22nd J-PARC PAC July 27-29, 2016

Spectroscopic Study of Hyperon Resonances below $K^{bar}N$ Threshold via the (K^-,n) Reaction on Deuteron

H. Noumi, *Osaka Univ. RCNP*, for the E31 collaboration

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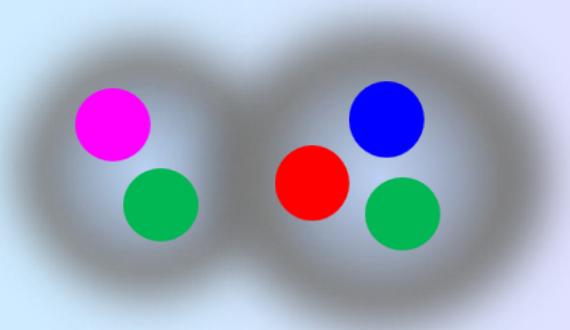
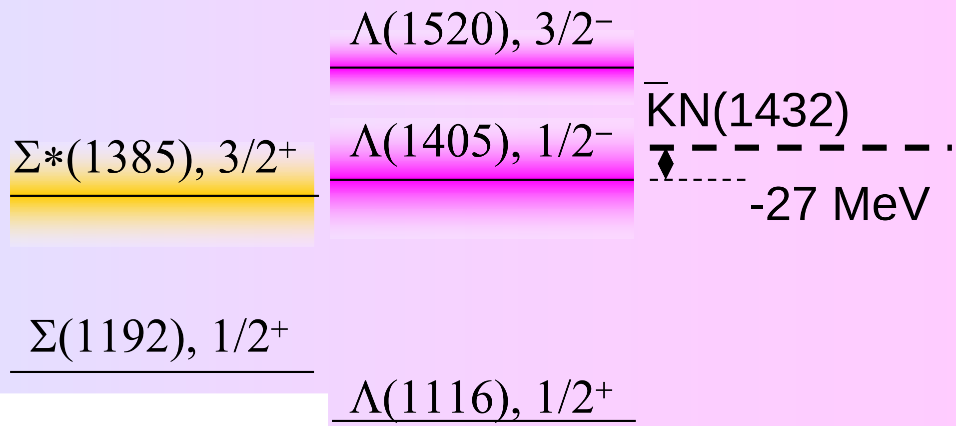
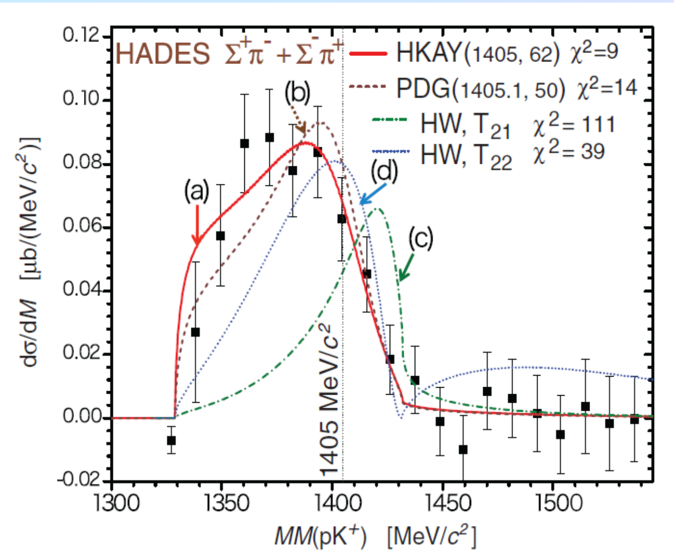
$\Lambda(1405)$: $1405.1^{+1.3}_{-0.9}$ MeV (PDG)

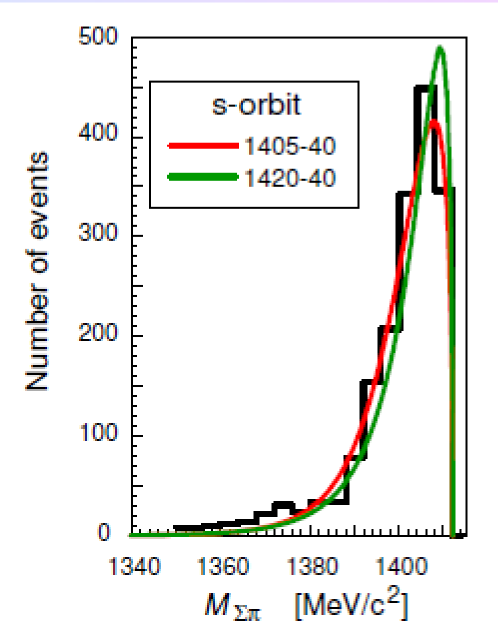
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons



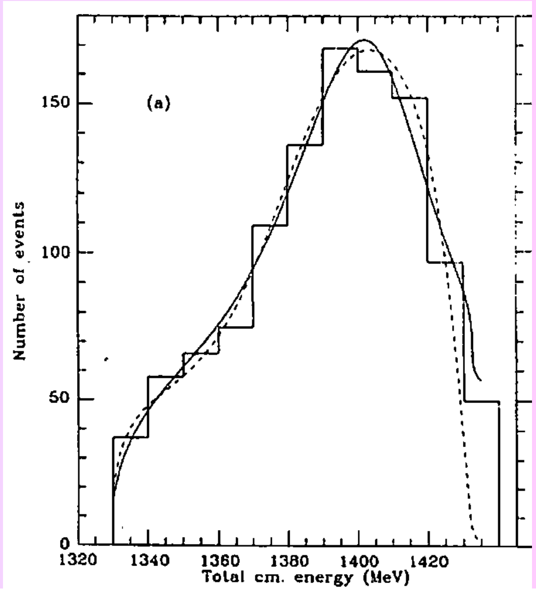




M. Hassanvand et al: πΣ IM Spec. of pp→K⁺πΣ



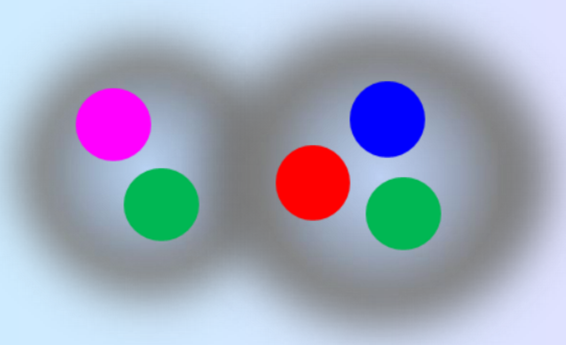
J. Esmaili et al: πΣ IM Spec. of Stopped K⁻ on ⁴He

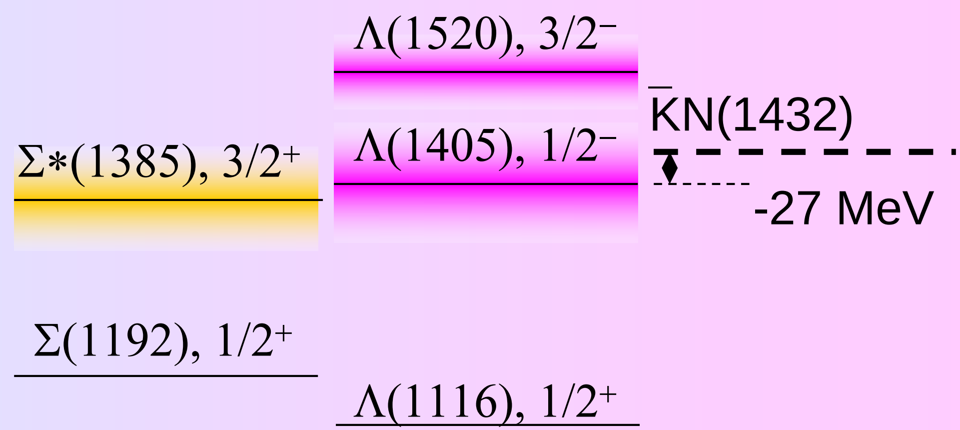


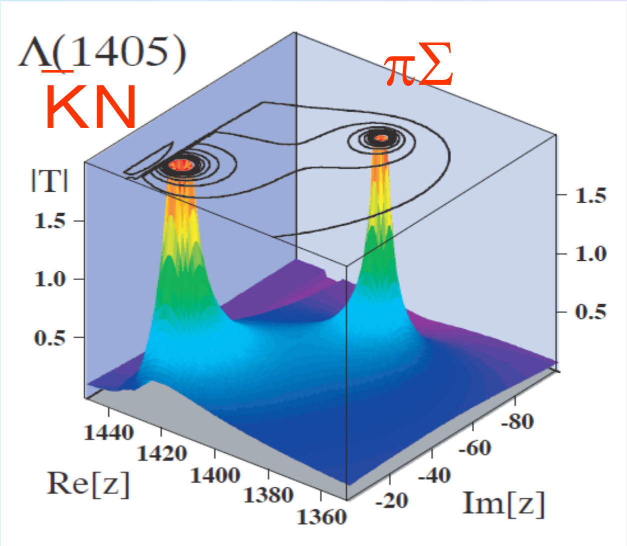
R.H. Dalitz et al: πΣ IM Spec. in K-p→ππΣ w/ M-matrix

$\Lambda(1405)$: Double pole?

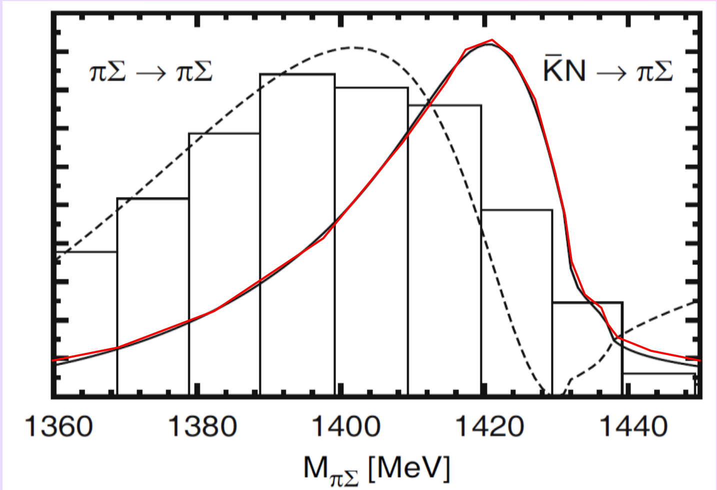
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons







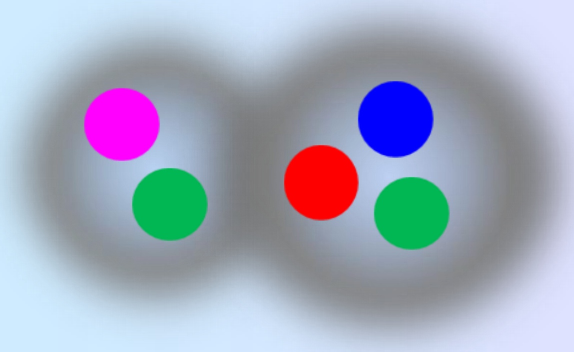
ChU model, T. Hyodo

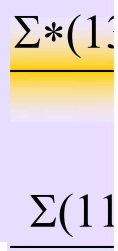


Chiral Unitary Model:
D. Jido et al., NPA725(03)181

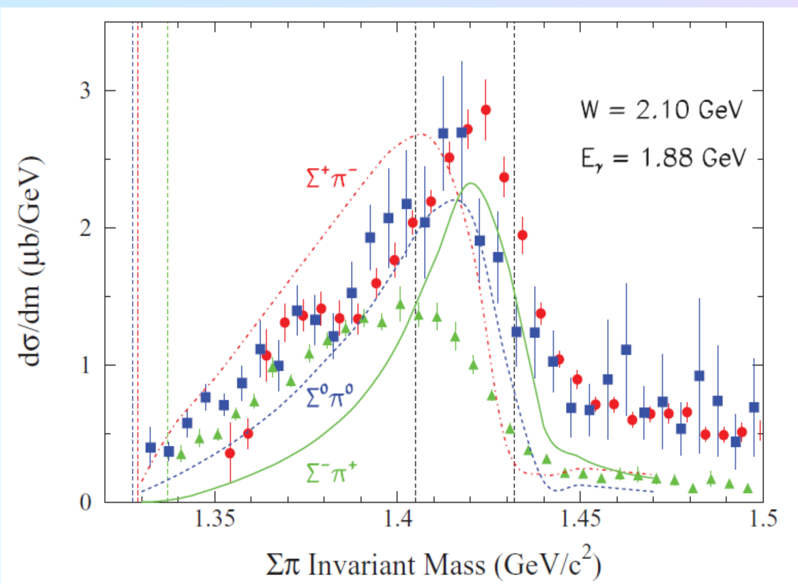
Λ(1405) : Controversial Experimental Data?

$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons



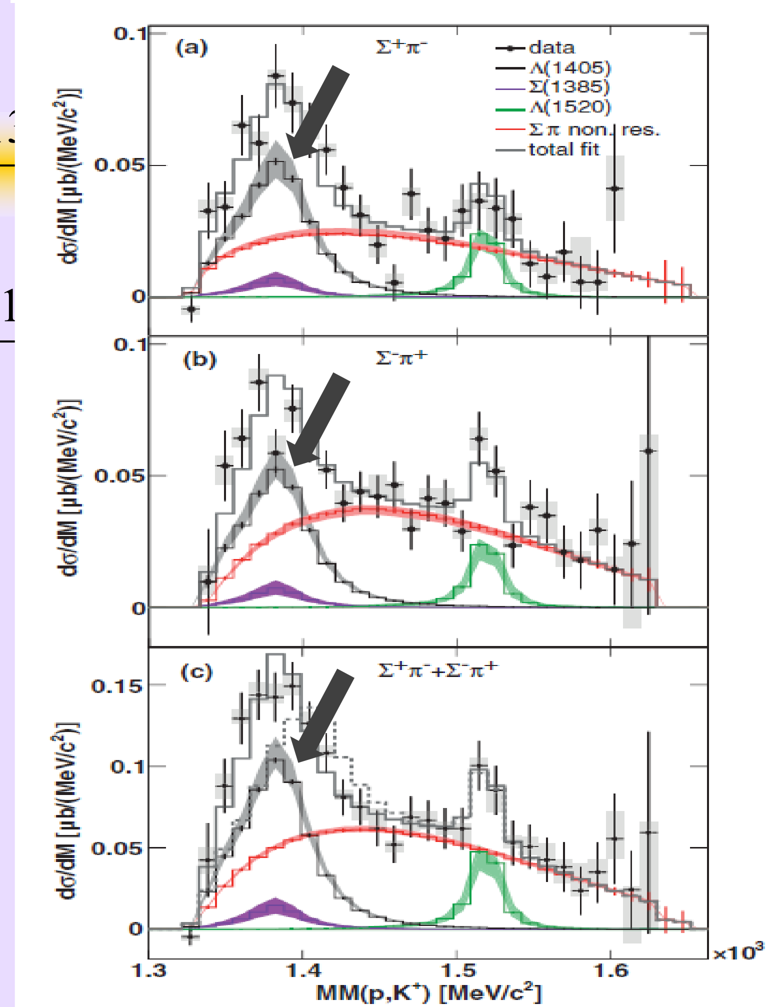


$\gamma p \rightarrow K^+\pi^-\Sigma^+, K^+\pi^0\Sigma^0, K^+\pi^+\Sigma^-$



CLAS collaboration: PRC87, 035206

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

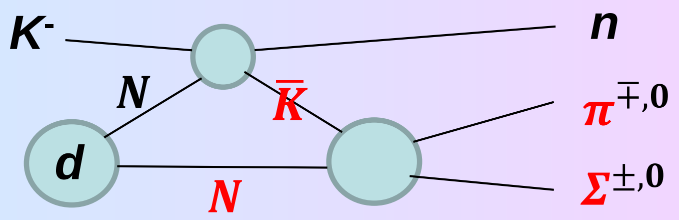


HADES collaboration: PRC87, 025201

E31:

- aims to conclude if Λ(1405) appears at ~1405 MeV or ~1420 MeV in a $\bar{K}N \rightarrow \pi\Sigma$ scattering.
  - ✓ This provides basic information on a longstanding argument on a deeply bound kaonic nuclei.

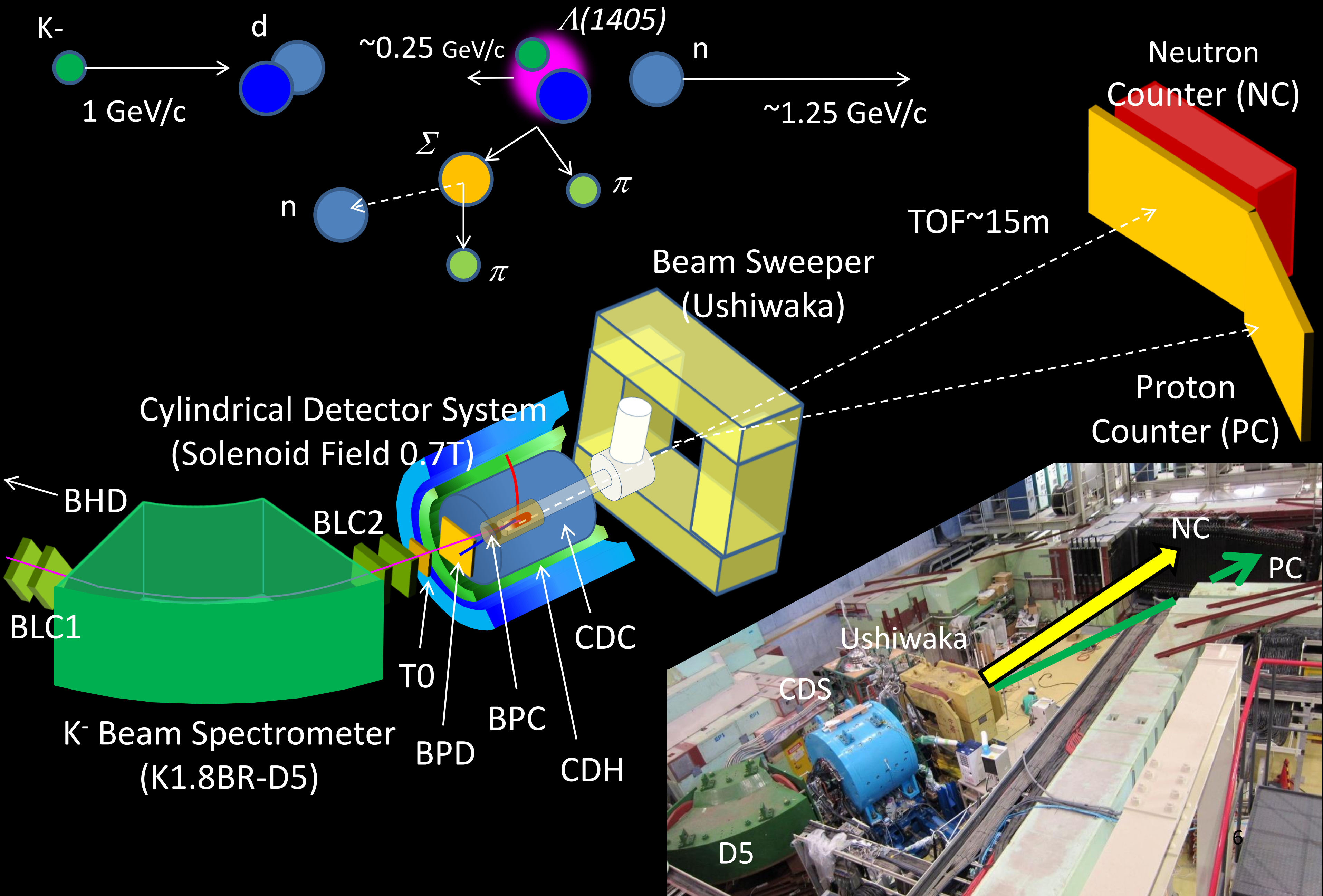
- employs $d(K^-,n)\pi\Sigma$ reactions at θ_n~0 deg., which is expected to enhance an S-wave $\bar{K}N \rightarrow \pi\Sigma$ scattering even below the $\bar{K}N$ threshold to form Λ(1405).



- ID's all the final states to decompose the I=0 and 1 ampl's.

$\pi^{\pm}\Sigma^{\mp}$	I=0, 1	Λ(1405), Σ(1385), non-resonant
$\pi^0\Sigma^0$	I=0	Λ(1405) (I=0, S wave), non-resonant
$\pi^0\Lambda$ [$\pi^-\Sigma^0$]	I=1	Σ(1385) (I=1, P wave), non-resonant [$d(K^-,p)\pi^-\Sigma^0$]

Experimental Setup for E31

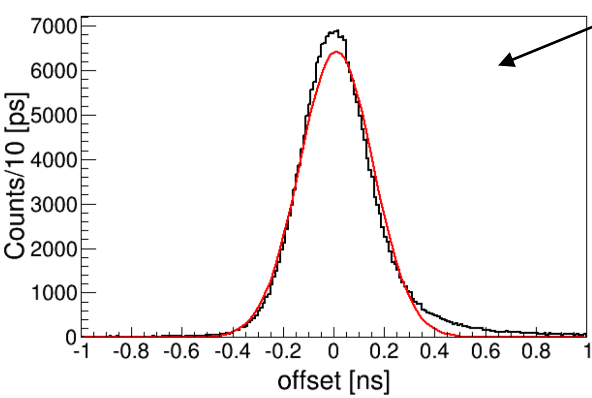


E31 Run Summary

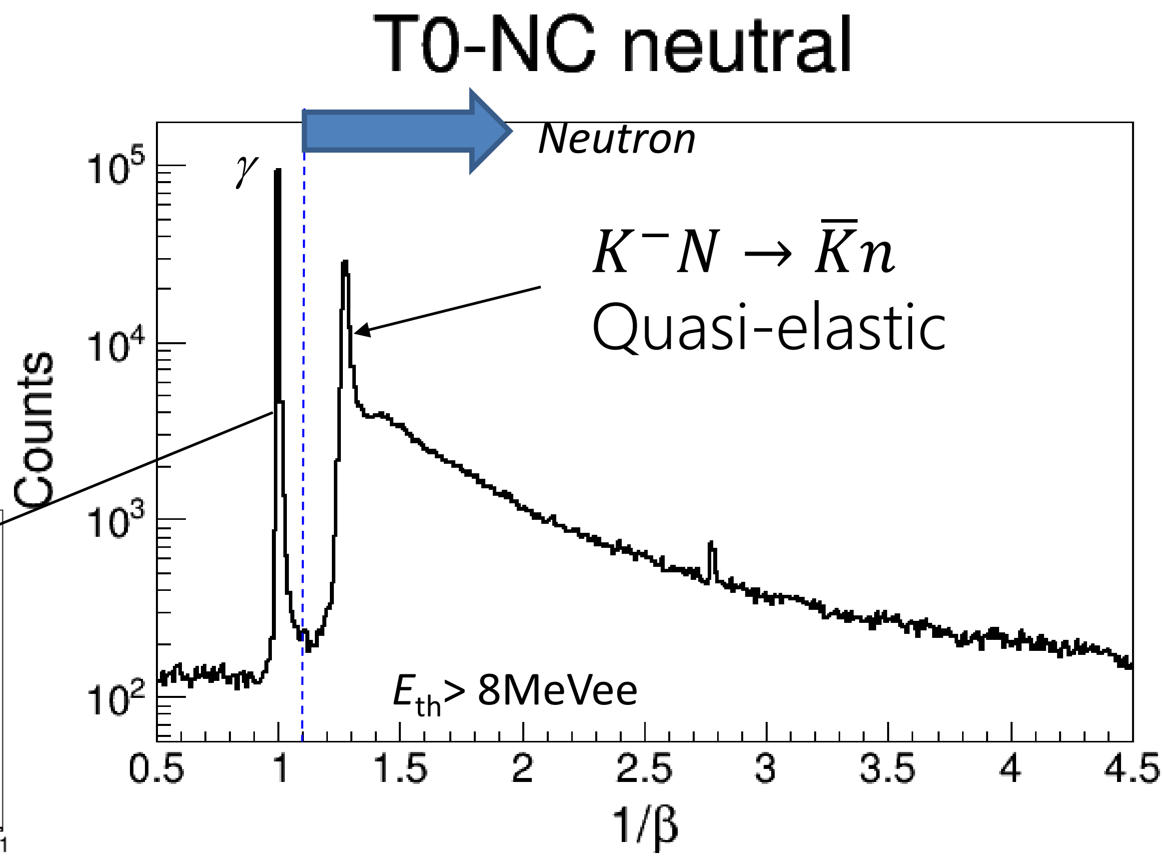
E31 run		Beam Power	Beam Time	Executed/ Proposed
pre	May 2015	27 kW	2.2d	~5%
1^{st}	May-June 2016	43 kW	~7d	~30%
2^{nd}	Spring? 2017	45 kW (Expected)	~18(+2)d (request)	100%

Forward Neutron 1/β spectrum

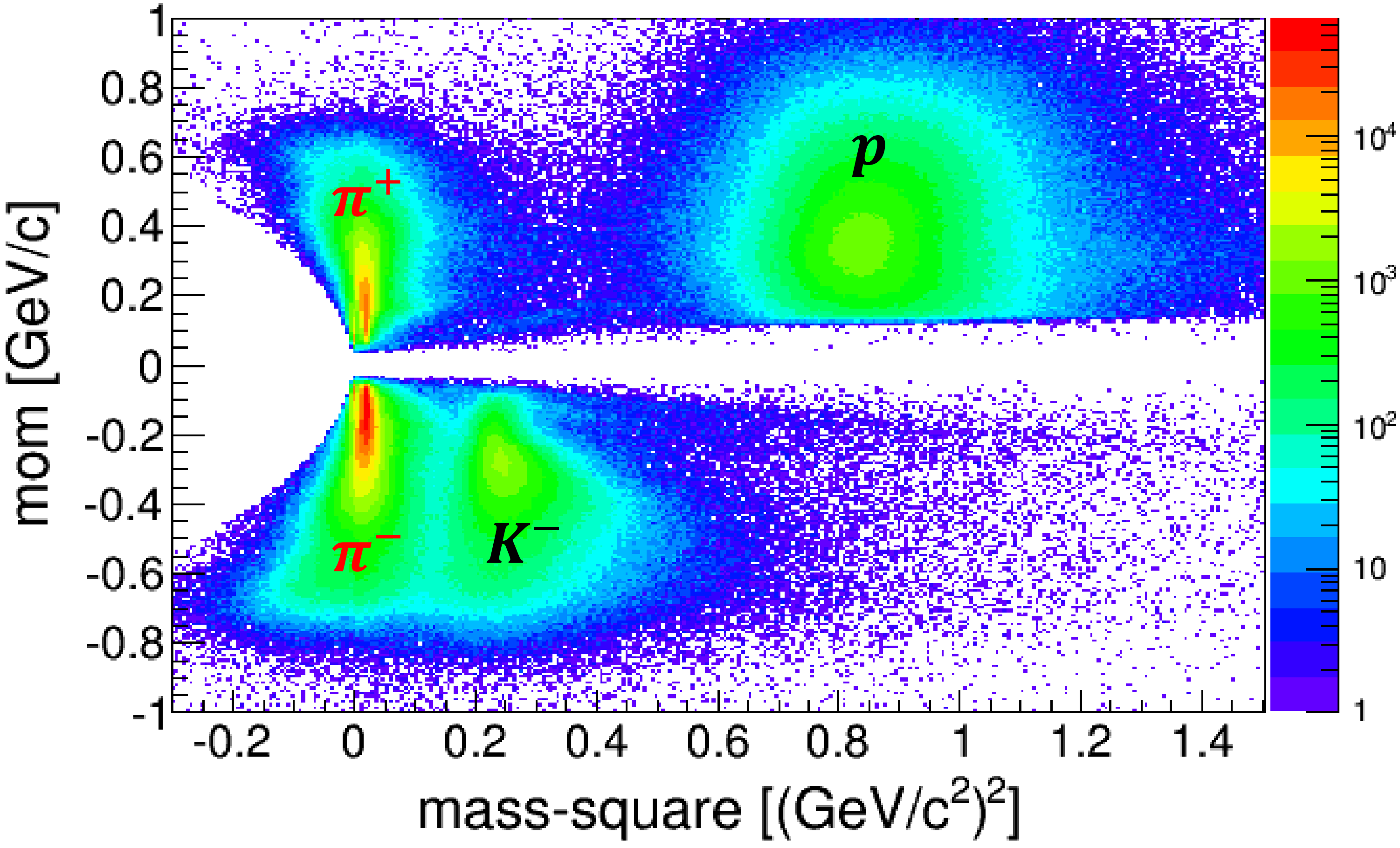
γ peak



σ_{TOF}~145 ps @ β=1



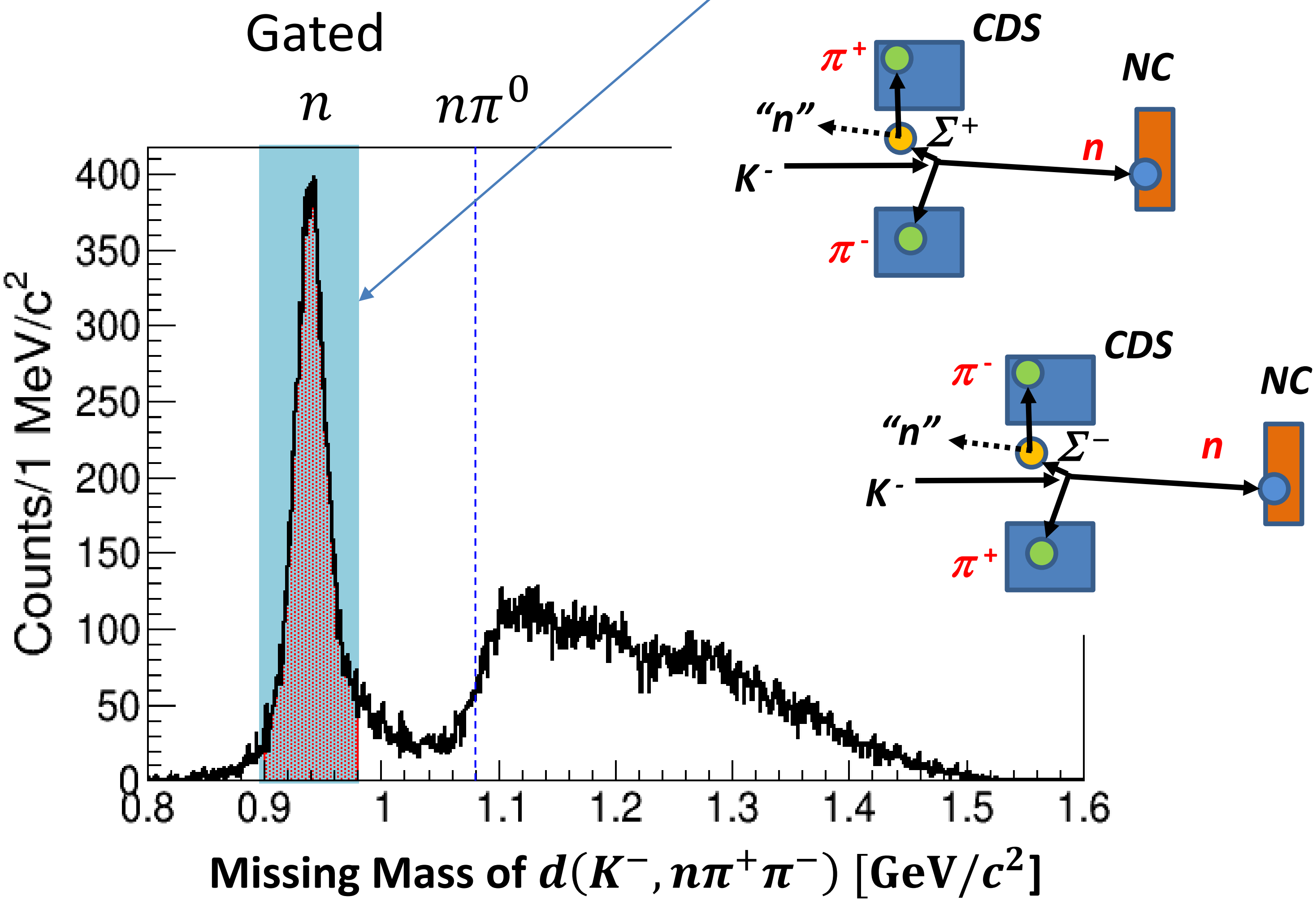
Particle ID (CDS)



I = 0, 1 channel

$d(K^-, n)X_{\pi^\pm\Sigma^\mp}$

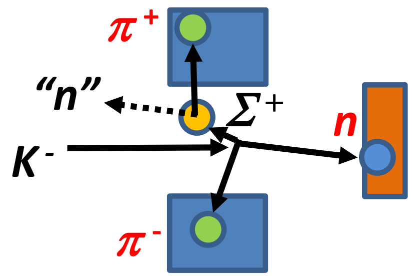
$$d(K^-, n\pi^+\pi^-)n_{missing}$$

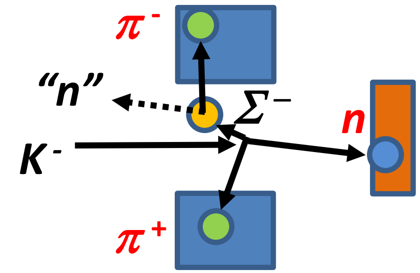


$d(K^-, n\pi^+\pi^-)$"n" sample contains...

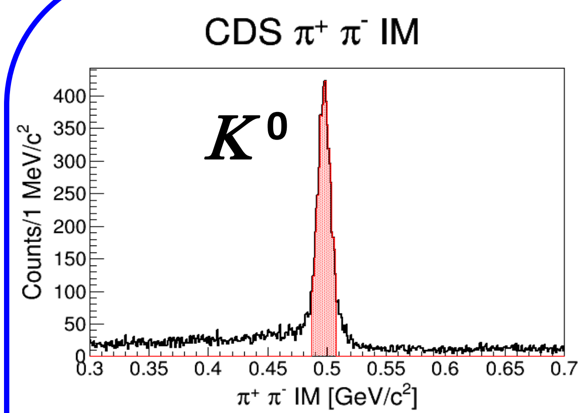
Signal Events

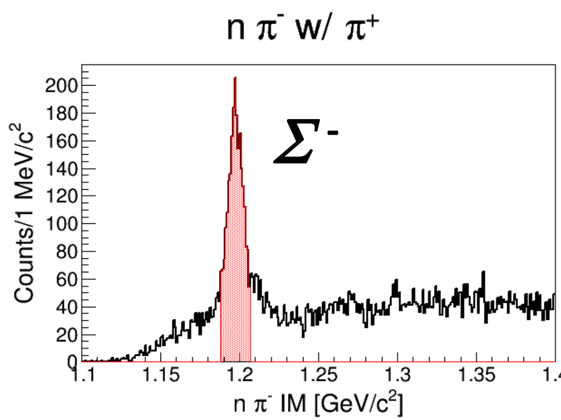
$$d(K^-, n)X_{\pi^\pm\Sigma^\mp}$$

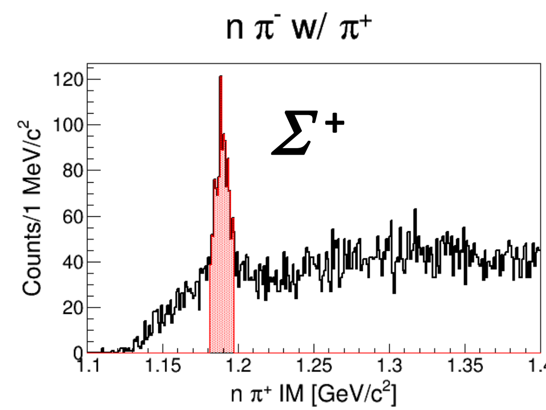


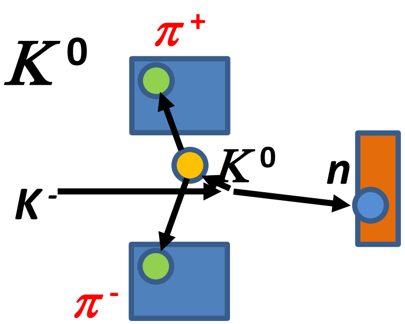


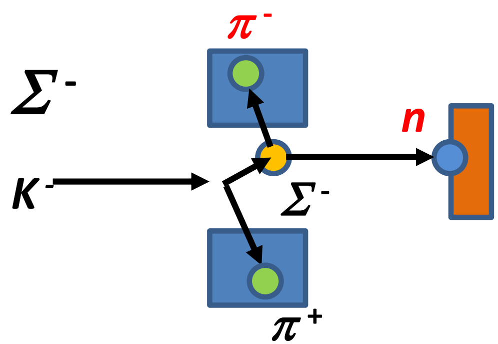
Background Events

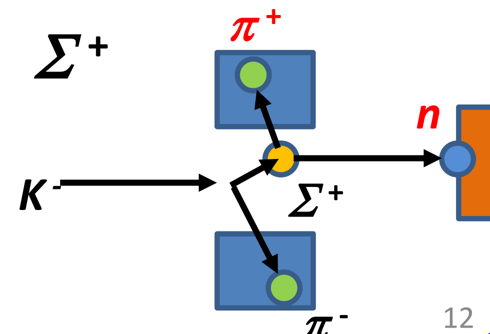




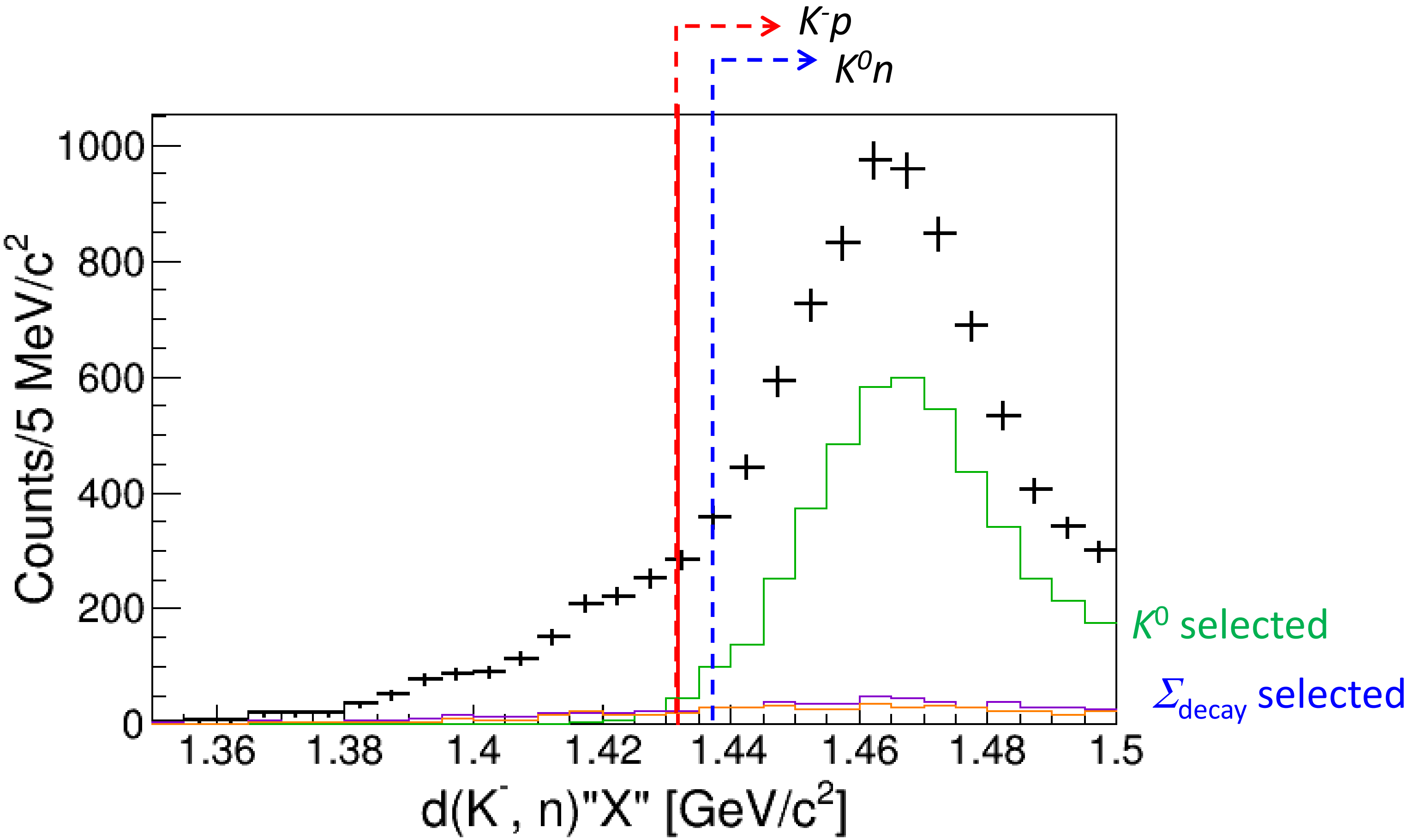






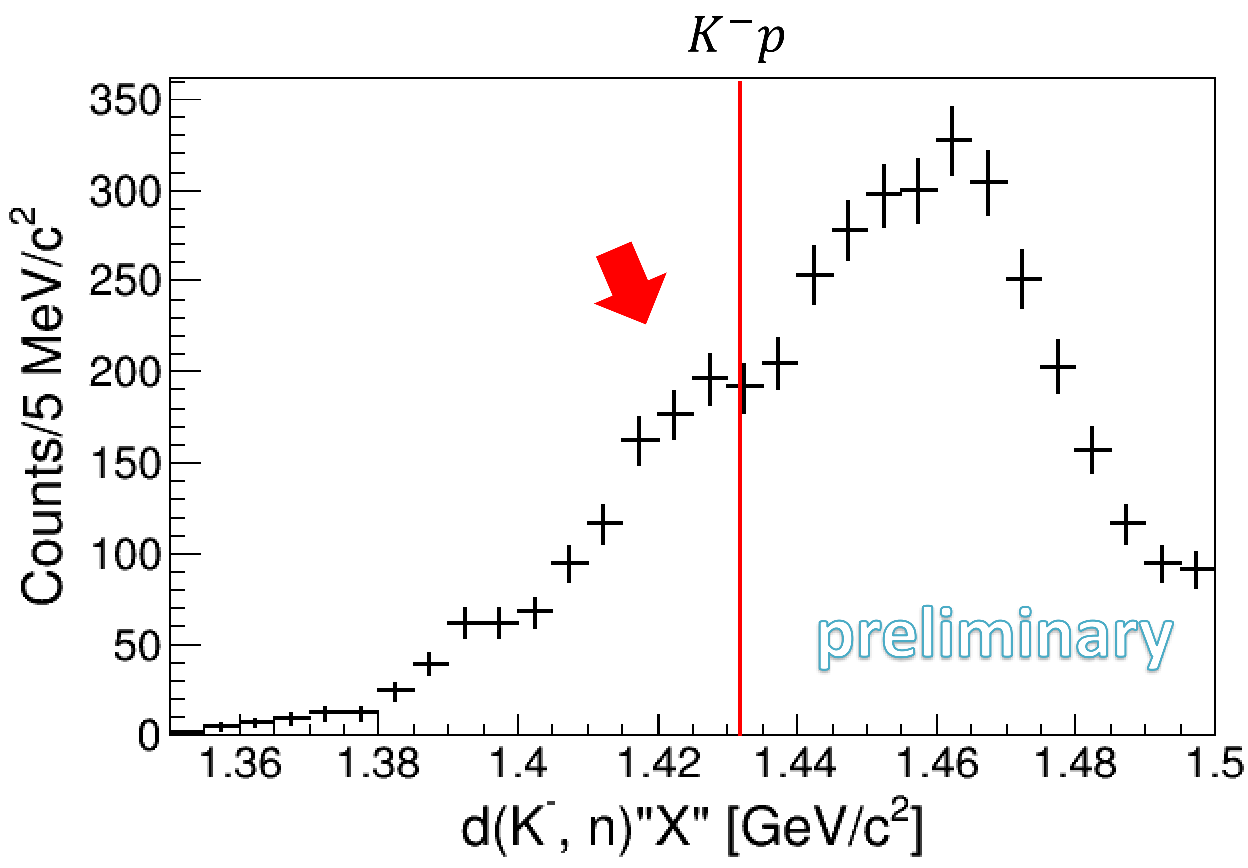


Semi-inclusive d(K⁻,n)X $_{\pi+\pi-"n"}$ spectrum

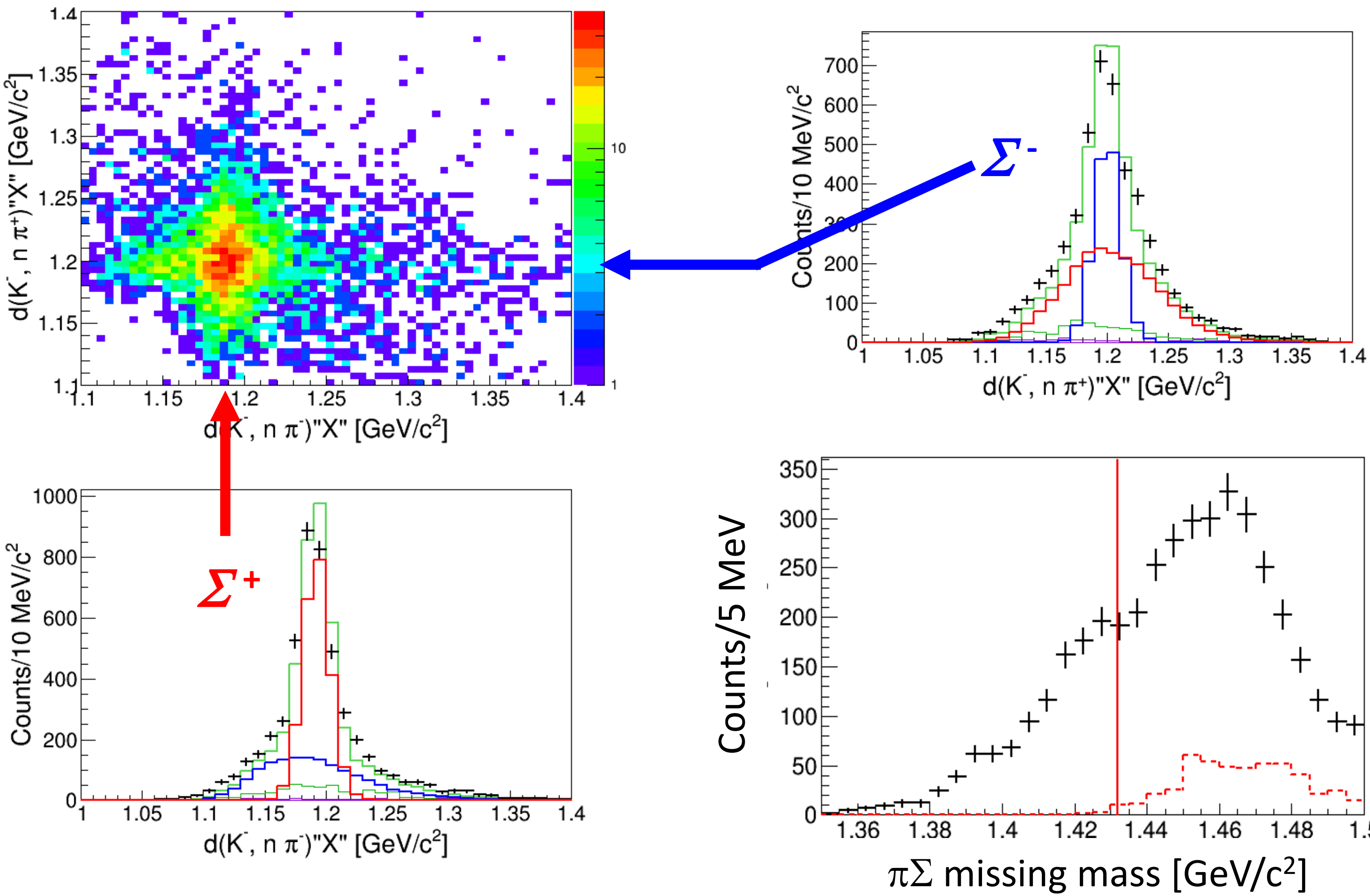


$d(K^-,n)X_{\pi^\pm\Sigma^\mp}$ Spectrum

Missing mass spectrum of the $d(K^-,n)X_{\pi^\pm\Sigma^\mp}$ reaction
K^0 and Σ_{decay} events have been excluded.

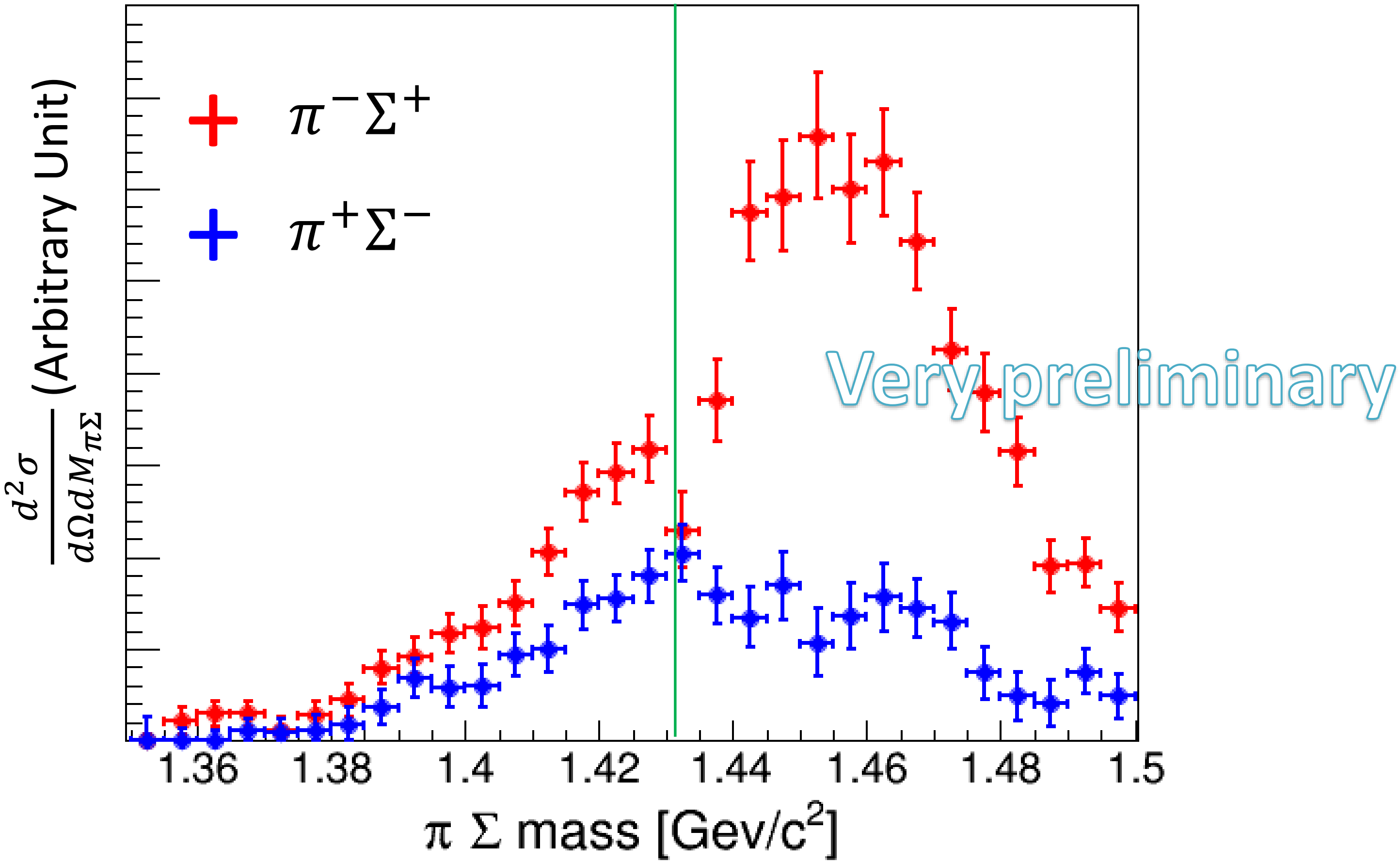


$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation (template fitting)



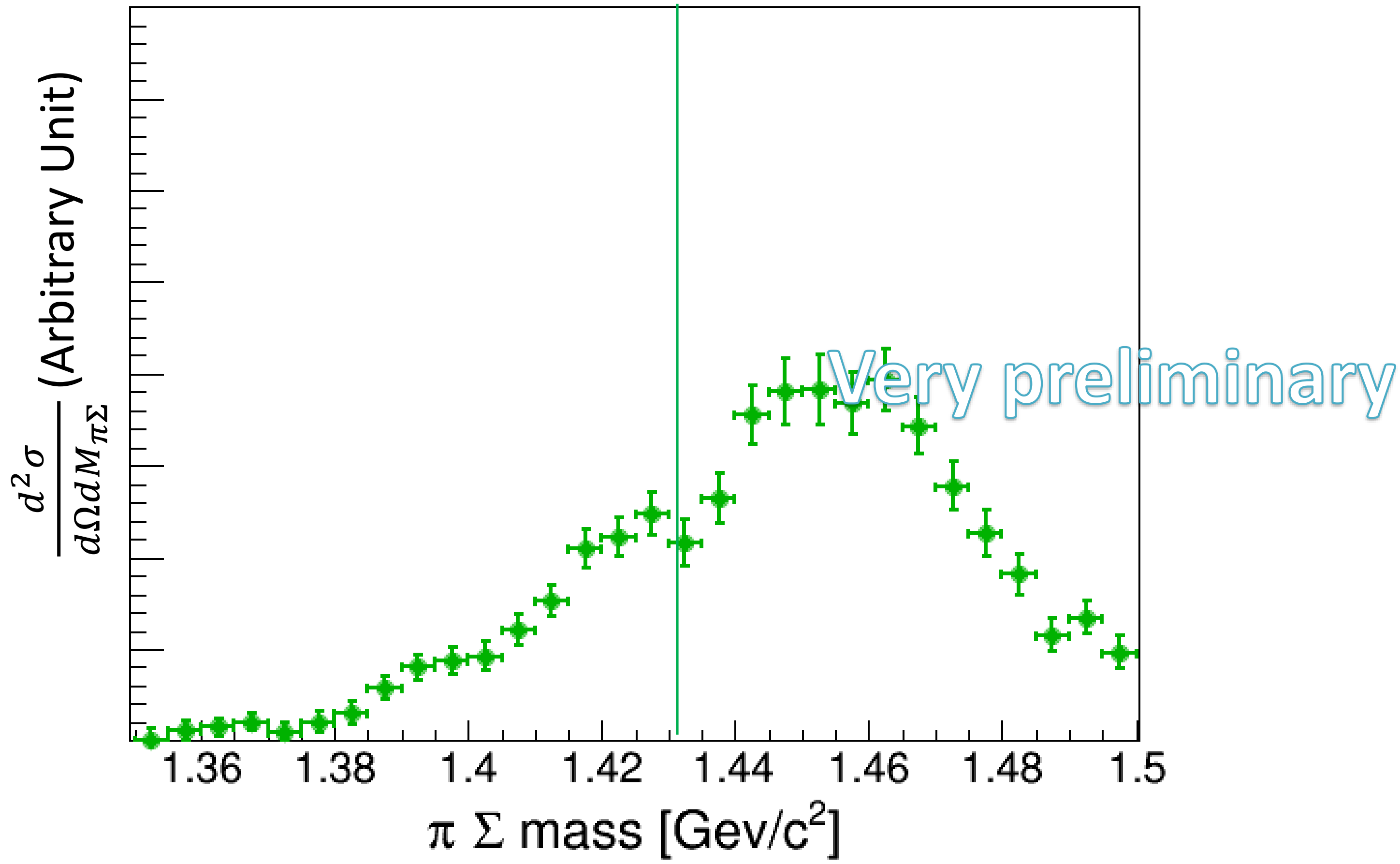
$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation

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



$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode Average

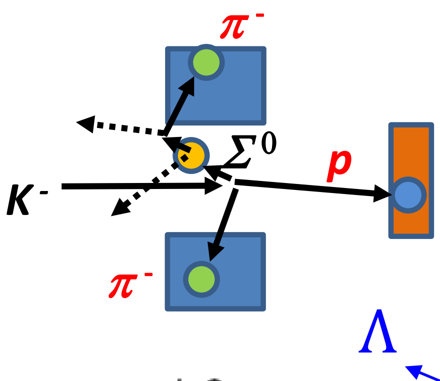
$$\frac{d\sigma}{d\Omega}(av) = \frac{1}{3}|f_{I=0}|^2 + \frac{1}{2}|f_{I=1}|^2$$



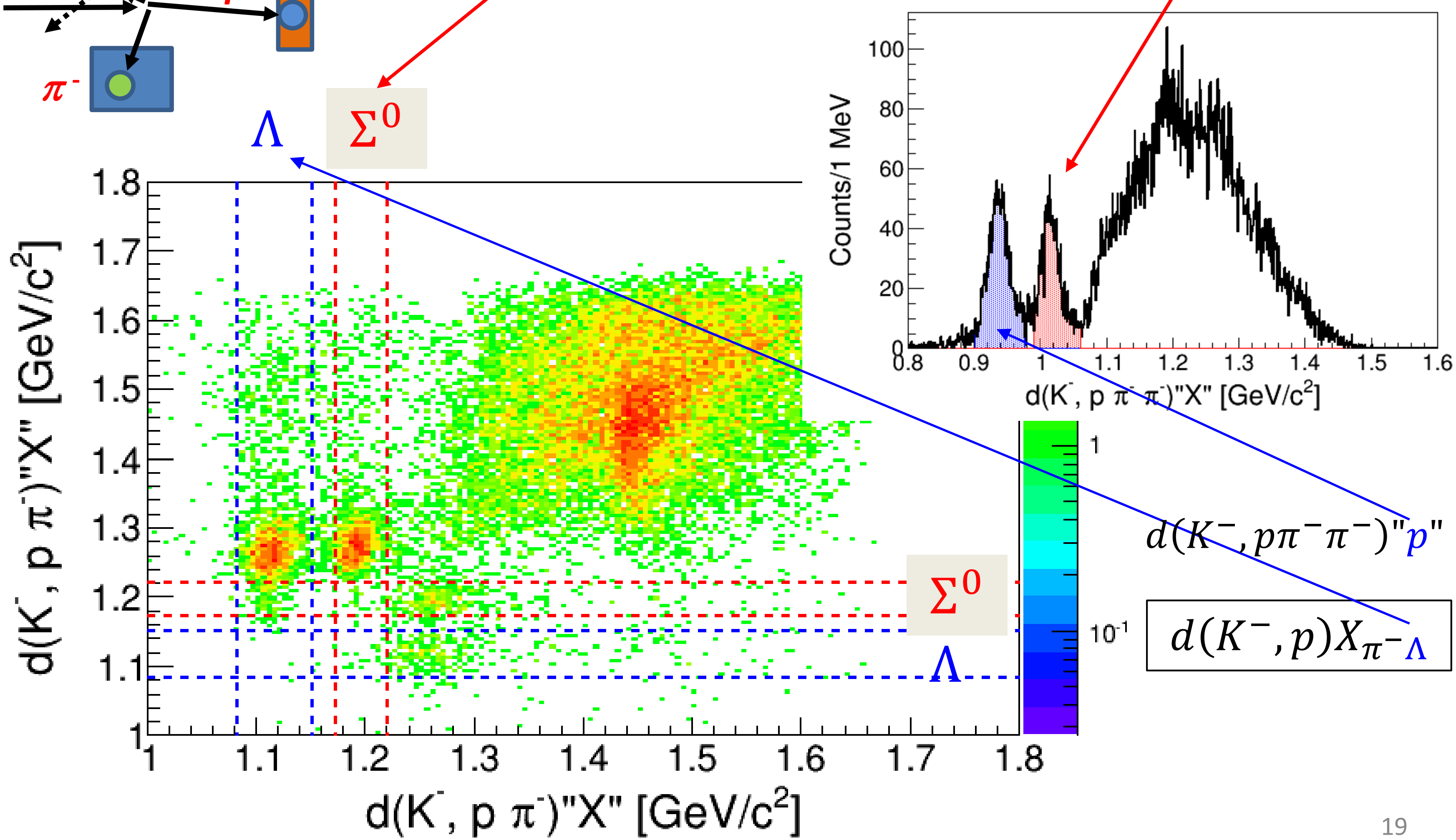
I = 1 channel

$$d(K^{-},p)X_{\pi^{-}\Sigma^{0}}$$

$d(K^-, p)X_{\pi^-\Sigma^0}$ Mode ($I = 1$)



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

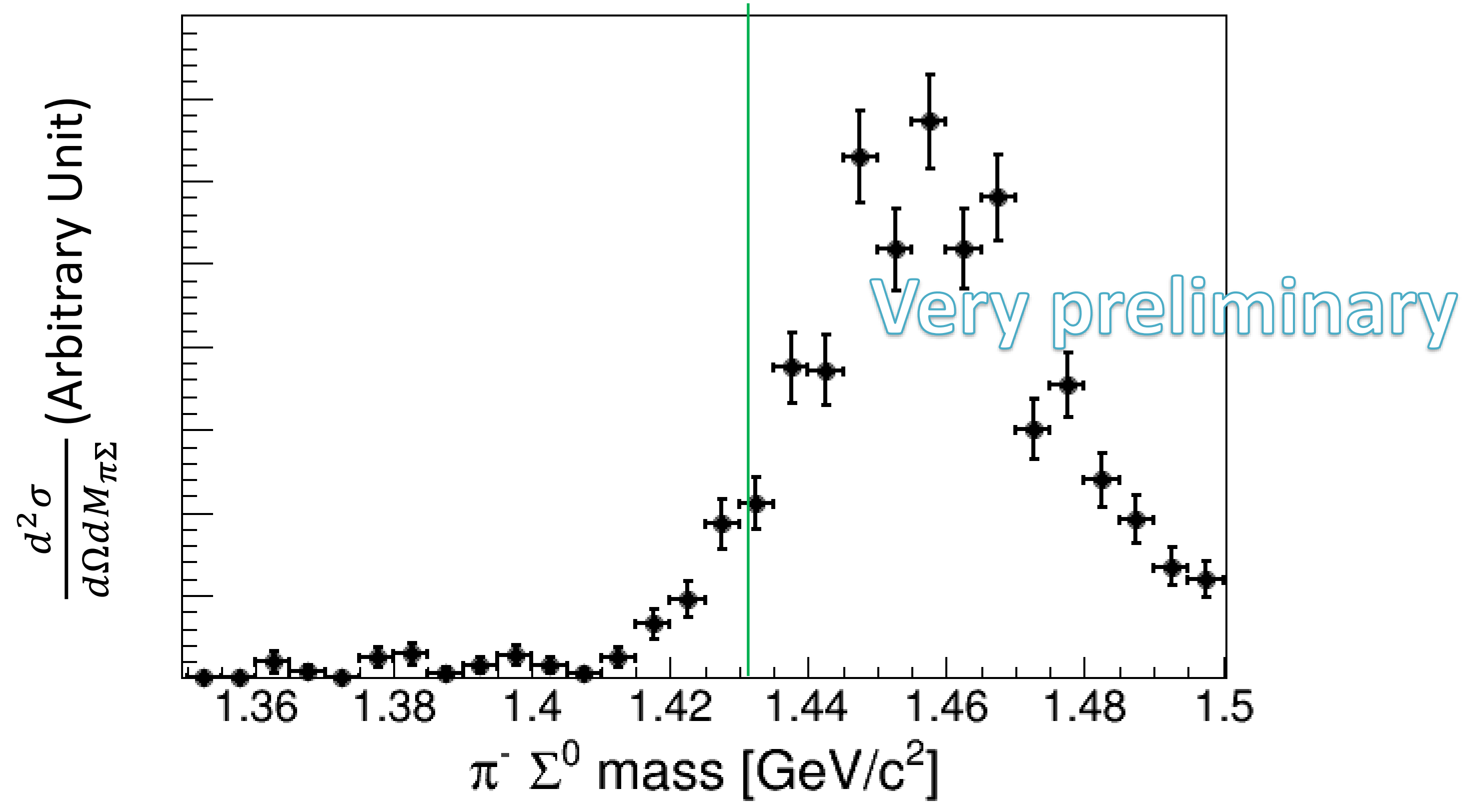


$d(K^-, p\pi^-\pi^-)$"p"

$d(K^-, p)X_{\pi^-\Lambda}$

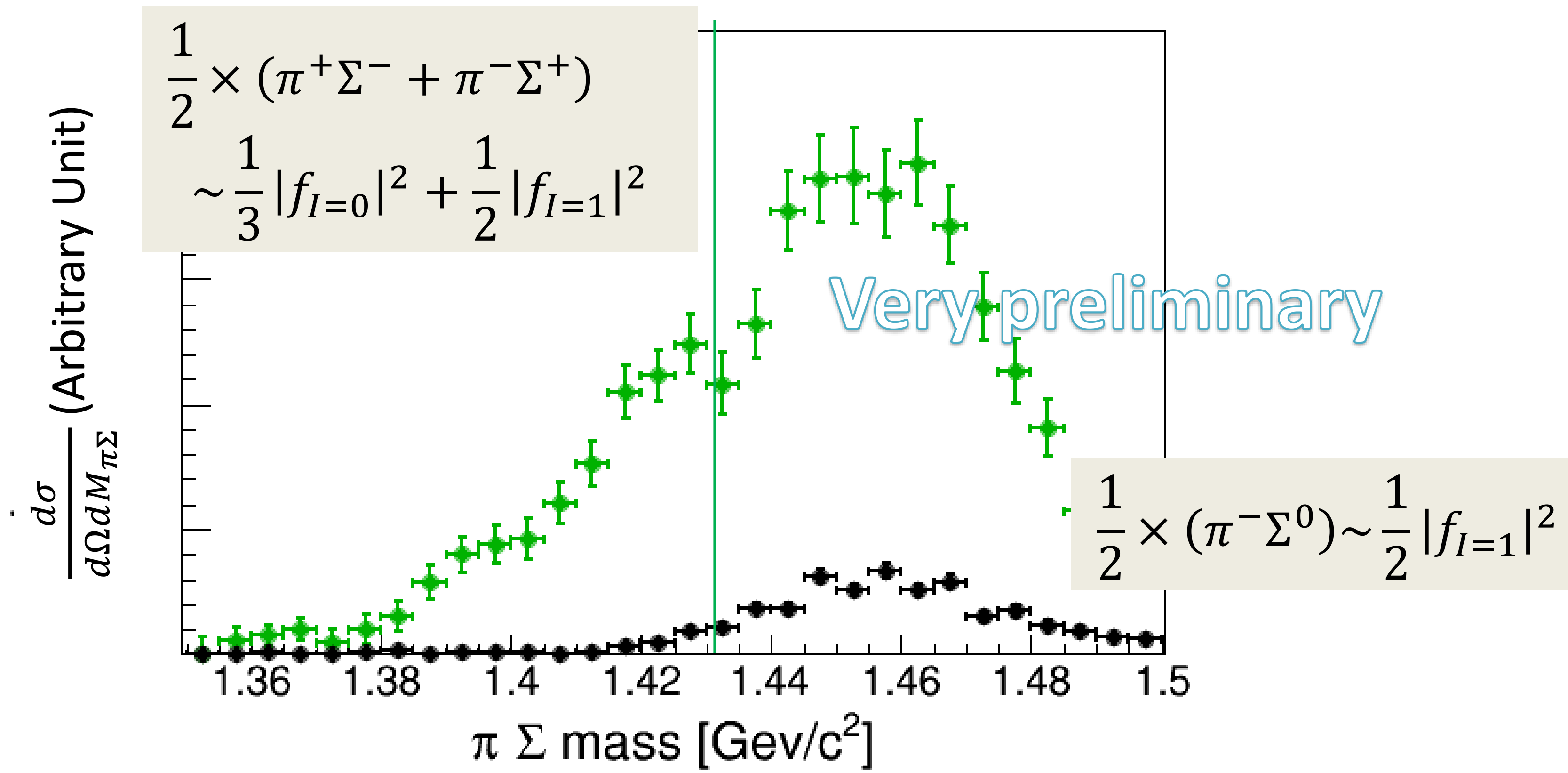
$d(K^-, p)X_{\pi^-\Sigma^0}$ Mode ($I = 1$)

$$\frac{d\sigma}{d\Omega}(\pi^-\Sigma^0) = |f_{I=1}|^2$$



$\pi^+\Sigma^- / \pi^-\Sigma^+$ Average (I=0, 1) *V.S.* $\pi^-\Sigma^0$ Mode (I=1)

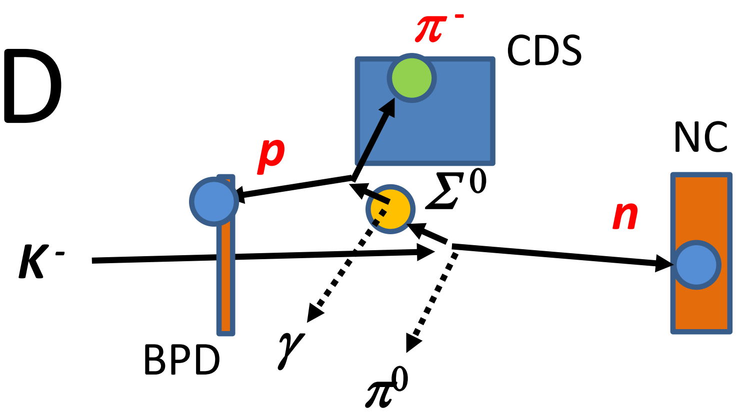
- *The I=1 amplitude seems to be suppressed!?*

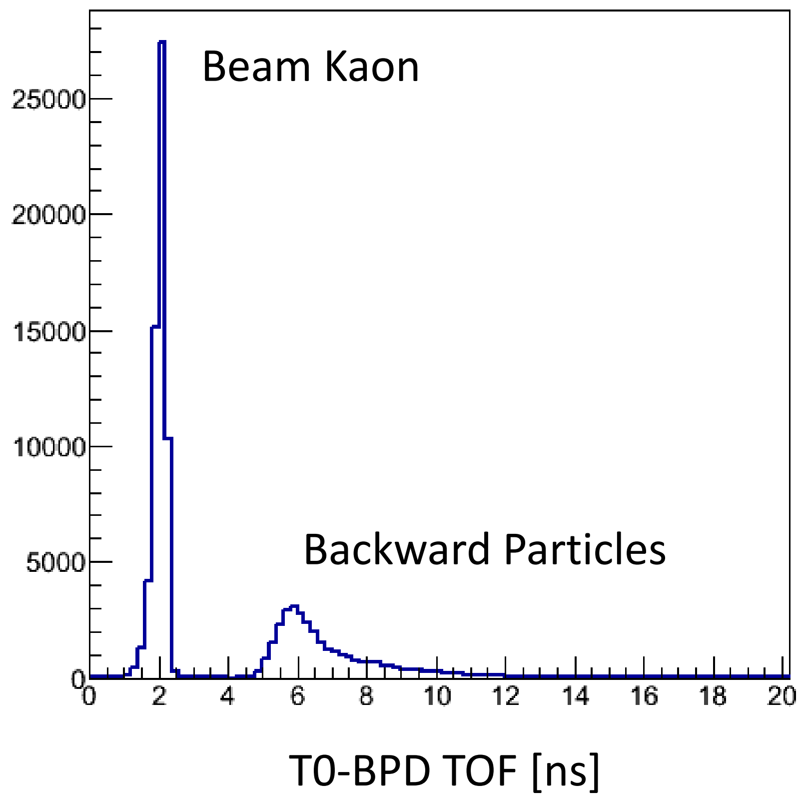


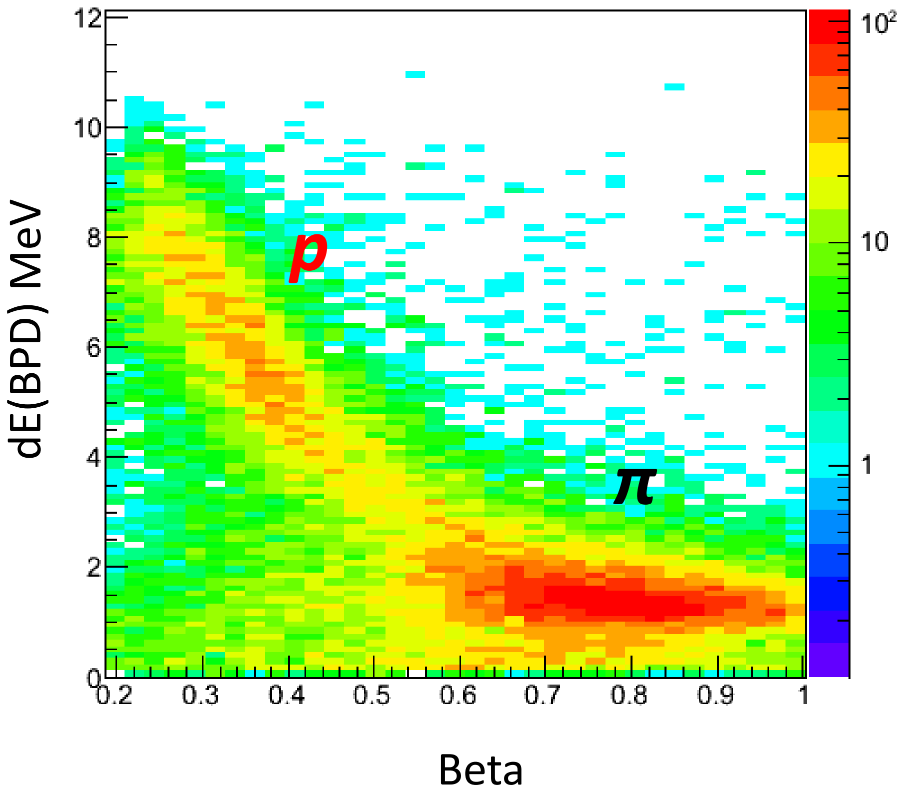
I = 0 channel

$d(K^{-}, n)X_{\pi^0\Sigma^0}$

Backward Proton ID



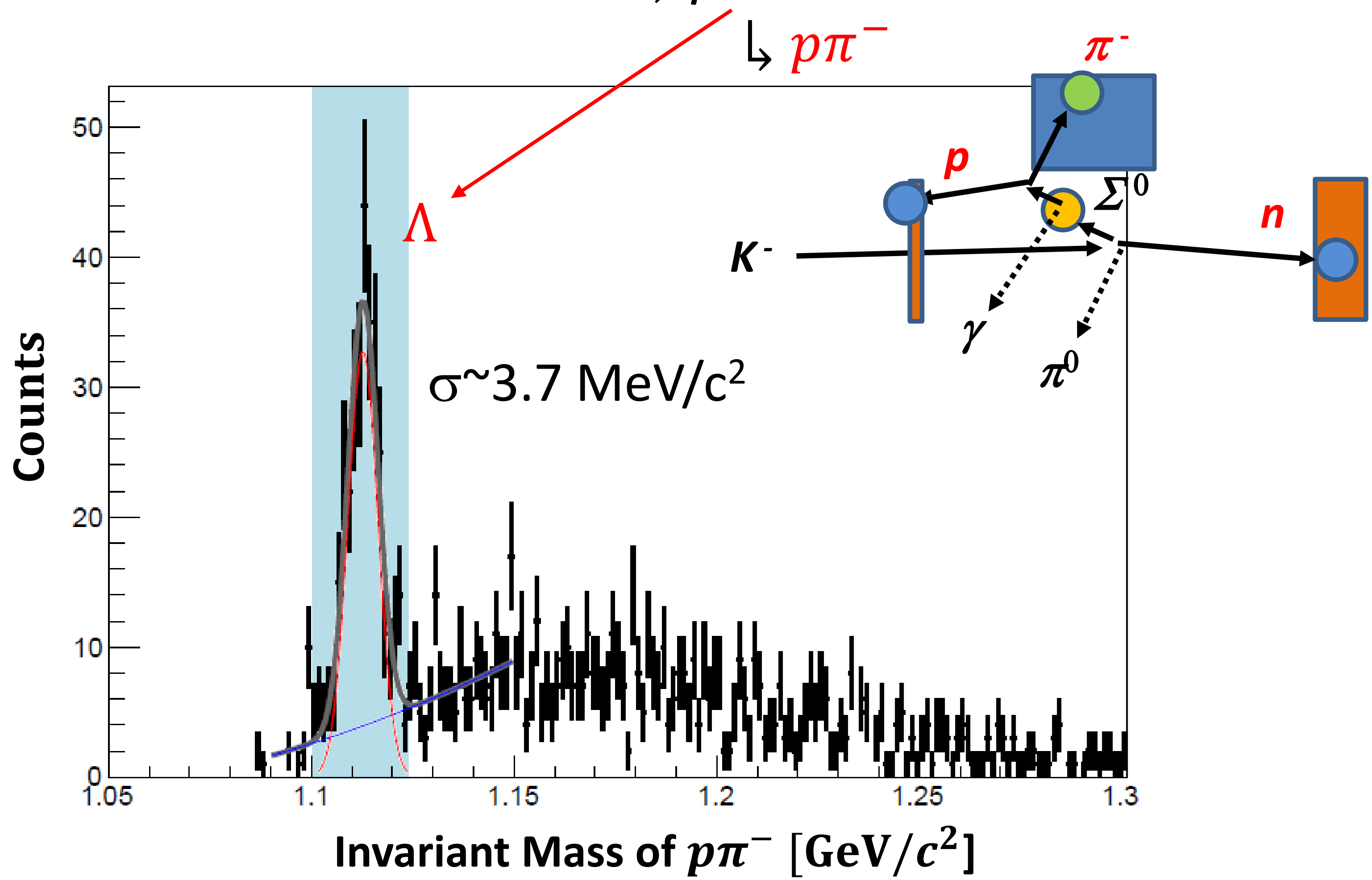




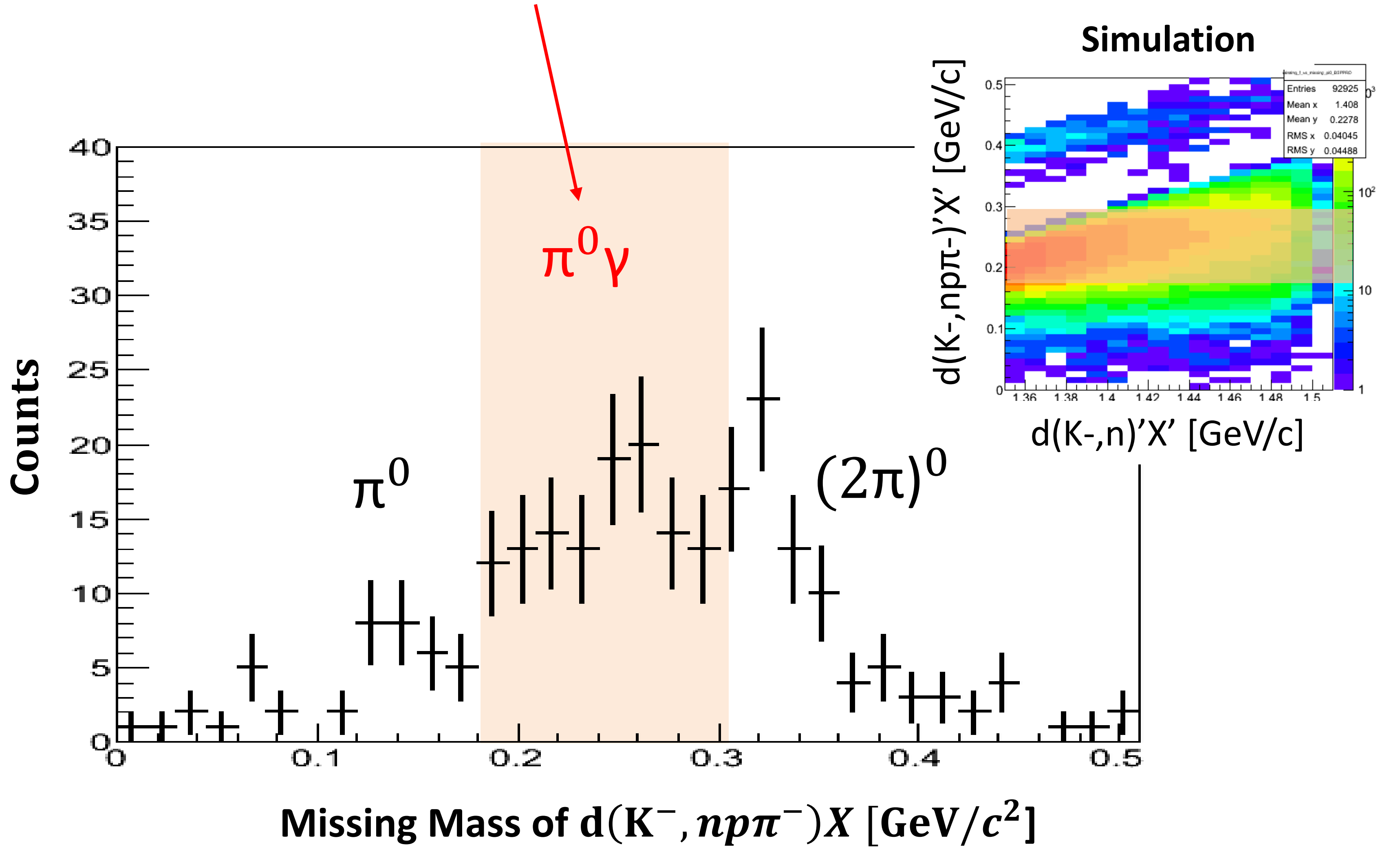
$d(K^-, n)X_{\pi^0\Sigma^0}$ mode (I=0)

$\hookrightarrow \gamma\Lambda$

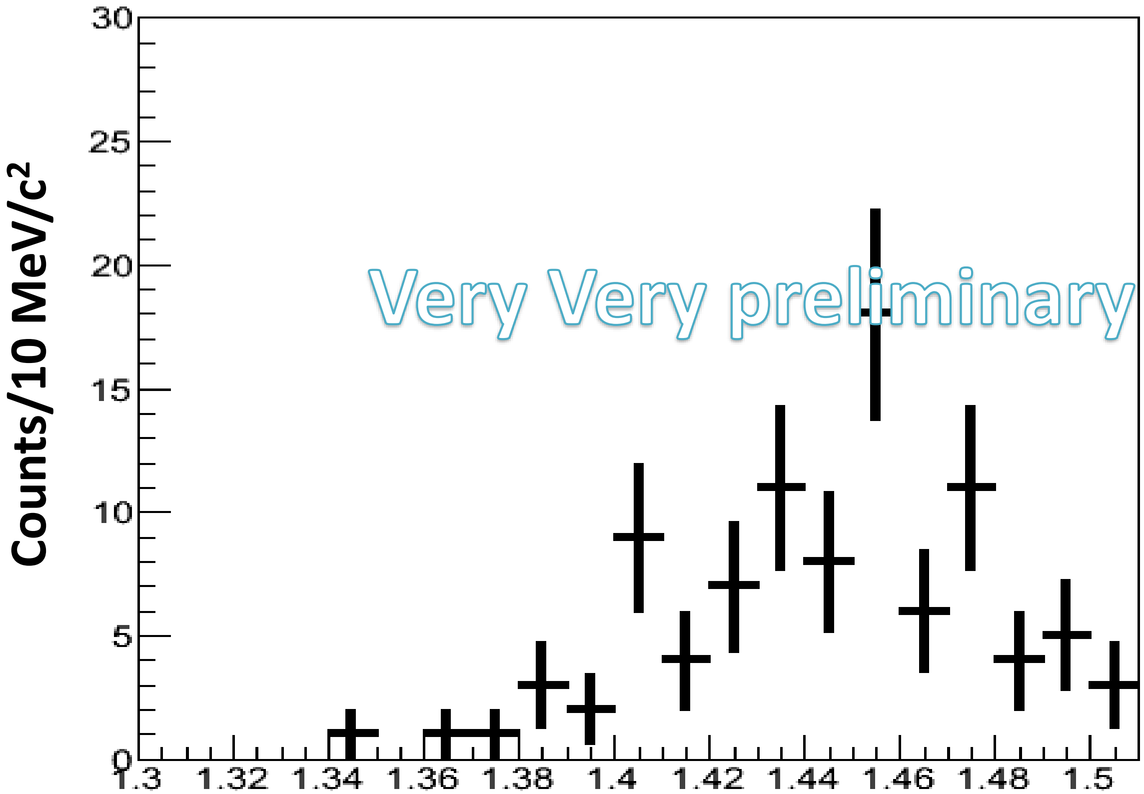
$\hookrightarrow p\pi^-$



$d(K^-, n\Lambda)X_{\pi^0\gamma}$ in $d(K^-, n)X_{\pi^0\Sigma^0}$



First Observation of $d(K^{-},n)X_{\pi^0\Sigma^0}$ Mode ($I=0$)



Missing Mass of $d(K^{-},n)X_{\pi^0\Sigma^0}$ [GeV/c^2]

Remarks

- Structures below and above the $\bar{K}N$ threshold are observed in $d(K^-,n)X_{\pi^\pm\Sigma^\mp}$
  - Effect of the interference term is seen.
- Pure I=1 channel, $d(K^-,p)X_{\pi^-\Sigma^0}$, is observed.
  - I=1 amplitude seems to be suppressed below the $\bar{K}N$ threshold. (to be confirmed with high statistics)
  - I=0 amp. seems dominant in $\pi^\pm\Sigma^\mp$ modes, assuming similarity of the reaction mechanism among $d(K^-,n)X_{\pi^\pm\Sigma^\mp}$ and $d(K^-,p)X_{\pi^-\Sigma^0}$.
- Pure I=0 channel, $d(K^-,n)X_{\pi^0\Sigma^0}$, is observed.
  - It must be confirmed if spectrum shape and strength are consistent with the other modes.

Request

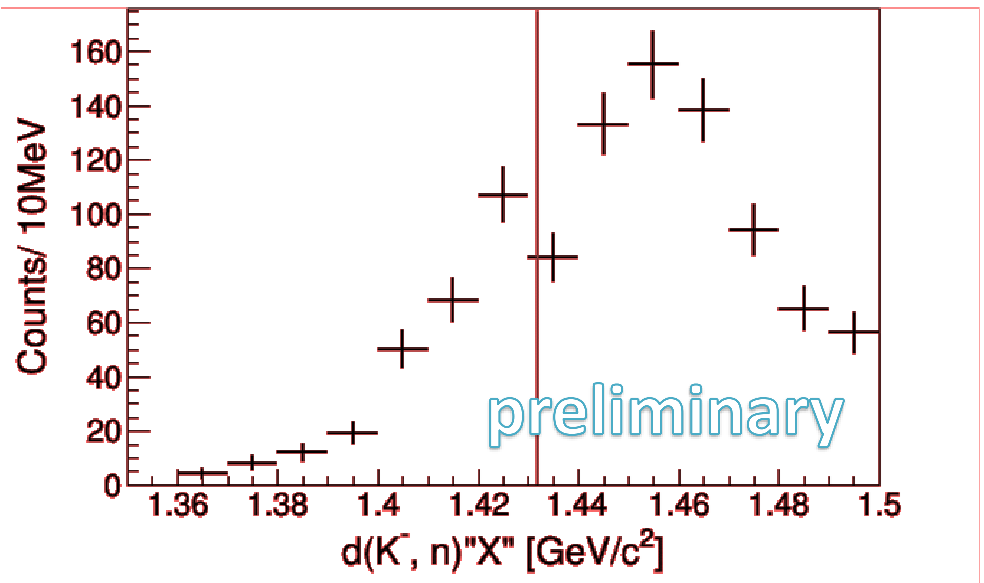
- To complete the E31 experiment, we request beam time of 18 days, 45 kW for physics run + 2 day for start-up.
  - We will measure spectrum shape and strength of the pure I=0 mode ($\pi^0\Sigma^0$)
  - We will increase statistics further to confirm the structures in the $\pi^\pm\Sigma^\mp$ modes and the magnitude of the $\pi^-\Sigma^0$ (I=1) mode.

$Backup$

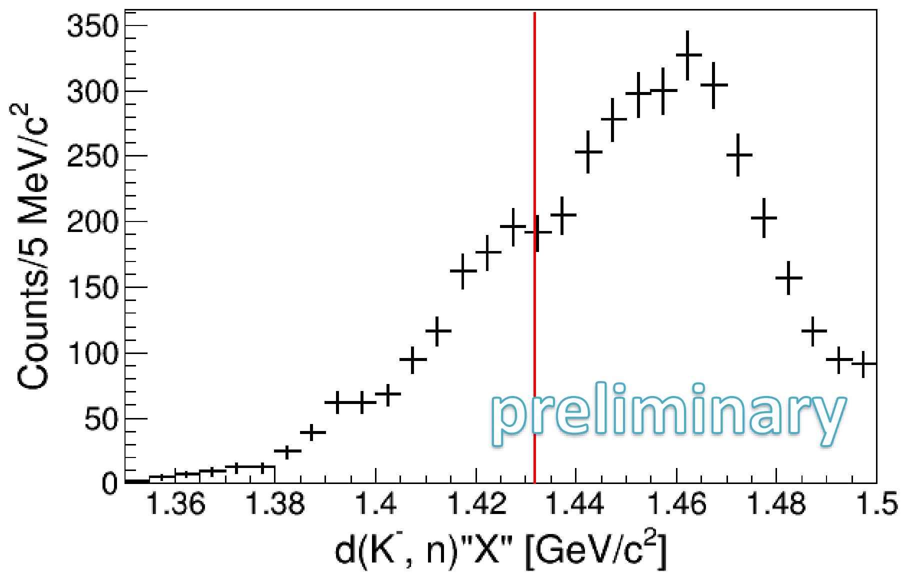
$d(K^-, n)X_{\pi^\pm\Sigma^\mp}$ Spectrum

Missing mass spectrum of the $d(K^-, n)X_{\pi^\pm\Sigma^\mp}$ reaction
K^0 and Σ_{decay} events have been excluded.

E31-pre

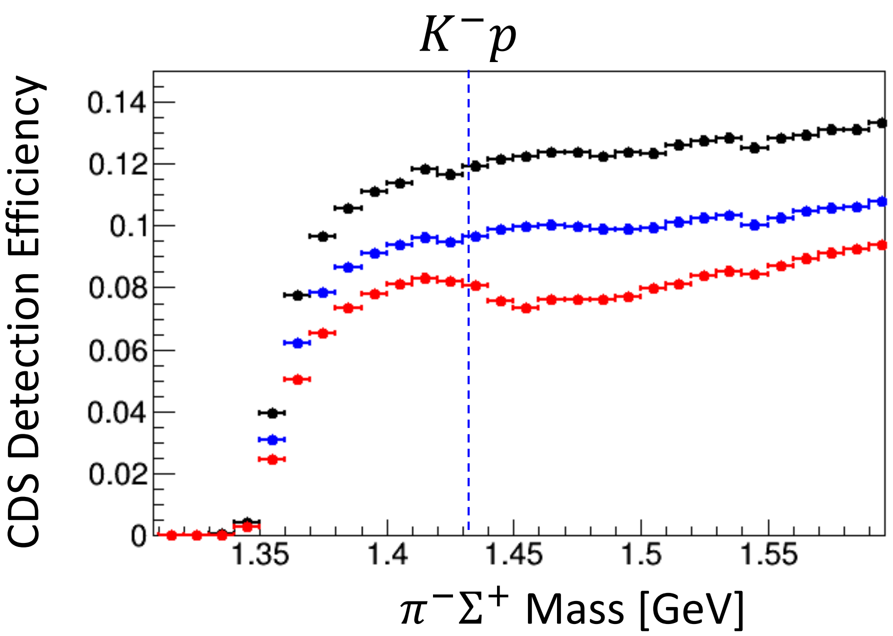


E31-1st

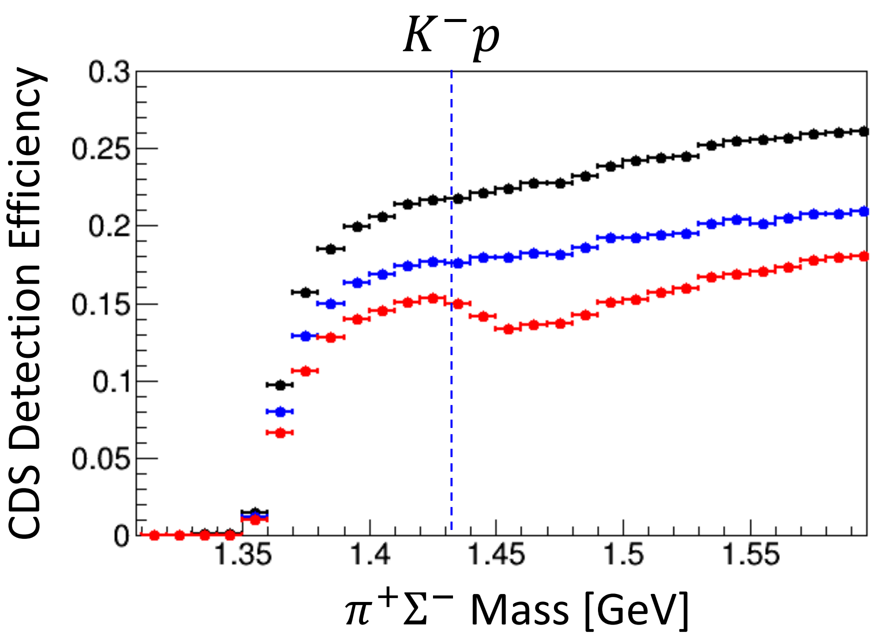


CDS Acceptance does not make an dip at 1.43-1.44 GeV/c^2.

$\pi^-\Sigma^+$ mode

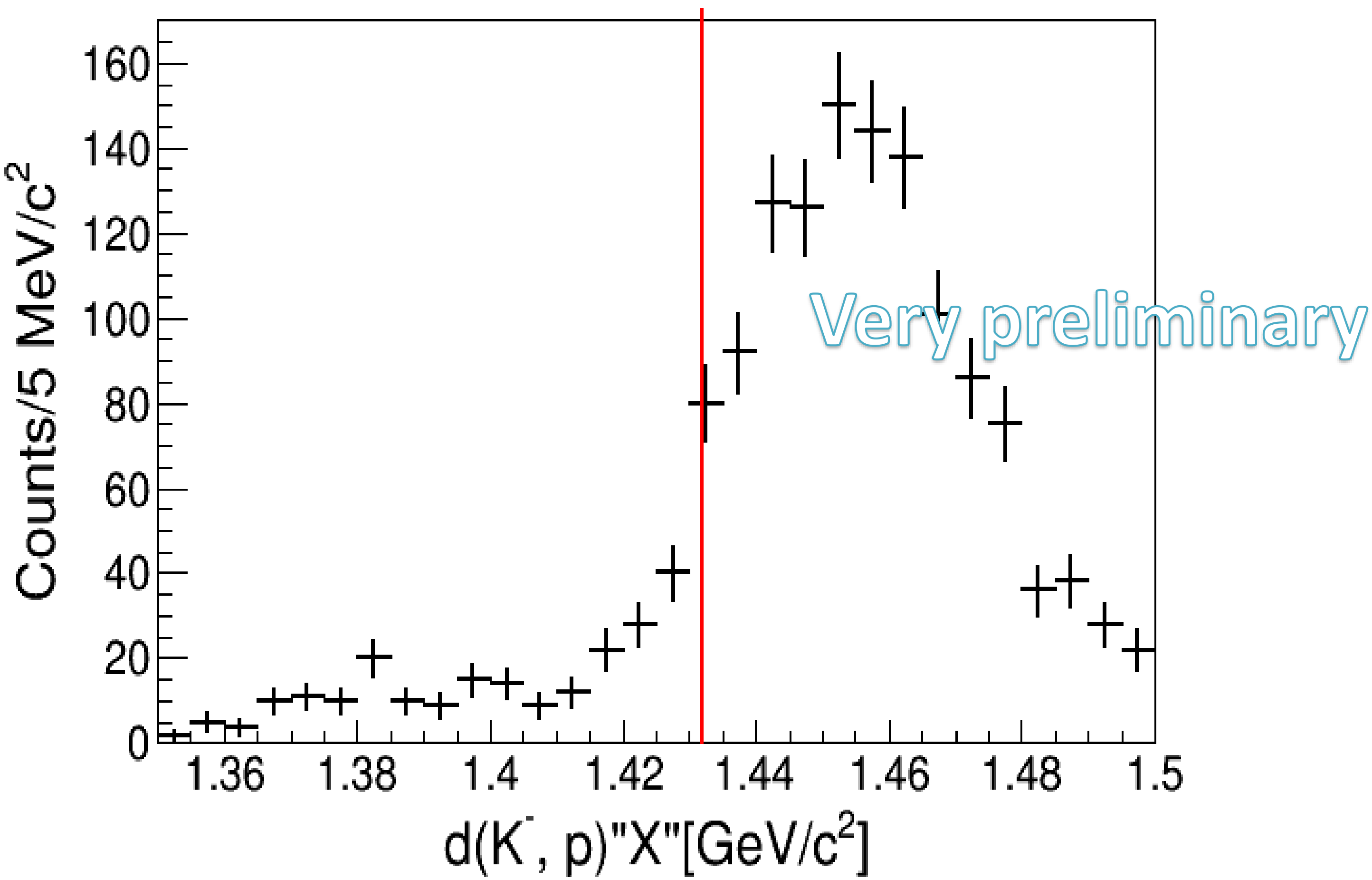


$\pi^+\Sigma^-$ mode



Black : $\pi^+\pi^-$ detection
Blue : $d(K^-, n\pi^+\pi^-)$"n" selection
Red : $\Sigma_{decay}, \overline{K}^0$ cut

$d(K^-, p)X_{\pi^-\Lambda}$ Mode ($I = 1$)



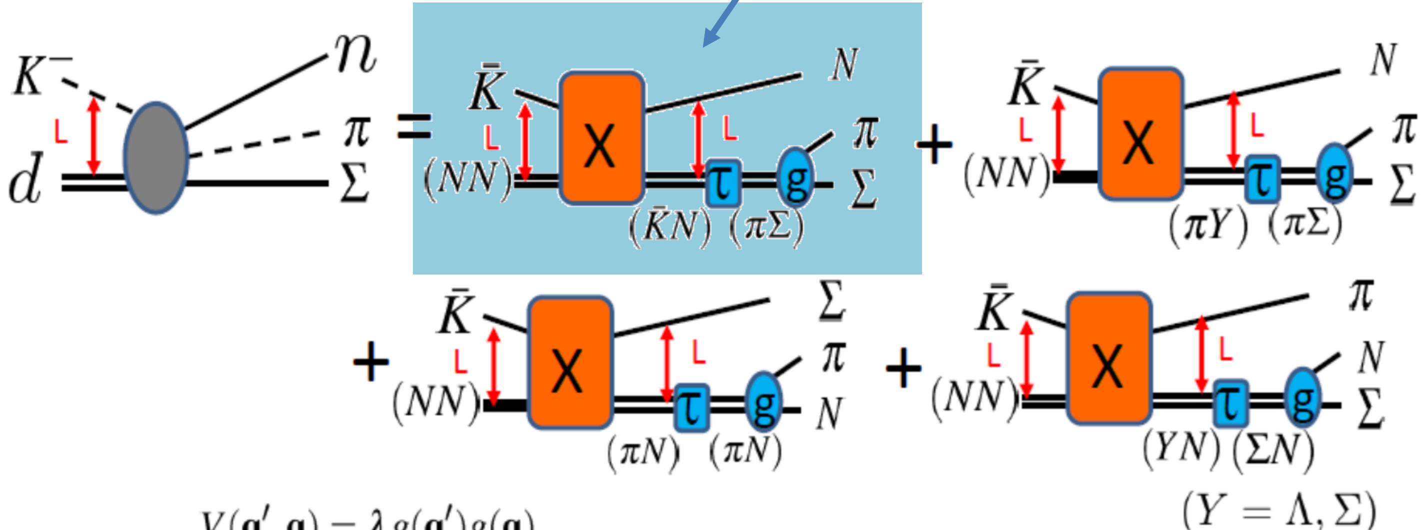
Faddeev Cal. (AGS)

S. Ohnishi, Y. Ikeda, T. Hyodo, E. Hiyama, and W. Weise

$K^-d \rightarrow \pi\Sigma n$ reaction

Dominant at θ_n=0

$\bar{K}NN - \pi\Sigma N - \pi\Lambda N$



$$V(\mathbf{q}',\mathbf{q}) = \lambda g(\mathbf{q}')g(\mathbf{q})$$

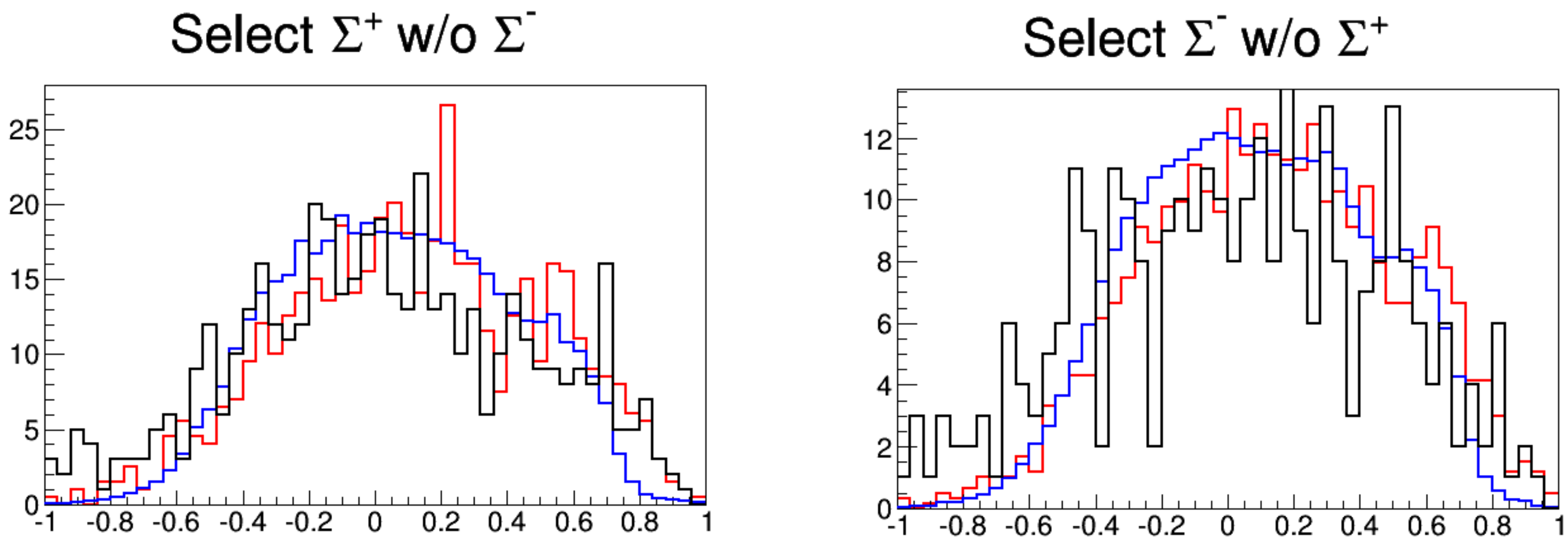
$$t_i(\mathbf{q}',\mathbf{q},W-E_i) = g(\mathbf{q}')\tau(W-E_i)g(\mathbf{q})$$

Alt-Grassberger-Sandhas(AGS) eq. : X_{ij}; quasi two-body amplitude

$$X_{i,j}(\mathbf{p}_i,\mathbf{p}_j,W) = (1-\delta_{i,j})Z_{i,j}(\mathbf{p}_i,\mathbf{p}_j,W) + \sum_{n\neq i}\int d\mathbf{p}_n Z_{i,n}(\mathbf{p}_i,\mathbf{p}_n,W)\tau_n(W-E_n)X_{n,j}(\mathbf{p}_n,\mathbf{p}_j,W)$$

Angular Distribution/Acceptance

d(K^-, n $\pi^{-/+}$) ("$\Sigma^{+/-}$") cosθ in πΣ CM Frame

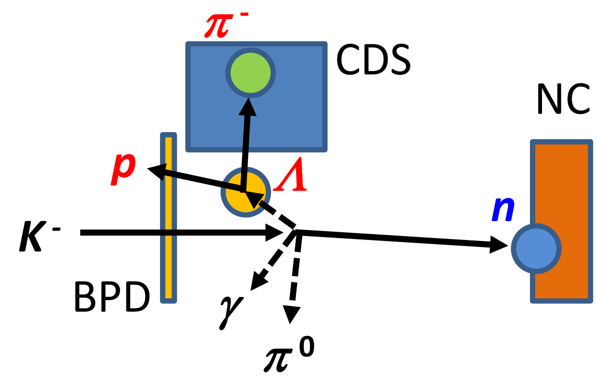


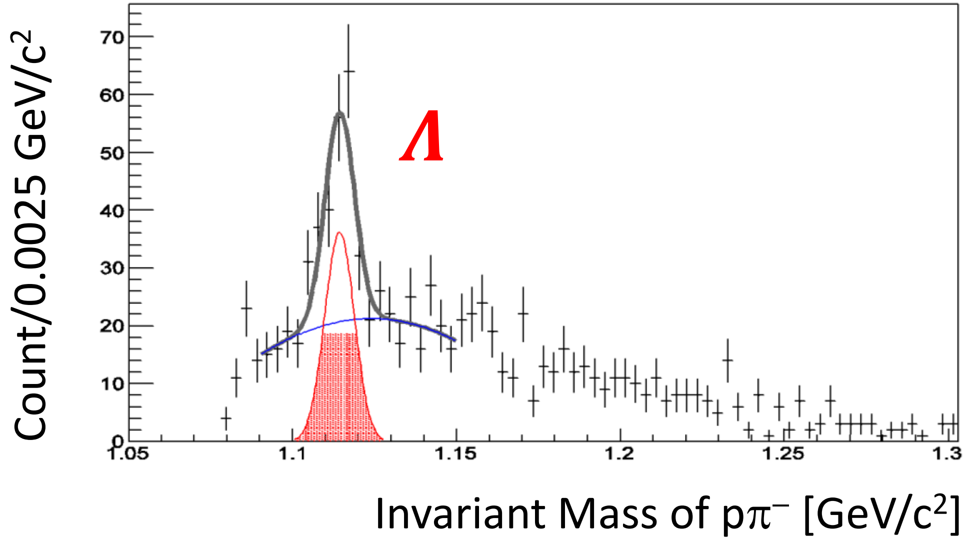
Black : Data

Red : MC Brit-Wigner (1.405 GeV/c²)

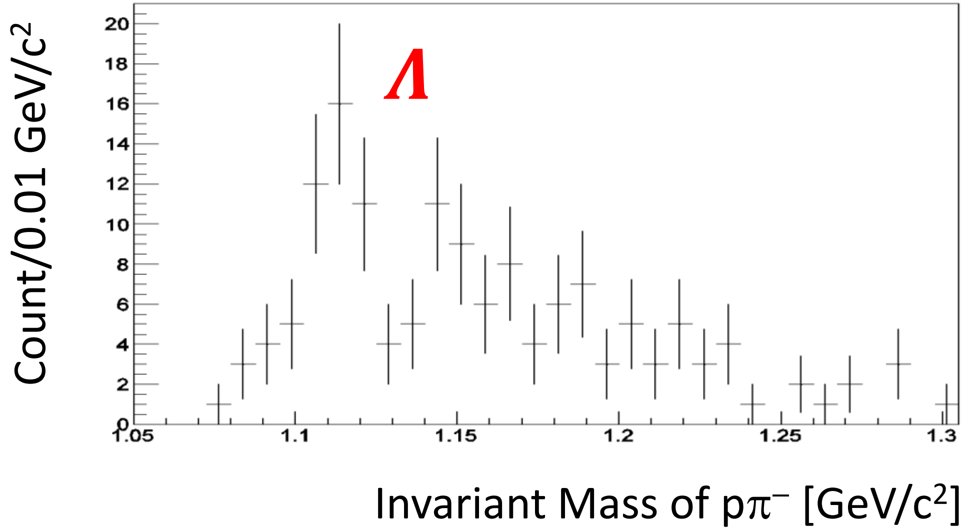
Blue: MC Flat (1.34~1.60 GeV/c²)

$\pi^0\Sigma^0$ mode ID (in progress)



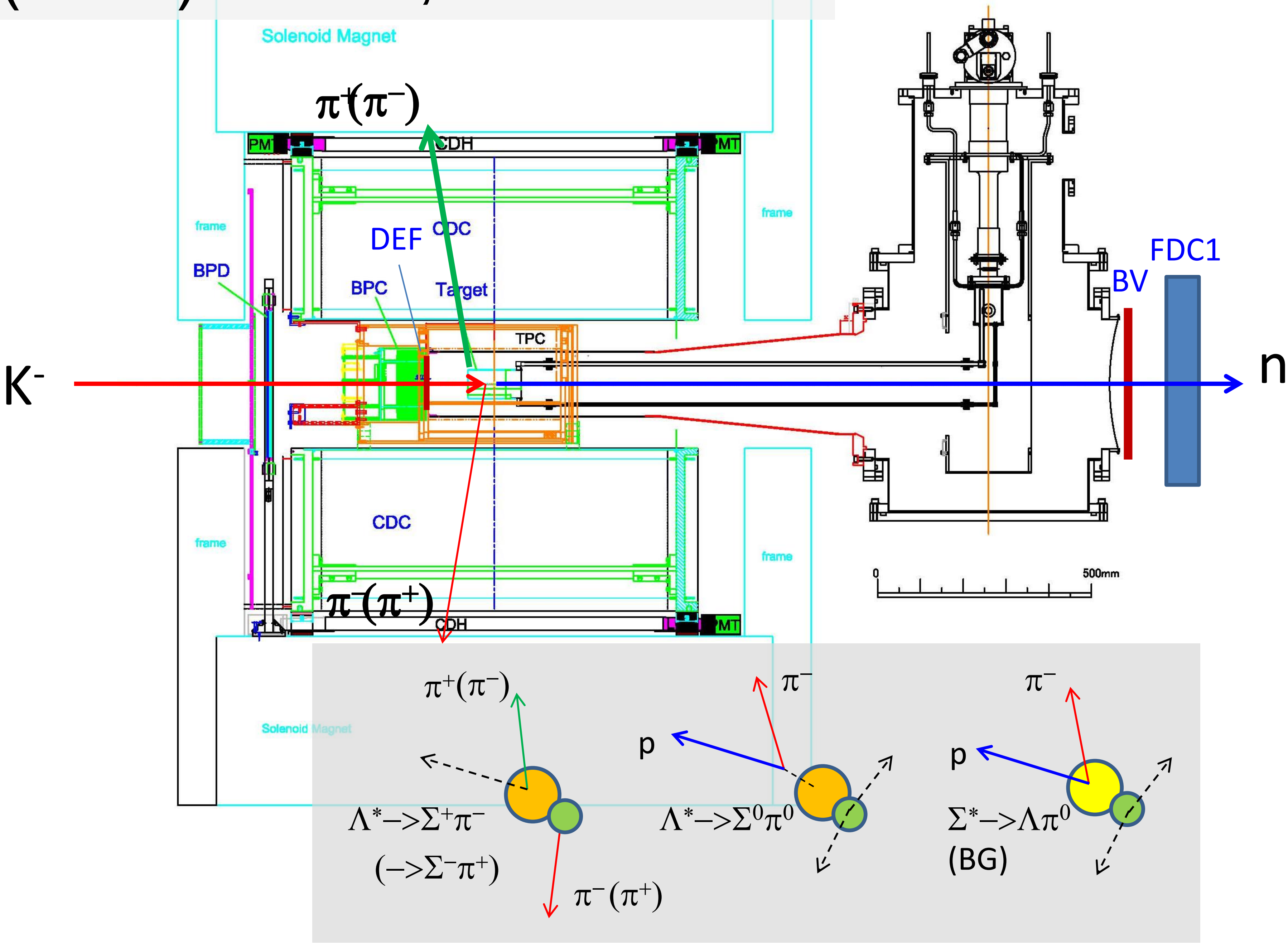


BPD(p)+CDS(π^-)

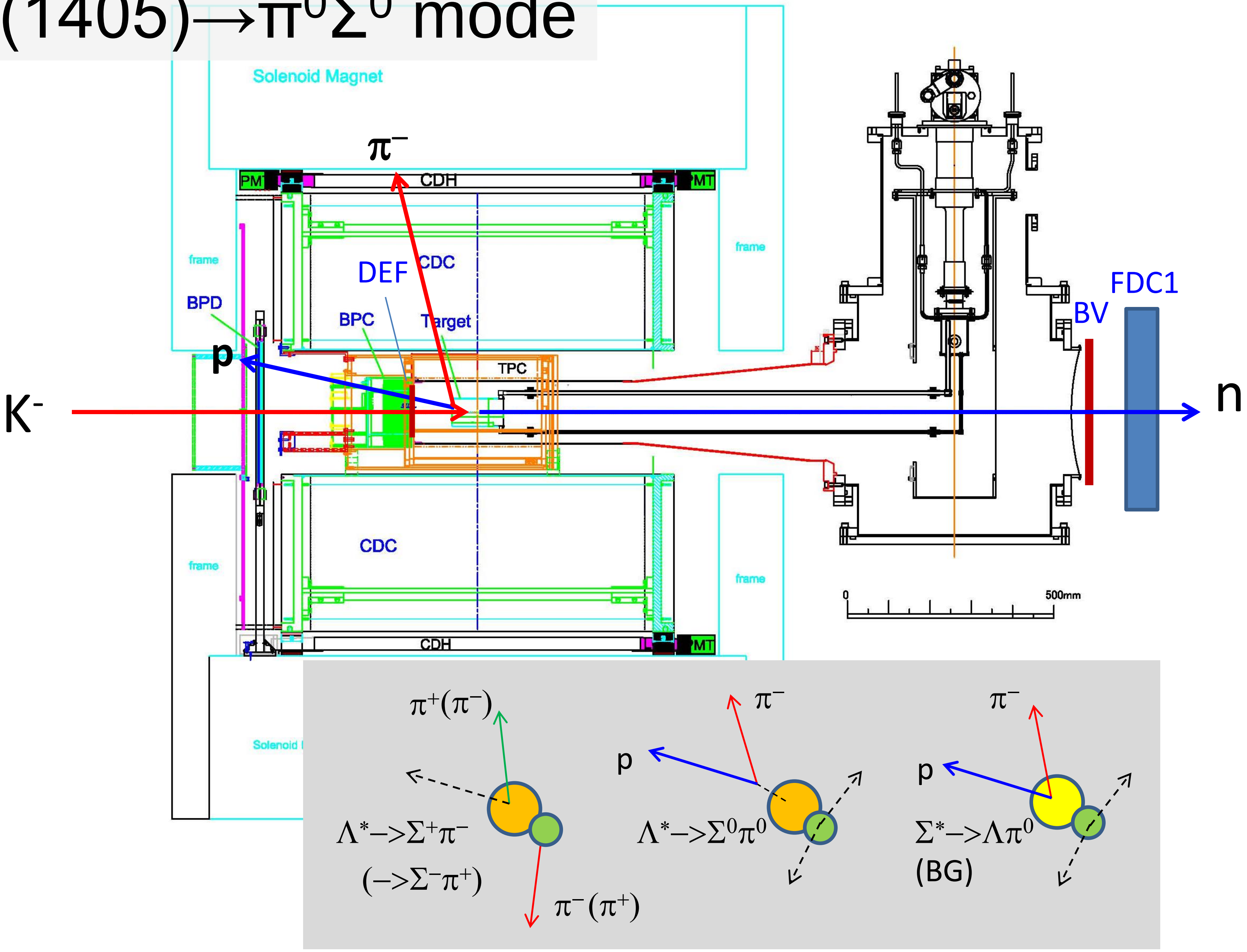


BPD(p)+CDS(π^-)
+NC(n)

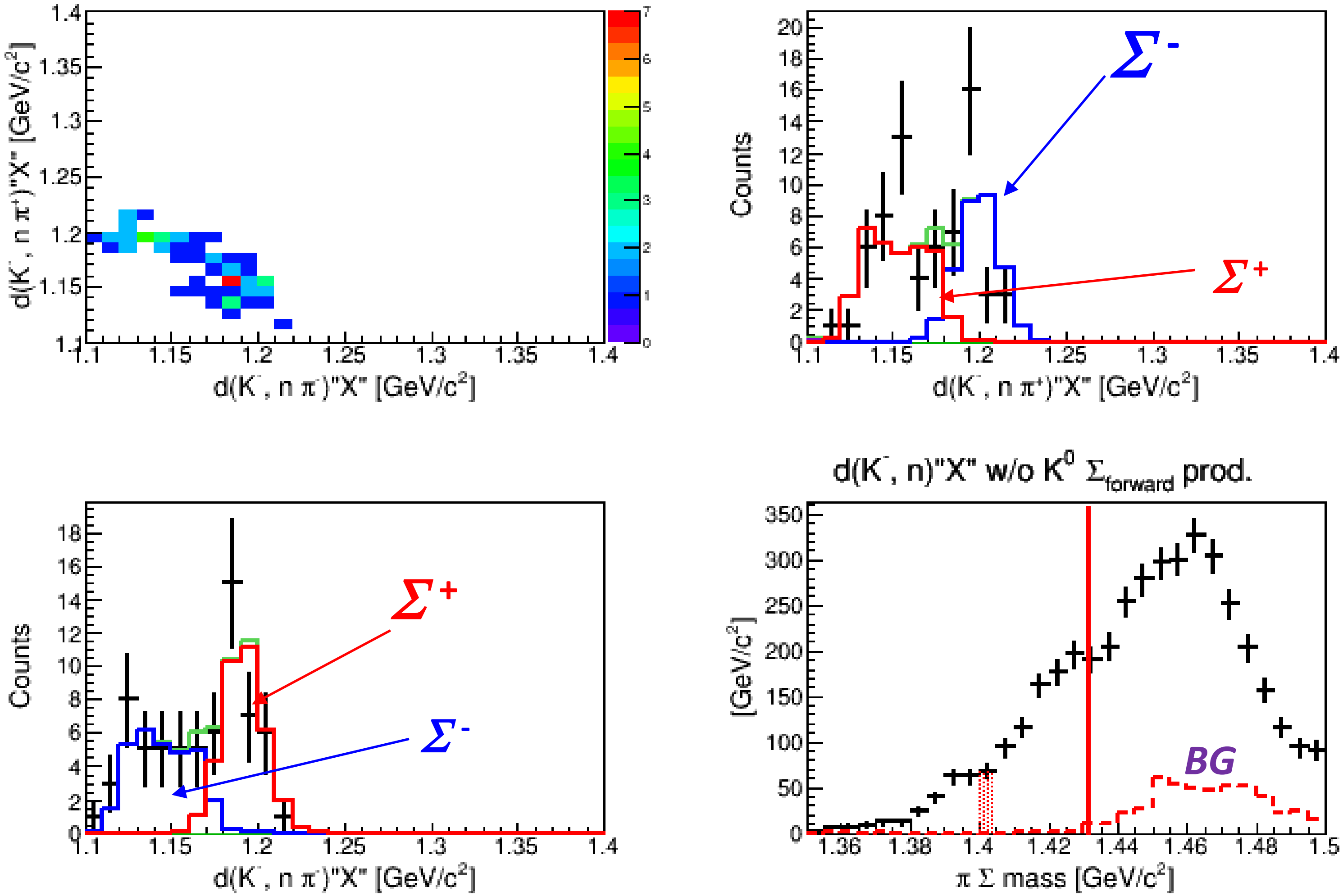
Λ(1405)→$\pi^-\Sigma^+$, $\pi^+\Sigma^-$ modes



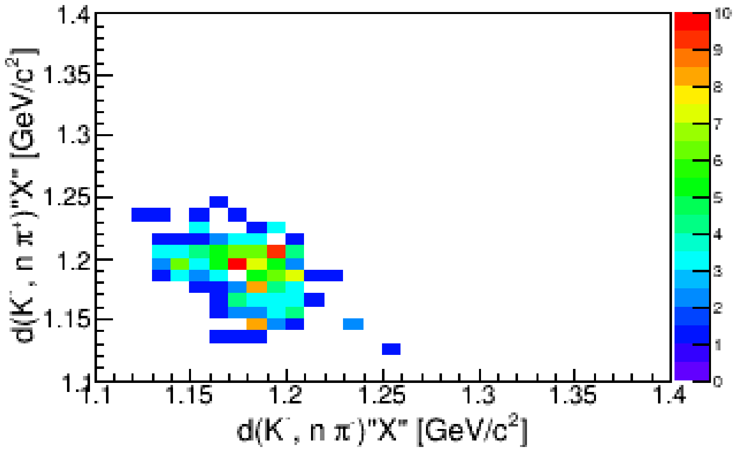
Λ(1405)→$\pi^0\Sigma^0$ mode

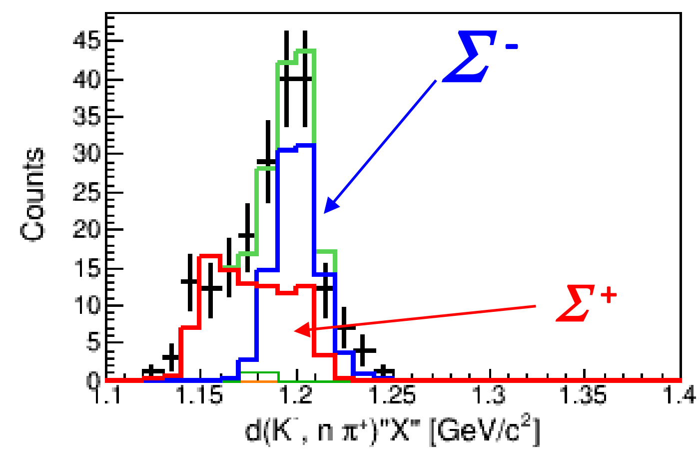


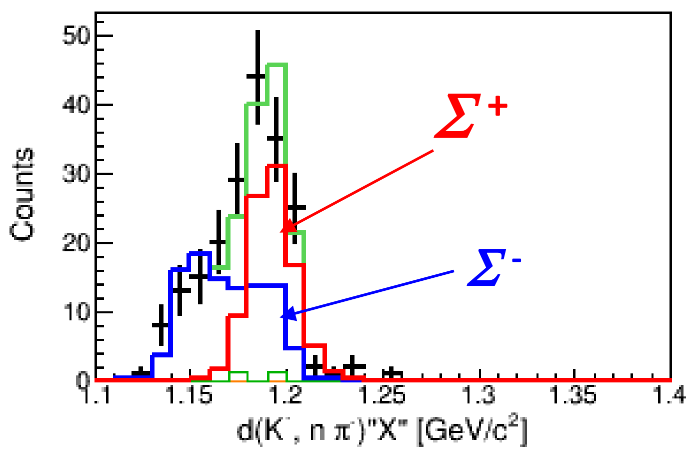
$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation ($M_{\pi\Sigma}$=1.400-1.405 GeV/c^2)

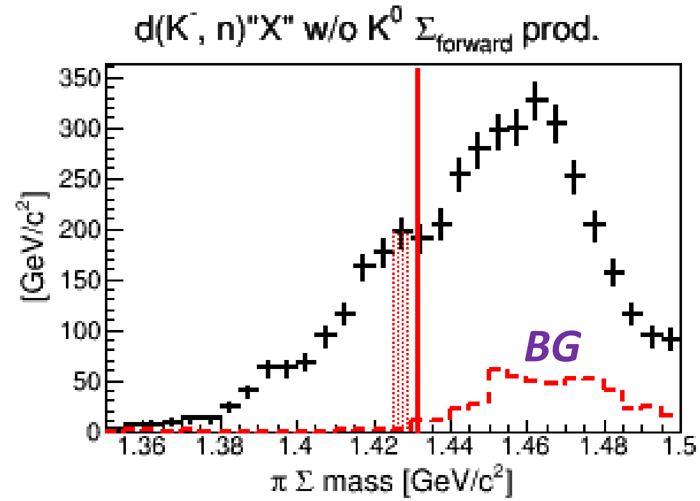


$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation ($M_{\pi\Sigma}$=1.425-1.430 GeV/c^2)

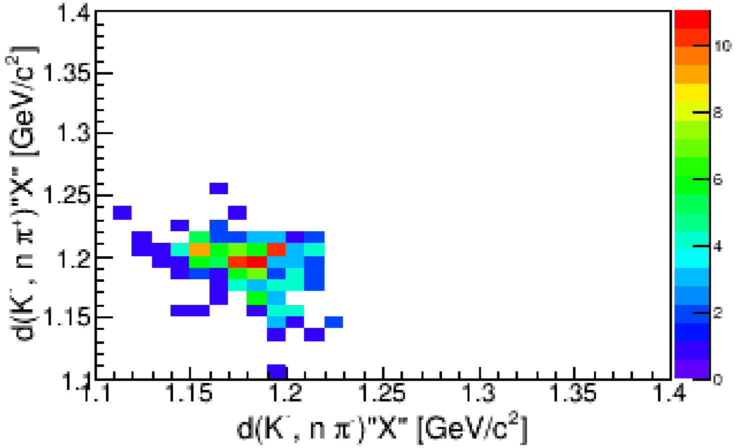


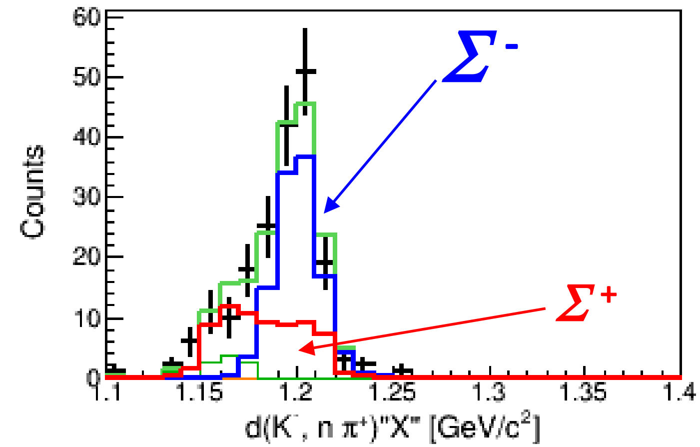


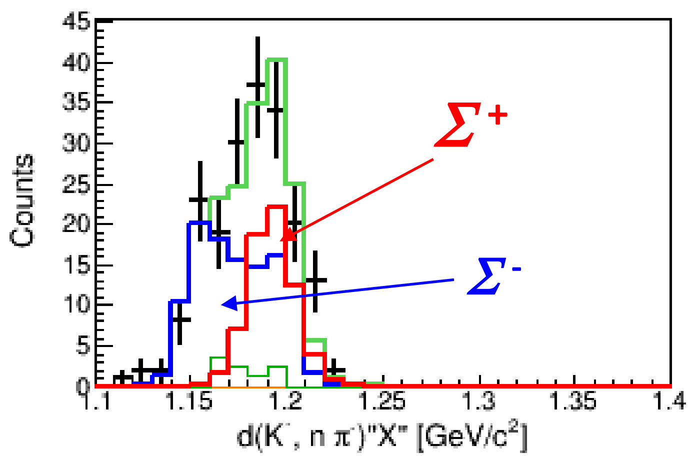


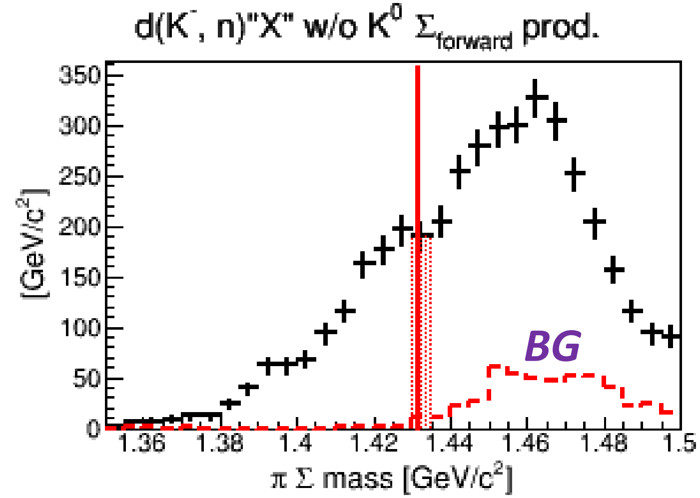


$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation ($M_{\pi\Sigma}$=1.430-1.435 GeV/c^2)

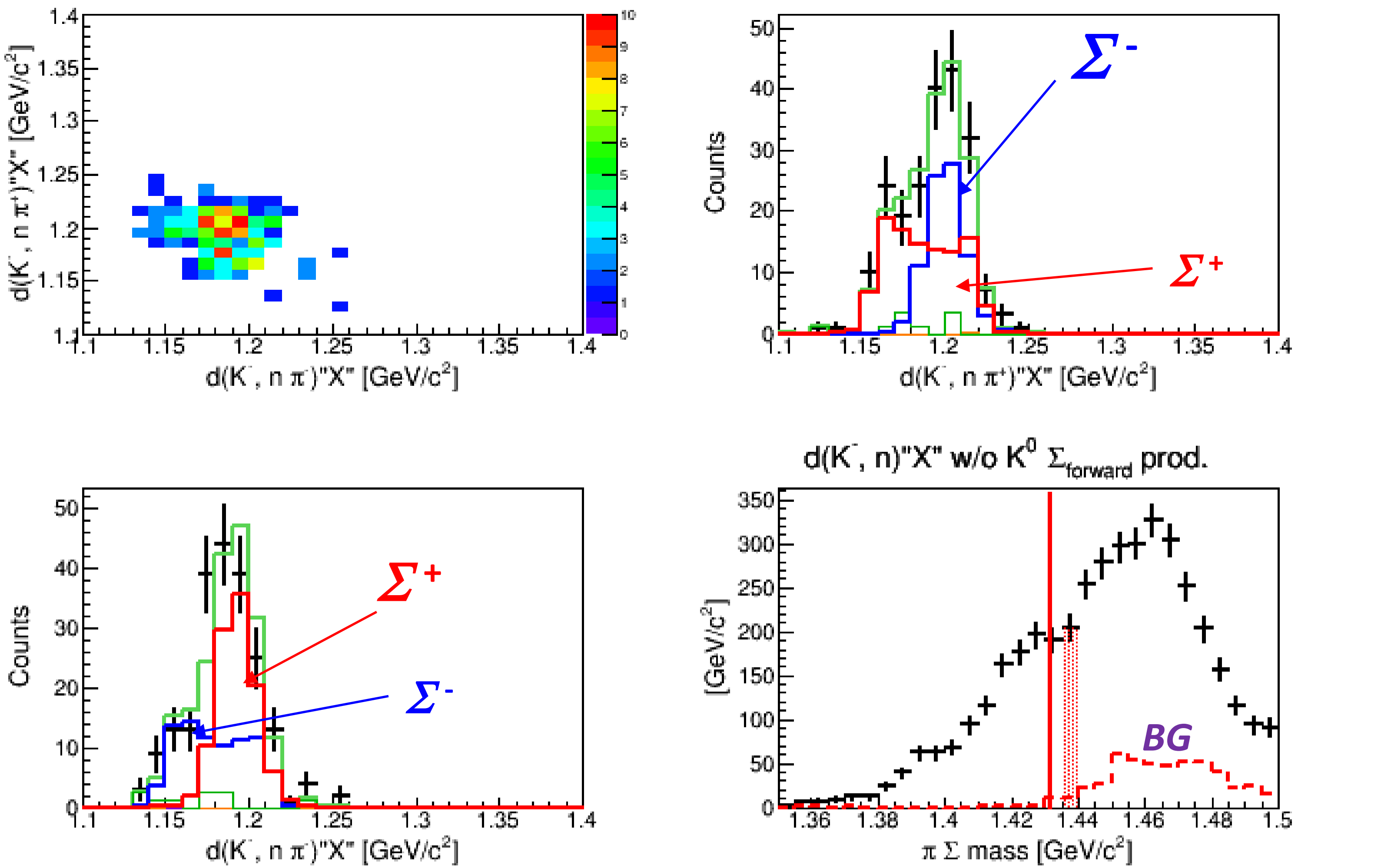




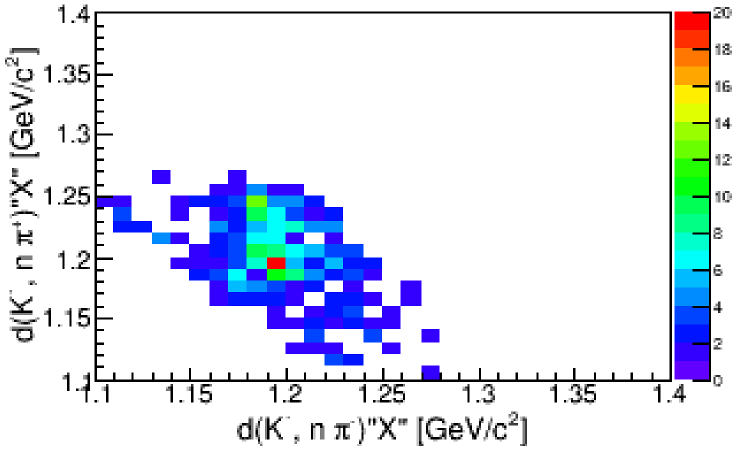


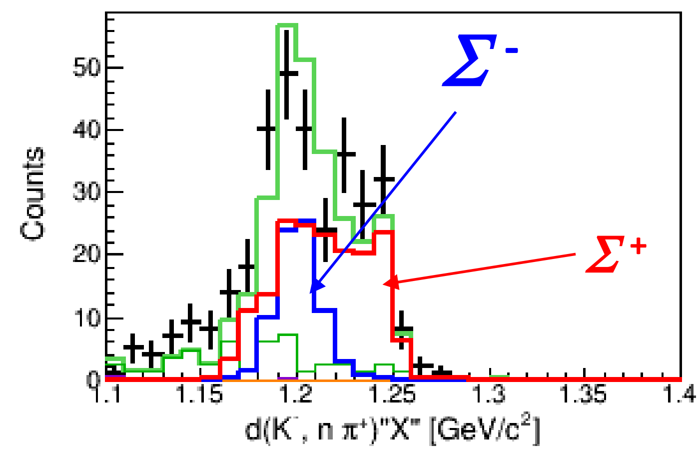


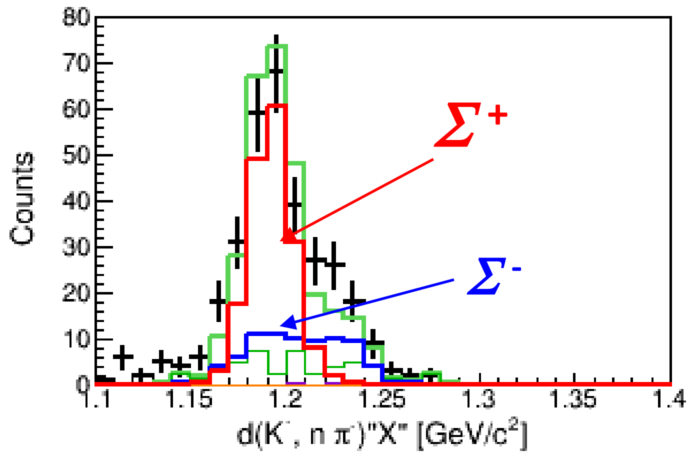
$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation ($M_{\pi\Sigma}$=1.435-1.440 GeV/c^2)

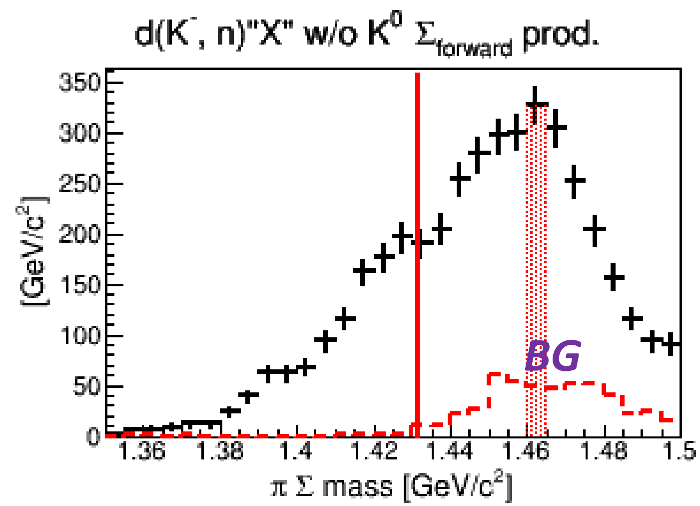


$\pi^+\Sigma^-/\pi^-\Sigma^+$ Mode separation ($M_{\pi\Sigma}$=1.460-1.465 GeV/c^2)





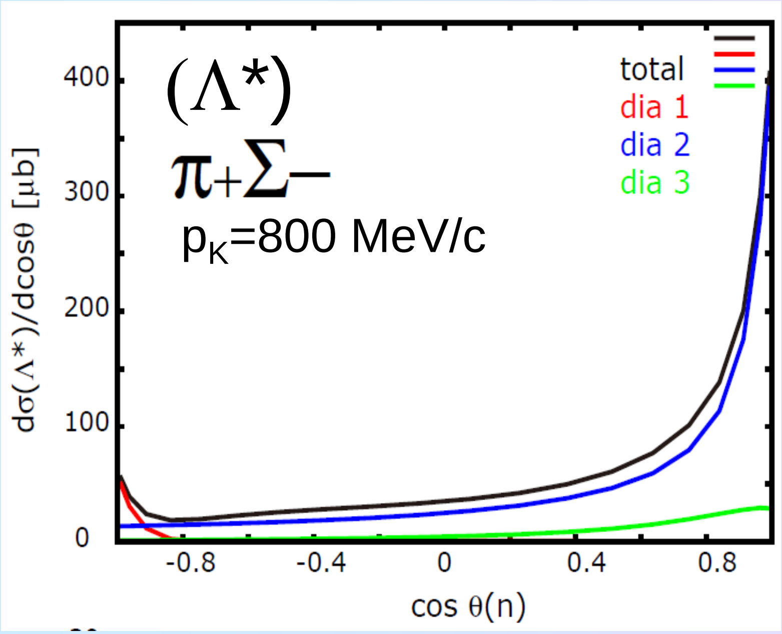


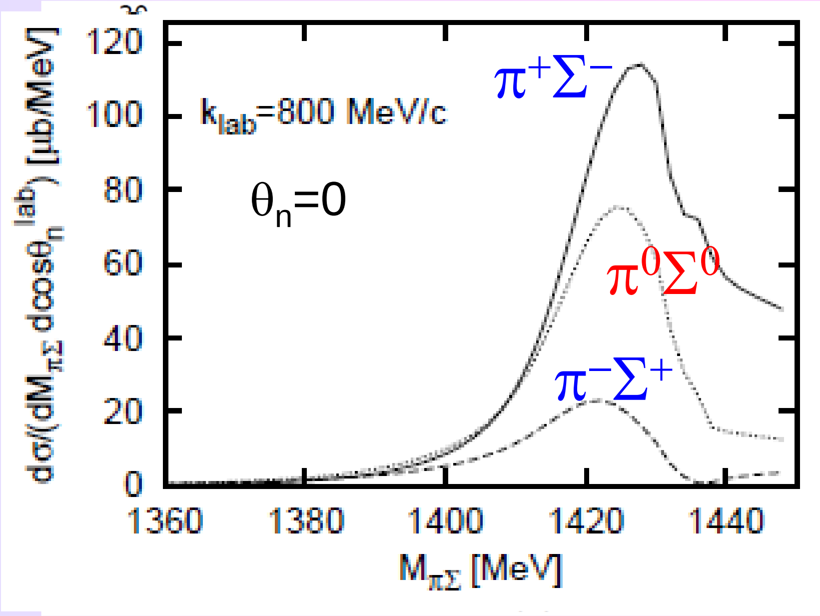


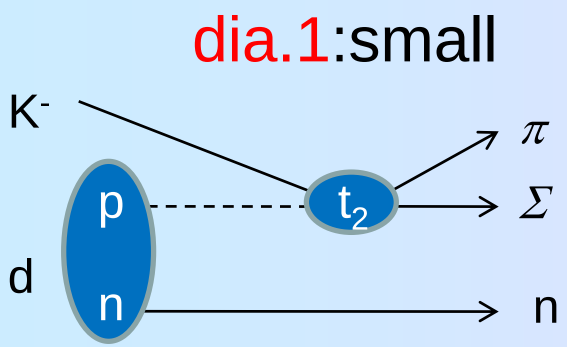
Λ(1405): S-wave $K^{bar}N \rightarrow \pi\Sigma$ scattering below $K^{bar}N$ threshold

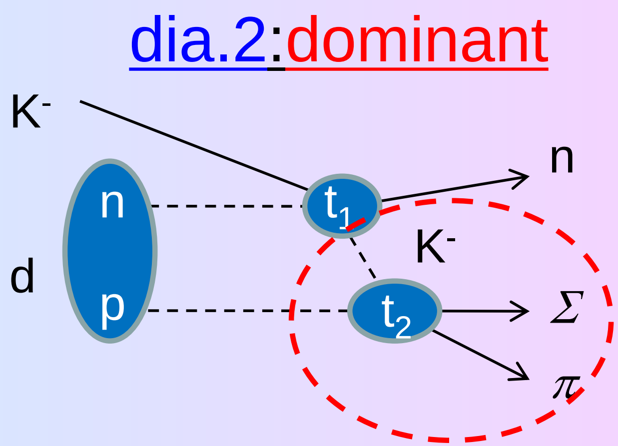
d(K^-,n) may enhance the S-wave scattering at θ_n = 0 degree.

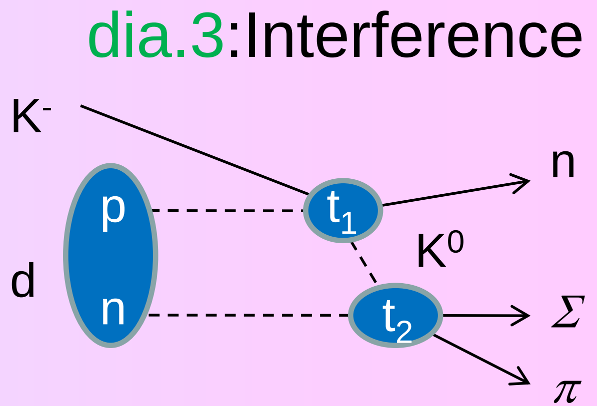
J. Yamagata-Sekihara, T. Sekihara, and D. Jido











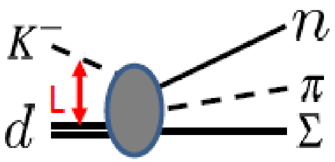
Faddeev Cal. (AGS)

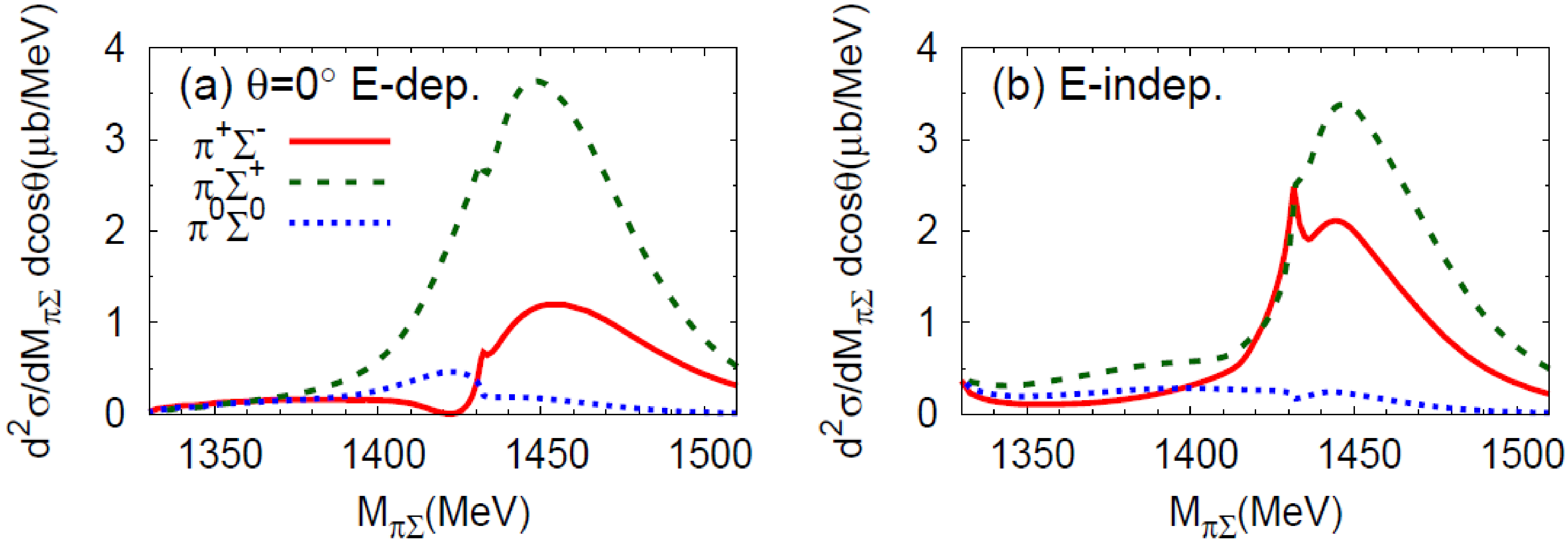
S. Ohnishi, Y. Ikeda, T. Hyodo, E. Hiyama, and W. Weise

Nucl-th: **arXiv:1512.00123**

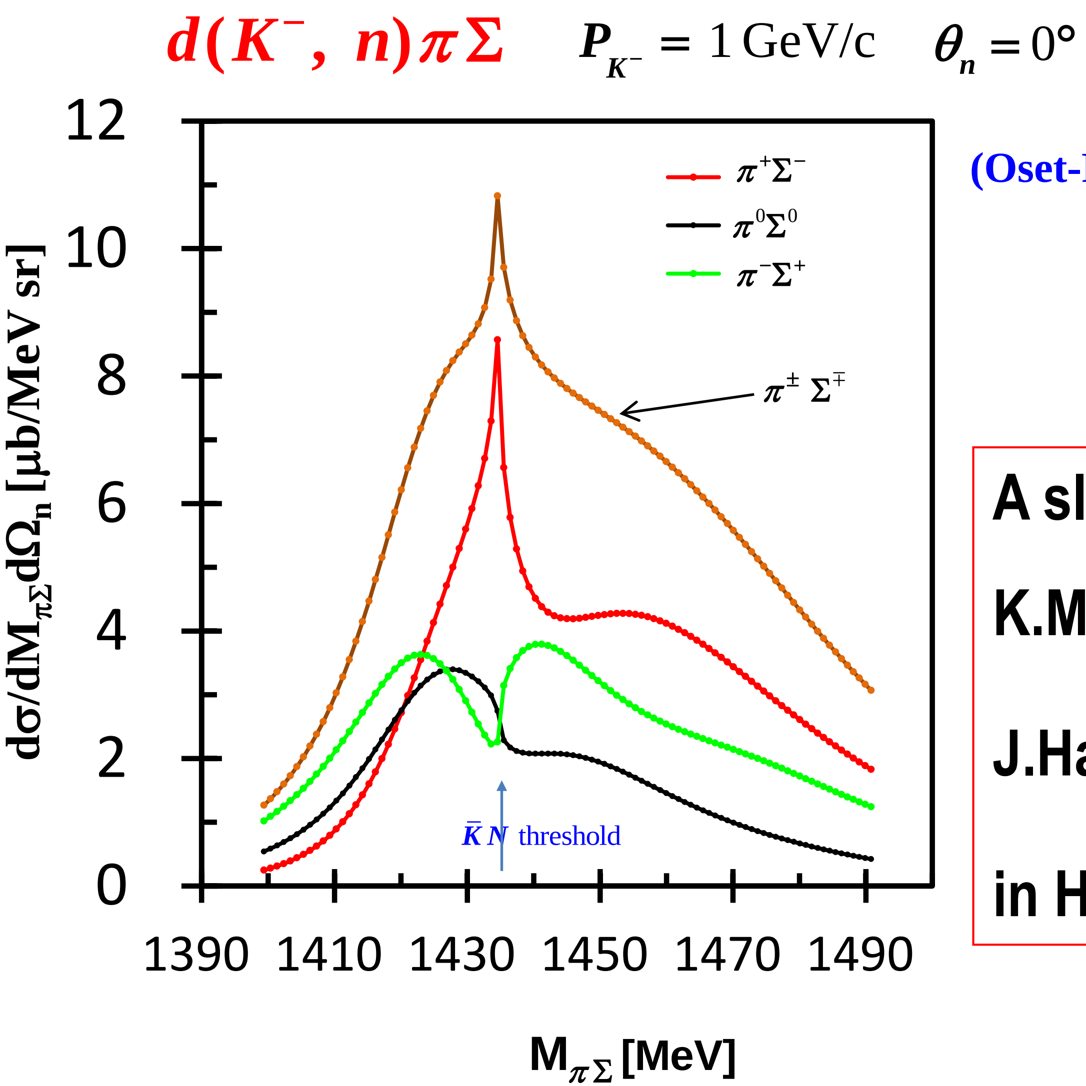
Angular dependence

θ; *n* angle in C.M.





Faddeev calculation (isospin basis)



(Oset-Ramos potential)

A slide presented by

K.Miyagawa (Okayama)

J.Haidenbauer (Jülich)

in HYP2015