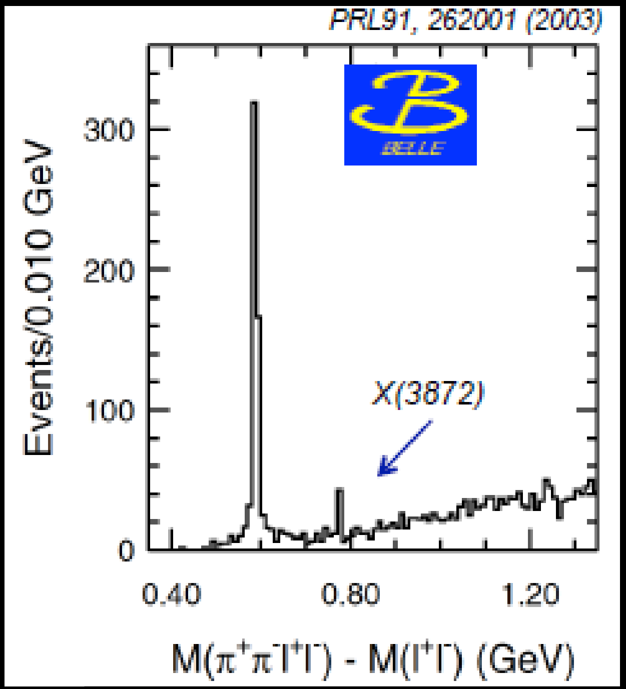
“3rd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics”, Collegium Maius
24-28 June, 2019

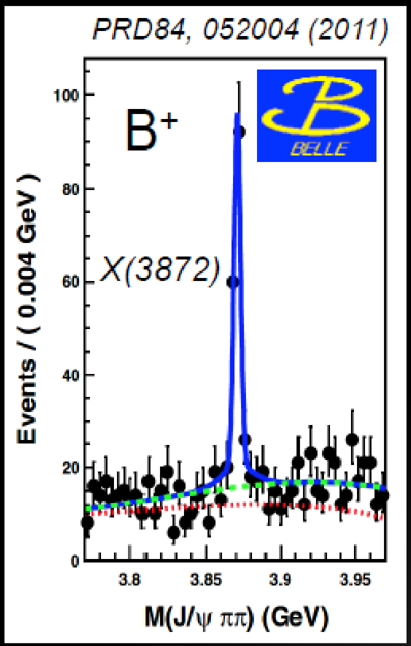
Experimental Study of $\Lambda(1405)$ resonance via kaon-induced reactions on deuteron

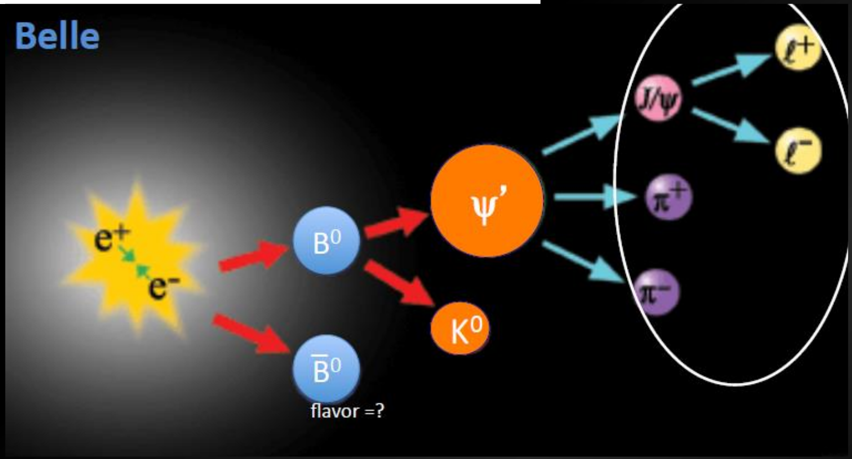
Hiroyuki Noumi[*,#] for the J-PARC E31 collaboration

* *RCNP, Osaka University*
[#] *Institute of Particle and Nuclear Studies, KEK*

X(3872)

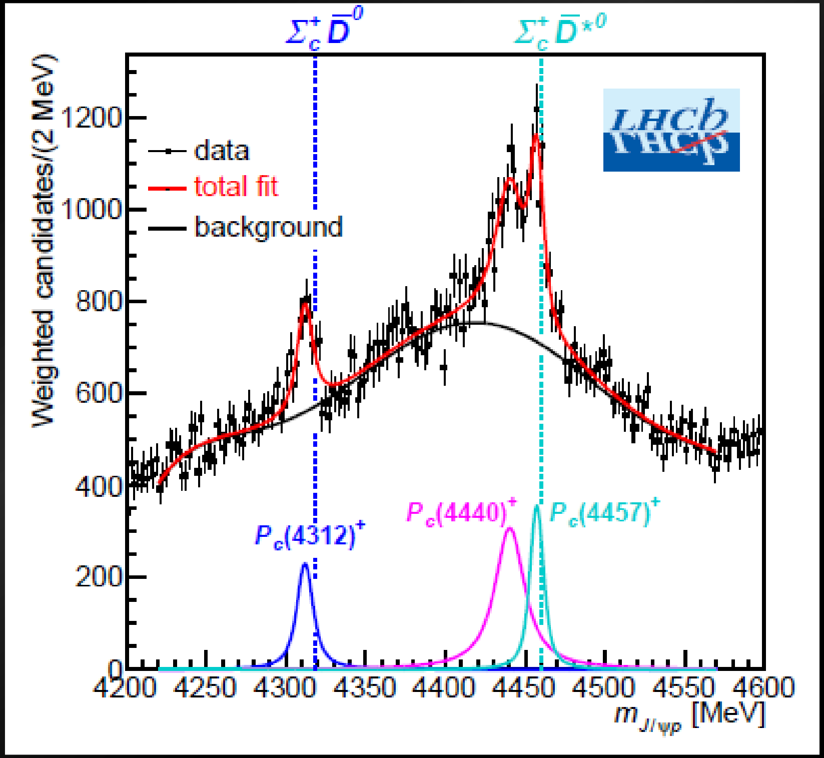






Pc's

arXiv:1904.03947

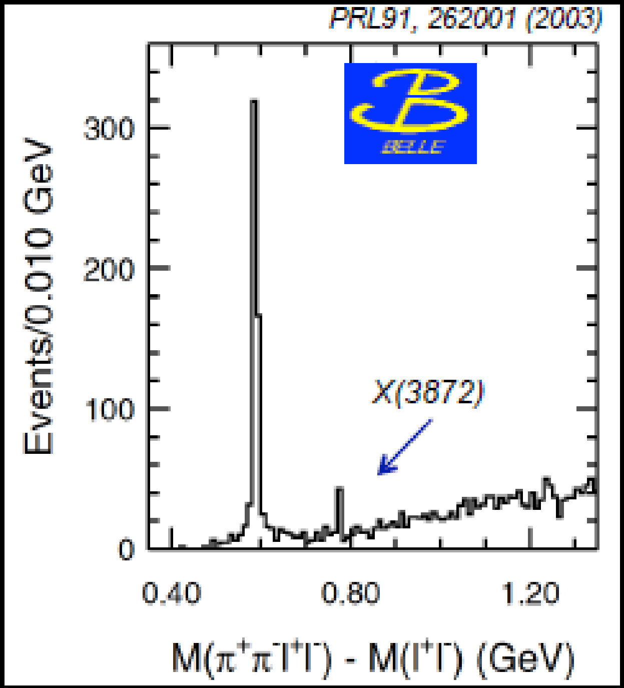


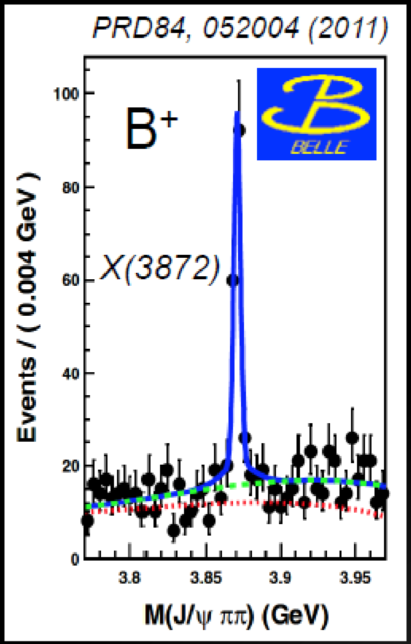
X(3872)

$\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$ molecular state
Phys. Rev. D92,094003 (2015)

$\bar{D}\Sigma_c$, $\bar{D}^*\Sigma_c$ states
Phys.Rev.Lett. 122 (2019) 242001
……

Pc's





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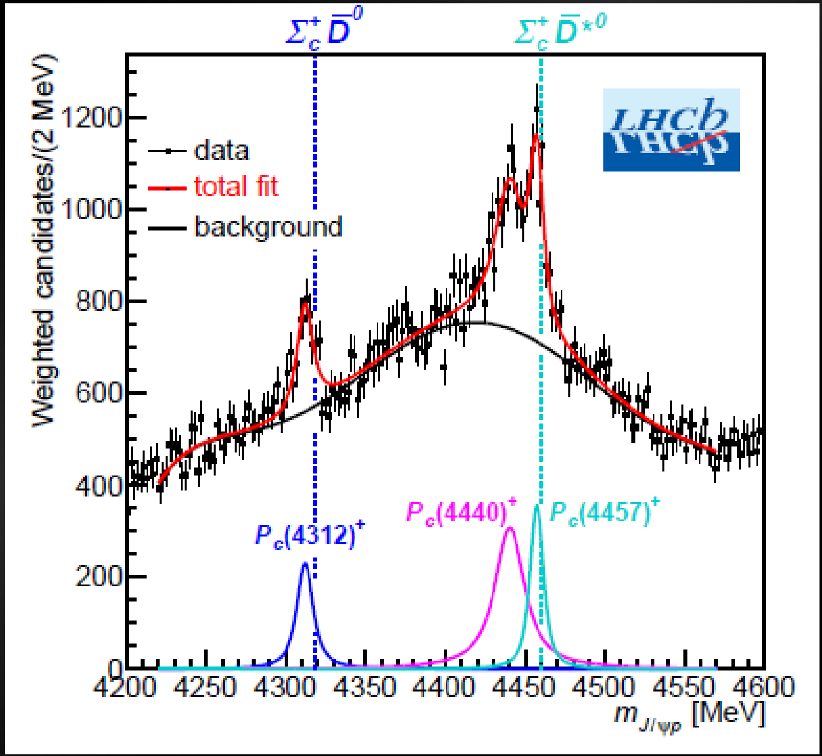
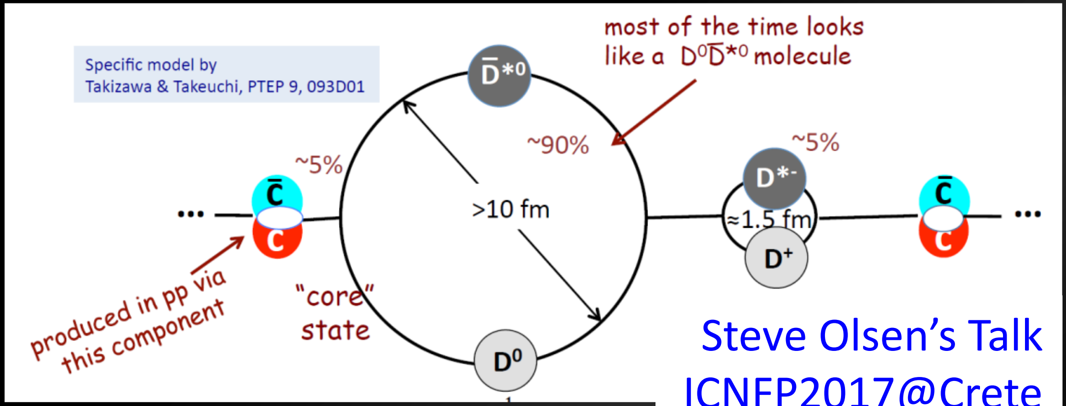
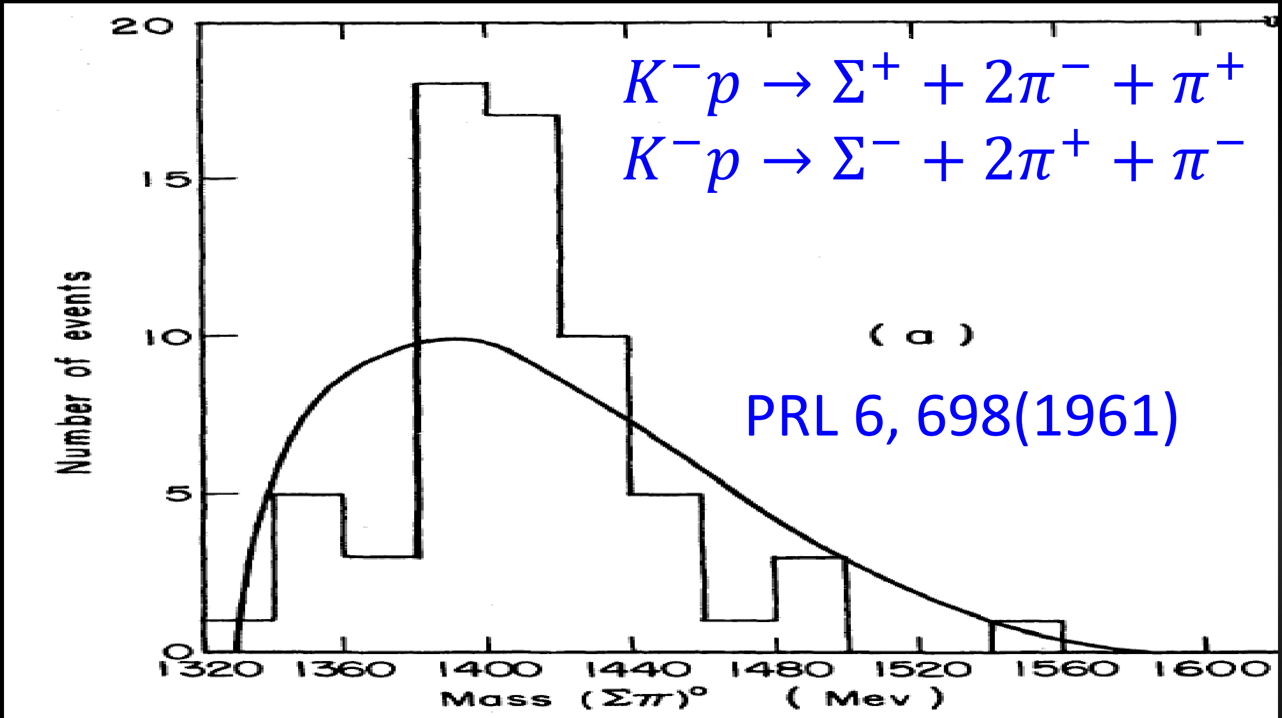




Steve Olsen's Talk
ICNFP2017@Crete

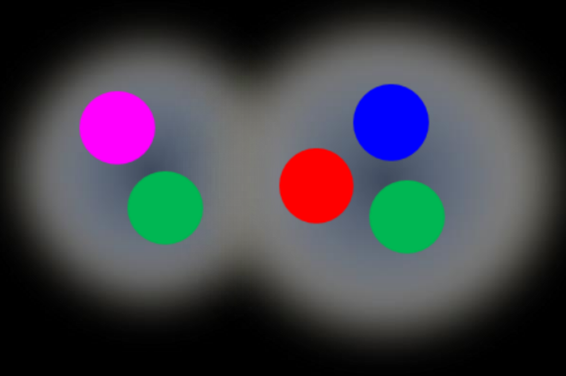
Λ(1405) since 1961

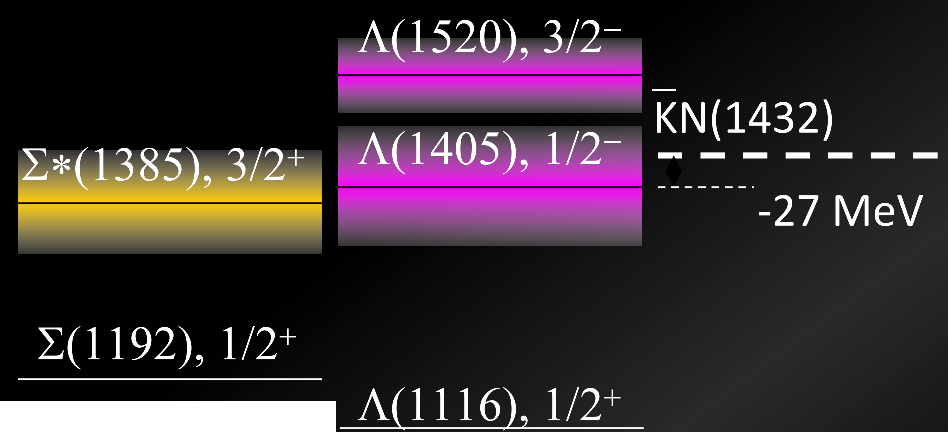


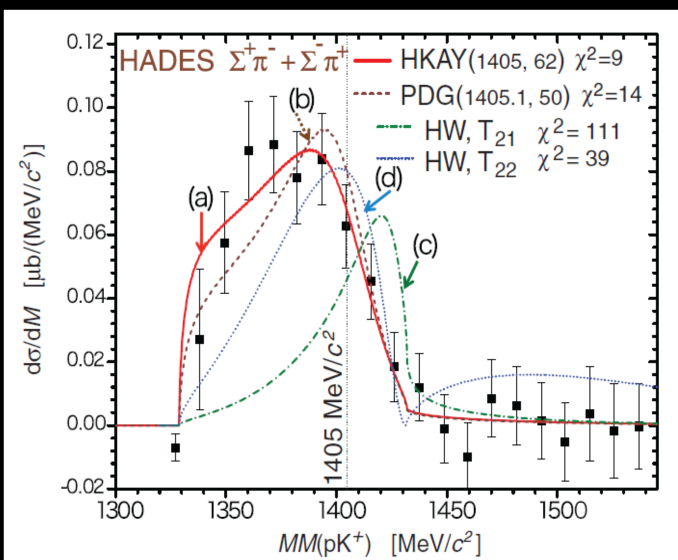
- Well-known lightest Hyperon Resonance w/ a negative parity, sitting just below the KbarN mass threshold

$\Lambda(1405)$: $1405.1^{+1.3}_{-0.9}$ MeV (PDG in 2019)

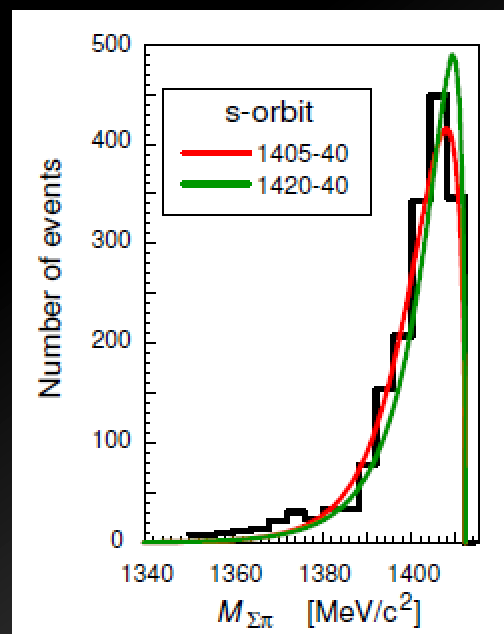
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{\bar{K}N}$, lightest in neg. parity baryons



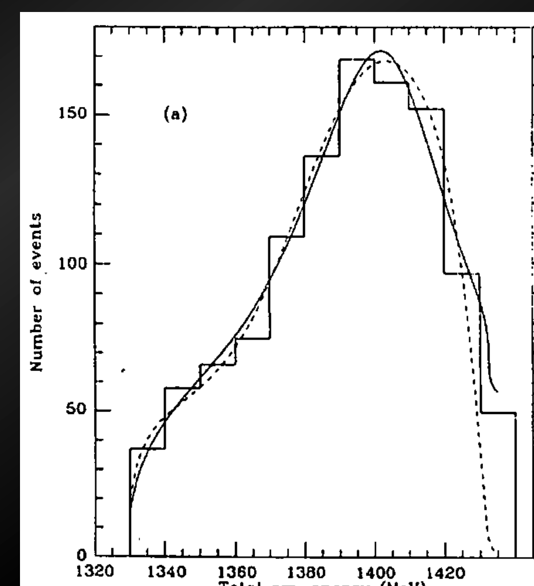




M. Hassanvand et al: $\pi\Sigma$ IM Spec. of pp→$K^+\pi\Sigma$



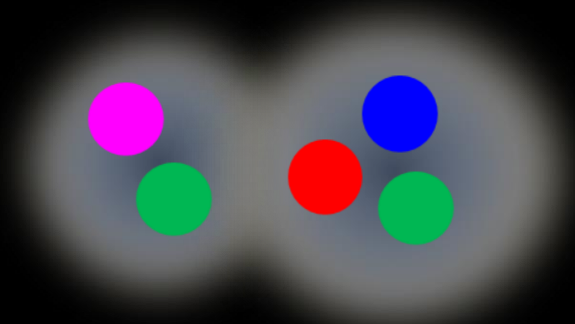
J. Esmaili et al: $\pi\Sigma$ IM Spec. of Stopped K^- on ^{4}He

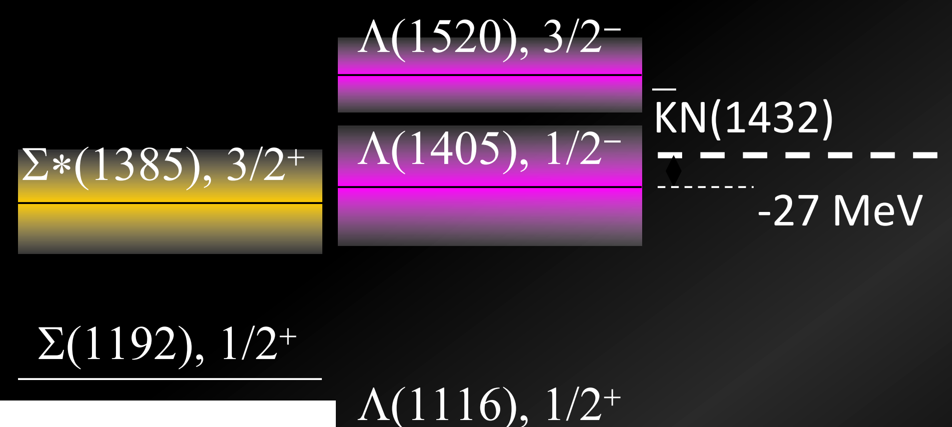


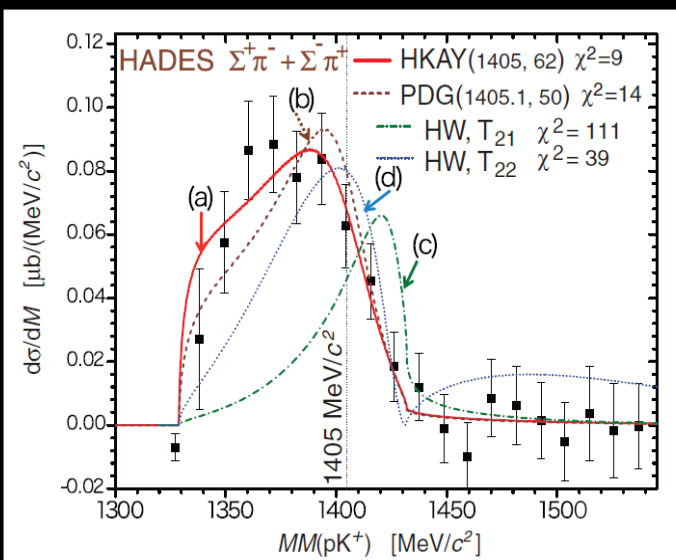
R.H. Dalitz et al: $\pi\Sigma$ IM Spec. in K-p→$\pi\pi\Sigma$ w/ M-matrix

$\Lambda(1405)$: $1405.1^{+1.3}_{-0.9}$ MeV (PDG in 2019)

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







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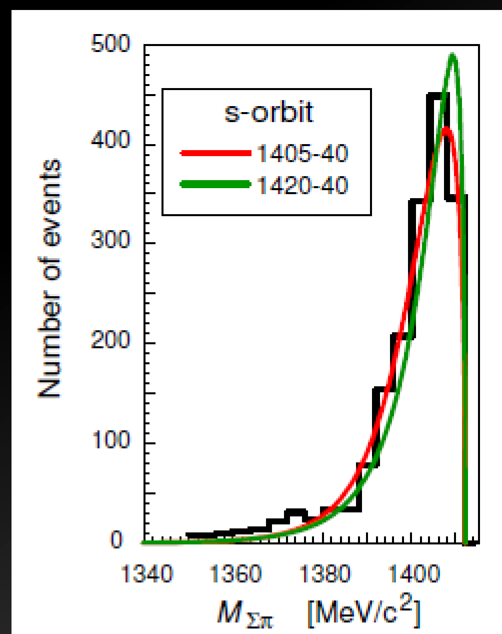

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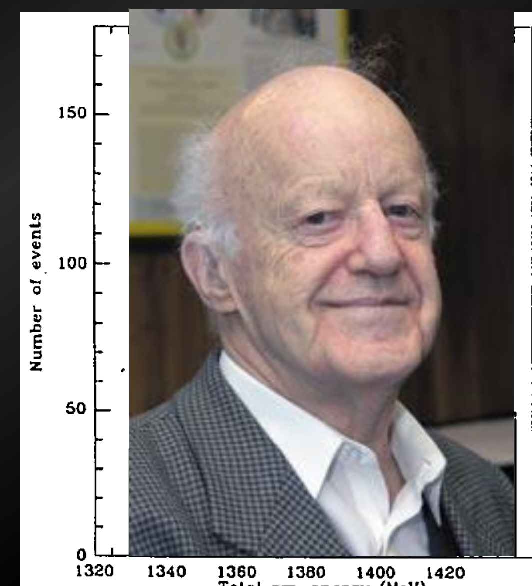
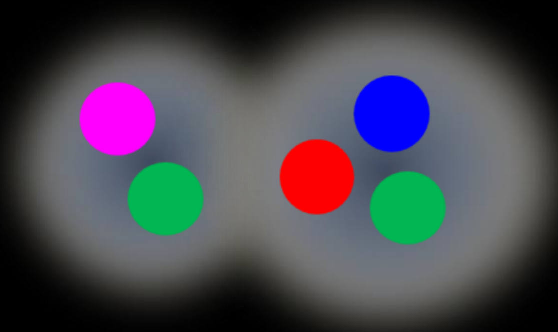
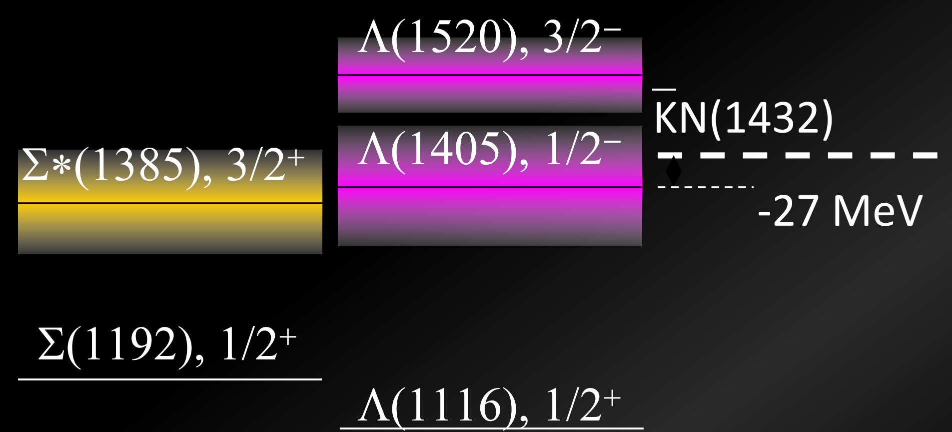


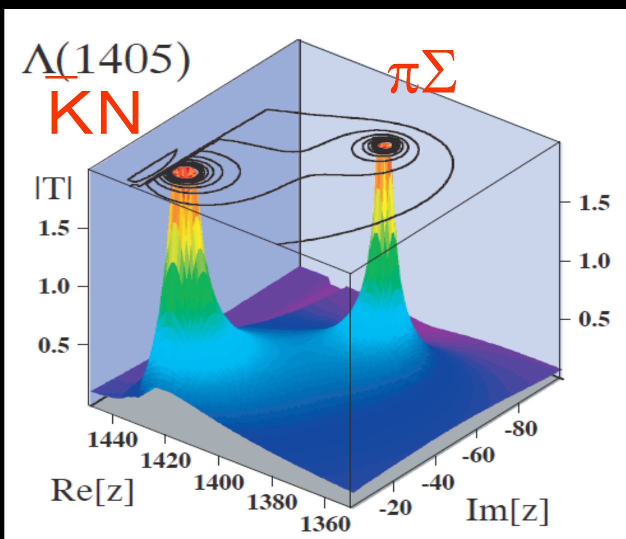
R.H. Dalitz et al: $\pi\Sigma$ IM Spec. in K-$p \to \pi\pi\Sigma$ w/ M-matrix

Λ(1405) : Double pole?

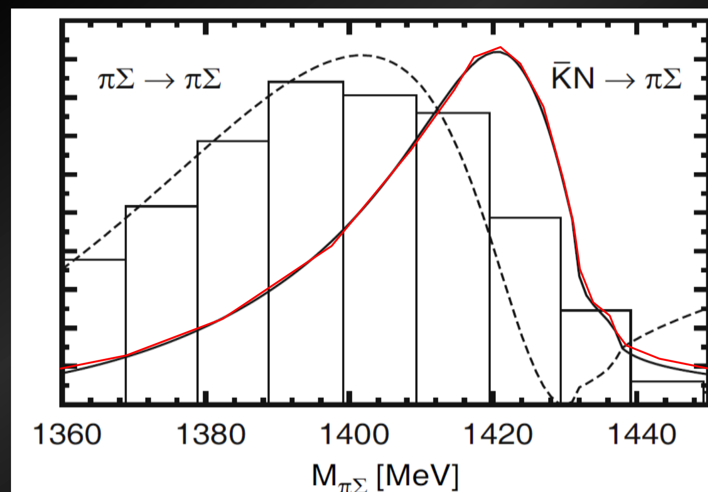
$J^P = \frac{1}{2}^-$, $I = 0$, $M_{\Lambda(1405)} < M_{KbarN}$, lightest in neg. parity baryons





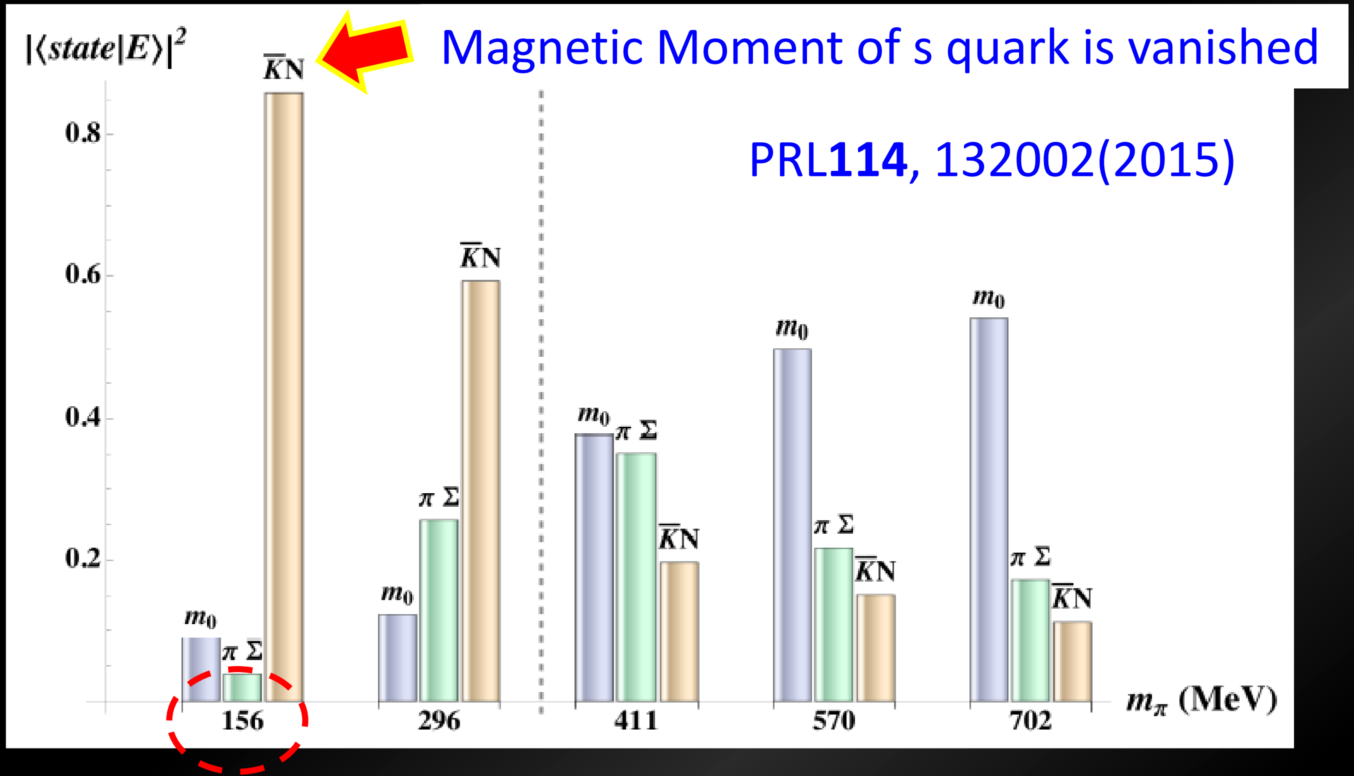


ChU model, T. Hyodo



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

LQCD Evidence that Λ(1405) is a $K^{bar}N$ molecule



- Study of $K^{bar}N$ scattering below the $K^{bar}N$ thres. are important.

Pole Structure of the Lambda(1405) Region

PDG Reviews: Ulf-G. Meissner and T. Hyodo (Nov. 2015)

Table 1: Comparison of the pole positions of $\Lambda(1405)$ in the complex energy plane from next-to-leading order chiral unitary coupled-channel approaches including the SIDDHARTA constraint.

approach	pole 1 [MeV]	pole 2 [MeV]
Refs. 11,12, NLO	$1424^{+7}_{-23} - i\ 26^{+3}_{-14}$	$1381^{+18}_{-6} - i\ 81^{+19}_{-8}$
Ref. 14, Fit II	$1421^{+3}_{-2} - i\ 19^{+8}_{-5}$	$1388^{+9}_{-9} - i\ 114^{+24}_{-25}$
Ref. 15, solution #2	$1434^{+2}_{-2} - i\ 10^{+2}_{-1}$	$1330^{+4}_{-5} - i\ 56^{+17}_{-11}$
Ref. 15, solution #4	$1429^{+8}_{-7} - i\ 12^{+2}_{-3}$	$1325^{+15}_{-15} - i\ 90^{+12}_{-18}$

$\Lambda(1405)$: $1405.1^{+1.3}_{-1.0}$ MeV (Part. Listing in '19)

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

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

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R.H. Dalitz et al: $\pi\Sigma$ IM Spec. in $K^-p \rightarrow \pi\pi\Sigma$ w/ M-matrix

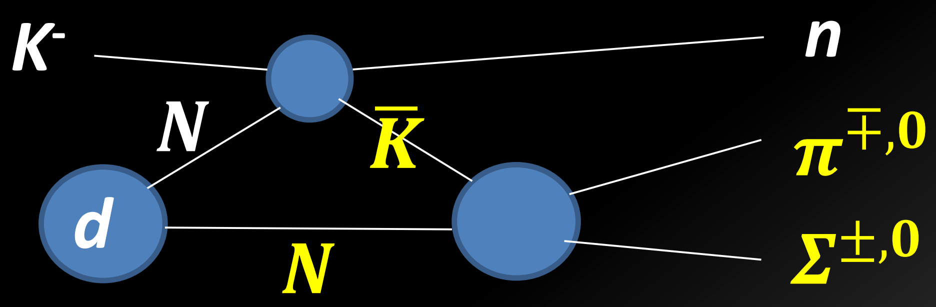
Questions on $\Lambda(1405)$

- $K^{bar}N$ int. and its pole position are still unclear.
  - Basic information on Kaonic Nuclei
- Not yet demonstrated if it is a molecular state.
  - To establish it as an exotic state
    - Hadron Picture in excited states
    - New question related to classification in CQM
  - Formation probability in hadronization
    - ExHIC (Phys.Rev. C84 (2011) 064910)

Important to study Low Energy $K^{bar}N$ scattering

K^barN scattering below the K^barN thres. (J-PARC E31)

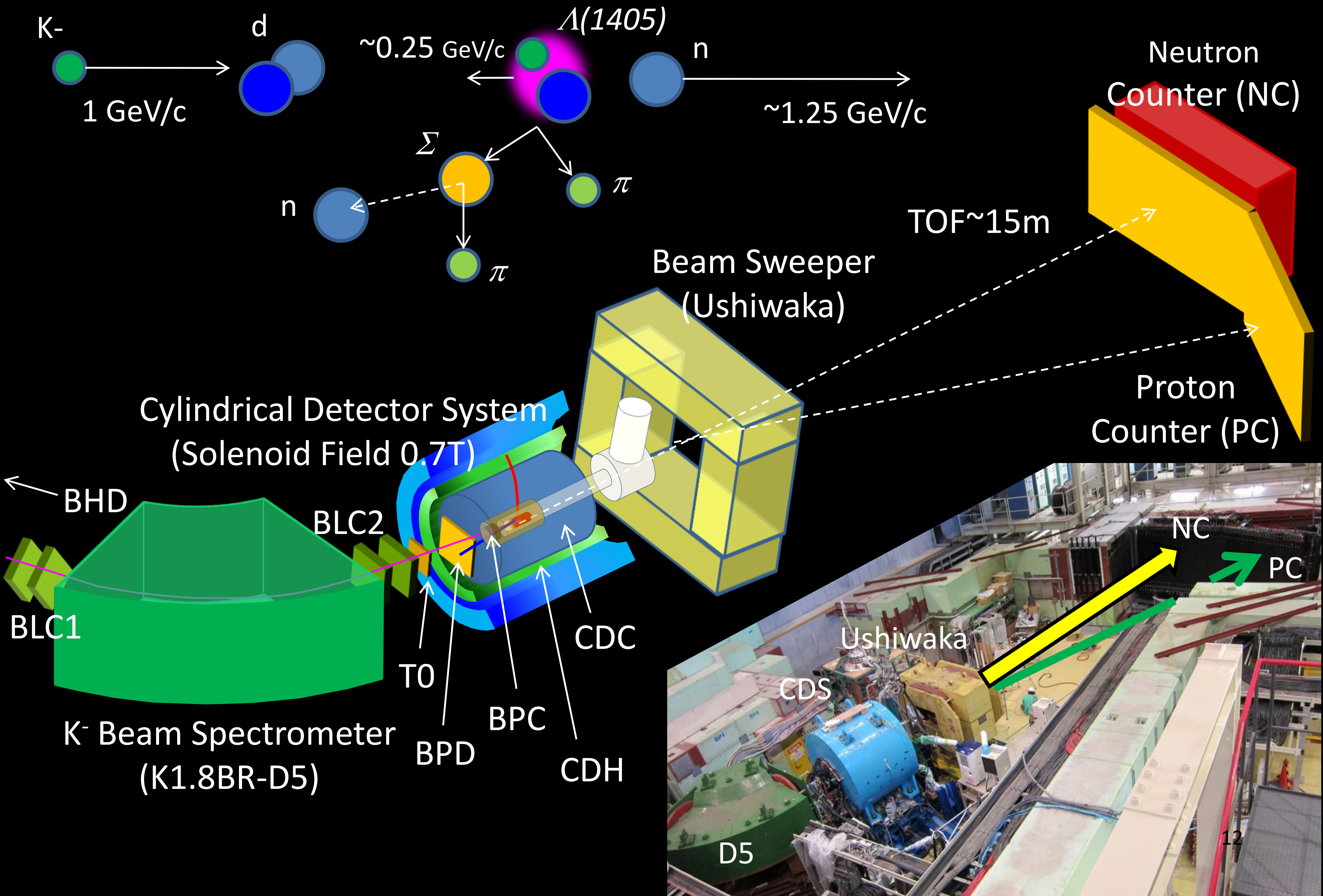
- measuring an *S*-wave $\bar{K}N \rightarrow \pi\Sigma$ scattering below the $\bar{K}N$ threshold in the *d*(*K*⁻,*n*)$\pi\Sigma$ reactions at a forward angle of *n*.



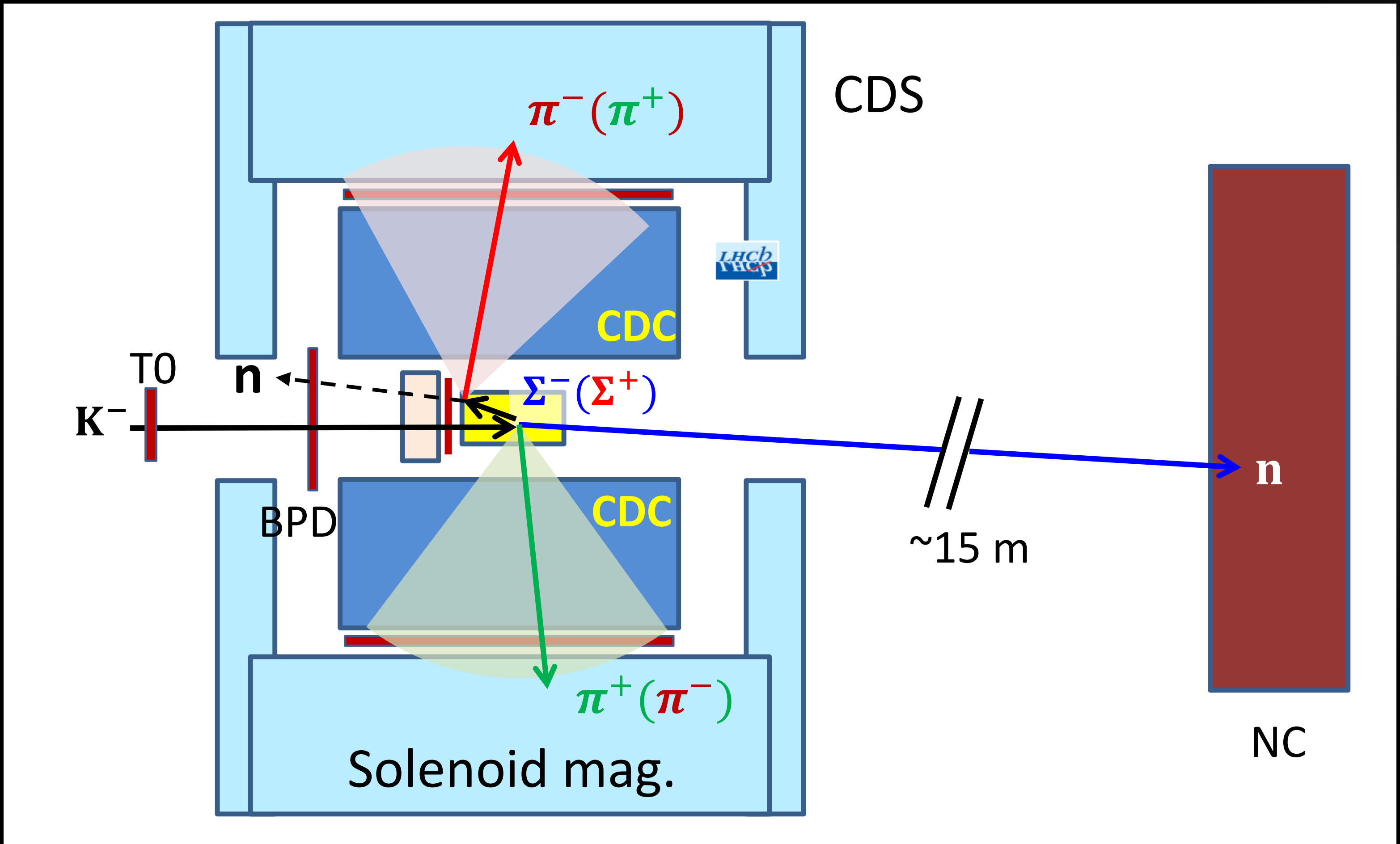
- ID's all the final states to decompose the I=0 and 1 ampl's.

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

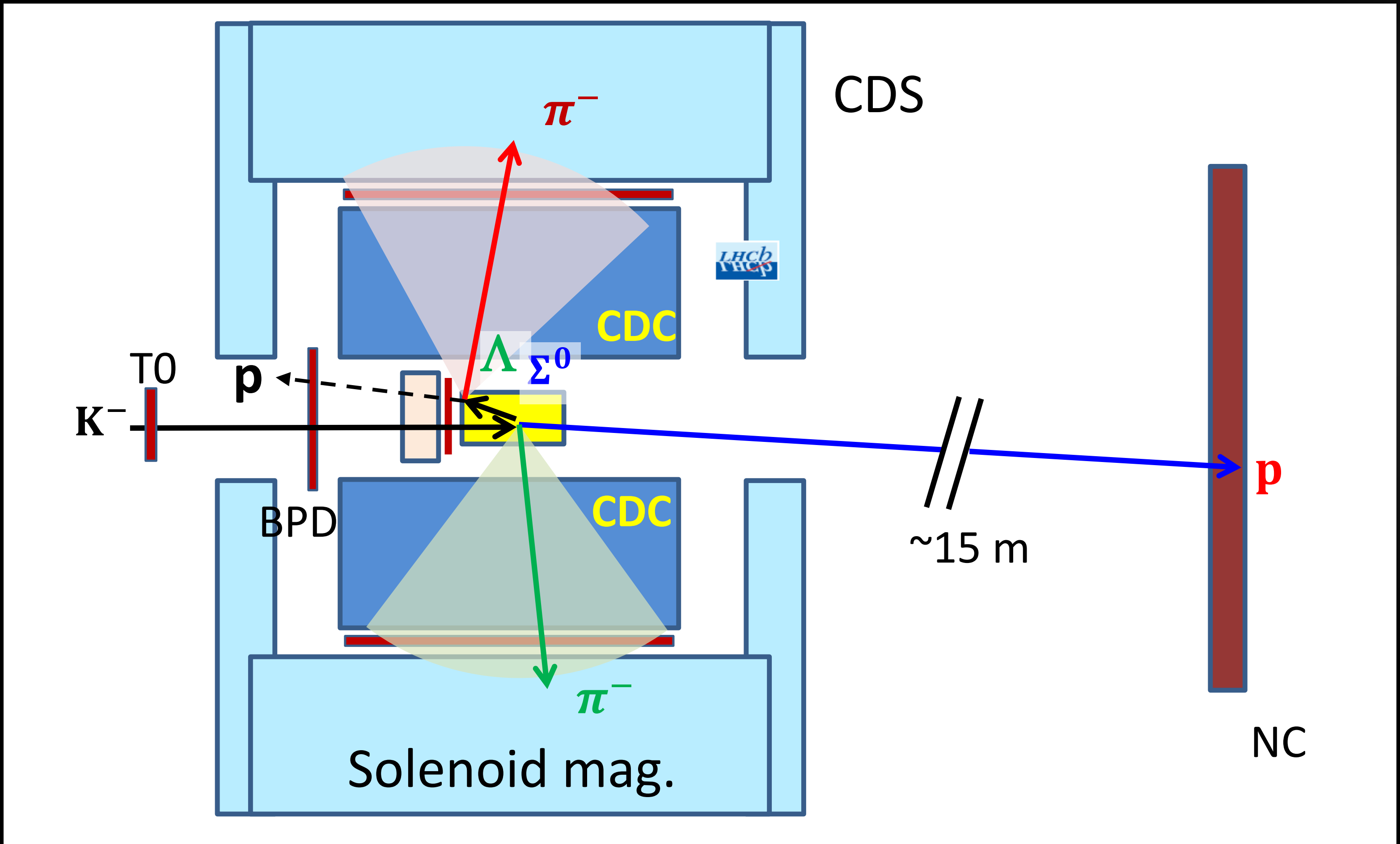
Experimental Setup for E31



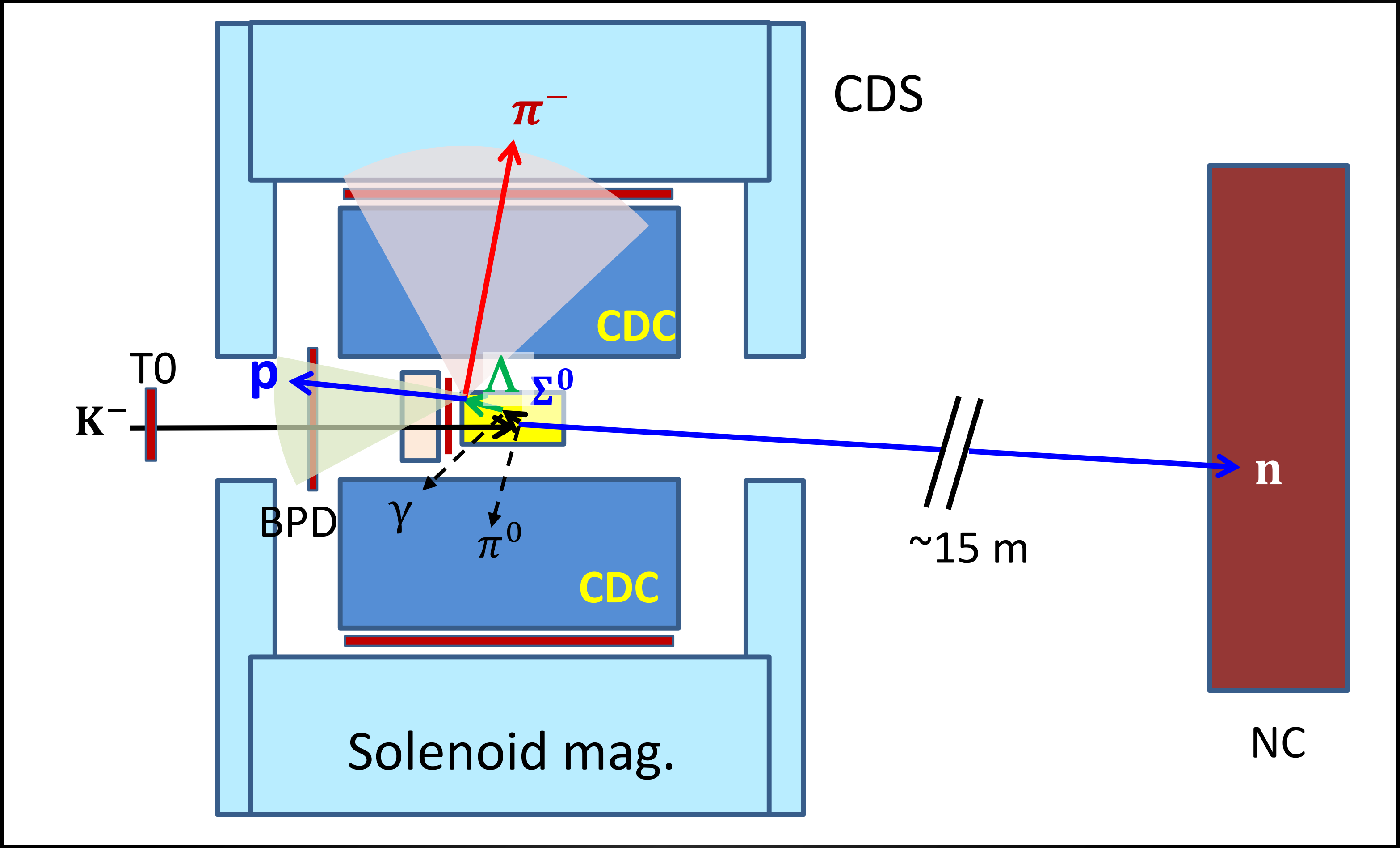
Event topology of $d(K^-, n)X_{\pi^\pm\Sigma^\mp}$



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



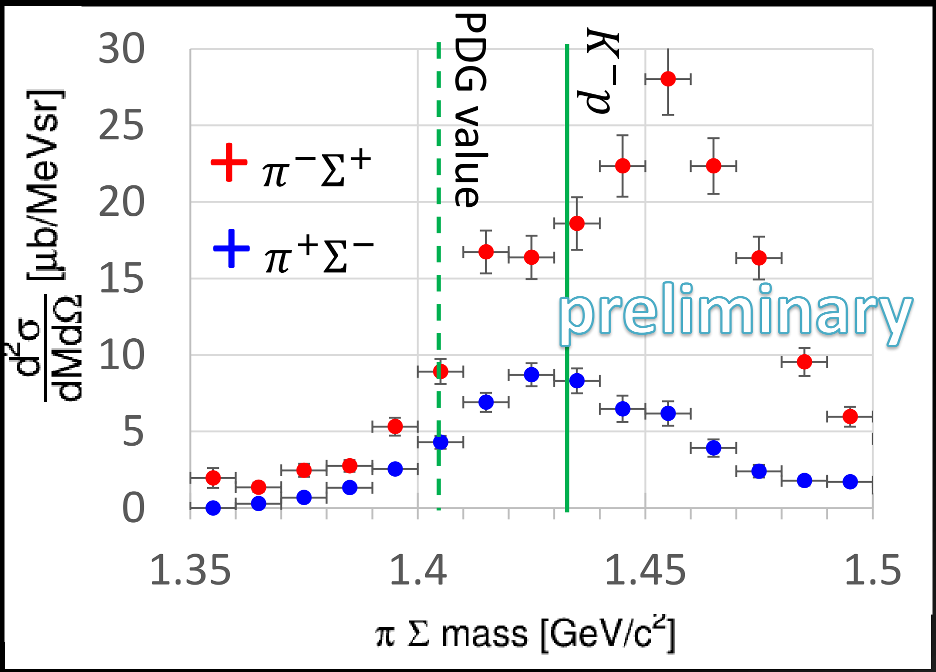
Event topology of $d(K^-, n)X_{\pi^0\Sigma^0}$

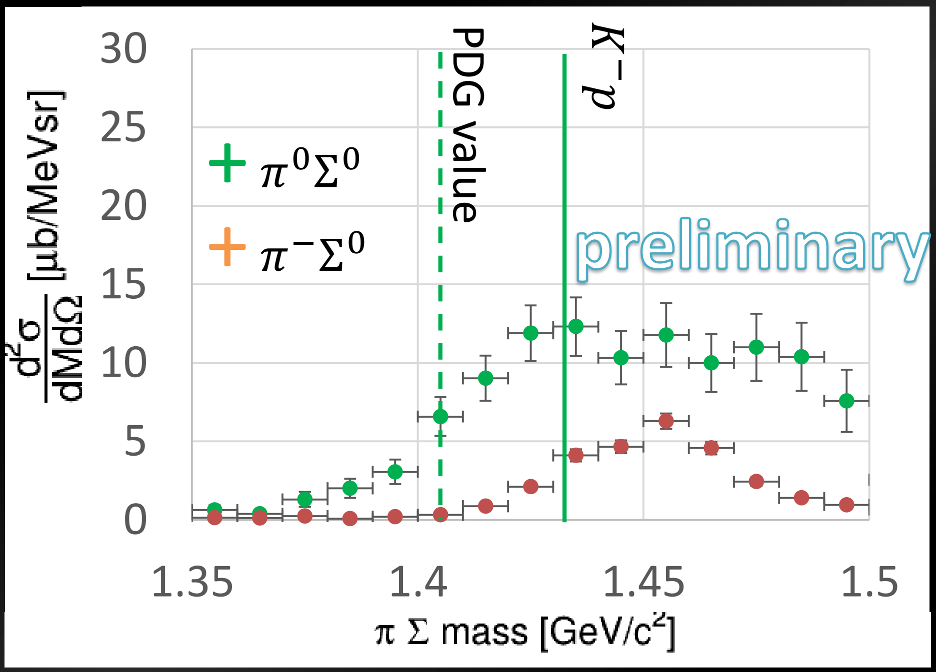


BG Process: $d(K^-, n)X_{\pi^0\Lambda}$, $d(K^-, n)X_{\pi^0\pi^0\Lambda}$,
$d(K^-, n)X_{\pi^-\Sigma^+}$, $d(K^-, \Sigma^- p)X$

$\pi^+\Sigma^-/\pi^-\Sigma^+$ $(I=0,1)$

$\pi^0\Sigma^0(I=0)$ $\pi^-\Sigma^0(I=1)$





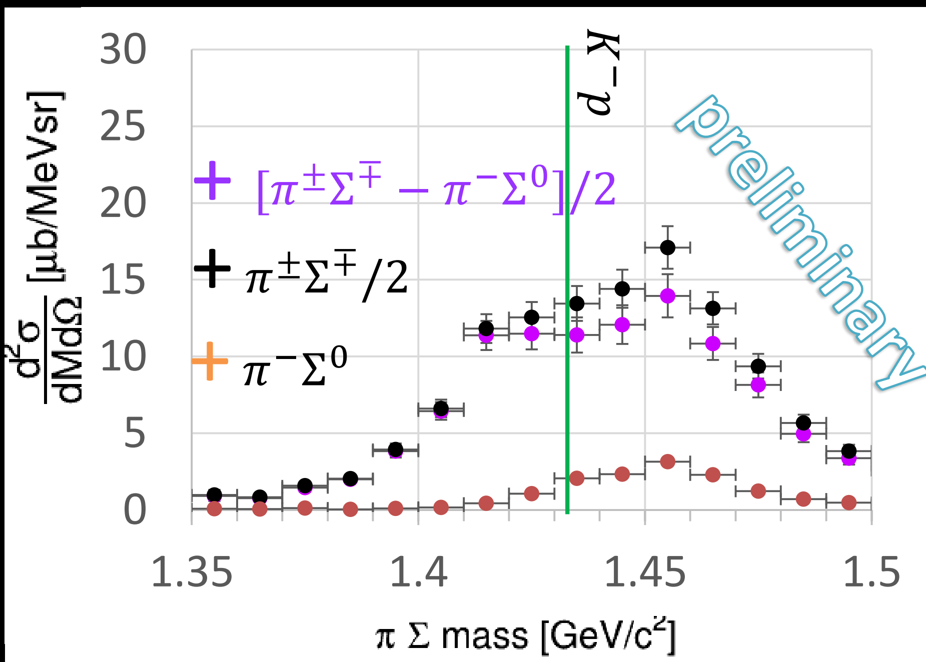
$$\frac{d\sigma}{d\Omega}(\pi^-\Sigma^+/\pi^+\Sigma^-) \propto \frac{1}{3}|f_{I=0}|^2+\frac{1}{2}|f_{I=1}|^2 \pm \frac{\sqrt{6}}{3}Re(f_{I=0}f_{I=1}^*)$$

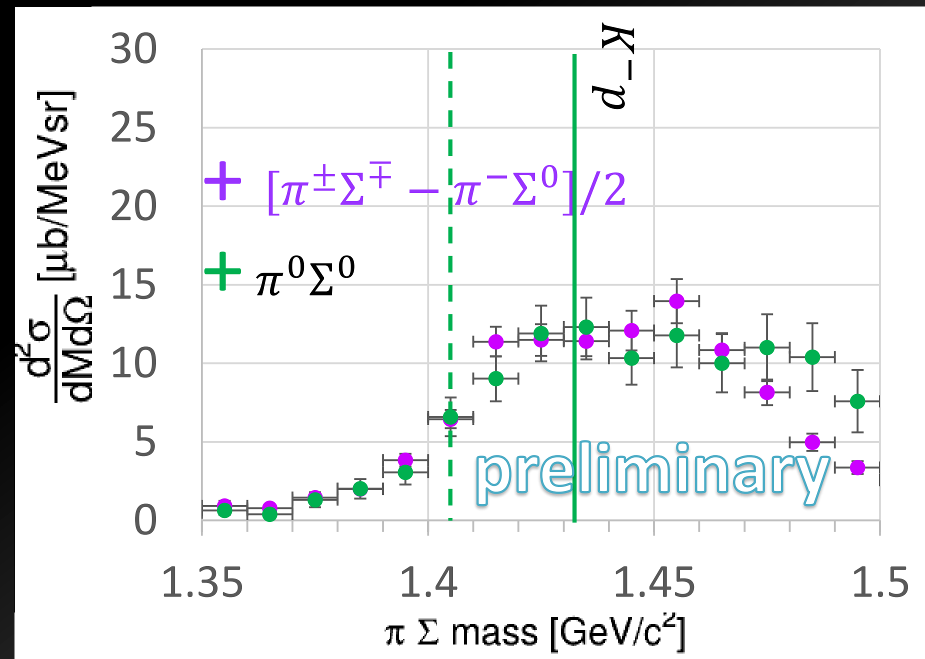
$$\frac{d\sigma}{d\Omega}(\pi^0\Sigma^0) \propto \frac{1}{3}|f_{I=0}|^2$$

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

$$\pi^{\pm}\Sigma^{\mp}/2\ (I=0,1) \qquad \pi^0\Sigma^0 (I=0)$$

$$[\pi^{\pm}\Sigma^{\mp}-\pi^{-}\Sigma^{0}]/2\ (I=0)$$





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

$$\frac{d\sigma}{d\Omega}([\pi^{\pm}\Sigma^{\mp}-\pi^{-}\Sigma^{0}]/2) \propto \frac{1}{3}|f_{I=0}|^2$$

$$\frac{d\sigma}{d\Omega}([\pi^{\pm}\Sigma^{\mp}-\pi^{-}\Sigma^{0}]/2) \propto \frac{1}{3}|f_{I=0}|^2$$

$$\frac{d\sigma}{d\Omega}(\pi^{0}\Sigma^{0}) \propto \frac{1}{3}|f_{I=0}|^2$$

Remarks

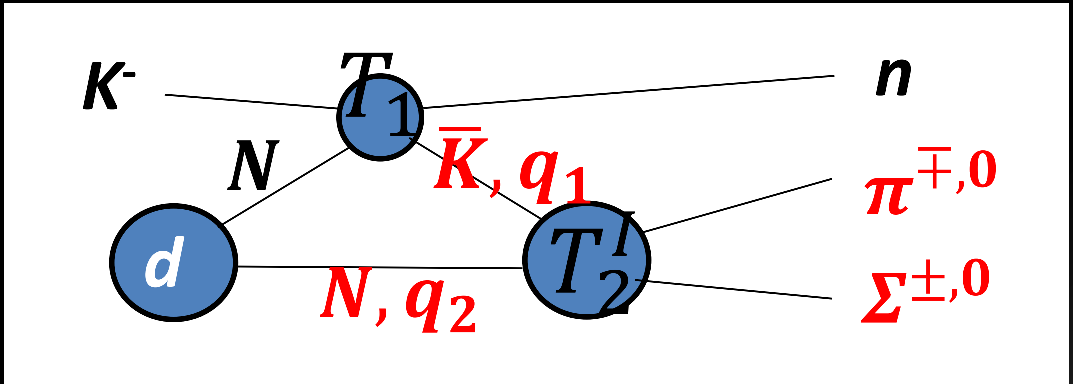
- We first measured a complete set of $\bar{K}N \rightarrow \pi\Sigma$ data below and above the $\bar{K}N$ threshold.
  - We are very close to finalize the spectra.
- Structures below and above the $\bar{K}N$ threshold are observed in $d(K^-,n)X_{\pi^\pm\Sigma^\mp}$
  - Interference btw I=0 and 1.
  - I=0 amp. seems dominant in $\pi^\pm\Sigma^\mp$ modes.
    - From measured pure I=1 channel, $d(K^-,p)X_{\pi^-\Sigma^0}$.

Outlook
(instead of summary)

Pole position?

- $K^{bar}N$ Scattering Amplitudes to be extracted
- How to decompose the I=0 and 1 amps.
  – Significant yield nearby the $K^{bar}N$ threshold but no clear peak structure
  – A simple “BW + Some plausible function” seems too naïve to explain the spectra…

To deduce $\bar{K}N$ scattering amplitude



$$\left.\frac{d\sigma}{dM_{\pi\Sigma}}\right|_{\theta_n=0} \sim |\langle n\pi\Sigma| T_2^I(\bar{K}N,\pi\Sigma) g_2 G_0 g_1 T_1(K^- N,\bar{K}N) |K^-\Phi_d\rangle|^2$$

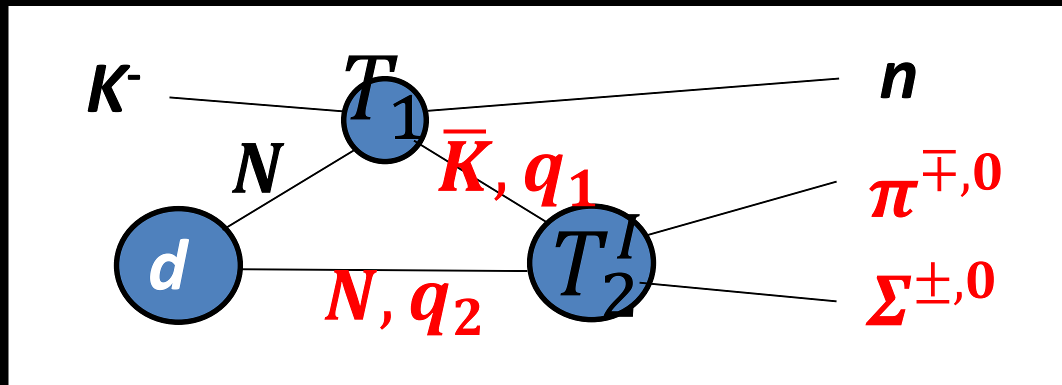
$$\sim \left|T_2^I\right|^2 F_{QF}(M_{\pi\Sigma})$$

$$T_{12} = \frac{1}{\sqrt{k_1}} e^{i\delta_0} \frac{\sqrt{ImA - \frac{1}{2}|A|^2 ImR k_2^2}}{1 - iAk_2 + \frac{1}{2}ARk_2^2} \quad (\bar{K}N \to \pi\Sigma)$$

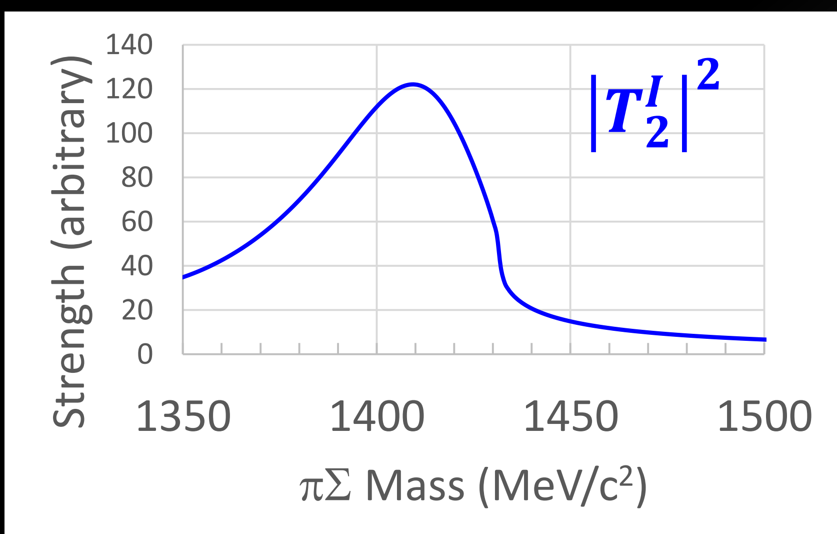
$$T_{22} = \frac{A}{1 - iAk_2 + \frac{1}{2}ARk_2^2} \quad (\bar{K}N \to \bar{K}N)$$

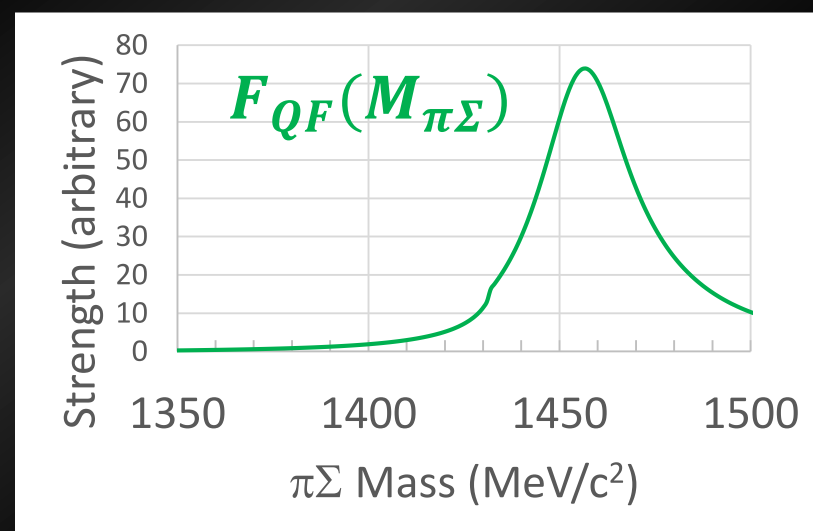
L. Lensniak, arXiv:0804.3479v1(2008)

To deduce $\bar{K}N$ scattering amplitude



$$\left.\frac{d\sigma}{dM_{\pi\Sigma}}\right|_{\theta_n=0} \sim \left|T_2^I\right|^2 F_{QF}(M_{\pi\Sigma})$$





Form Factor of $\Lambda(1405)$?

- To resolve "Not yet demonstrated if it is a molecular state"…
- Angular Distribution may provide a hint…

…as is the case for "K-pp"