J-PARC E31 - 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

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

1. Research Center for Nuclear Physics, Osaka University, Japan

2. University of Victoria, Canada, 3. Seoul National University, South Korea

4. Stefan Meyer Institut fur subatomare Physik, Austria,

5. INFN Sezione di Torino, Italy , 6.Universita' di Torino, Italy

7. Osaka University, Japan, 8. Laboratori Nazionali di Frascati dell'INFN, Italy

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

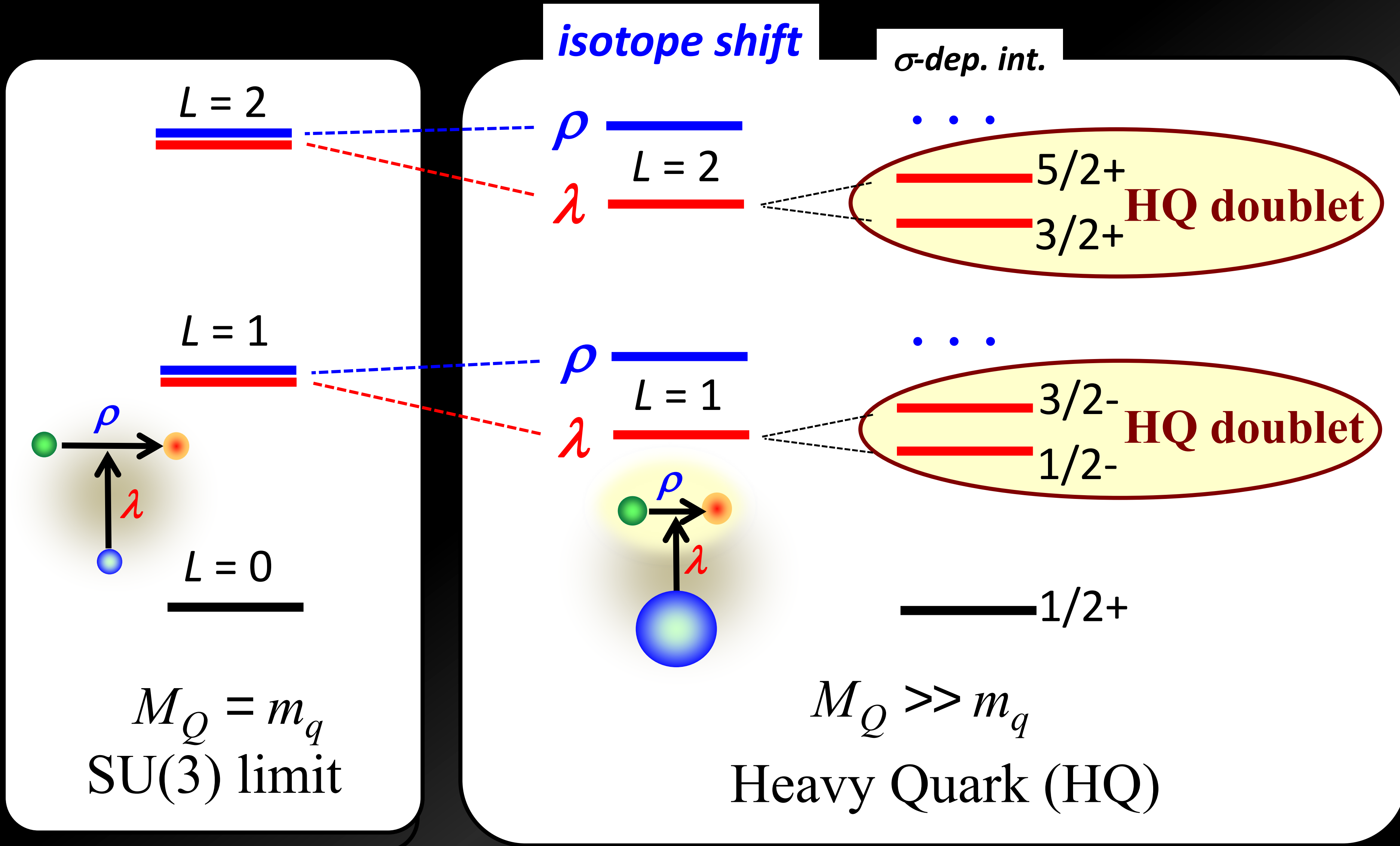
11. Osaka Electro-Communication University, Japan, 12. University of Tokyo, Japan

13. Kyoto University, Japan, 14. High Energy Accelerator Research Organization (KEK), Japan

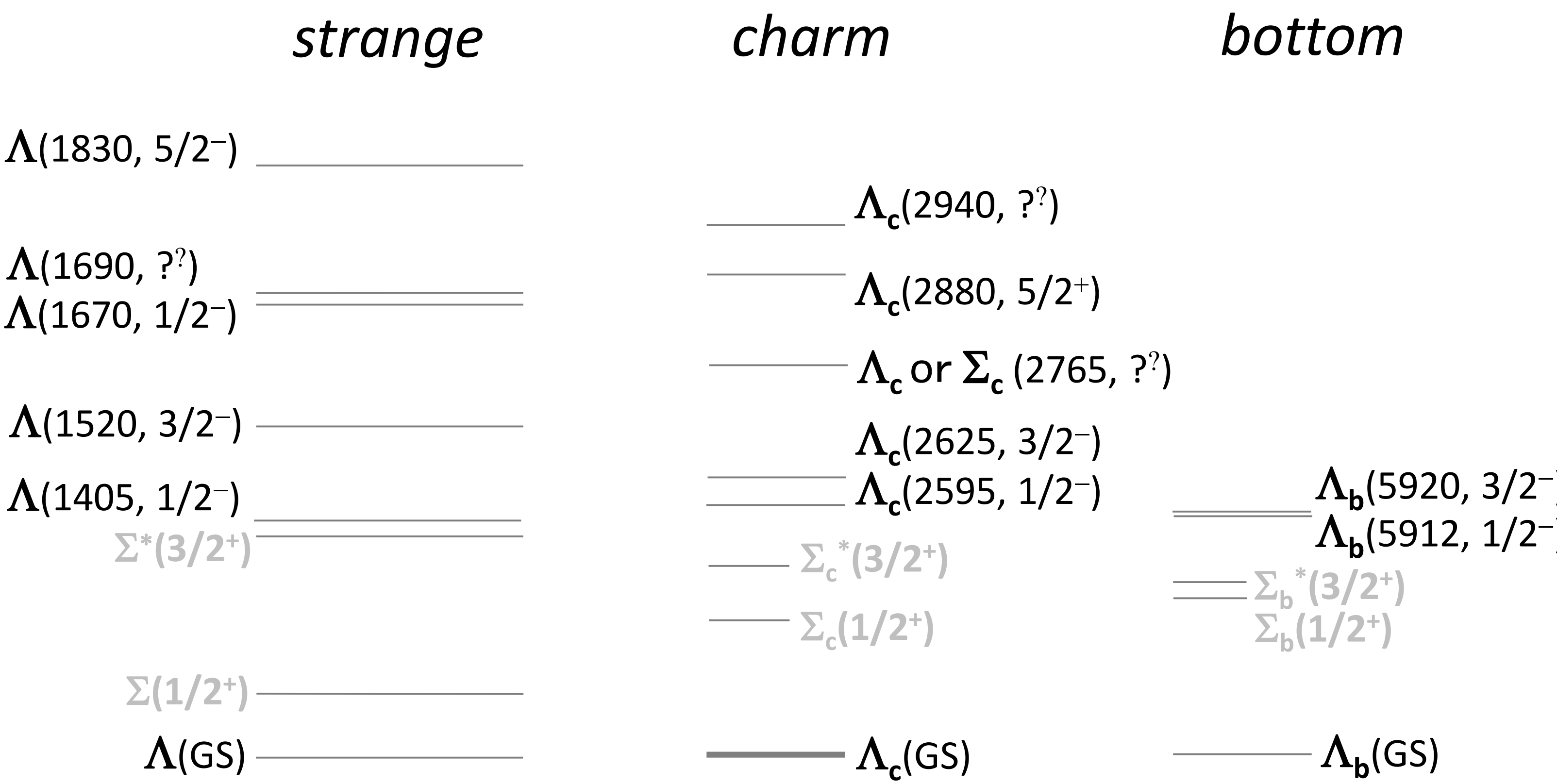
15. Technische Universitat Munchen, Germany, , 16. Tohoku University, Japan

A heavy quark differentiates ***diquark*** motions = modes

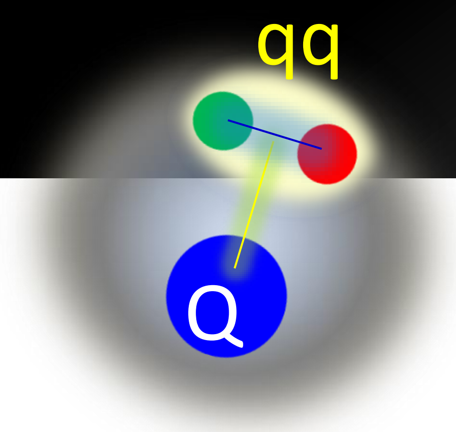
λ and ρ modes are distinct ~ ***isotope shift***

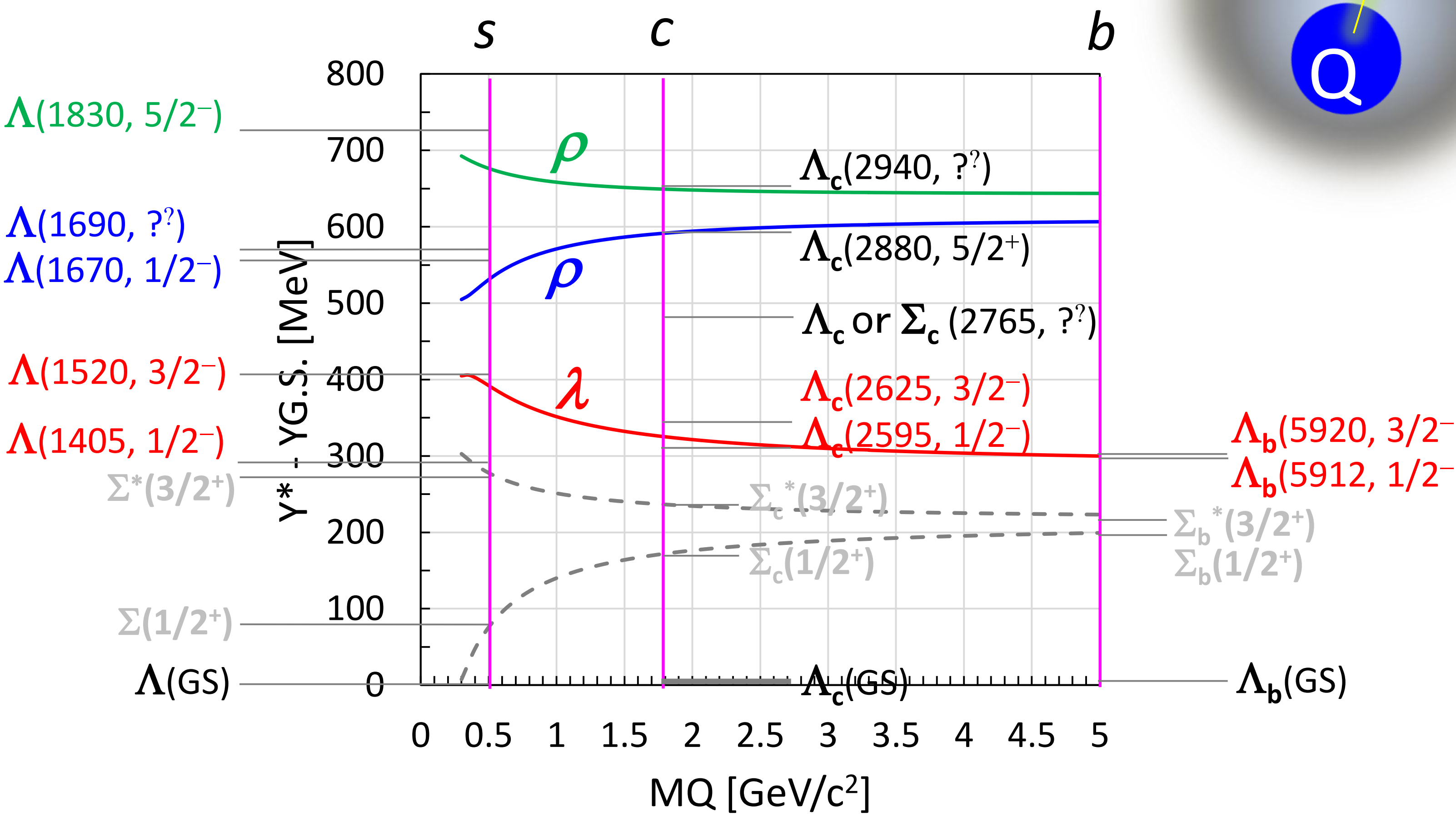


Lambda Baryons



Lambda Baryons

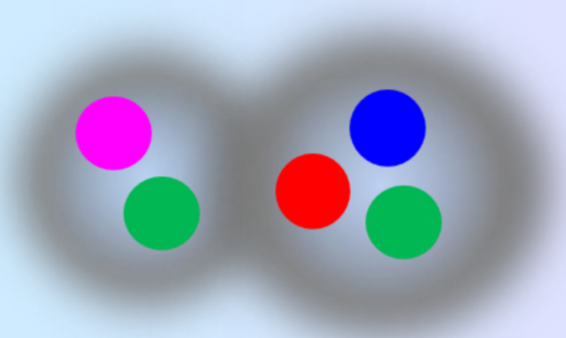


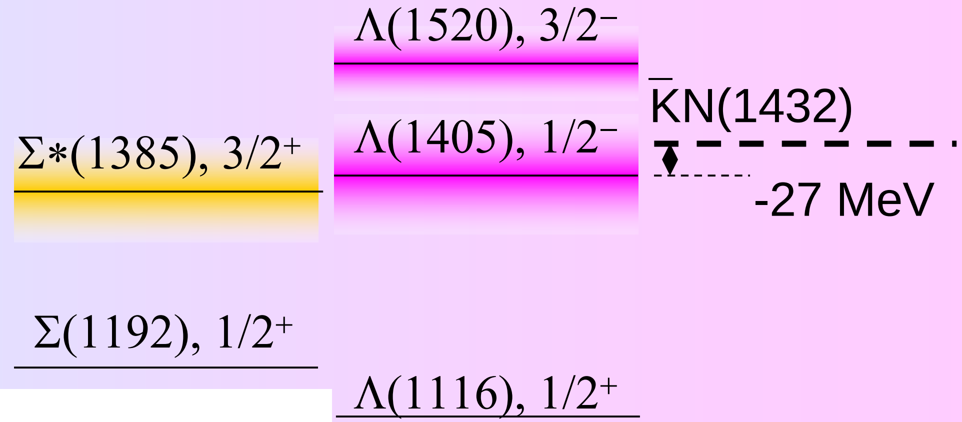


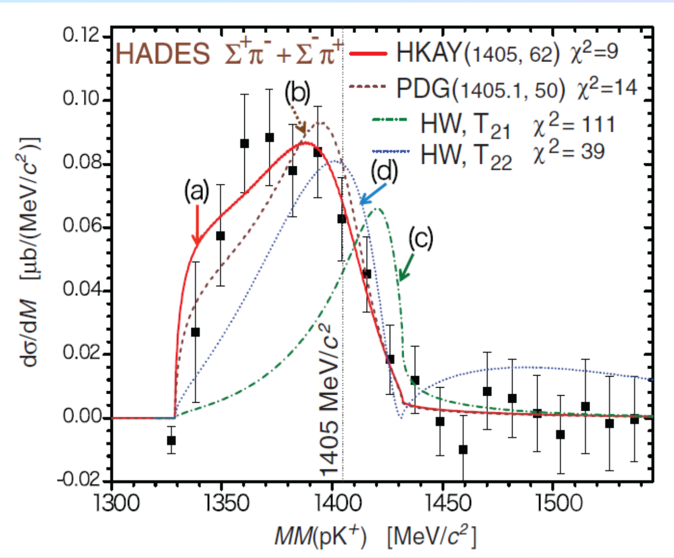
non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
ρ–λ mixing (cal. By T. Yoshida)

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

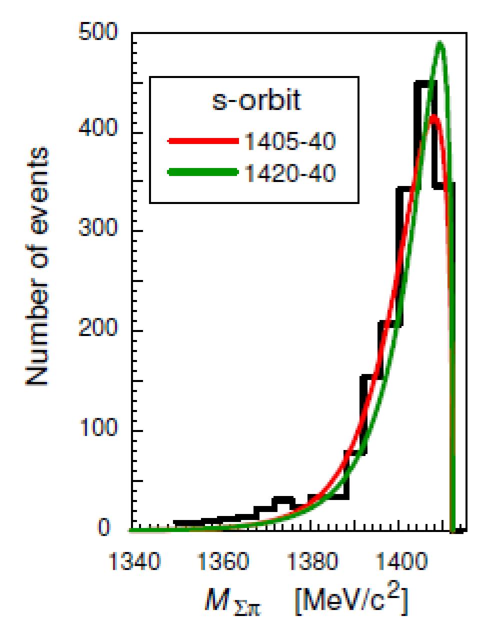
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons



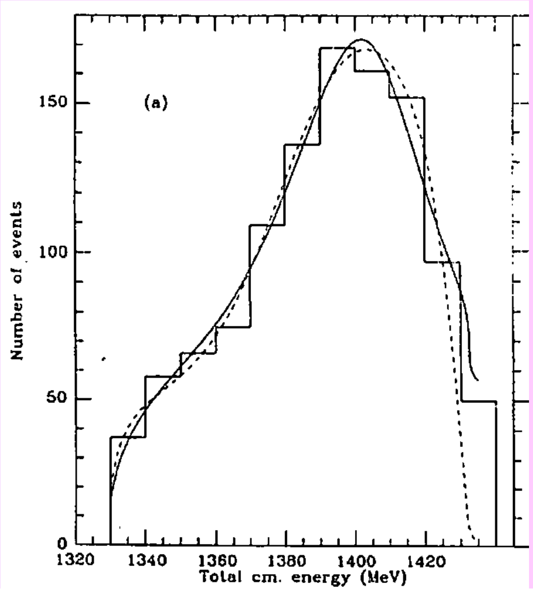




M. Hassanvand et al: $\pi\Sigma$ IM Spec. of $pp \to K^+\pi\Sigma$



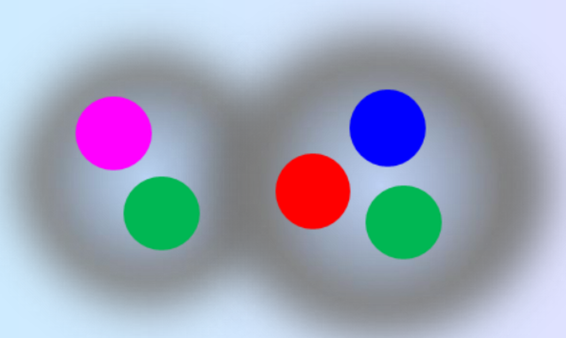
J. Esmaili et al: $\pi\Sigma$ IM Spec. of Stopped K^- on ^{4}He

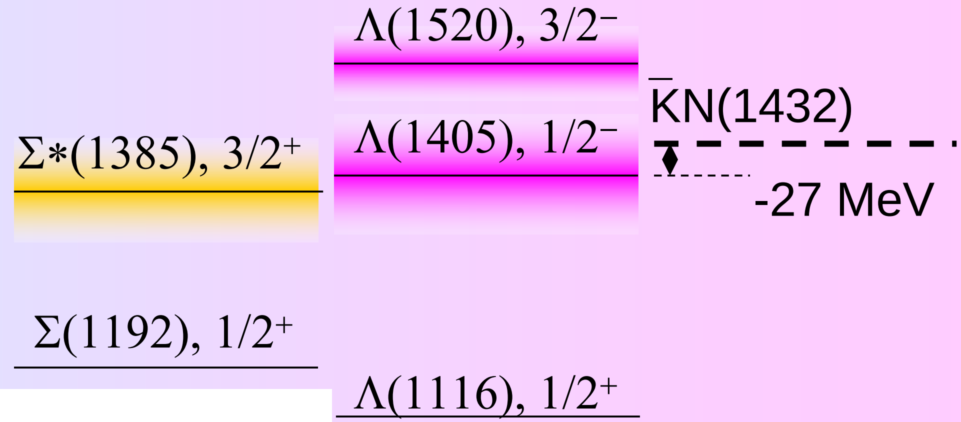


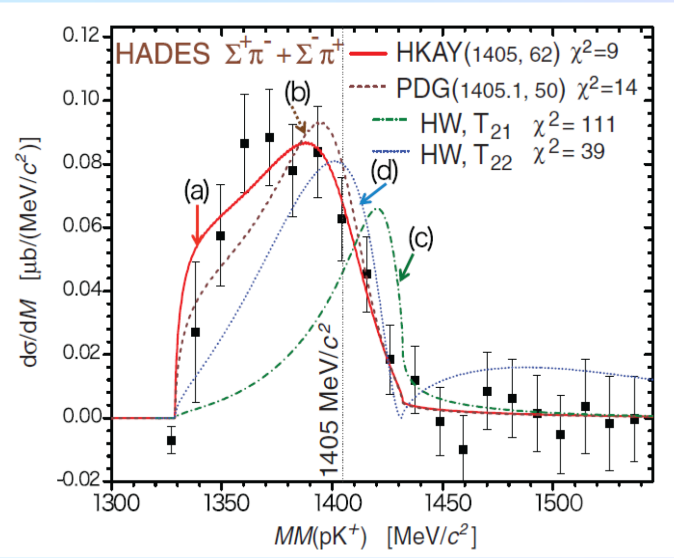
R.H. Dalitz et al: $\pi\Sigma$ IM Spec. in $K\text{-}p \to \pi\pi\Sigma$ w/ M-matrix

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

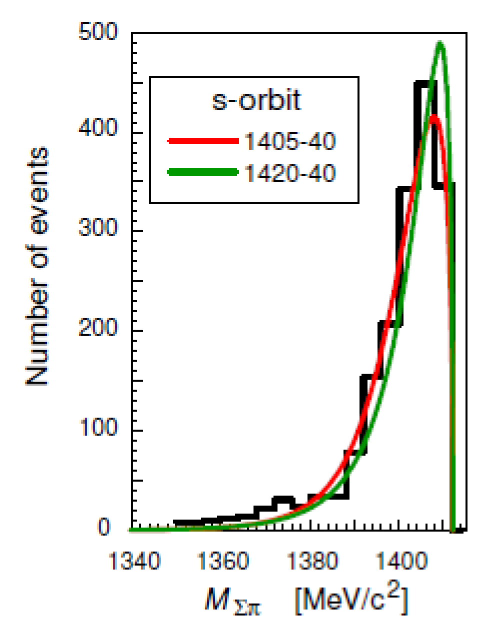
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons



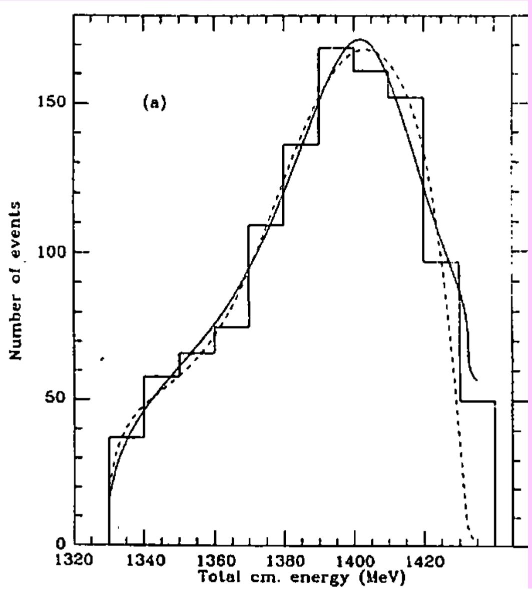




M. Hassanvand et al: πΣ IM Spec. of pp→K⁺πΣ



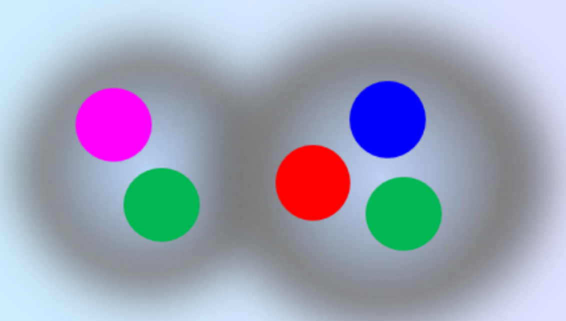
J. Esmaili et al: πΣ IM Spec. of Stopped K⁻ on ⁴He

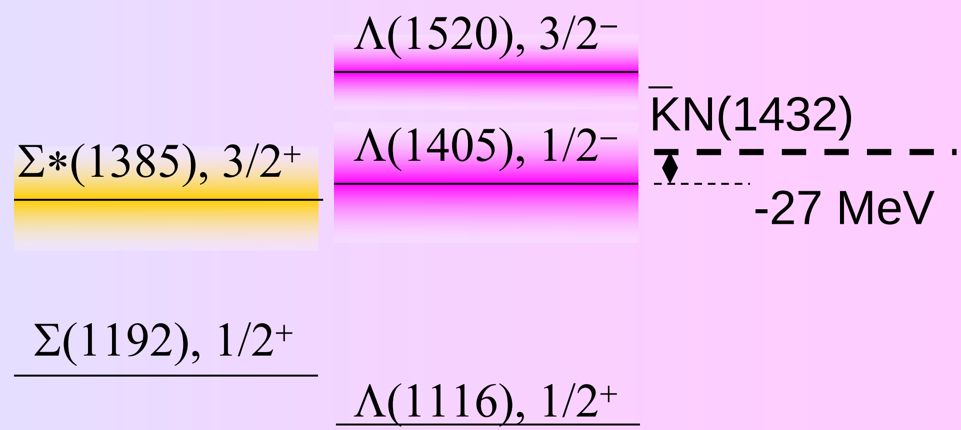


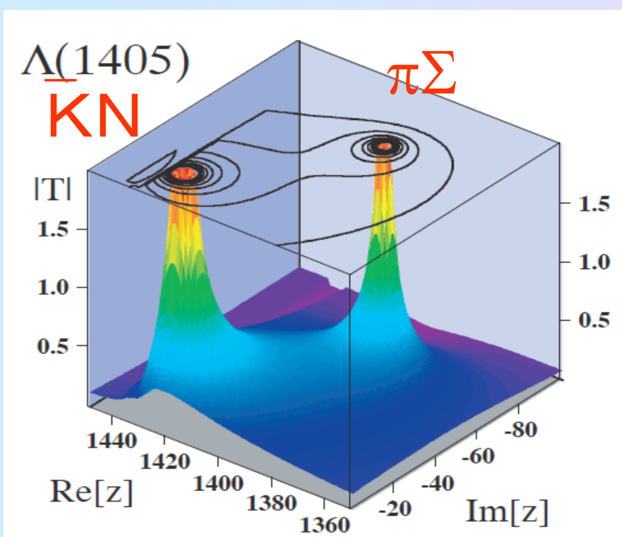
R.H. Dalitz et al: πΣ IM Spec. in K-p→ππΣ w/ M-matrix

Λ(1405) : Double pole?

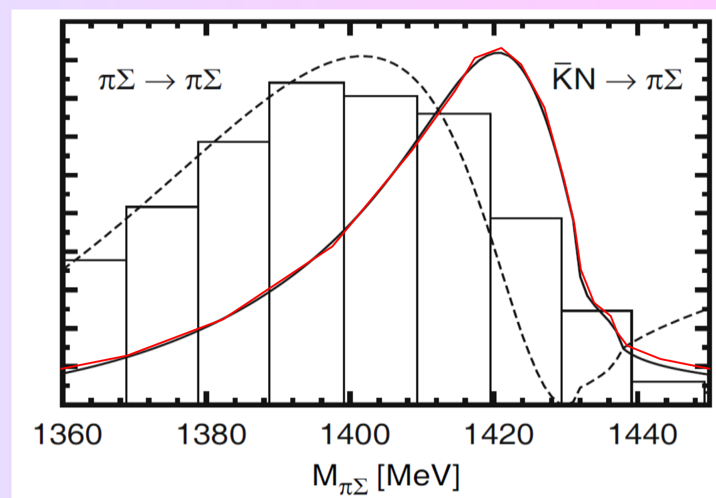
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons







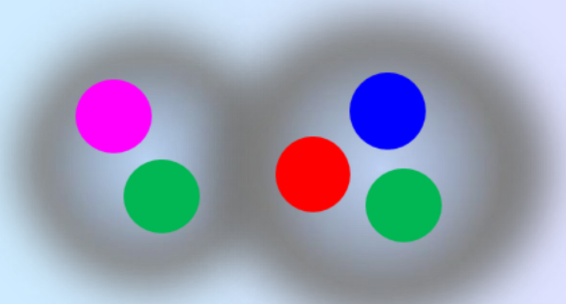
ChU model, T. Hyodo

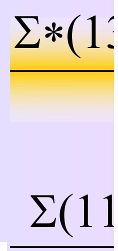


Chiral Unitary Model:
D. Jido et al., NPA725(03)181

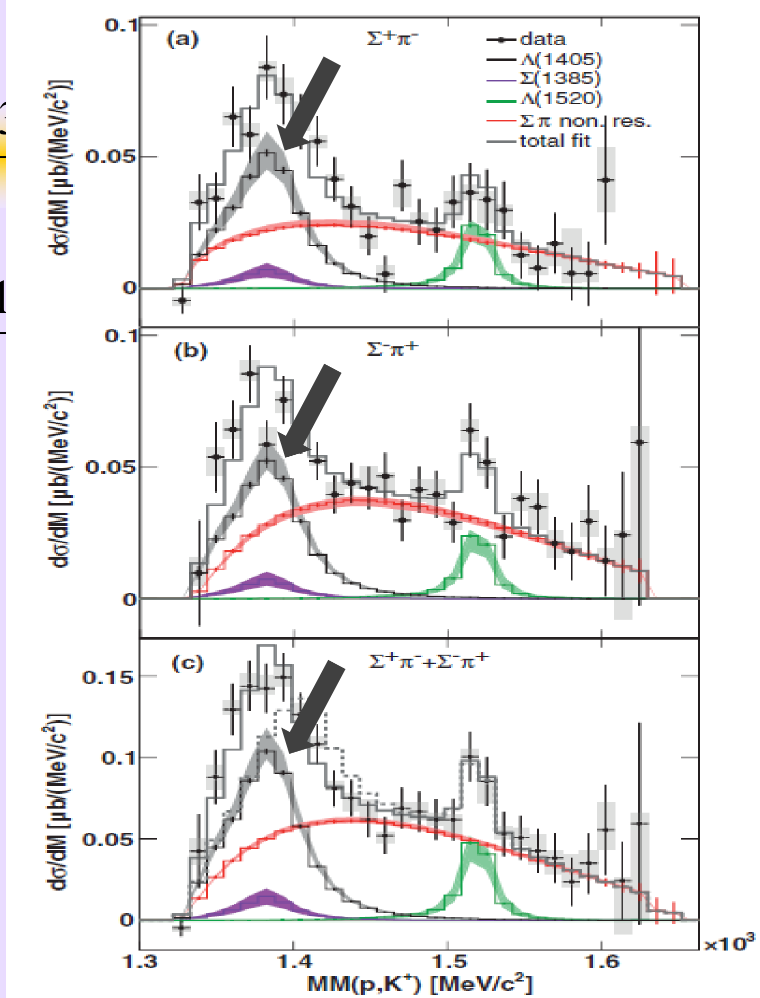
Λ(1405) : Controversial Experimental Data?

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

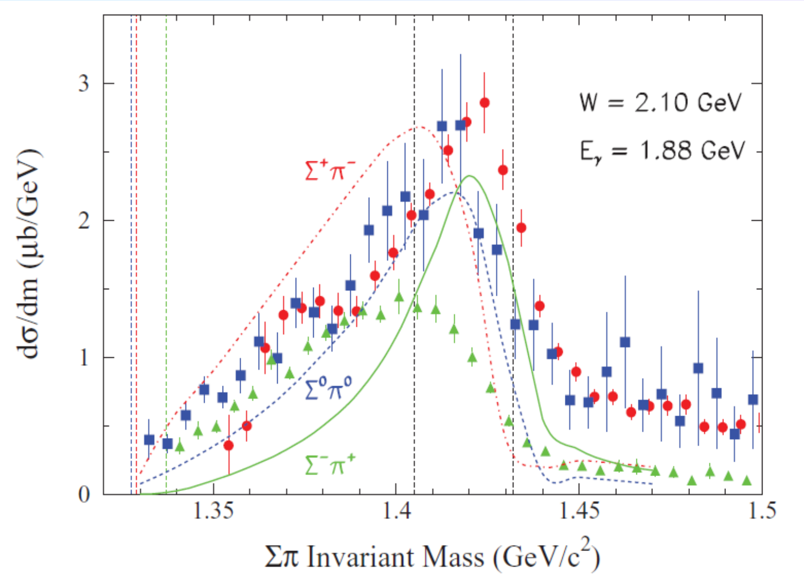




$pp \to K^+ p \pi^- \Sigma^+, K^+ p \pi^+ \Sigma^-$



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



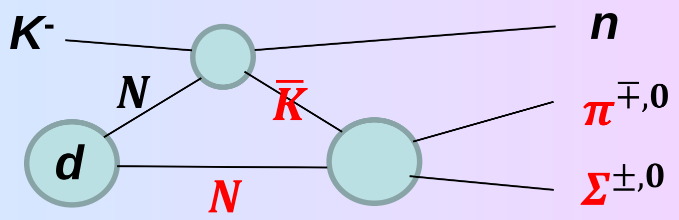
CLAS collaboration: PRC87, 035206

HADES collaboration: PRC87, 025201

E31:

- aims to conclude if $\Lambda(1405)$ 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 $\Lambda(1405)$.



- identifies all the final states to decompose the I=0 and 1 amplitudes.

$\Lambda(1405)$	I=0	S wave	$\pi^{\pm}\Sigma^{\mp}, \pi^0\Sigma^0$
$\Sigma(1385)$	I=1	P wave	$\pi^{\pm}\Sigma^{\mp}, \pi^0\Lambda$
Non-resonant	I=0,1	S,P,D,…	

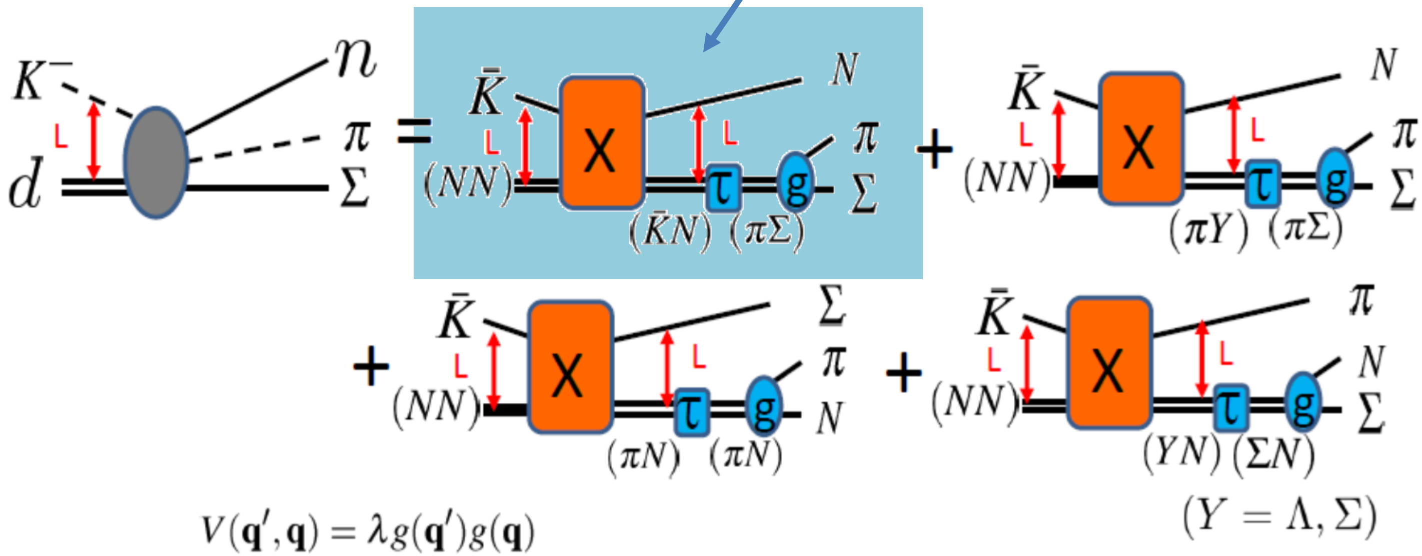
Faddeev Cal. (AGS)

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

Dominant at θ_n=0

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

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



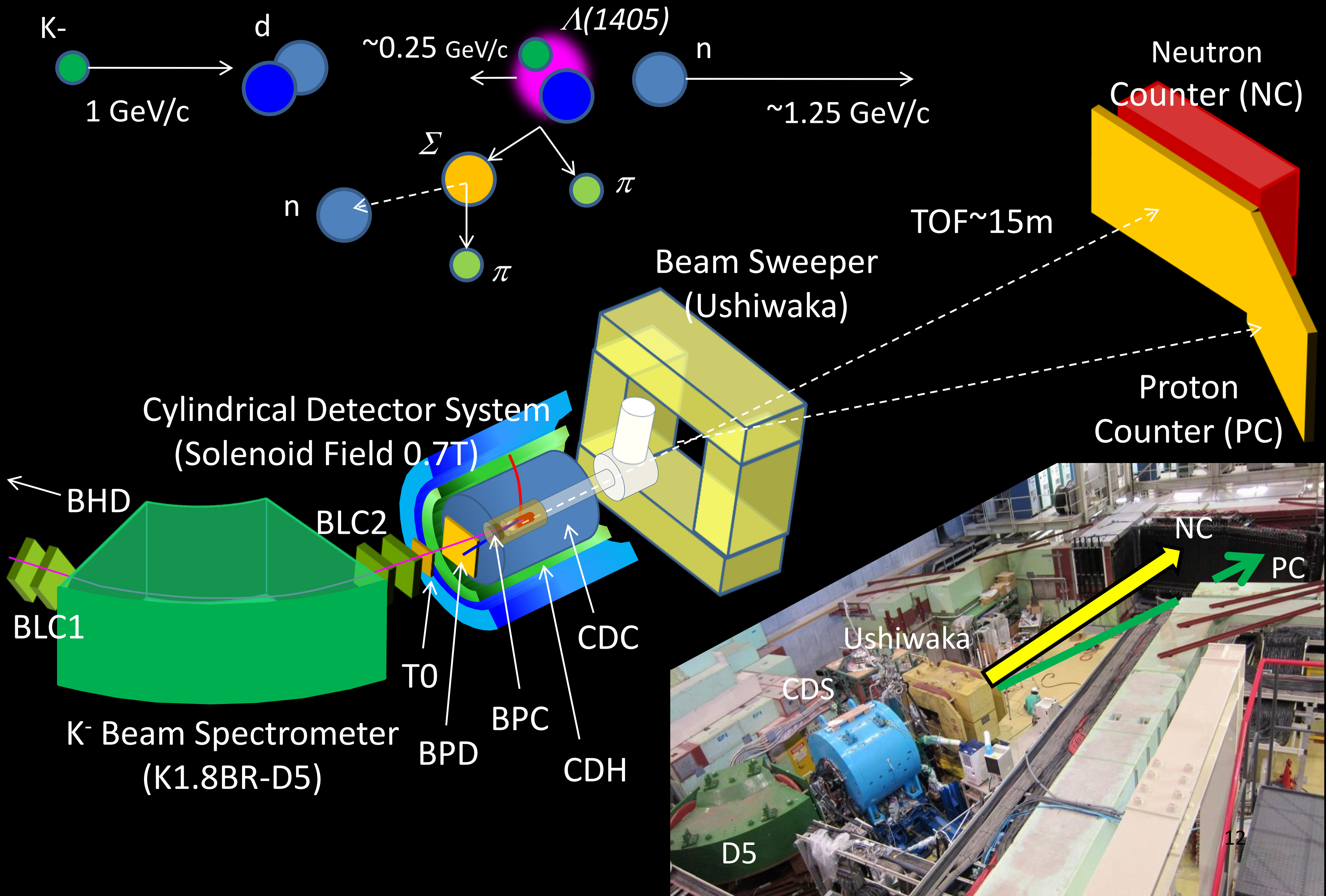
$$V(\mathbf{q}', \mathbf{q}) = \lambda g(\mathbf{q}') g(\mathbf{q})$$

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

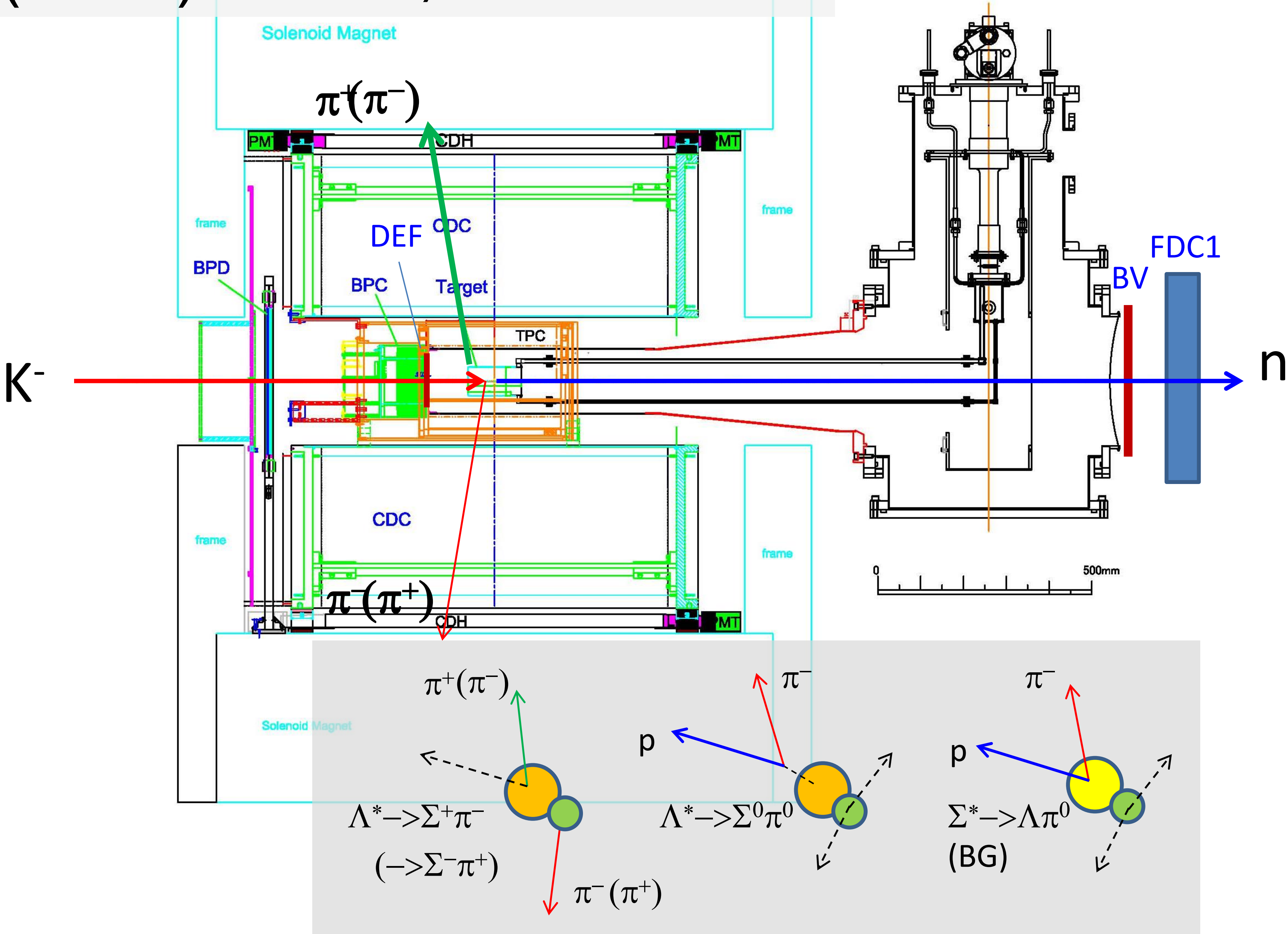
Alt-Grassberger-Sandhas(AGS) eq. : X_{ij} ; quasi two-body amplitude

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

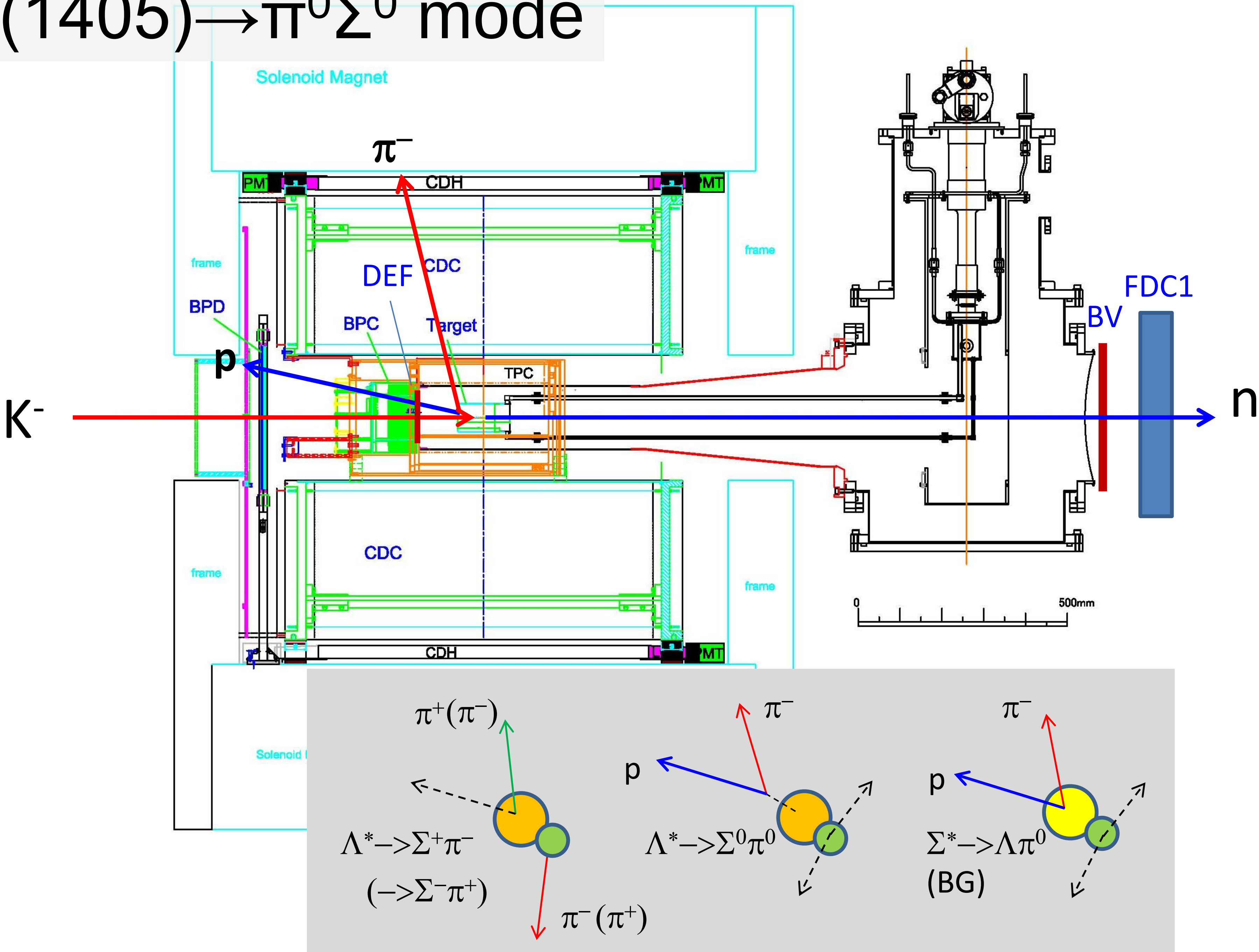
Experimental Setup for E31



$\Lambda(1405) \to \pi^-\Sigma^+$, $\pi^+\Sigma^-$ modes



Λ(1405)→$\pi^0\Sigma^0$ mode



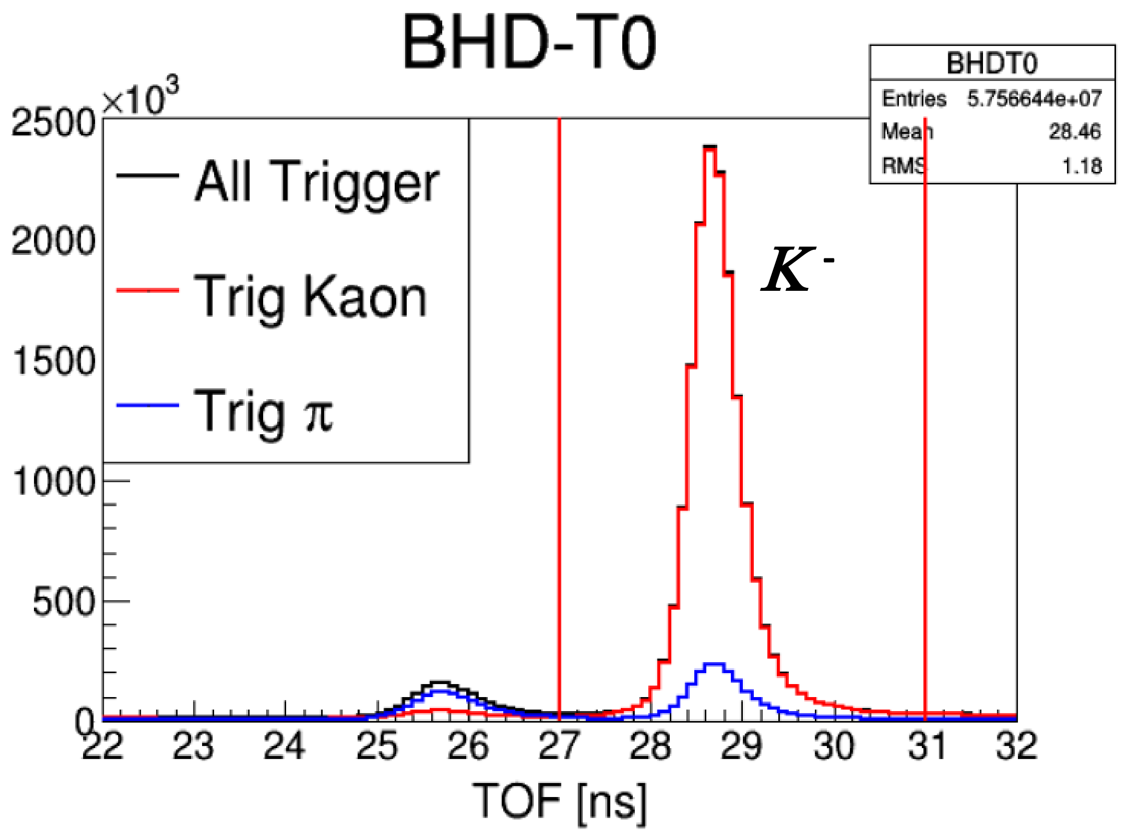
Run 62 (April-May, 2015)

- Beam time for E15 was allocated in order to take calibration data of elementary $K^{-}p \rightarrow K^{0}n$ and $K^{-}n \rightarrow K^{-}n$ reactions using H_2 and D_2 targets.
- This provided a good opportunity to evaluate feasibility for E31.
- We demonstrate the $d(K^{-},n)X_{\pi\Sigma}$ spectrum, based on the D_2 data for 2.2 days (26.5 kW).

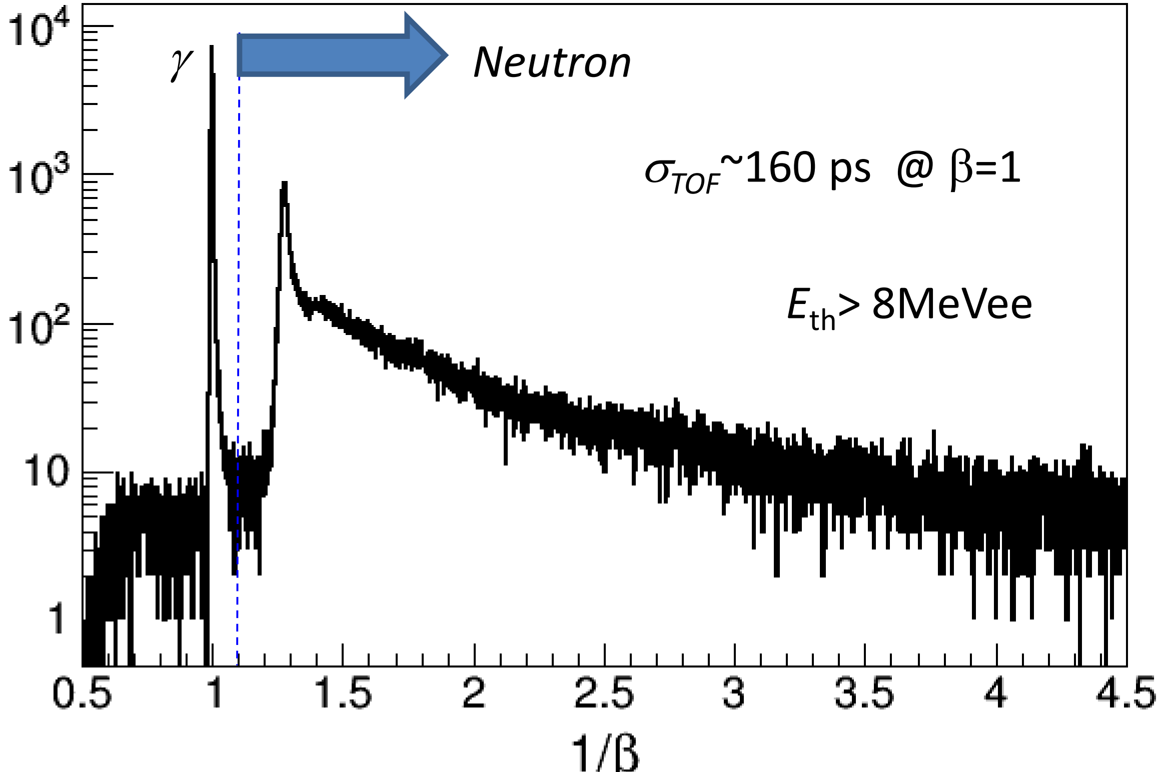
$\rightarrow$ >33kW from this Autumn?

Event selection for the (K^{-}, n) reaction

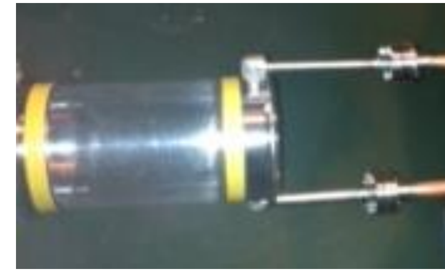
Kaon Beam Selection

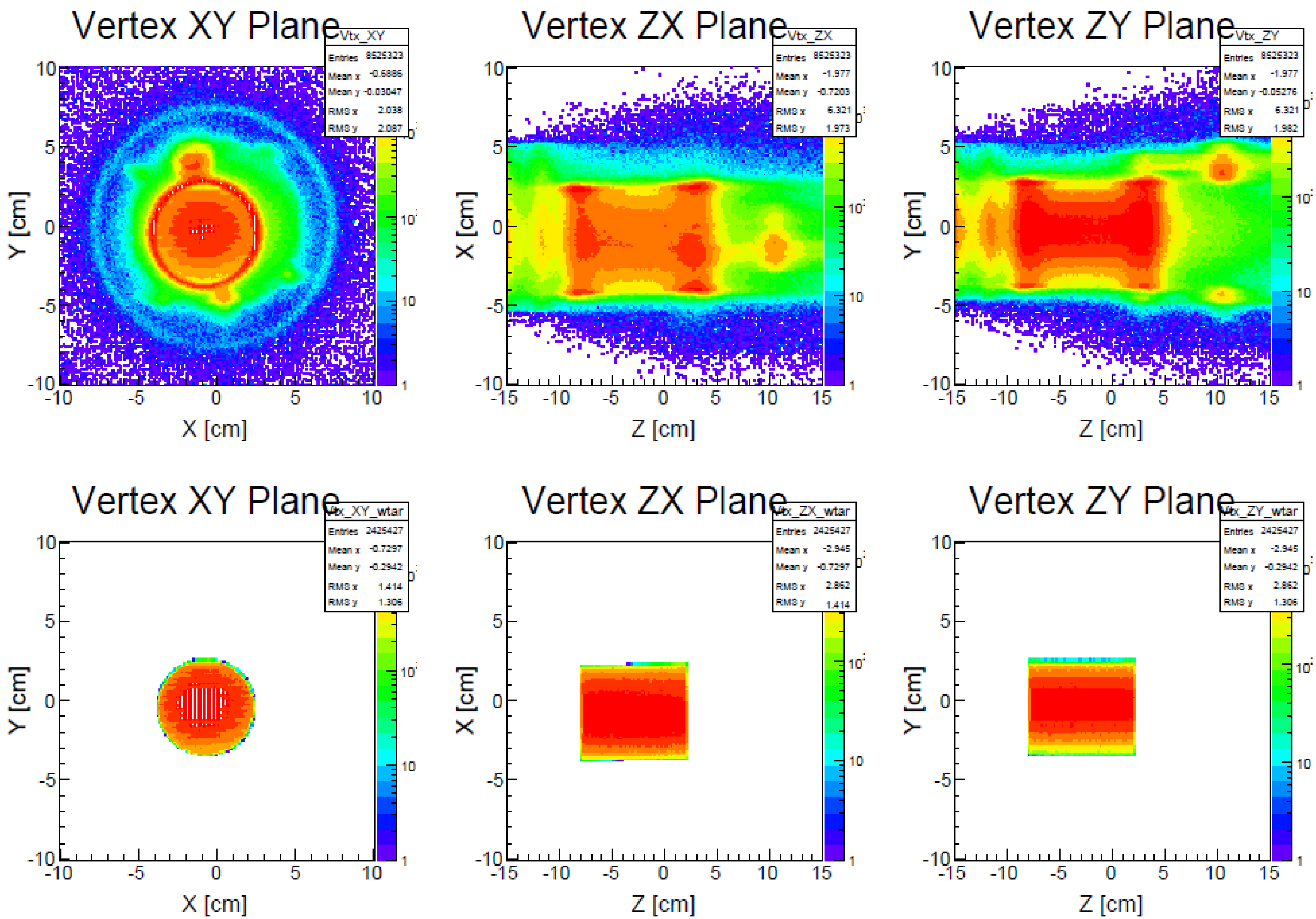


Neutron 1/β spectrum

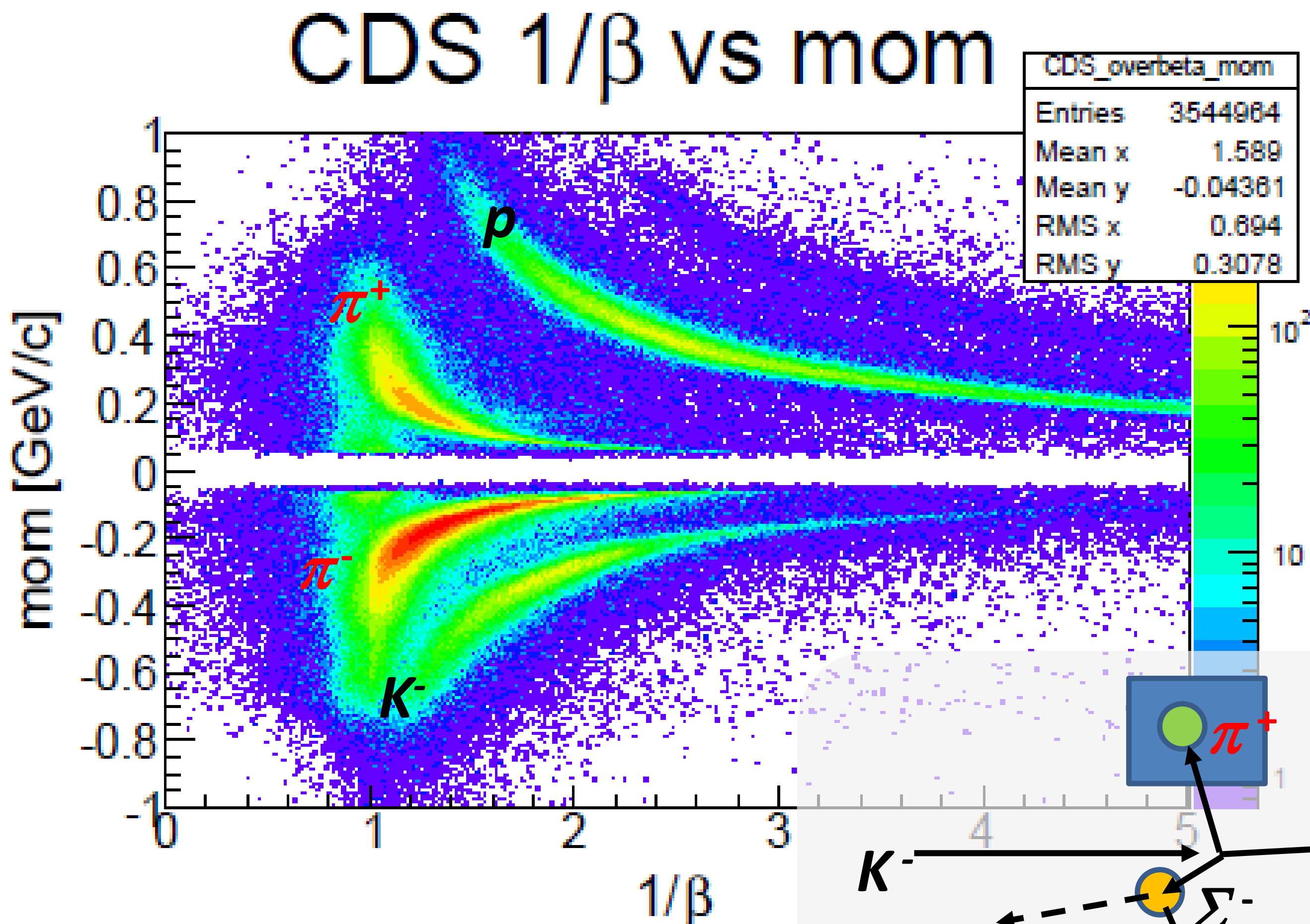


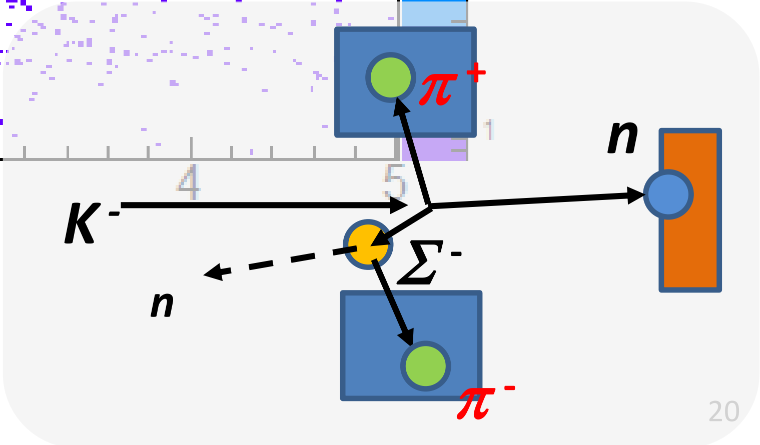
Reaction Vertex Selection



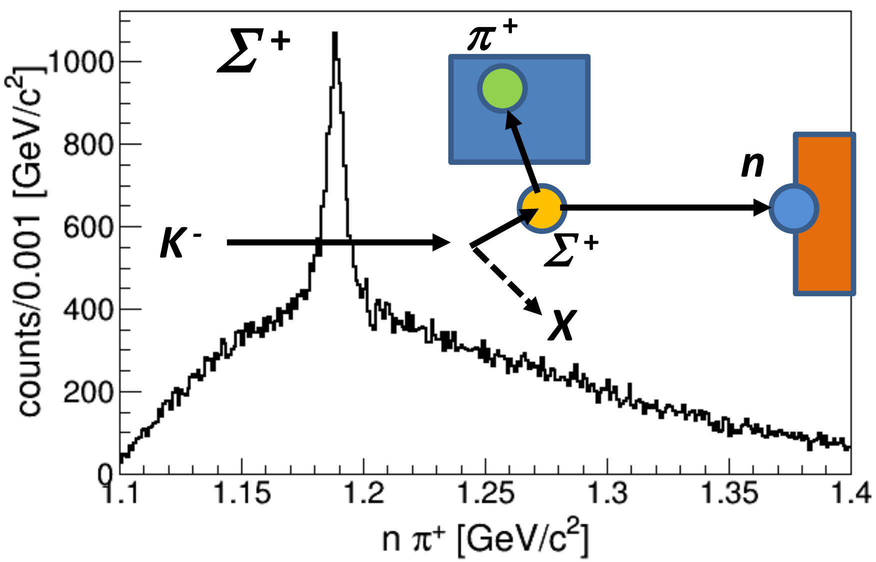


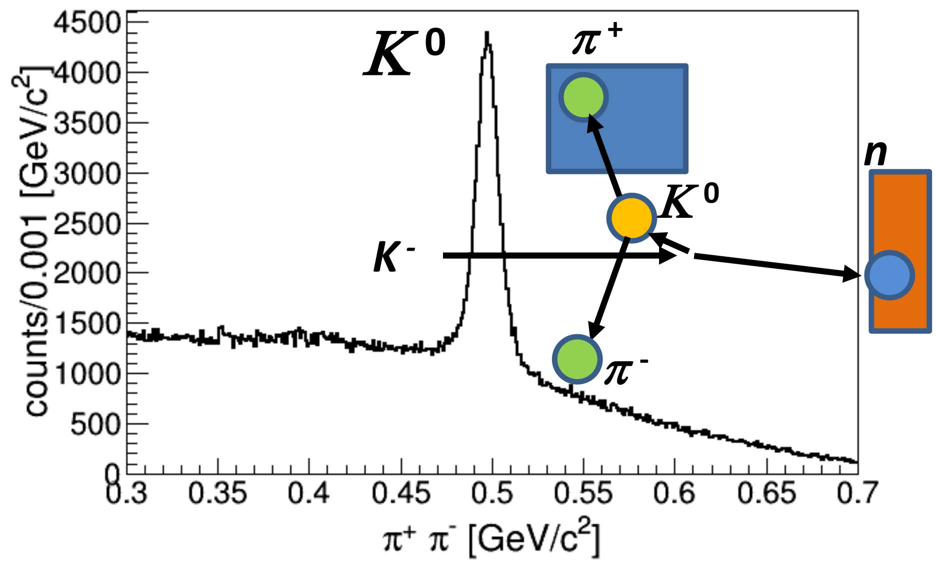
π^+ and π^- detection in CDS

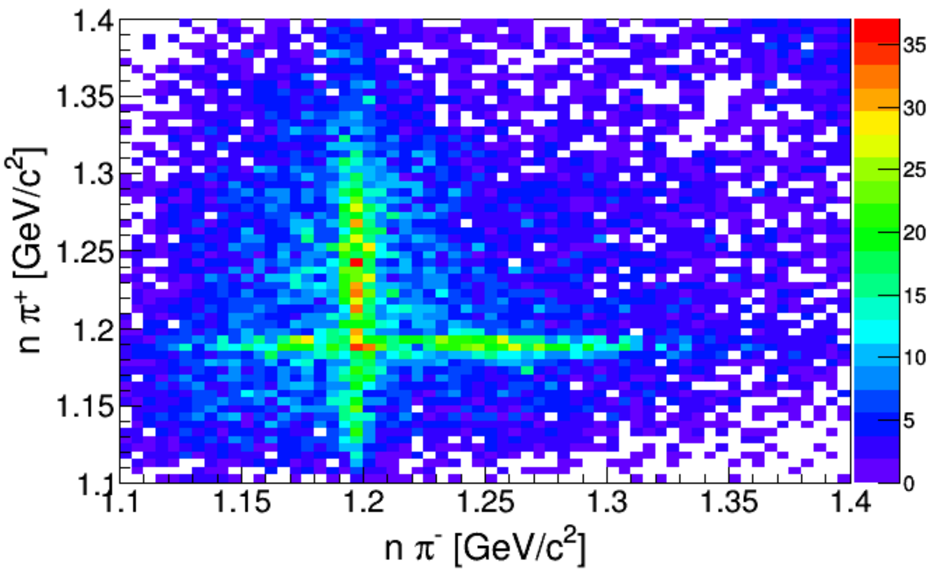


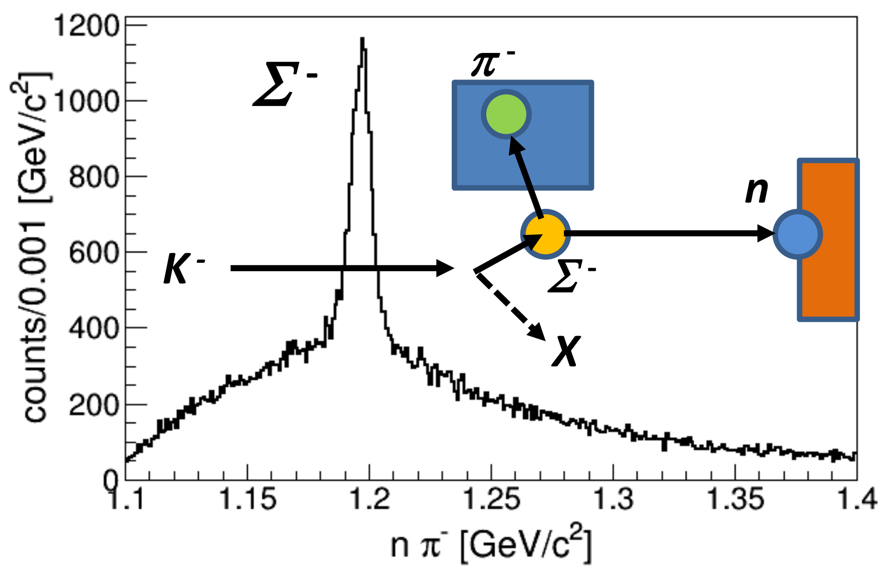


K^0 and Σ_{decay} reconstructions

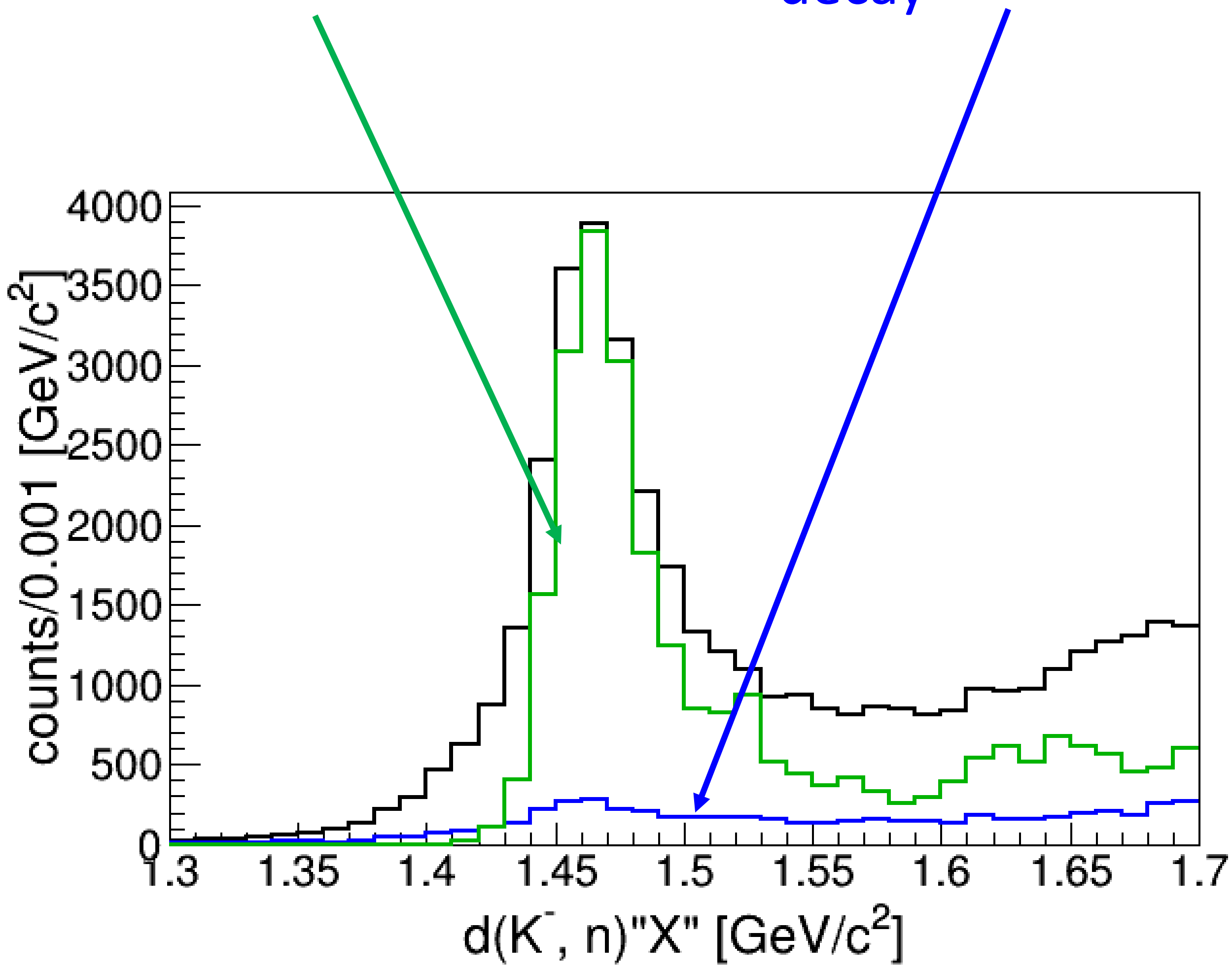




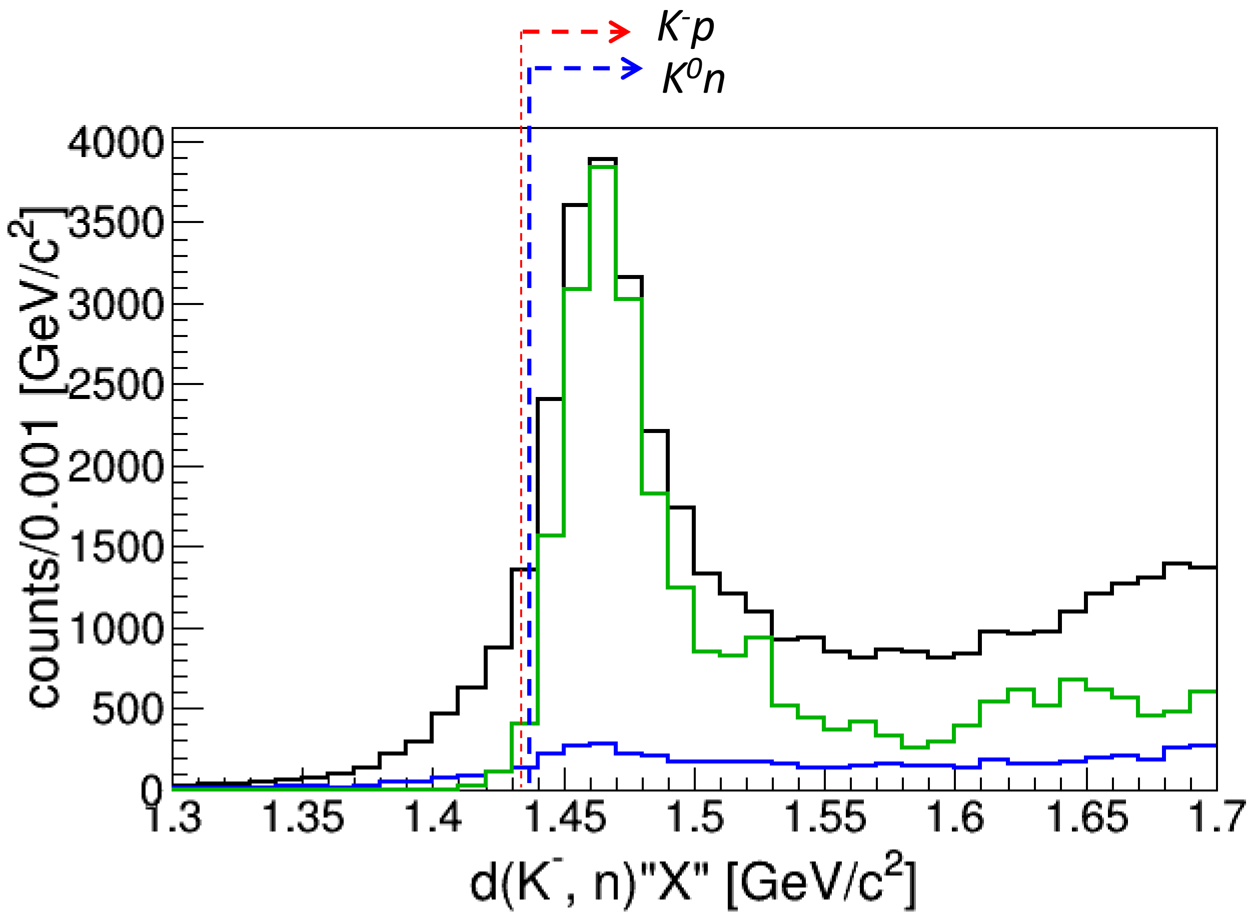




Semi-inclusive d(*K*$^-$,*n*)*X* spectra, K^0 selected (x10) , and Σ_{decay} selected (x10)

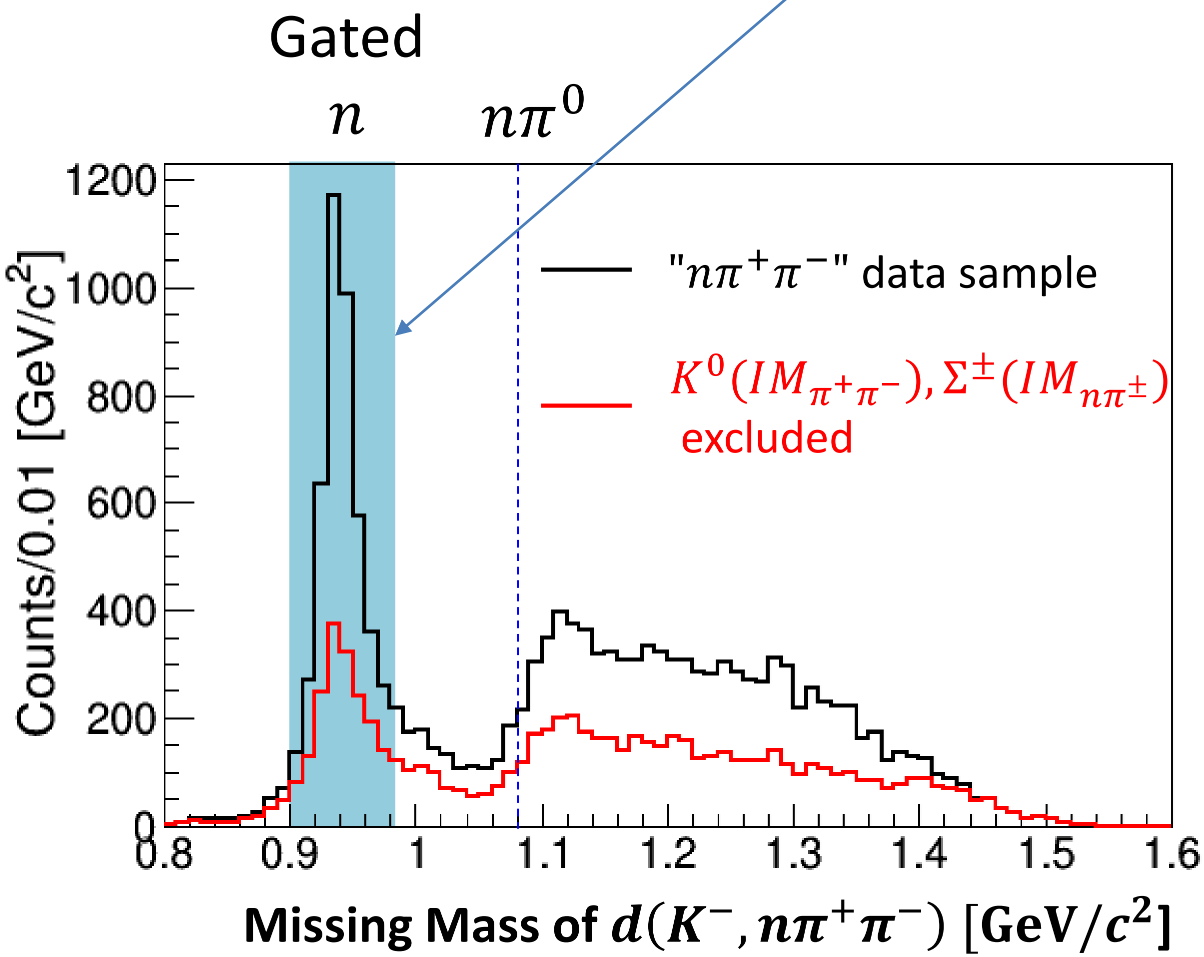


Semi-inclusive d(*K*⁻,*n*)*X* spectra, K^0 selected (x10) , and Σ_{decay} selected (x10)

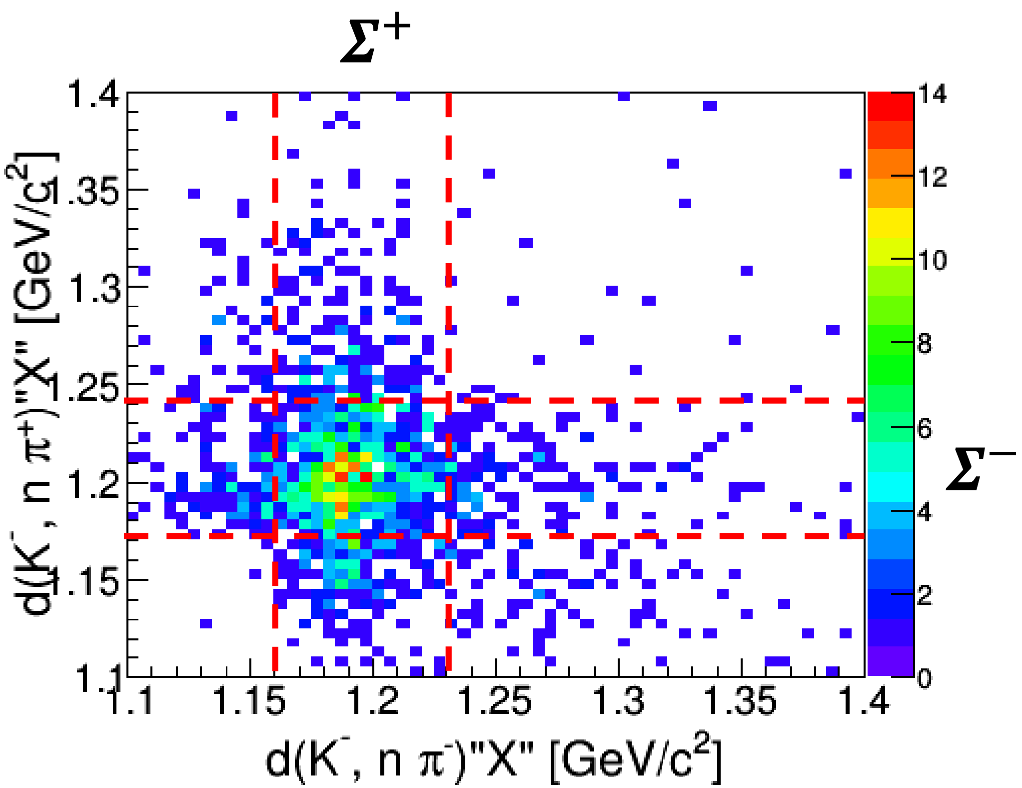


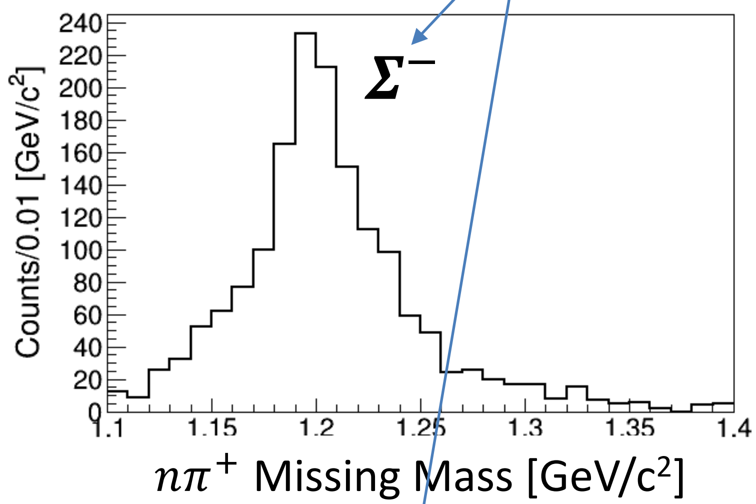
Event selection for exclusive $d(K^-, n)\pi^\pm\Sigma^\mp$ reactions

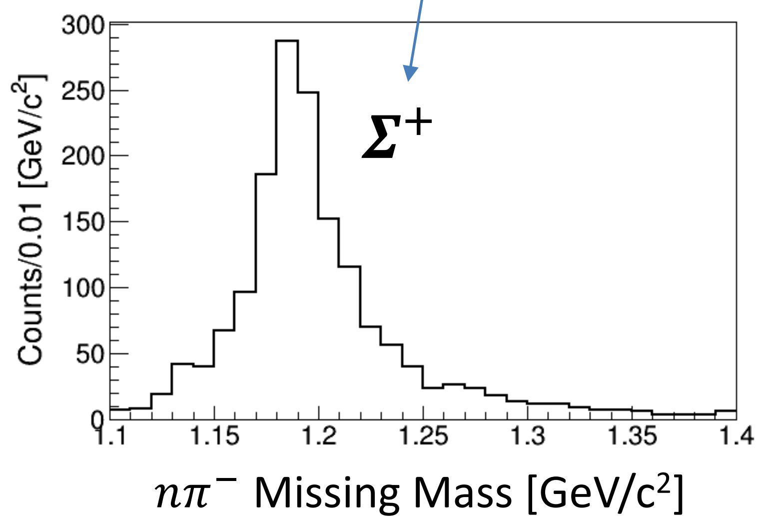
$$d(K^-, n\pi^+\pi^-)n_{missing}$$



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





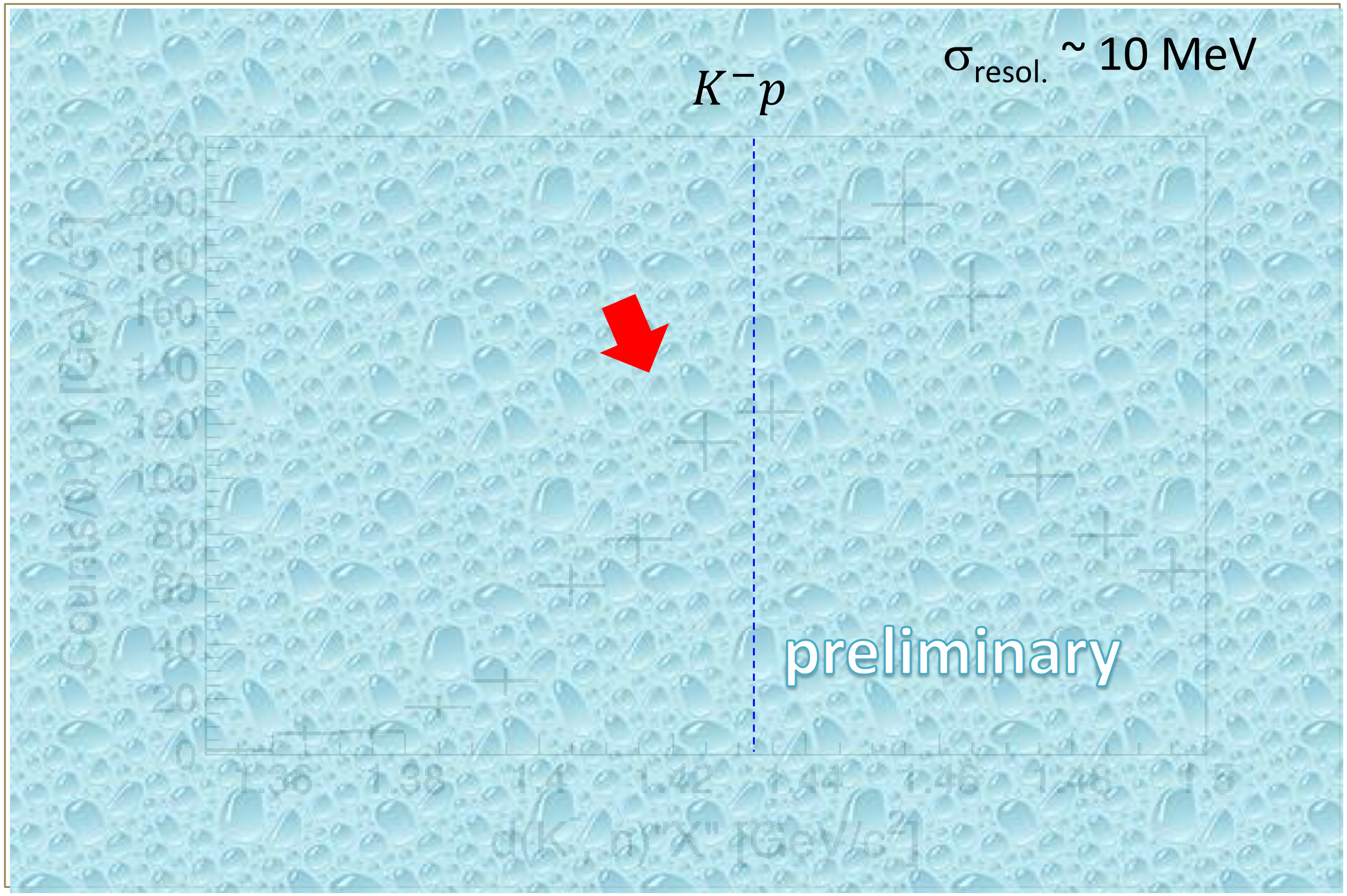


$$d(K^-, n)\pi^\pm\Sigma^\mp$$

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

Missing mass spectrum of the $d(K^-, n)X_{\pi^\pm\Sigma^\mp}$ reaction

K^0 and Σ_{decay} events have been excluded.



Remarks

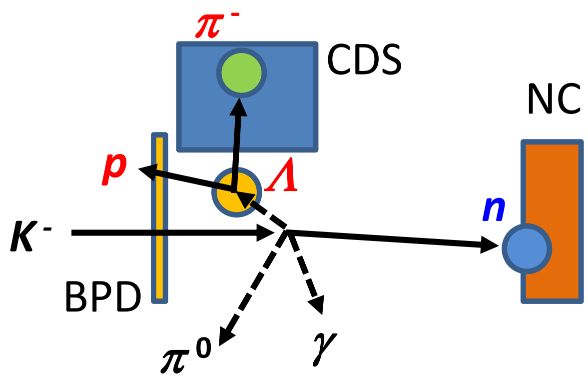
- The $d(K^{-},n)X_{\pi^{\pm}\Sigma^{\mp}}$ spectrum at θ_n=0 deg for the first time.
  - provides a $\overline{K}N \rightarrow \pi\Sigma$ scattering data below the $\overline{K}N$ threshold.
- A bump structure at ~1420 MeV has been observed.
  - Yield excess of bound region
  - Strength of unbound region

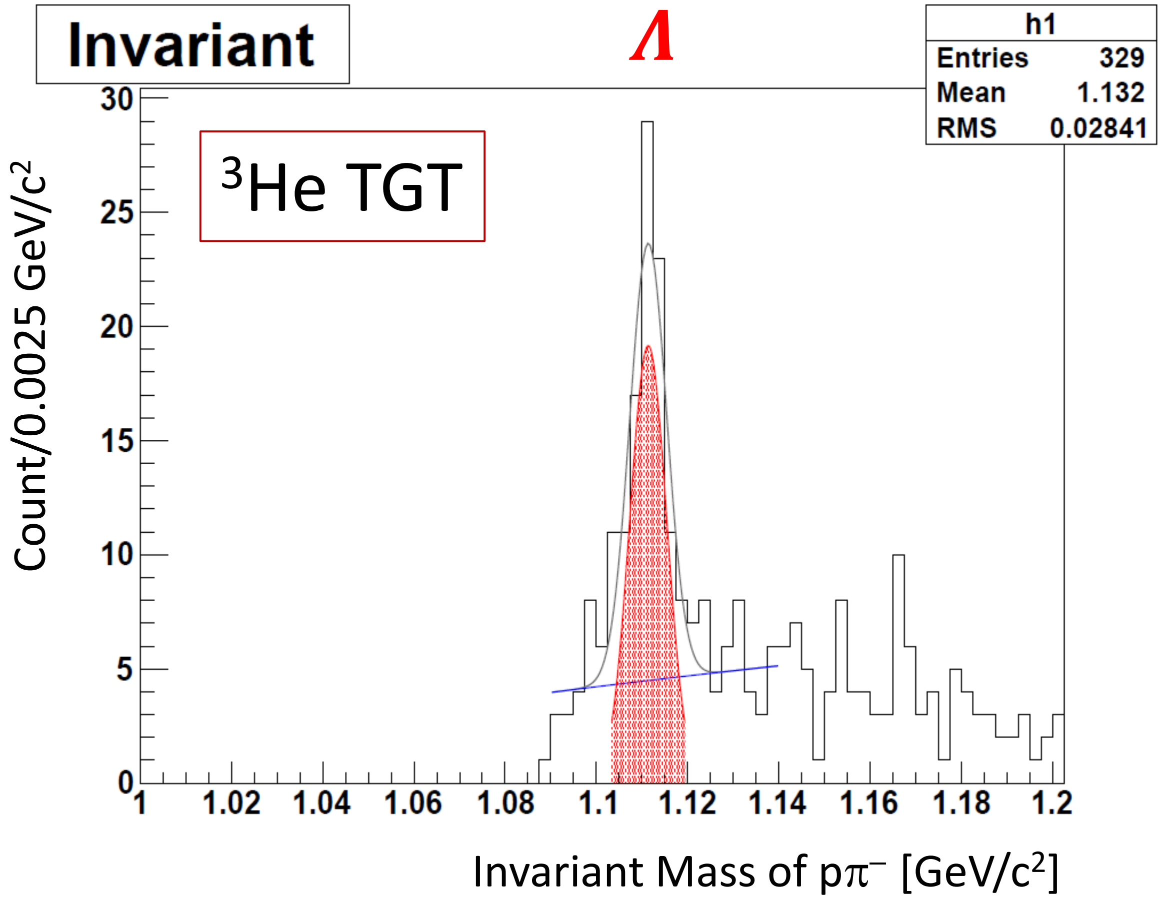
Experimental Issue

- Separated spectra in the final states
  Isospin decomposition
  - $\pi^{\pm}\Sigma^{\mp}$ identification separately to provide
    - I=1/I=0, interference term
    - S-wave Scattering? by Decay Angular Dist. (GJ frame)
  - $\pi^0\Sigma^0$ (I=0) analysis in progress
    - $\pi^0\Lambda$ (I=1), too.
    - Need statistics -> future beam time
  - $\pi\Lambda$ (I=1) mode : Σ^* sensitive to p-wave contribution?
- IM($\pi^{\pm}\Sigma^{\mp}$) analysis in event sample "$\pi^{\pm}\pi^{\mp}n$"
  - Angular distribution of Y* production
    - Need statistics -> future beam time

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

- BPD(p)+CDS(π^-)





Theoretical Analysis

- *What is ambiguous?*
  - *How tunable is the I=0/I=1 amplitude?*
  - *P-wave contribution (should be small?)*
- *Full calculation?*
  - *Faddeev?*
    - *Higher L btwn $\pi\Sigma$? (Difficult)*
    - *Validity of the S-wave $\bar{K}N \rightarrow \pi\Sigma$ is important.*
  - *Any other?*
    - *Green's Function Method …*
    - *Coupled channel*

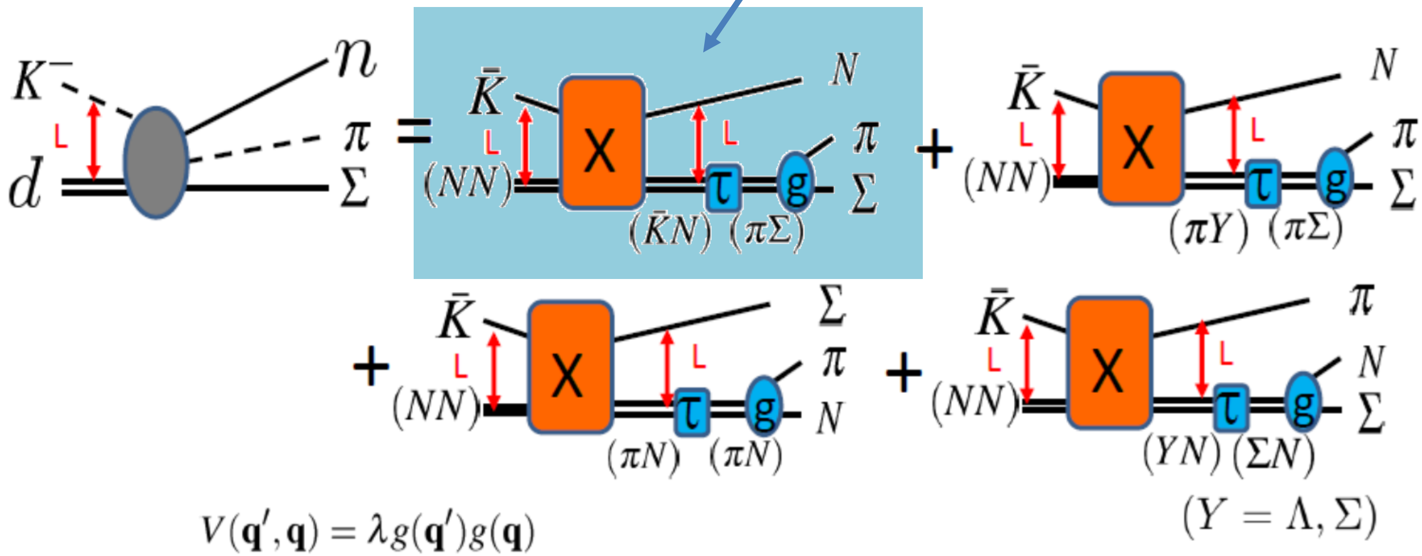
Faddeev Cal. (AGS)

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

Dominant at θ_n=0

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

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



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

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

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

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

What is next?

- *E31 should provide conclusive data for the $\overline{K}N$ interaction/pole…*
  - $\overline{K}N \rightarrow \pi^{\pm,0}\Sigma^{\mp,0}, \pi^0\Lambda$
- *How to conclude if double pole structure…*
  - *The $\pi\Sigma$ pole?*
  - *How to approach?*
  - *Different momentum (Δq) is helpful?*