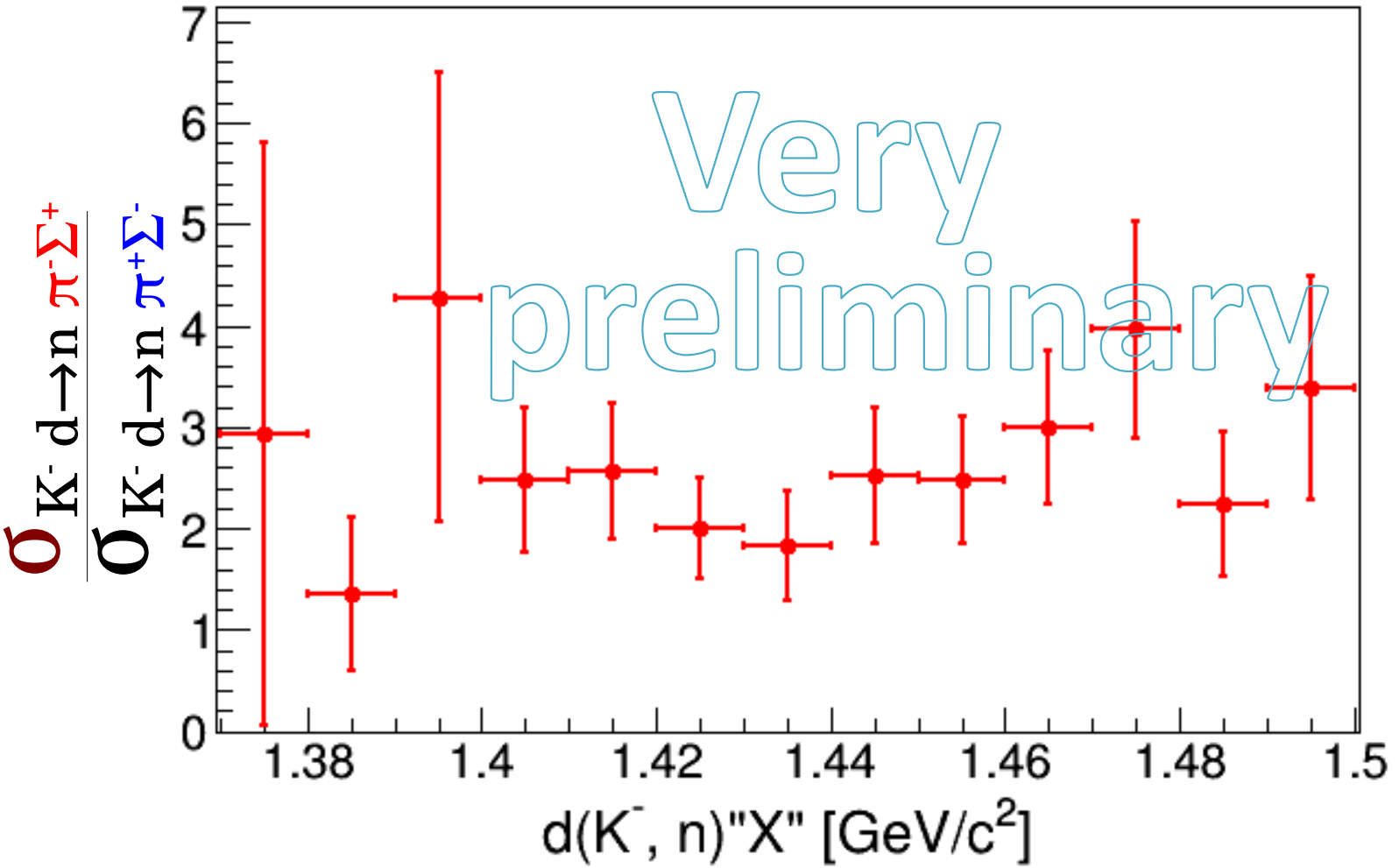
d(K⁻, n $\pi^-$)"X"




d(K⁻, n $\pi^+$)"X"



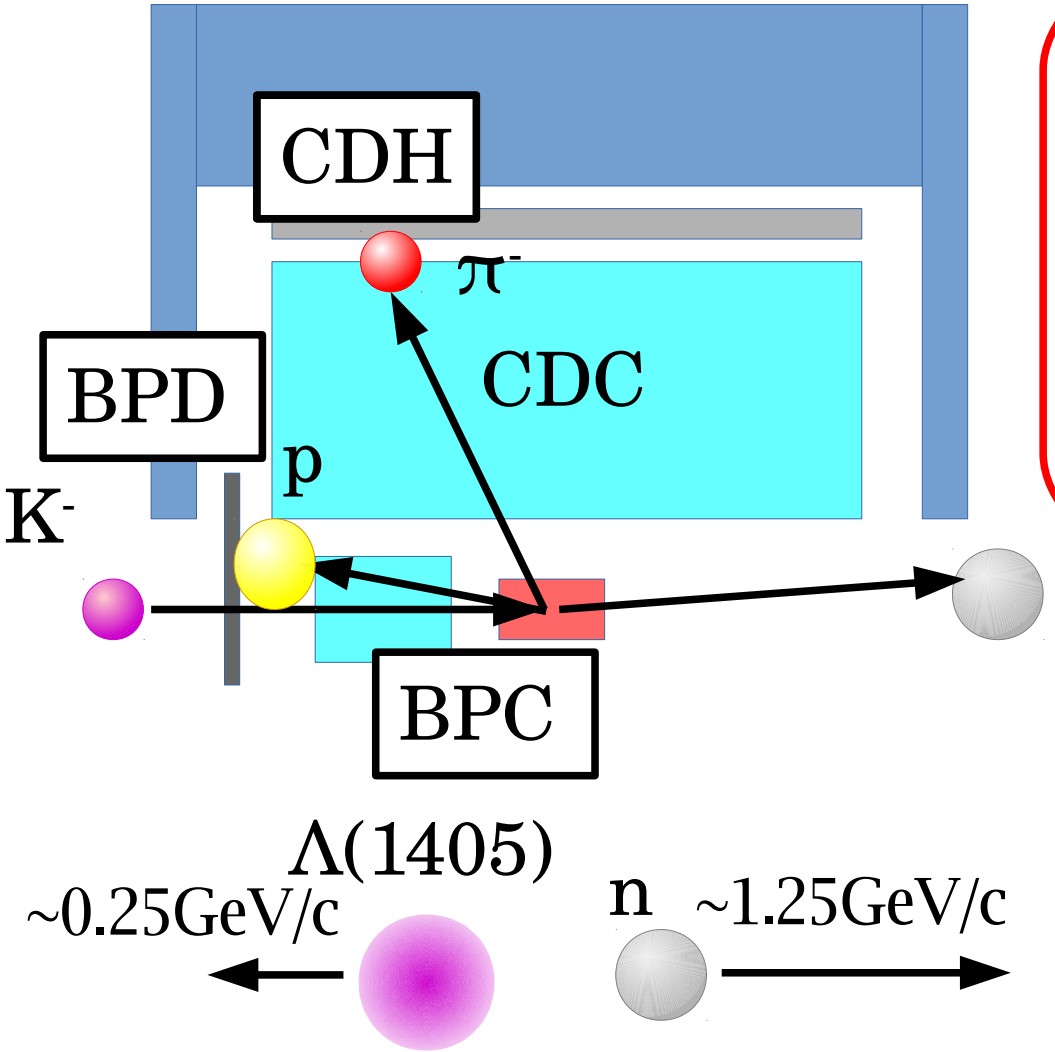
# Cross section ratio of $\pi^-\Sigma^+$ to $\pi^+\Sigma^-$

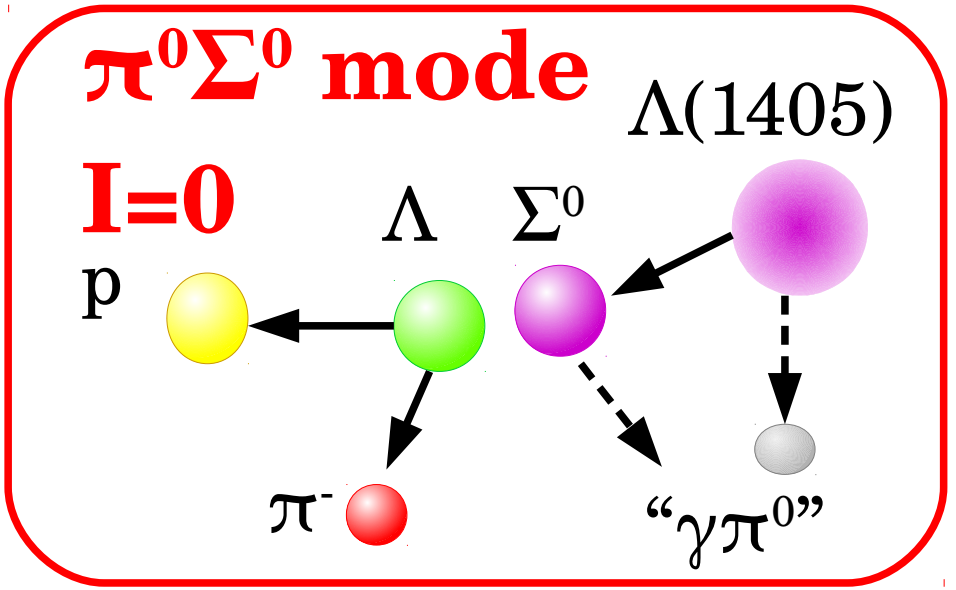


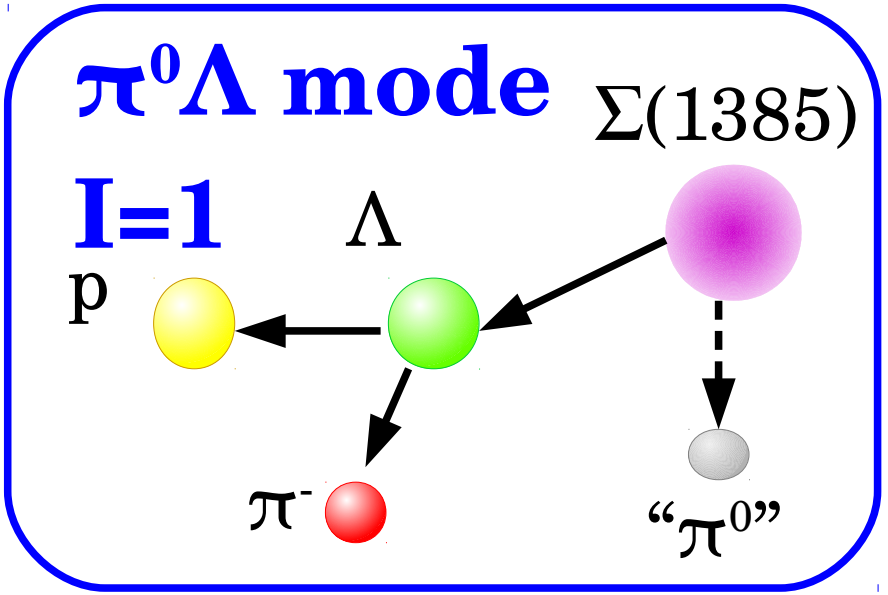

The $K^- d\to n\,\pi^-\Sigma^+$ mode is dominant.

# Analysis on $\pi^0\Sigma^0$ mode and $\pi^0\Lambda$ mode

# Mode identification $\pi^0\Sigma^0$, $\pi^0\Lambda$

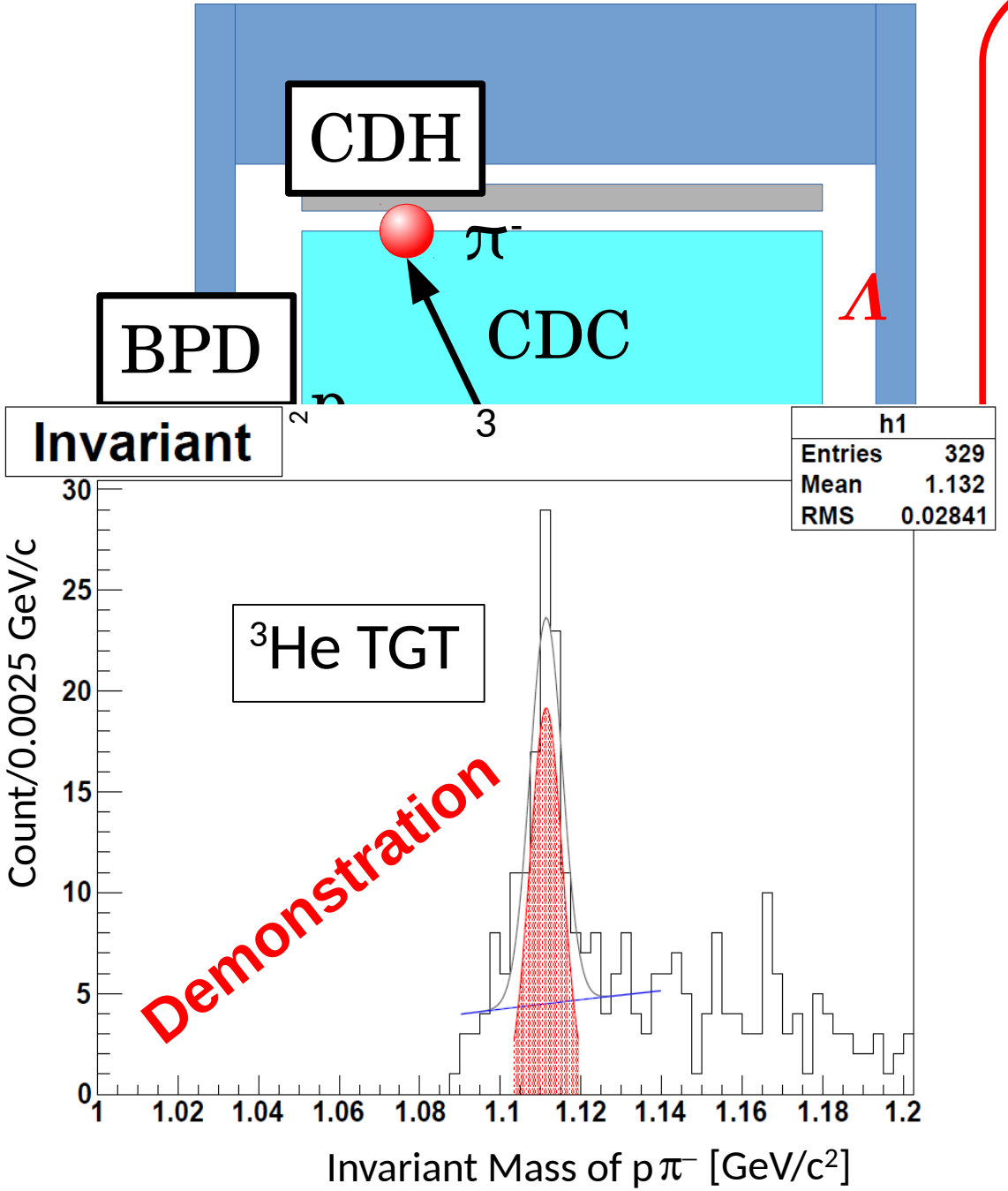


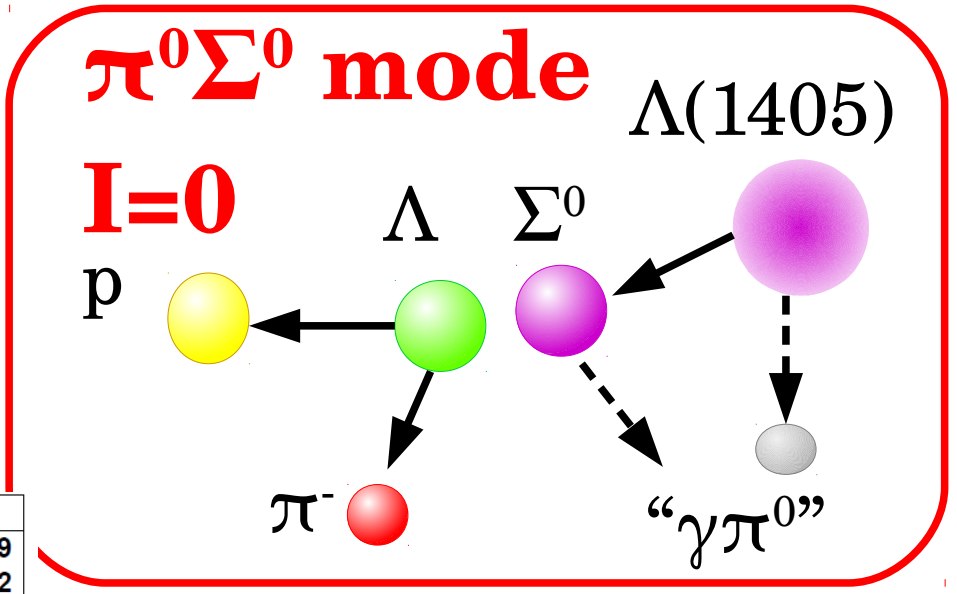



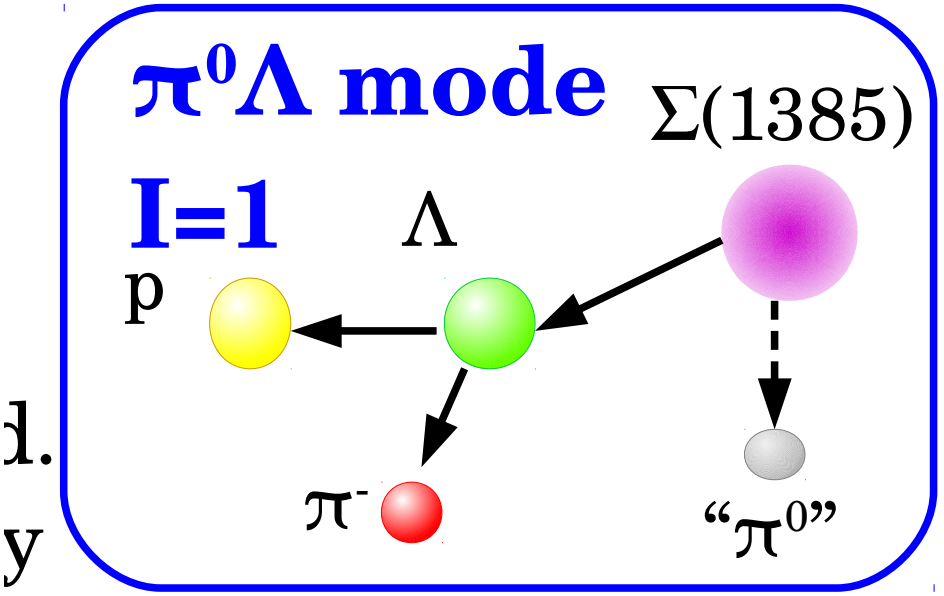




Proton is scattered backward.
These protons are detected by BPC & BPD.

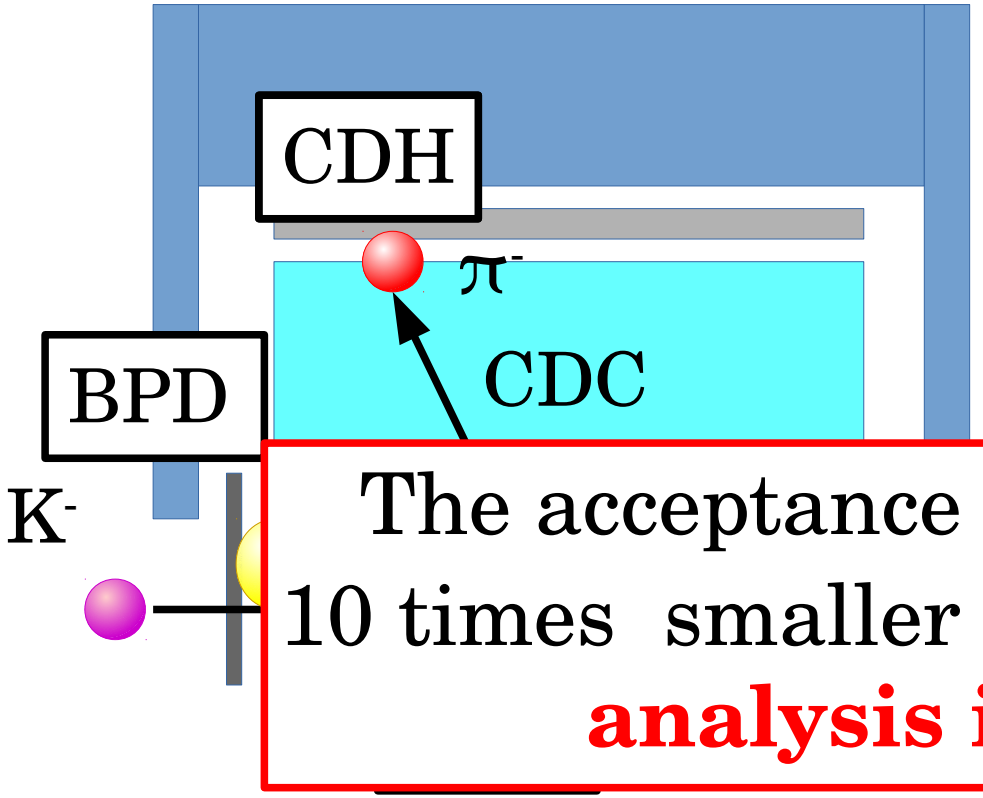
# Mode identification $\pi^0\Sigma^0$, $\pi^0\Lambda$

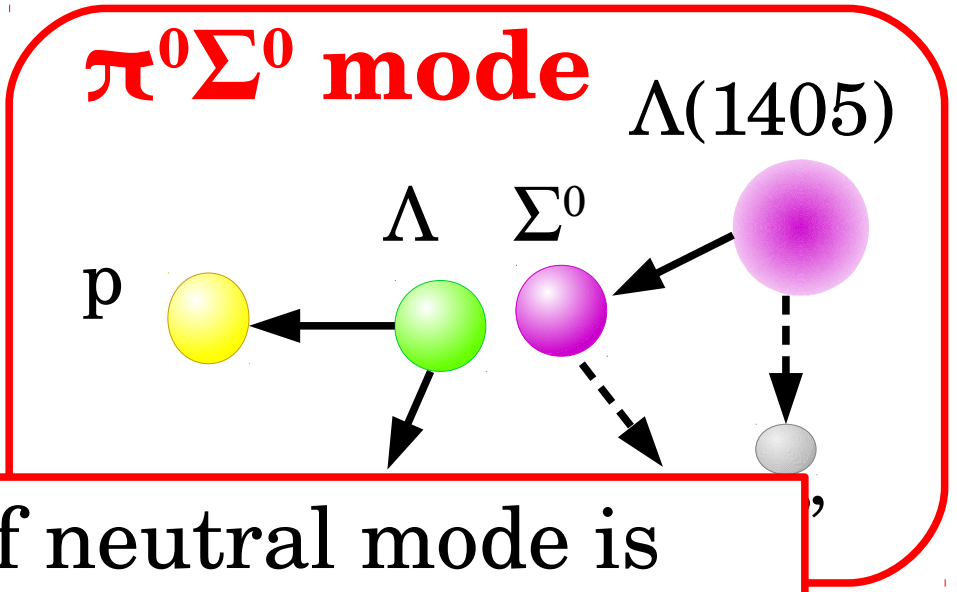


# Mode identification $\pi^0\Sigma^0$, $\pi^0\Lambda$

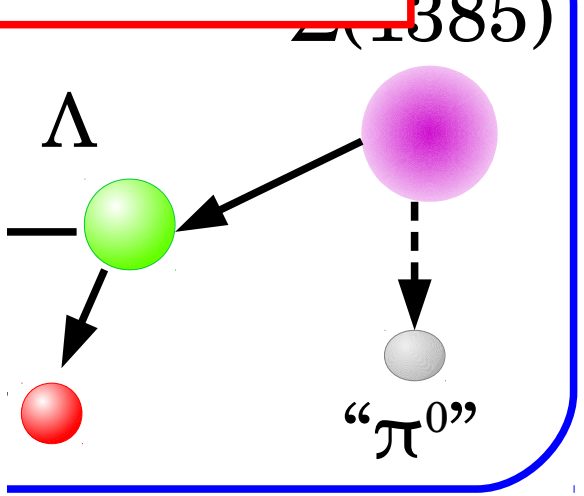



The acceptance of neutral mode is
10 times smaller than charged modes.
**analysis is ongoing**

Acceptance each mode

| | |
|---|---|
| 0.32 | $\Lambda \to \pi^+\Sigma^- \to \pi^+\pi^- n$ |
| 0.16 | $\Lambda \to \pi^-\Sigma^+ \to \pi^-\pi^+ n$ |
| 0.015 | $\Lambda \to \pi^0\Sigma^0 \to \pi^0\pi^- p$ |




E31 proposal:
http://j-parc.jp/researcher/Hadron/en/pac 0907/pdf/Noumi.pdf

# Summary

We have taken the data of the d($K^-$, n) reaction at the K1.8BR beam line.

→We obtain the d($K^-$, n)$\pi^{\mp}\Sigma^{\pm}$ spectrum.

We observed some events below the $\overline{K}N$ threshold.

We found that the $K^-d \rightarrow n\pi^-\Sigma^+$ mode is dominant.

We will provide more results soon.

→line sharps and cross section of $\pi^{\mp}\Sigma^{\pm}$.

→some information about $\pi^0\Sigma^0$, $\pi^0\Lambda$ modes.

We will continue experiment to increase 20 times more statistics.

We will be able to decompose all isospin mode.

The E31 will provide conclusive information for the structure of the $\Lambda(1405)$ and the $\overline{K}N$ interaction.

# Thank you for your attention

# The J-PARC E31 Collaboration

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*9. RIKEN, Japan, 10. Tokyo Institute of Technology, Japan*

*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

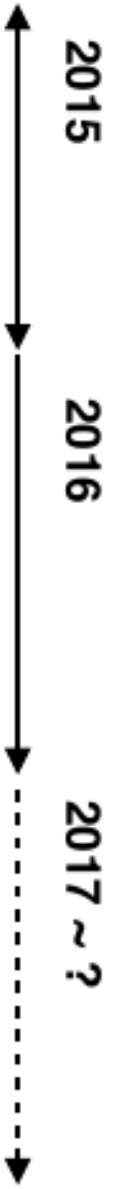
# Yield estimation

**The analysis is on going**

| | Power (Beam Time)* | Yield (1.4~1.43 GeV/$c^2$) | | Experimental Achievement expected |
|---|---|---|---|---|
| | | $\pi^{\pm}\Sigma^{\mp}$ mode | $\pi^0\Sigma^0$ mode | |
| May, 2015 (run#62) | 26.5 kW<br>2.2 days | 250 | TBA | 180 was expected in the $\pi^{\pm}\Sigma^{\mp}$ modes |
| Autumn, 2015<br>Case I | 40 kW<br>5 days | 870 | 30 | $\pi^{\pm}\Sigma^{\mp}$ mode ID separately |
| Autumn, 2015~<br>Case II | 40 kW<br>10 days | 1700 | 60 | Yield of the $\pi^0\Sigma^0$ mode be confirmed |
| Autumn, 2015~<br>Case III | 40 kW<br>20 days | 3400 | 130 | $\pi^0\Sigma^0$ mode line shape? |
| Autumn, 2015~<br>Case IV | 40 kW<br>27 days | 4700 | 180 | Proposed beam time |

# Outlook - E15 2nd & near future plan@K1.8BR

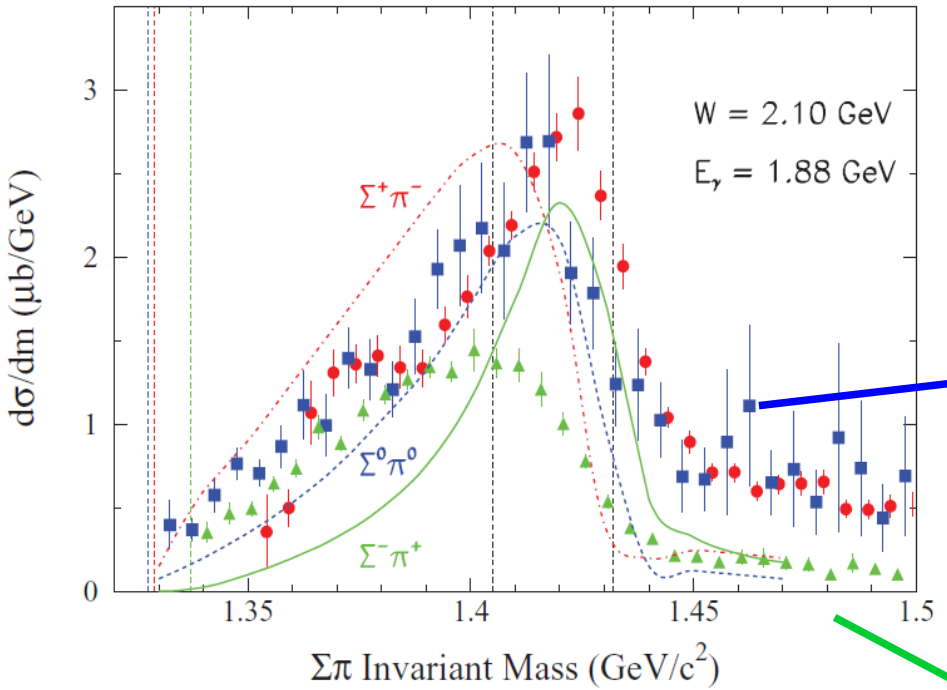
- **E15 2nd-stage physics run**
  - x10 statistics, ~10% of full proposal
  - Exclusive analysis
  - Kinematically complete measurement of $^{3}$He($K^{-}$,**Λpn**)
- **E31 pilot run (D2-target)**
- **E17→E62: $K^{-}$He x-ray measurement with TES**
  - TES: novel cryogenic detector, ~5 eV FWHM@6 keV
  - Feasibility test was successfully performed at PSI
- **E57: $K^{-}$d x-ray measurement with SDDs**



# Photo-production

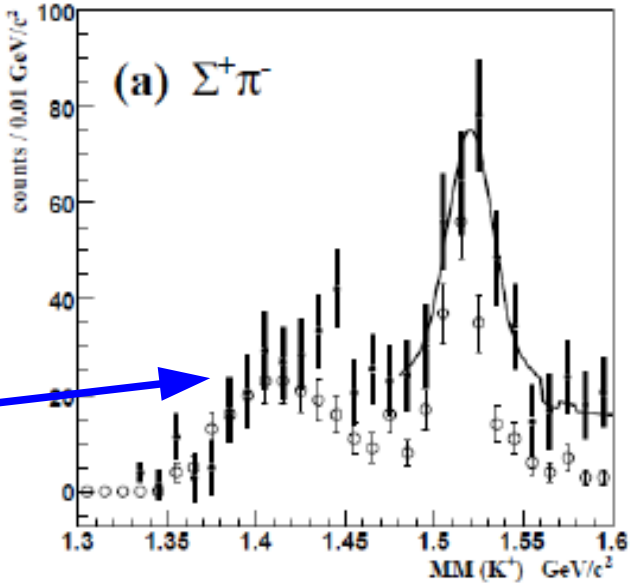
## CLAS collaboration

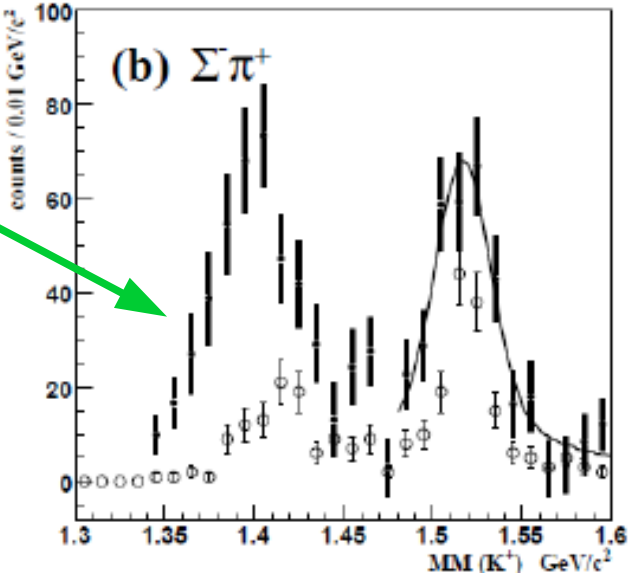
PRC87, 035206



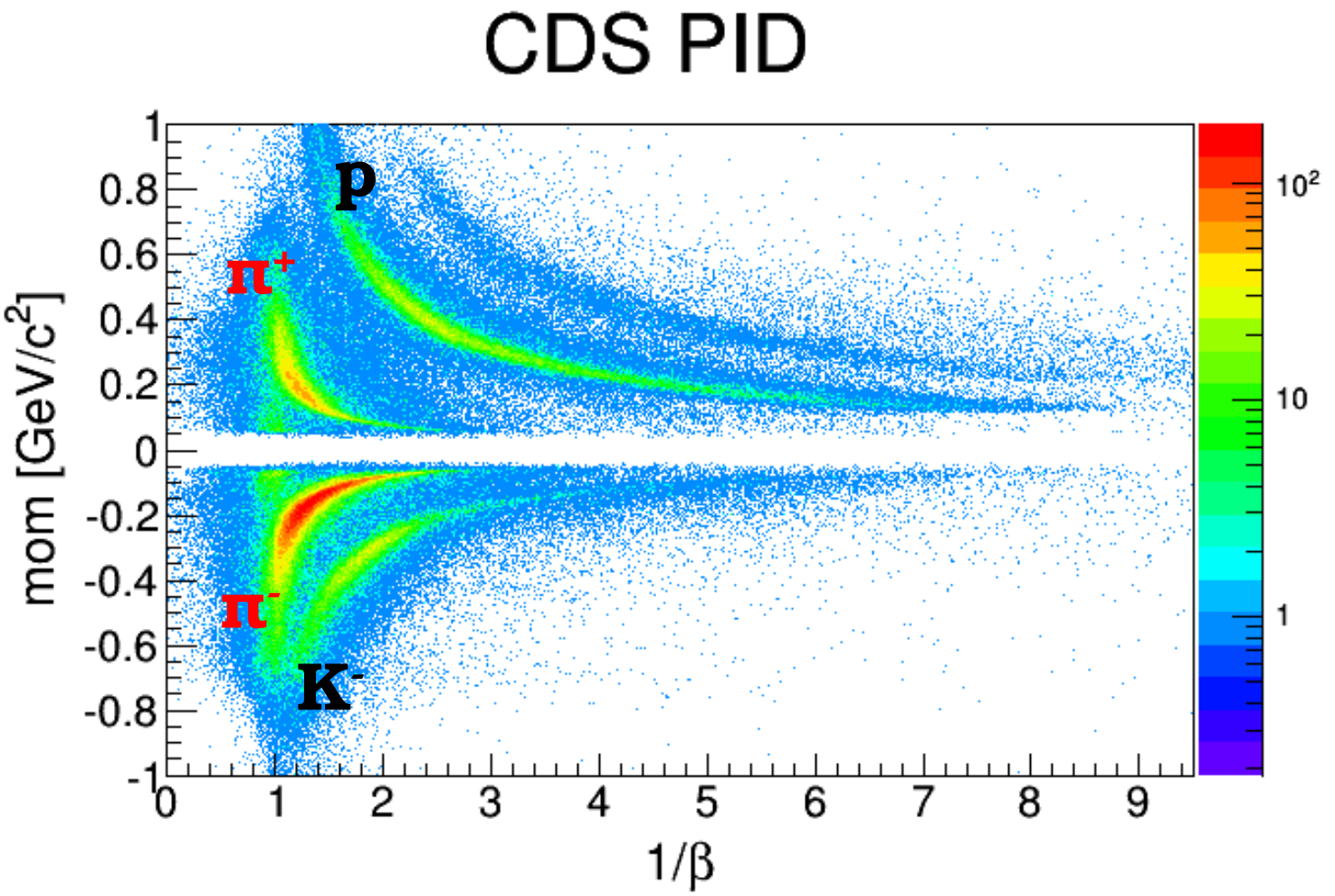

## LEPS

M. Niiyama et al.,
PRC78, 035202



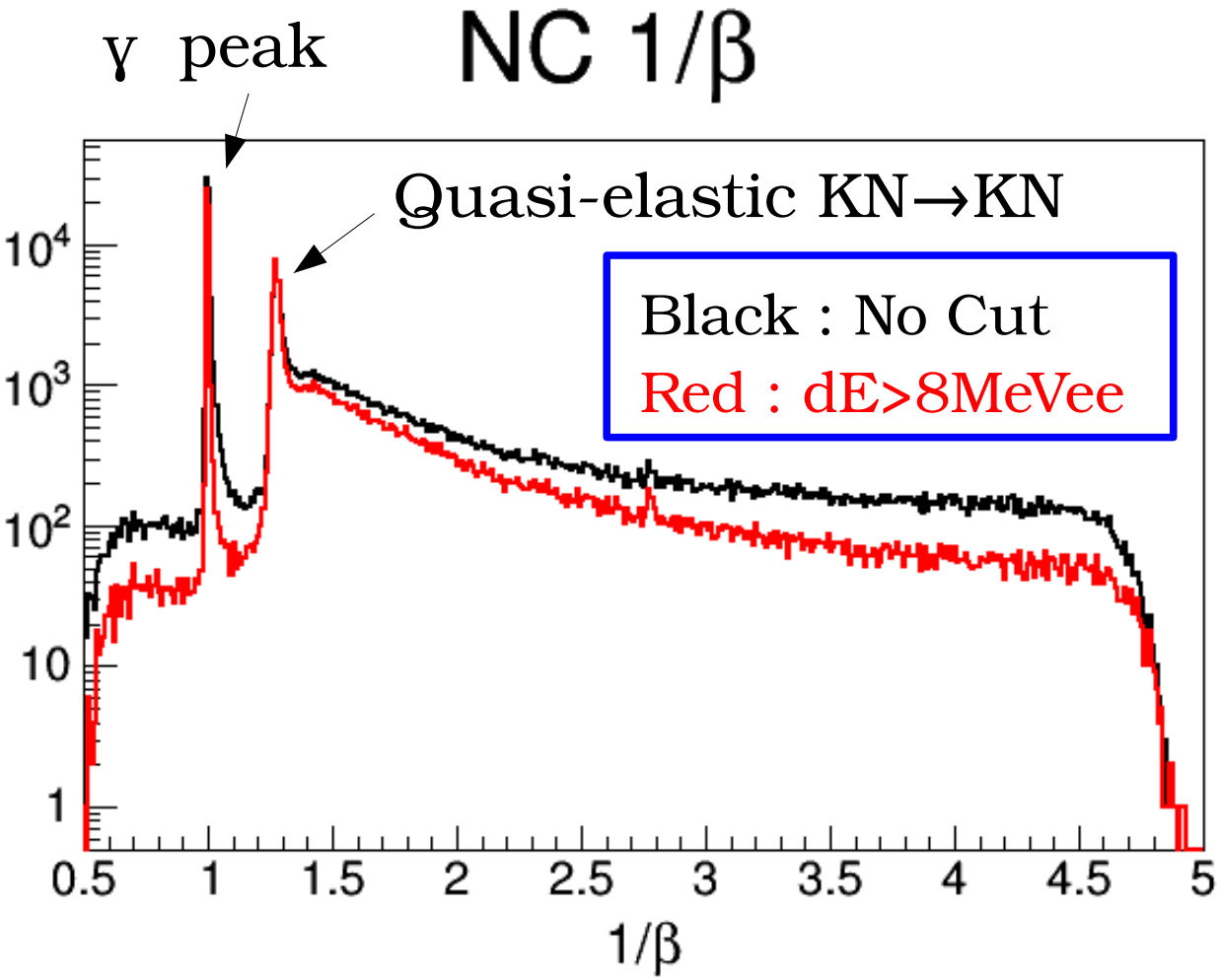



# Detector performance---CDS



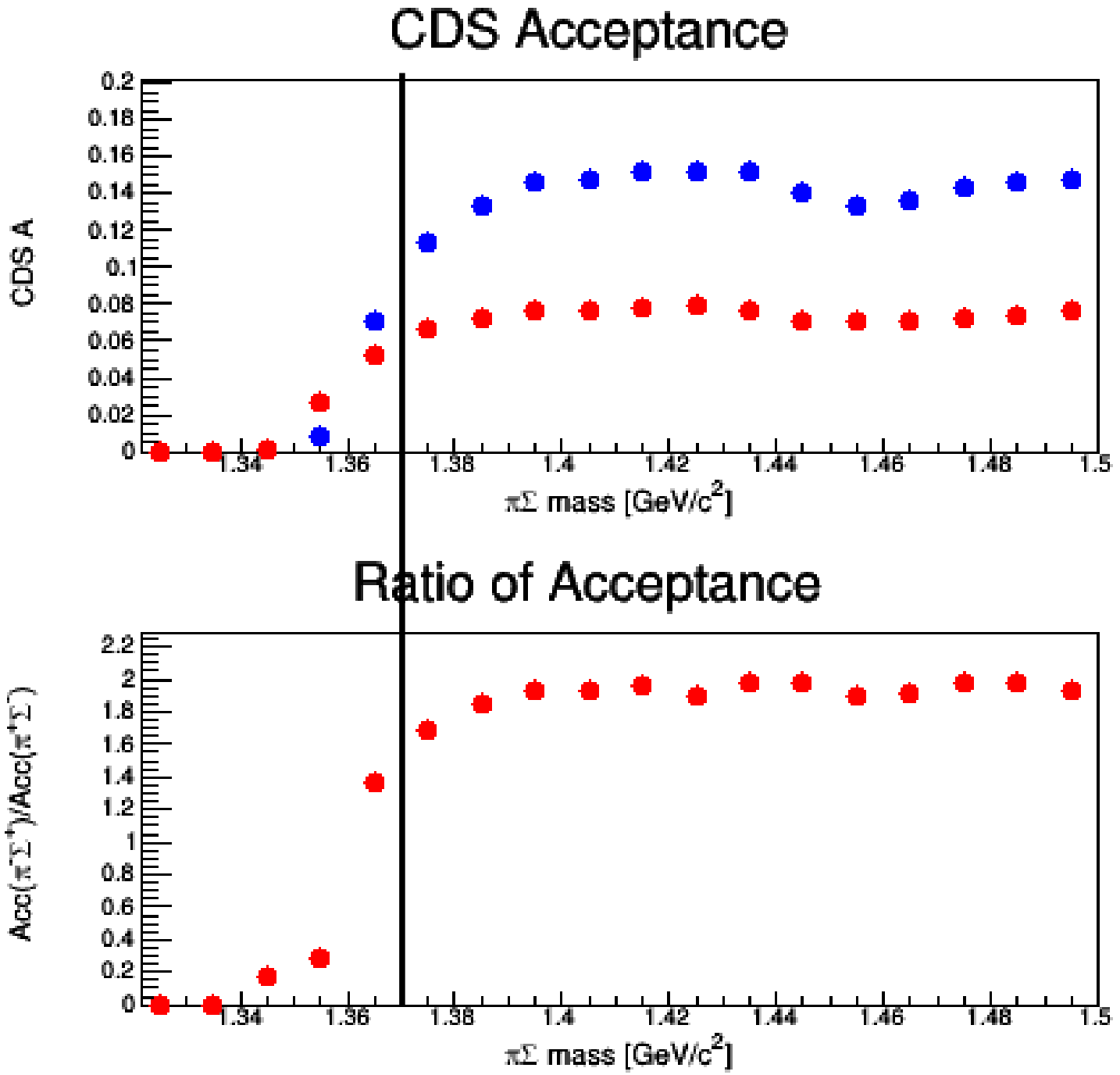

CDS successfully identify $\pi^-$, $K^-$, $\pi^+$, p.

# Detector performance---CDS




NC time resolution is estimated by 160ps at $\gamma$ peak.
Quasi-elastic peak is clearly seen.

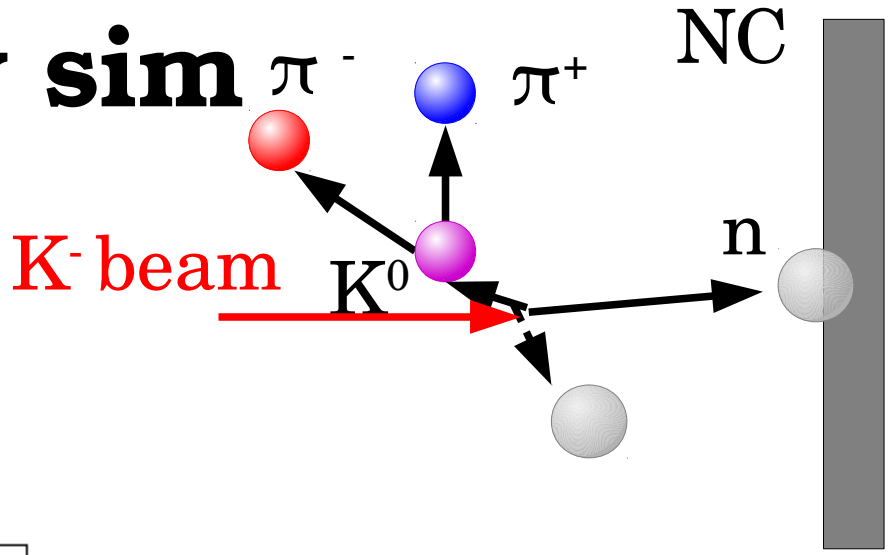
# Reaction : $K^- d \rightarrow \Lambda(1405)\, n$ : n=0 deg

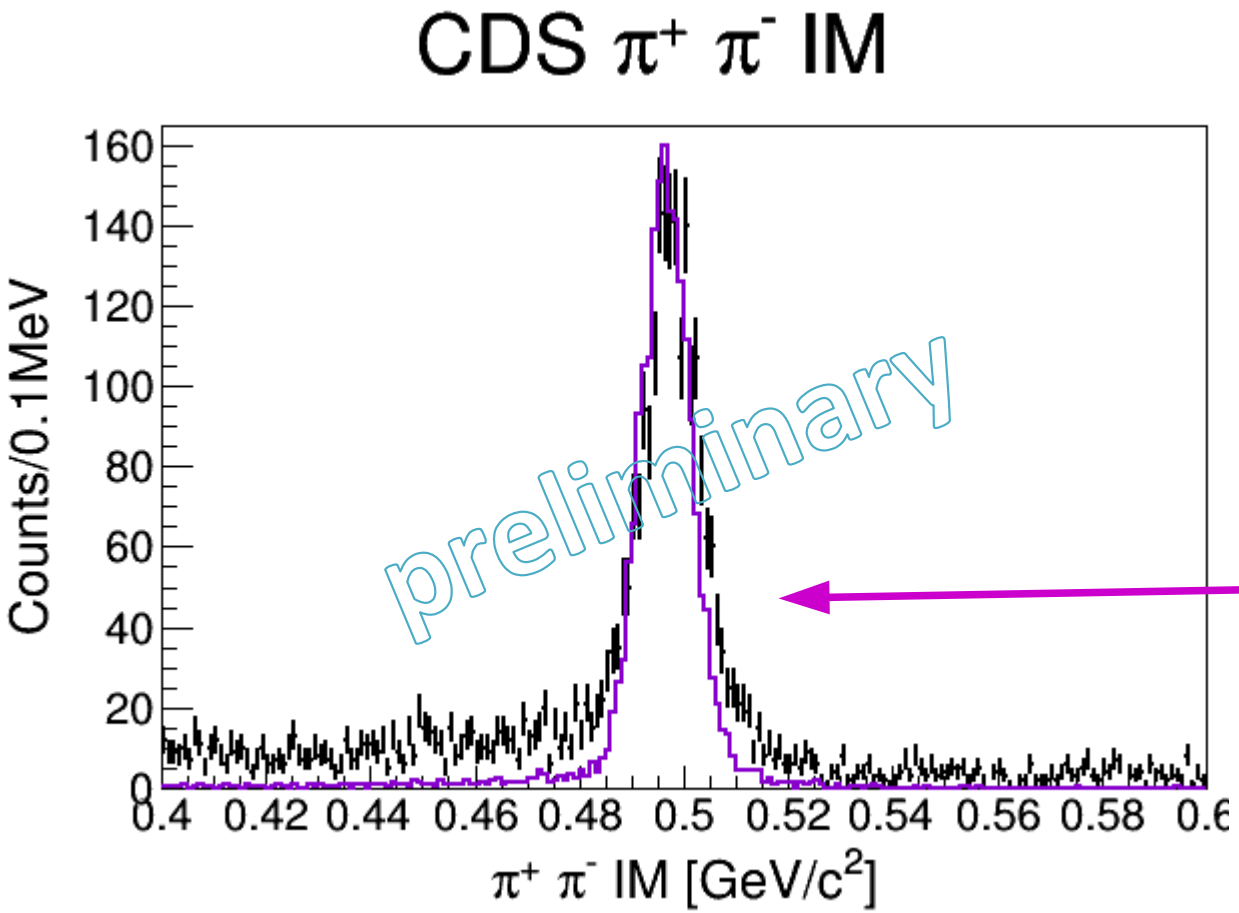


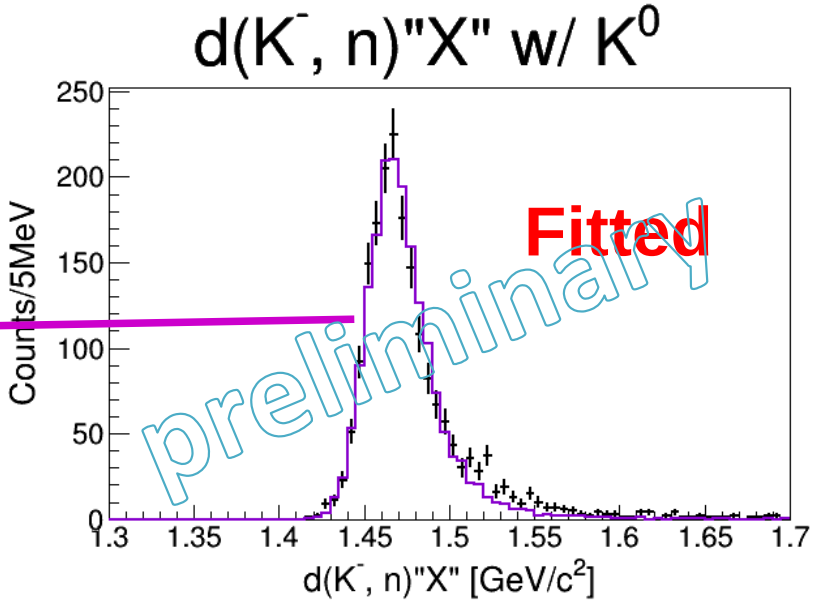
# Data reproduction by sim

CDS $\pi^+\pi^-$ invariant mass

Reaction : $K^- d \rightarrow K^0 n n_s$



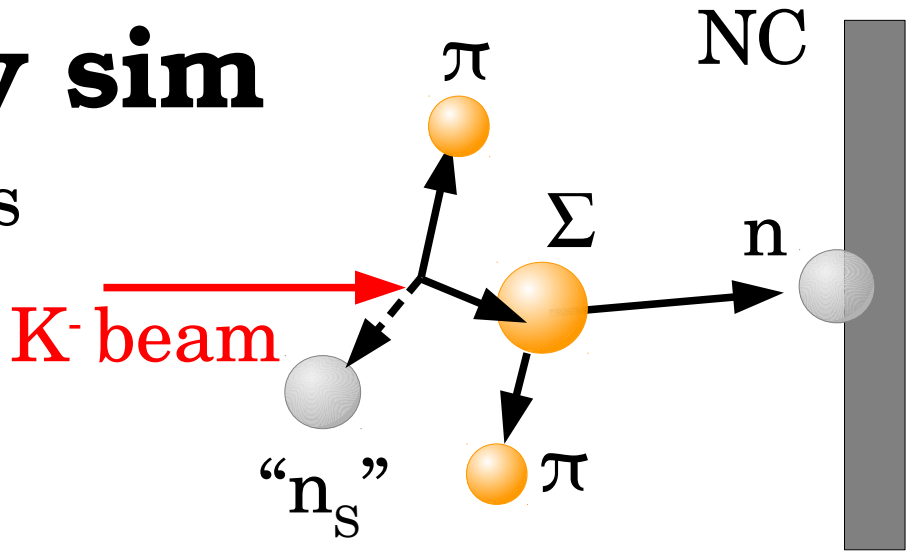



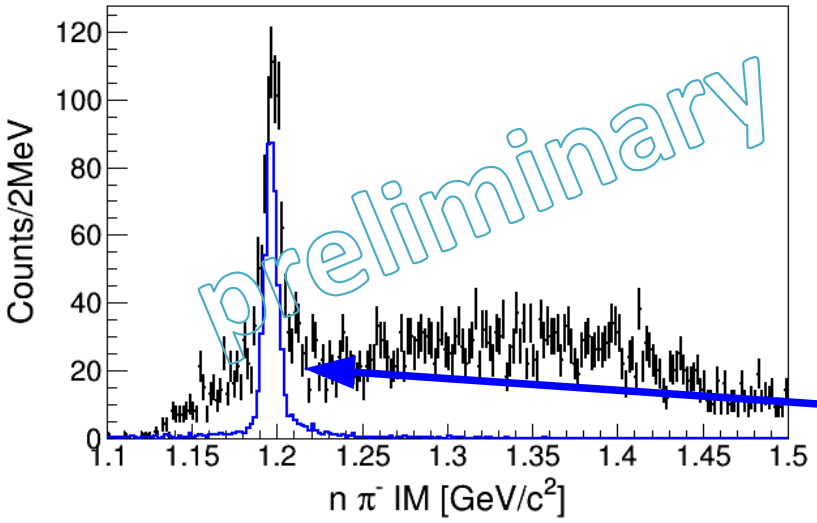
# Data reproduction by sim

n : NC π : CDS invariant mass

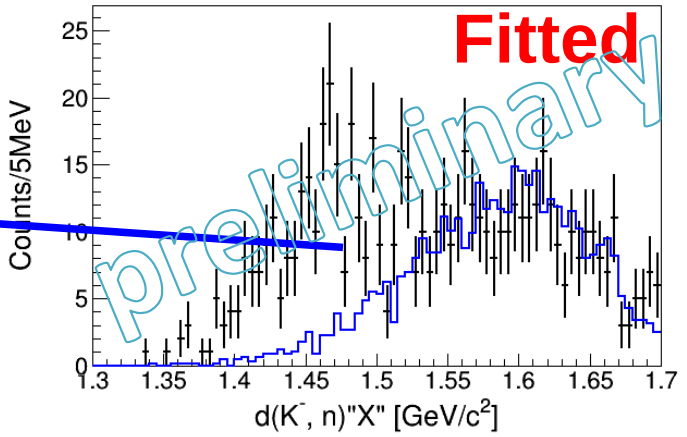
Reaction : $K^- d \rightarrow \pi \Sigma n_s$



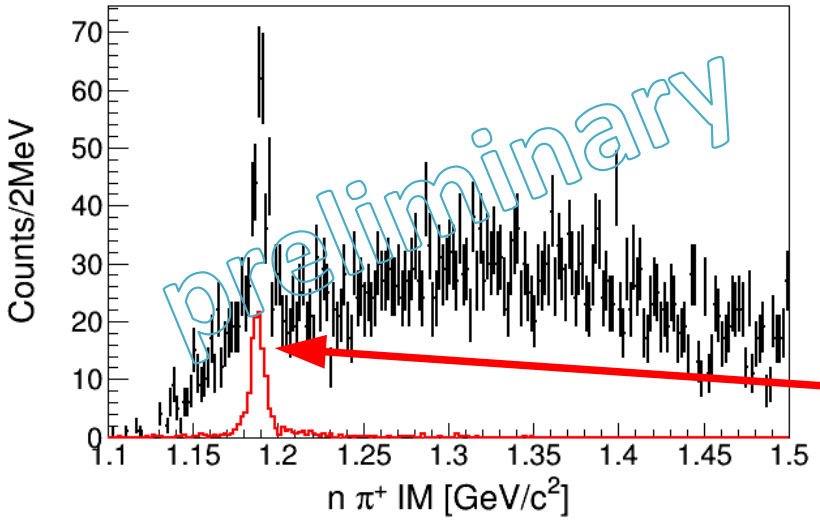

$n_{NC}$ $\pi^-$ IM



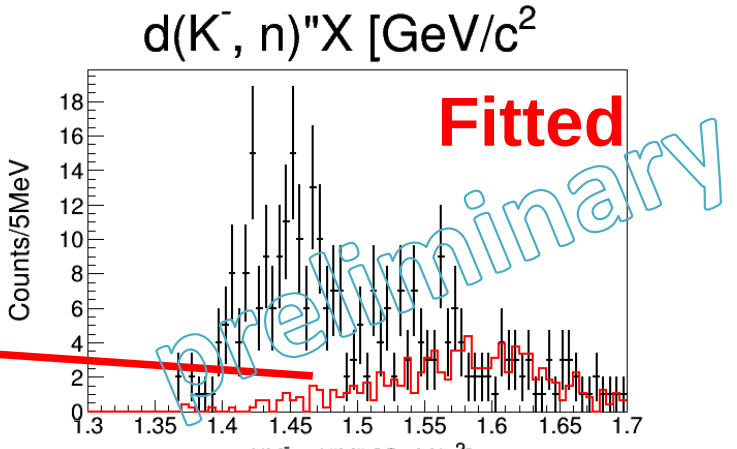

d(K⁻, n)"X [GeV/c²]




$n_{NC}$ $\pi^+$ IM



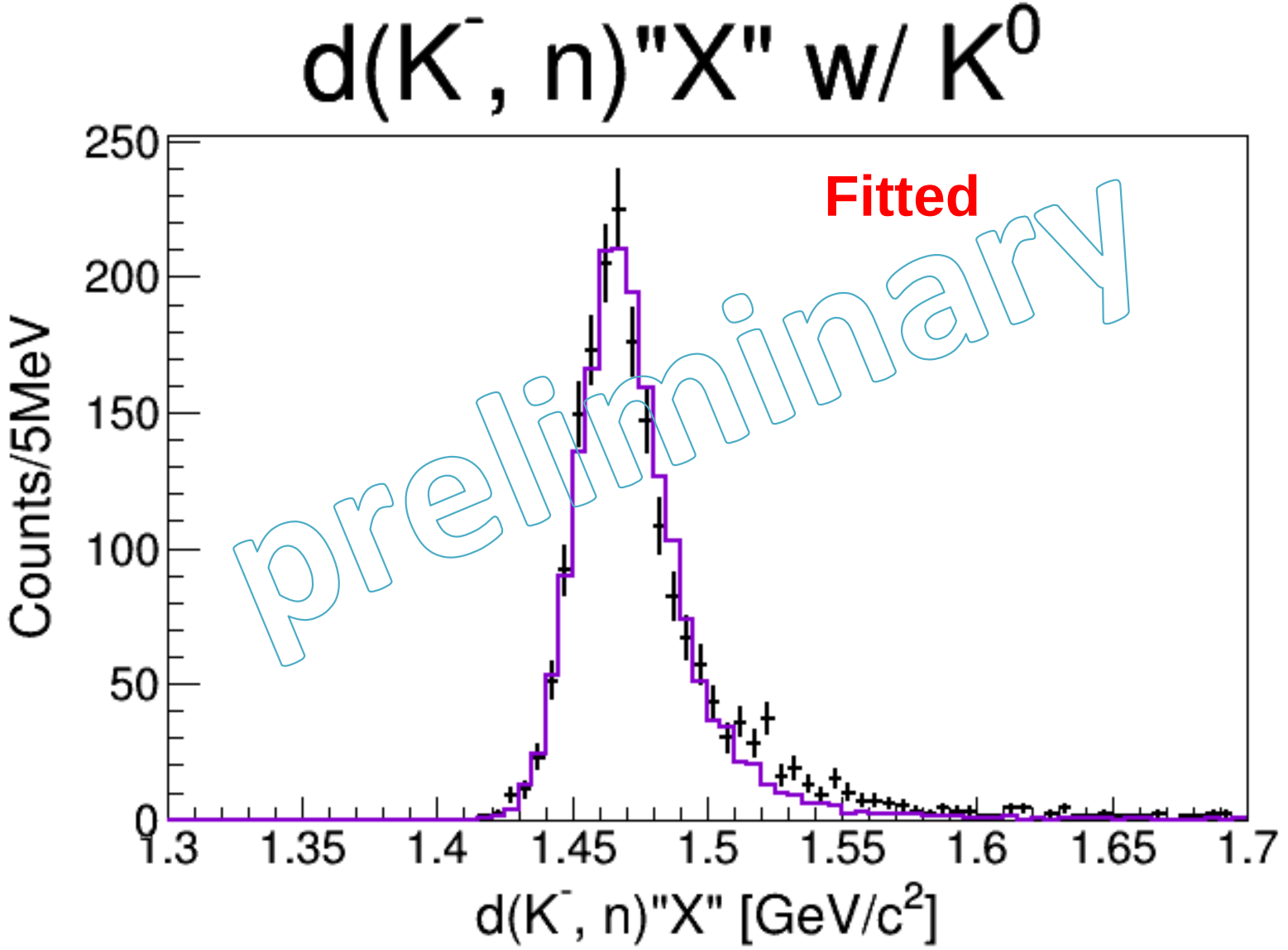

d(K⁻, n)"X [GeV/c²]



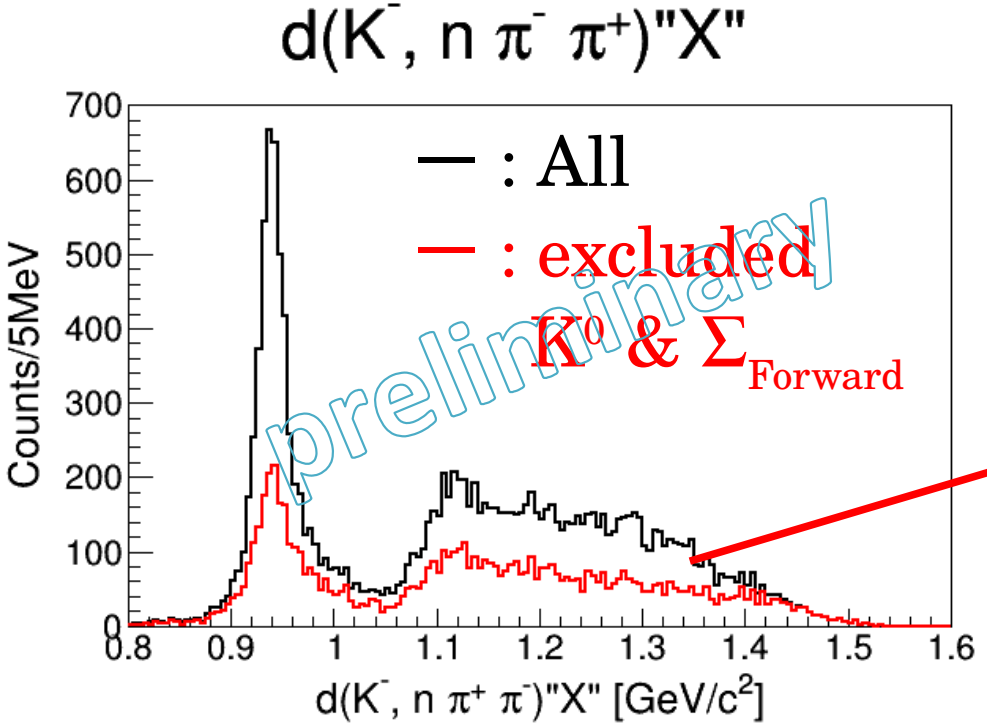
# Data reproduction by sim

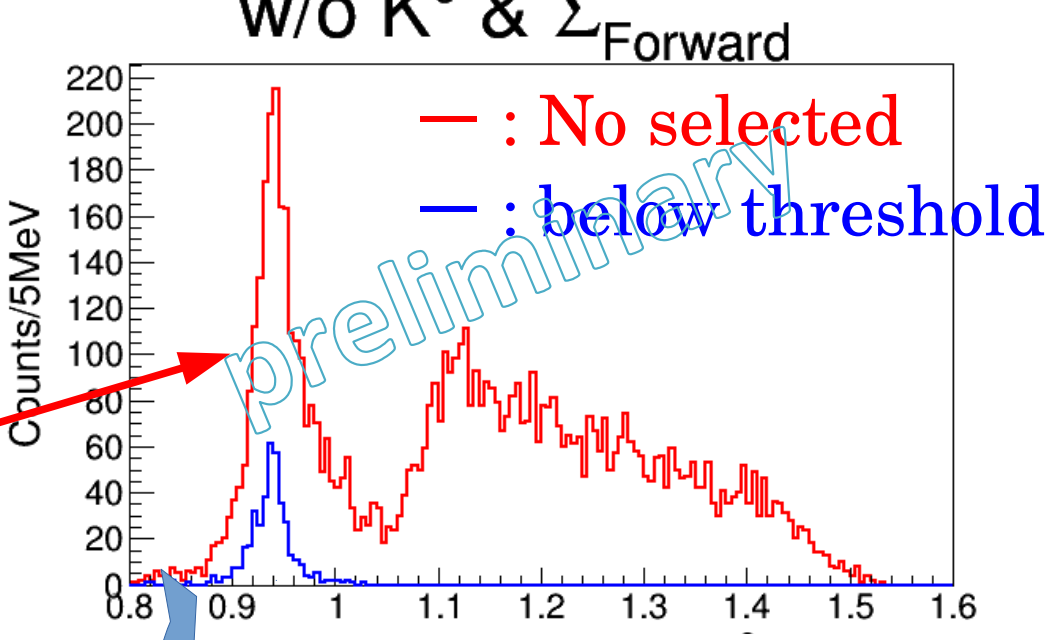
CDS $\pi^+ \pi^-$ invariant mass

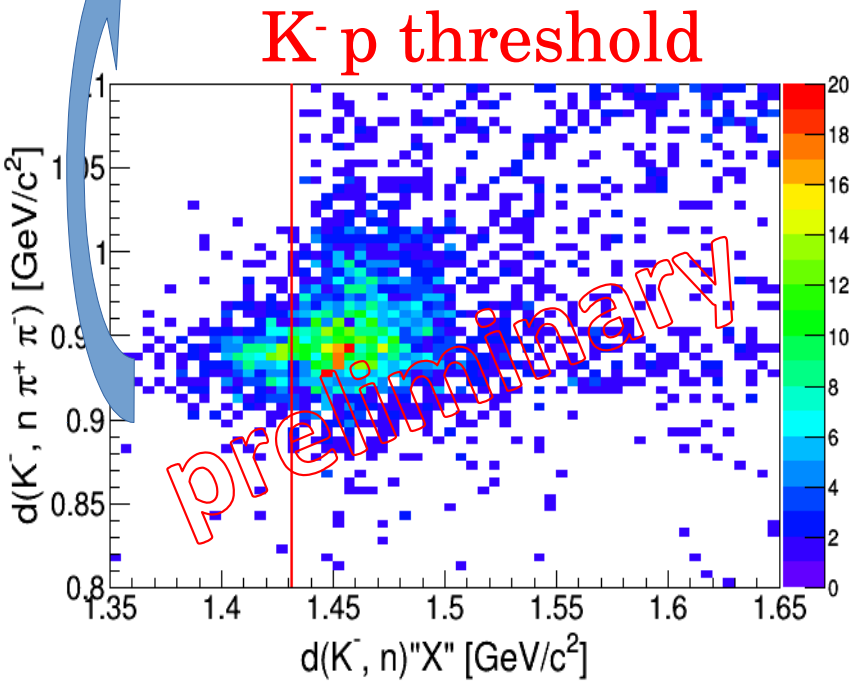
Reaction : $K^- d \rightarrow K^0 n n_s$



# $K^- d \to n \pi^+ \pi^- n$ events




d(K⁻, n $\pi^+ \pi^-$)"n" has a tail.
In the region below threshold,
The tail isn't seen.

This tail should to be removed.