Studies of exotic baryons with hadron beams at J-PARC

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Today's Exotic Baryons

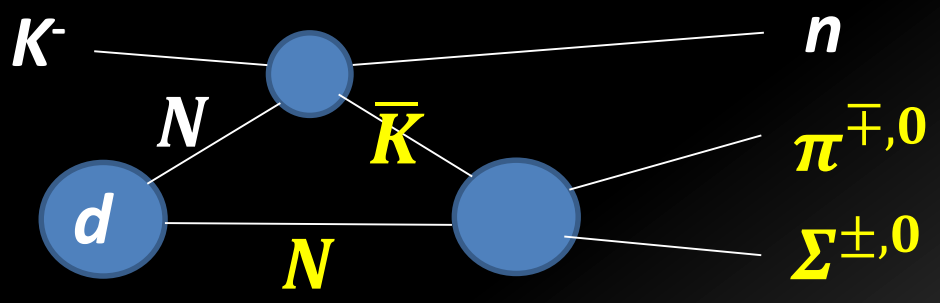
- $\Lambda(1405)$
  - With a Low-E Kaon beam
    - $K^{bar}N$ interaction and exotic hyperon
  - With a High-E pion beam
    - production and exotic hyperon
- P_c^0
  - With a High-E pion beam

Still $\Lambda(1405)$?

- $K^{bar}N$ int. and its pole position are still unclear.
  - Basic information on Kaonic Nuclei
- Not yet demonstrated if it is a molecular state.
  - Needed 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)

E31 aims at:

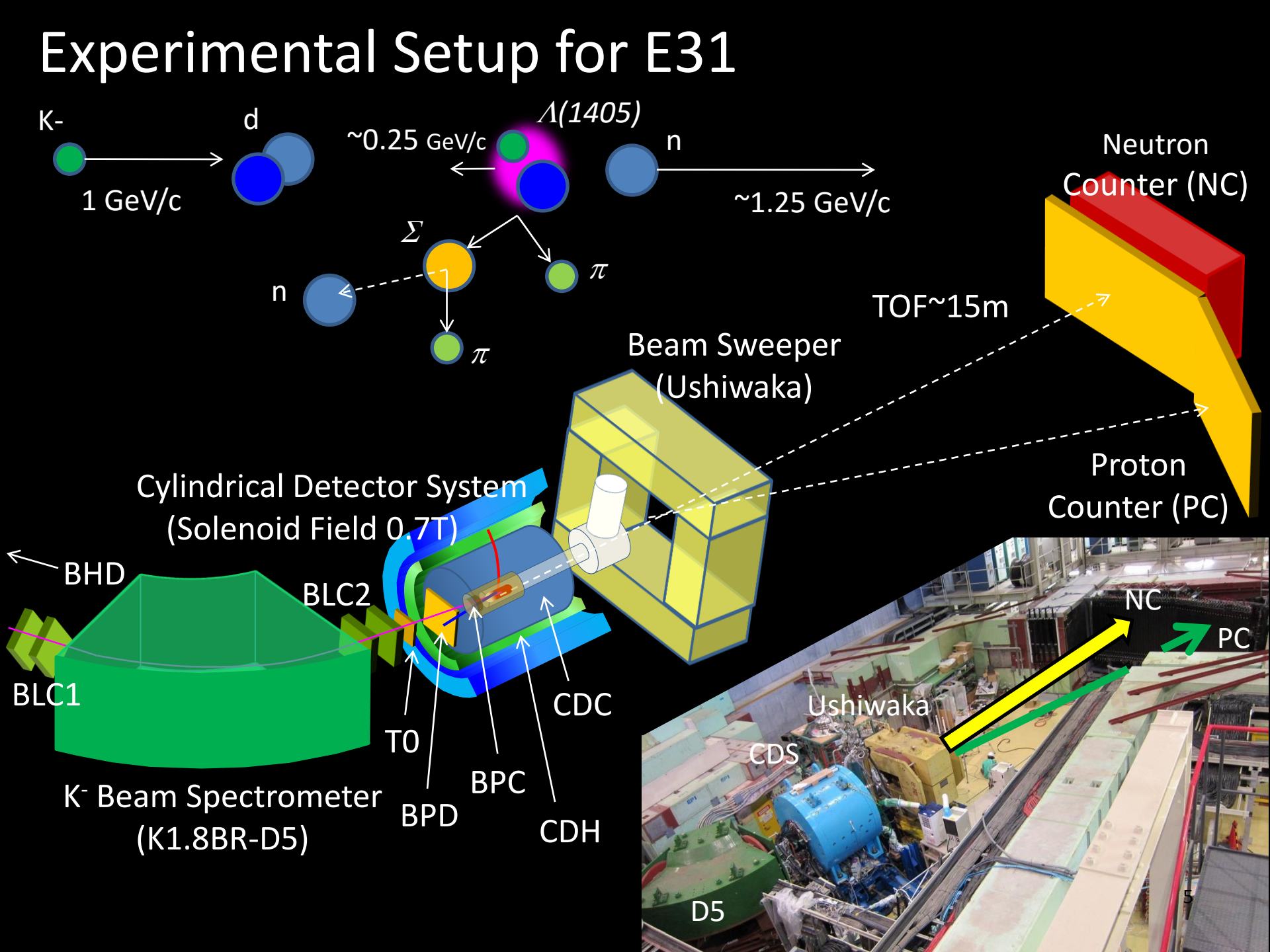
- measuring an *S*-wave $\bar{K}N \rightarrow \pi\Sigma$ scattering below the $\bar{K}N$ threshold in the $d(K^-,n)\pi\Sigma$ reactions at a forward angle of *n*.



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

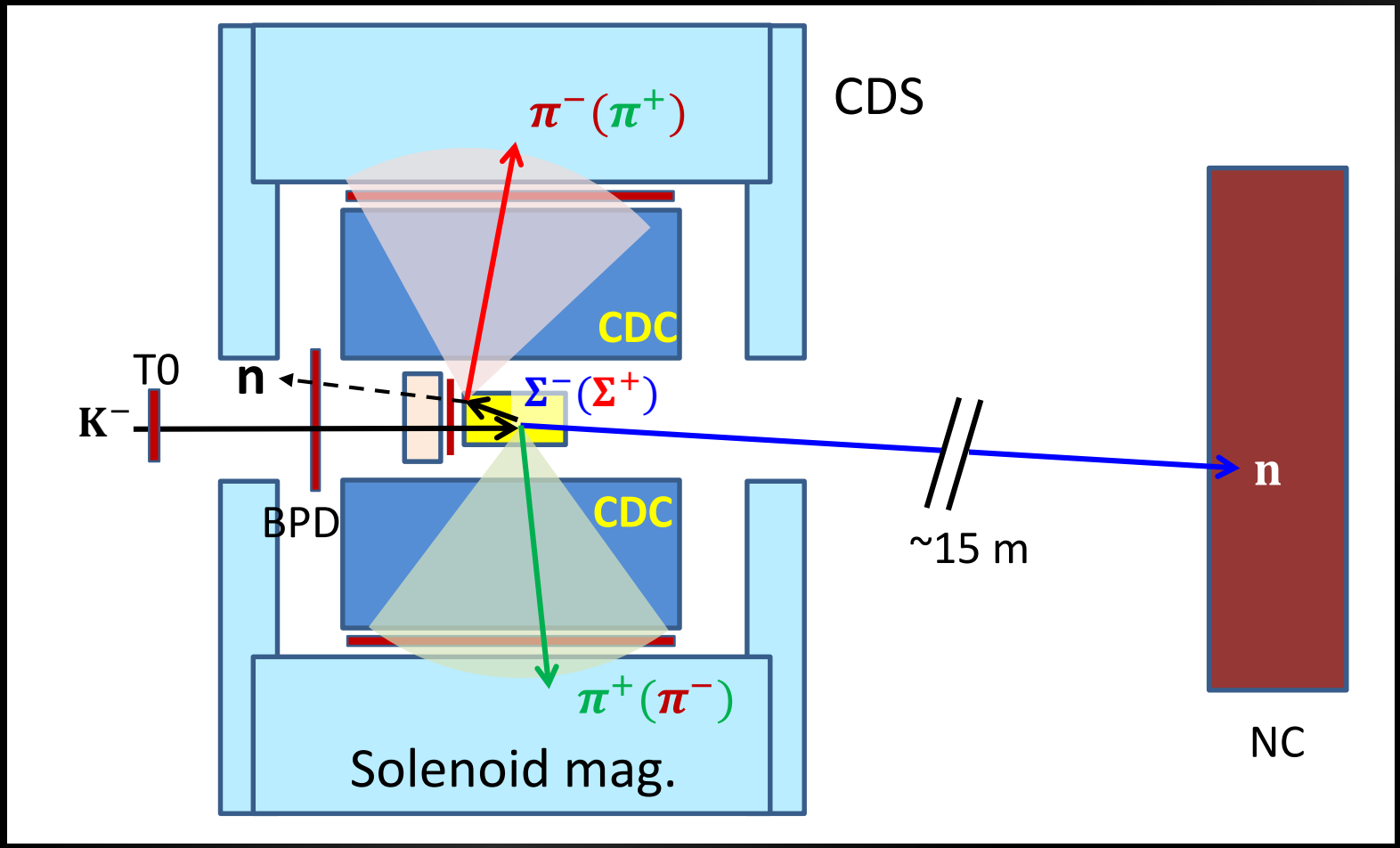
$\pi^{\pm}\Sigma^{\mp}$	I=0, 1	Λ(1405) (I=0, S wave), non-resonant[I=0/1] (Σ(1385) (I=1, P wave) to be suppressed)
$\pi^{-}\Sigma^{0}$ $[\pi^{-}\Lambda]$	I=1	non-resonant (Σ(1385) to be suppressed) $d(K^-,p)\pi^-\Sigma^0$ $[\pi^-\Lambda]$
$\pi^{0}\Sigma^{0}$	I=0	Λ(1405) (I=0, S wave), non-resonant

Experimental Setup for E31



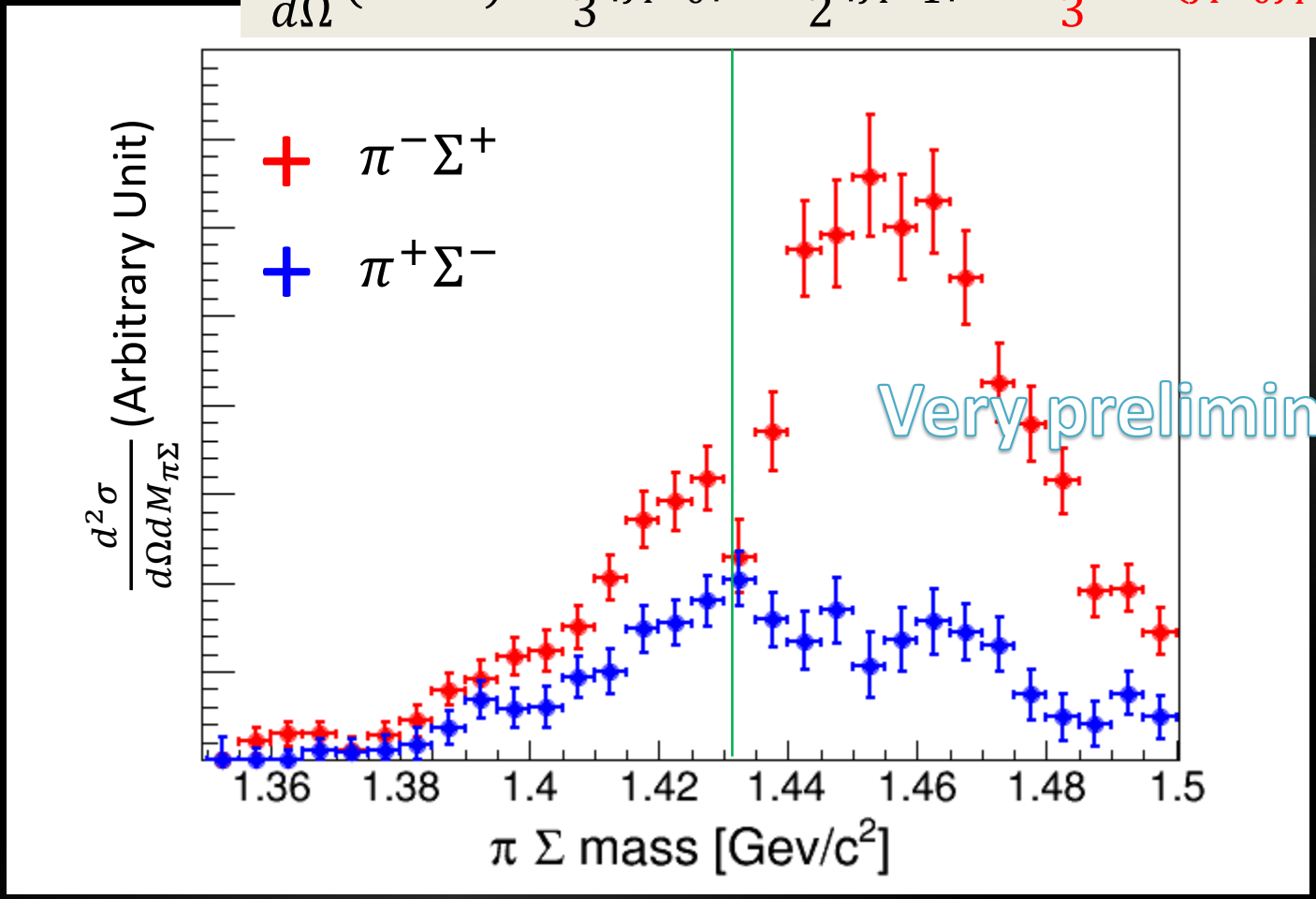
Schematic Drawings of Detectors

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



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

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



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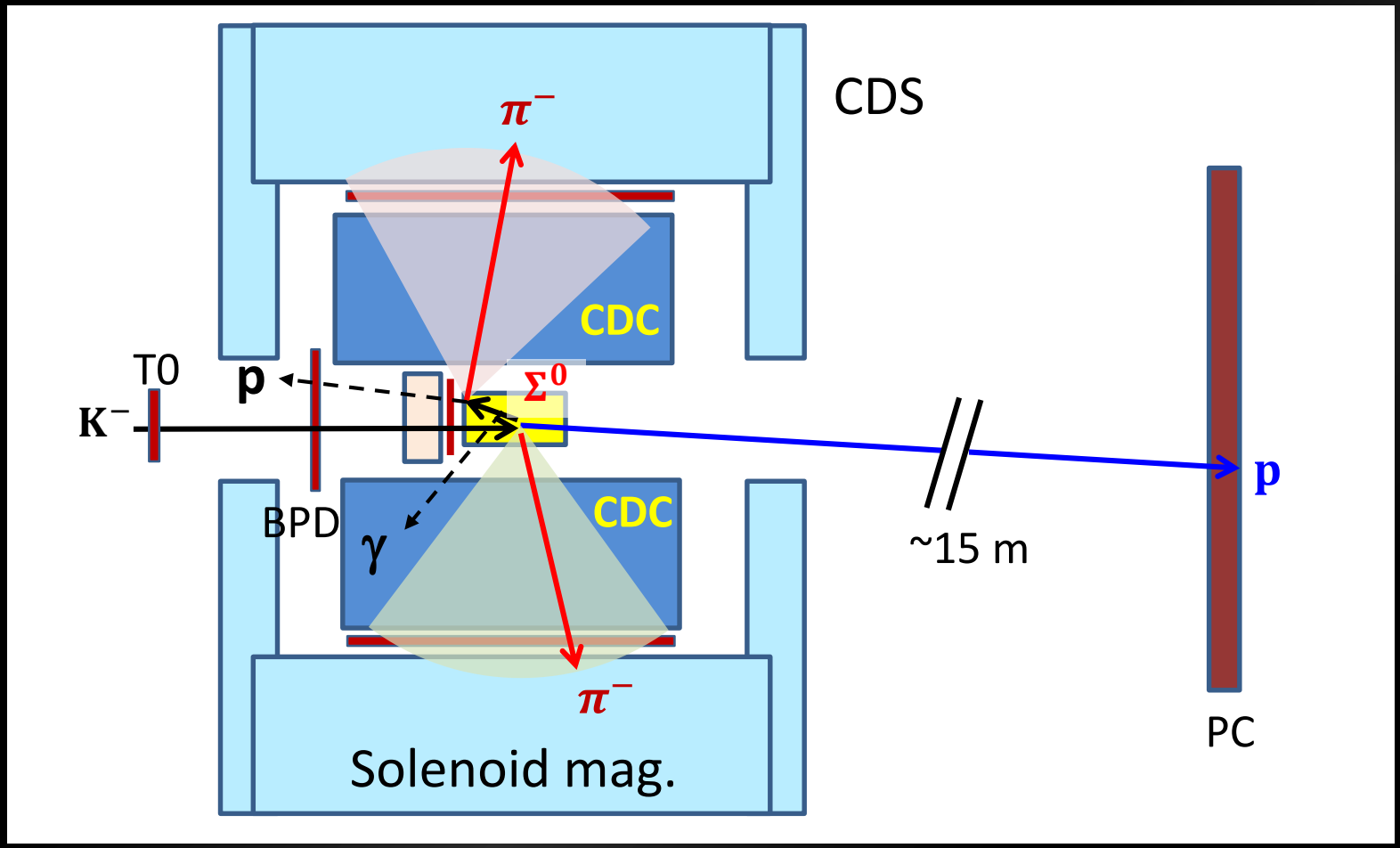
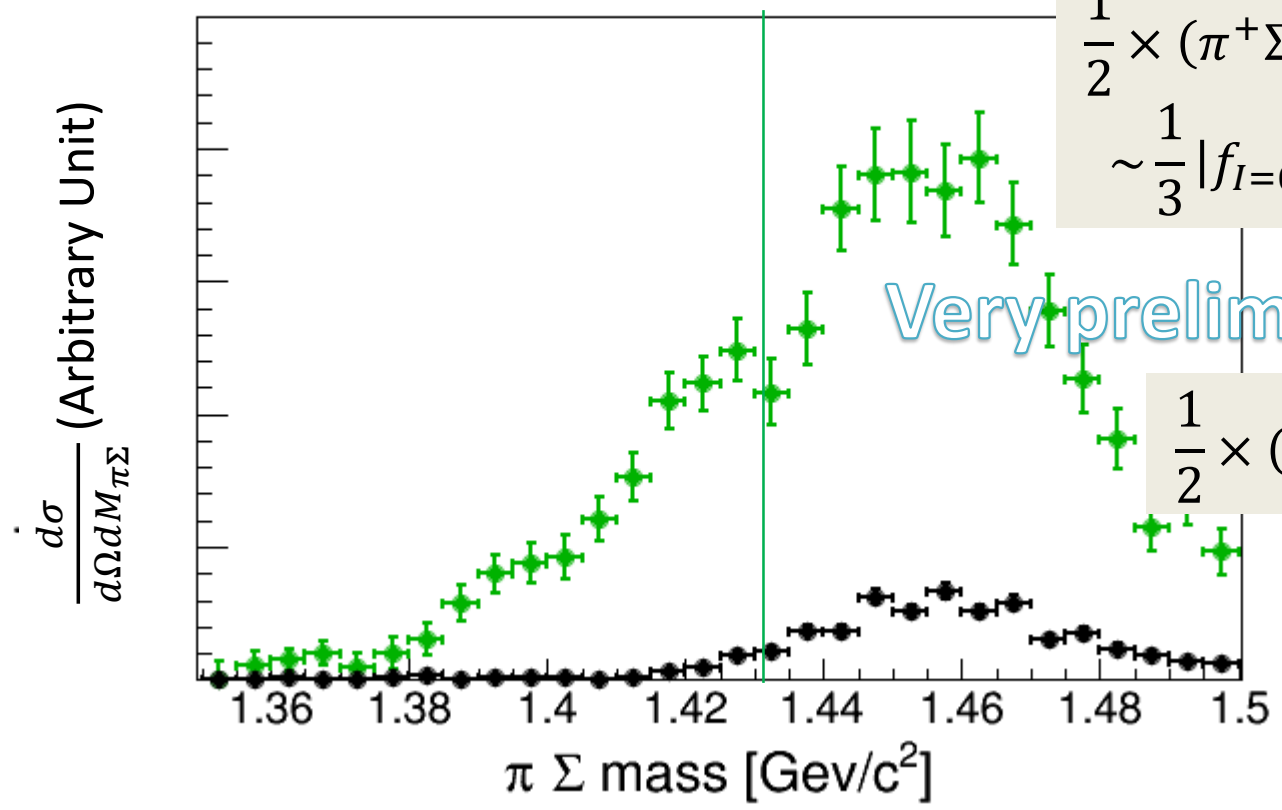


$\pi^+\Sigma^-/\pi^-\Sigma^+$ Average ($I = 0, 1$) *V.S.* $\pi^-\Sigma^0$ Mode ($I = 1$)

- *The I=0 amplitude seems dominant.*



$$\frac{1}{2}\times(\pi^+\Sigma^- + \pi^-\Sigma^+) \sim \frac{1}{3}|f_{I=0}|^2 + \frac{1}{2}|f_{I=1}|^2$$

Very preliminary

$$\frac{1}{2}\times(\pi^-\Sigma^0) \sim \frac{1}{2}|f_{I=1}|^2$$

$\Lambda(1405)$: $1405.1^{+1.3}_{-1.0}$ MeV (PDG Part. List'gs)

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

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

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

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

Pole Structure of the Lambda(1405) Region

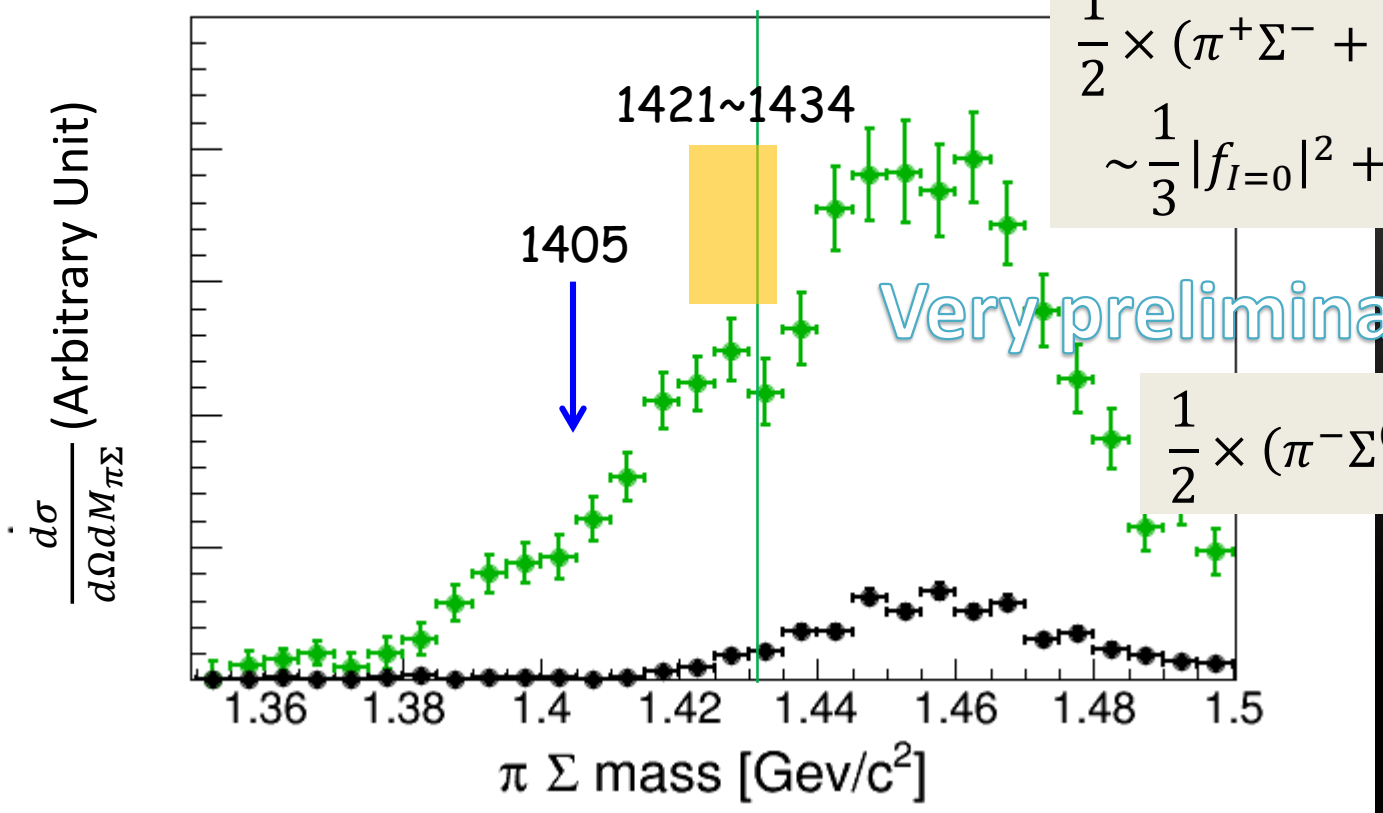
PDG Reviews: Ulf-G. Meissner and T. Hyodo (Nov. 2015)

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	$1429^{+8}_{-7} - i\,12^{+2}_{-3}$	$1325^{+15}_{-15} - i\,90^{+12}_{-18}$

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

- *The I=0 amplitude seems dominant.*



$$\frac{1}{2}\times(\pi^+\Sigma^- + \pi^-\Sigma^+) \sim \frac{1}{3}|f_{I=0}|^2 + \frac{1}{2}|f_{I=1}|^2$$

Very preliminary

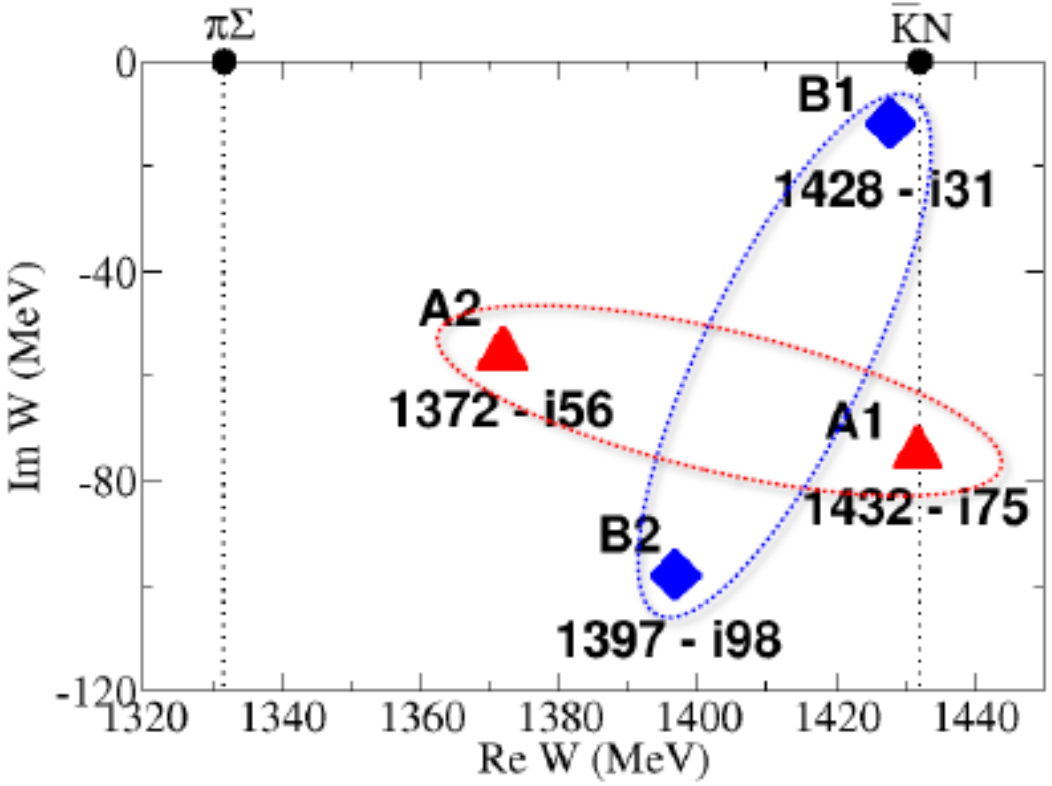
$$\frac{1}{2}\times(\pi^-\Sigma^0) \sim \frac{1}{2}|f_{I=1}|^2$$

S-wave resonances below $\bar{K}N$ threshold from the current analysis

HK, Nakamura, Lee, Sato, PRC92(2015)025205

 # NOTE: Further extensive analysis including the data below $\bar{K}N$ threshold is necessary to have *conclusive* results for the $\bar{K}N$ subthreshold region.

"Predicted" Λ^* (J^P = 1/2-) resonance poles below $\bar{K}N$ threshold



- ✓ Two resonance poles are found in both Models A and B.
  - A1 & B1 seem correspond to Λ(1405)
  - Another Λ resonance with mass 30-60 MeV lower than Λ(1405) (A2 & B2) is also found to exist.

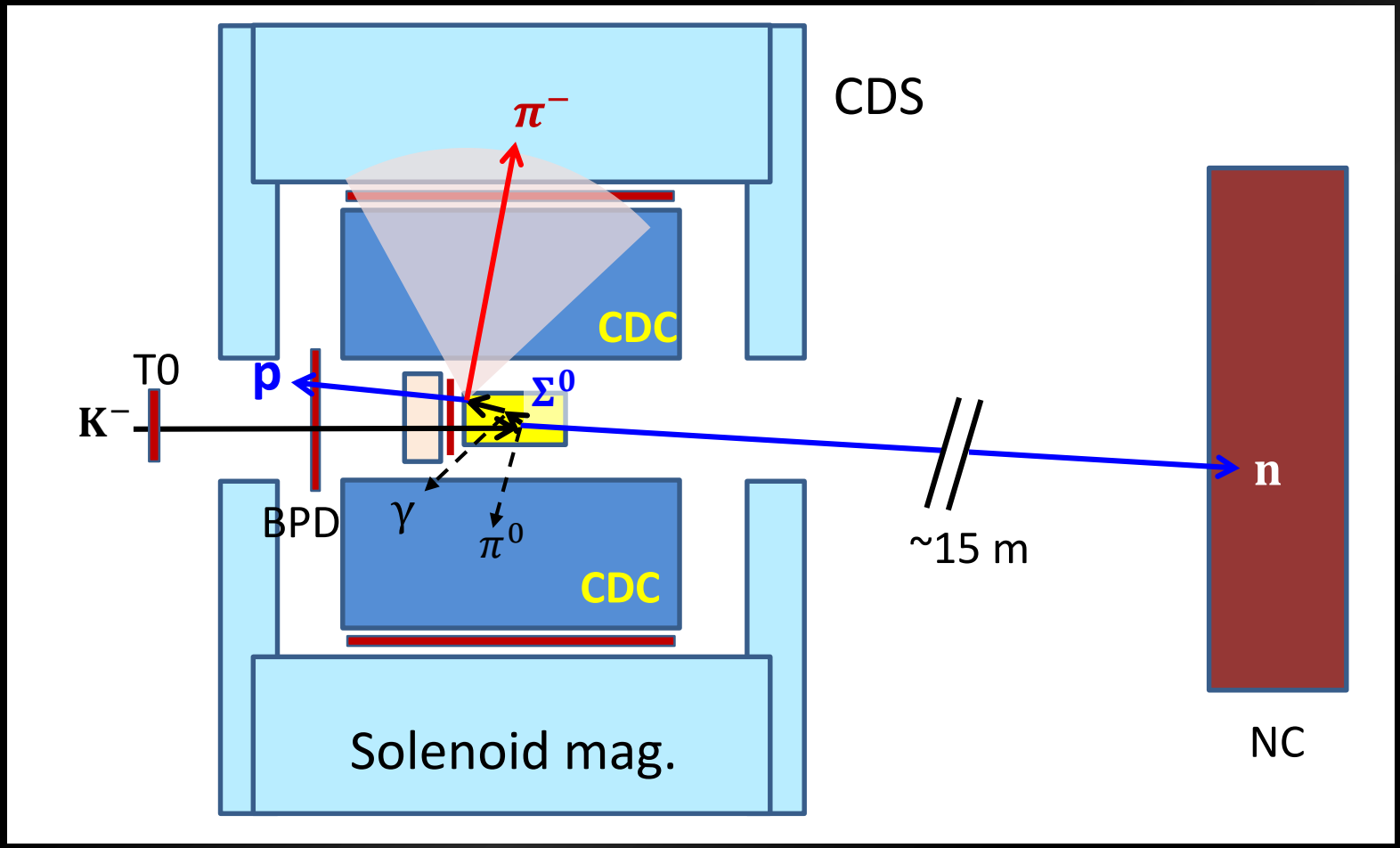
Red triangles: Model A
Blue diamonds: Model B

Remarks of E31 1st Run

- 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.
- Pure I=1 channel, $d(K^-, p)X_{\pi^-\Sigma^0}$, is observed.
  - 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 $d(K^-, p)X_{\pi^-\Sigma^0}$.

In E31 2nd Run

- To measure a Pure I=0 channel, $d(K^-, n)X_{\pi^0\Sigma^0}$



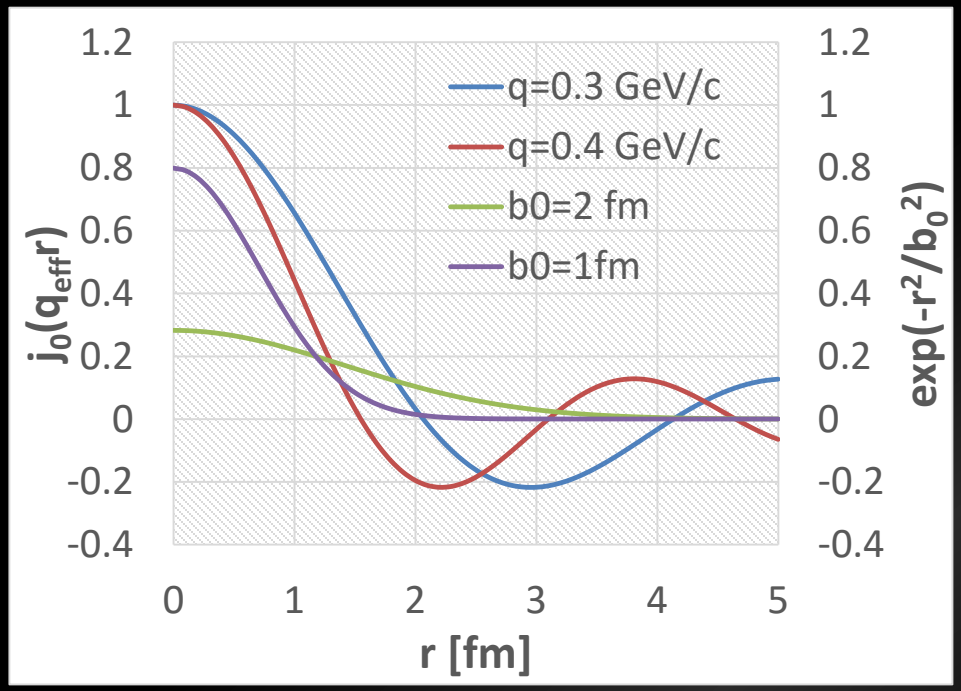
Further studies on $\Lambda(1405)$

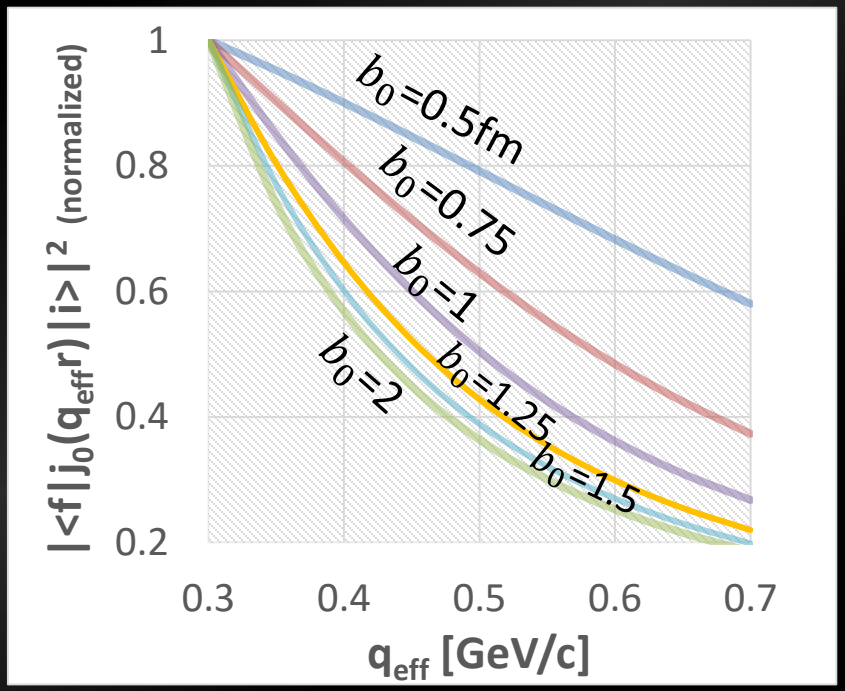
- Angular dependence of $d(K^-, n)X_{(\pi\Sigma)^0}$
  - "Sticking probability" of $\overline{K}$ to a residual N

$$I(q_{eff}; b_0) = |\langle f(b_0)|j_0(q_{eff}r/\hbar)\,|i\rangle|^2$$

$f(b_0) \sim N\exp(-r^2/b_0^2)$: S wave final state

q_{eff}: mom. transfer (angular dependent)

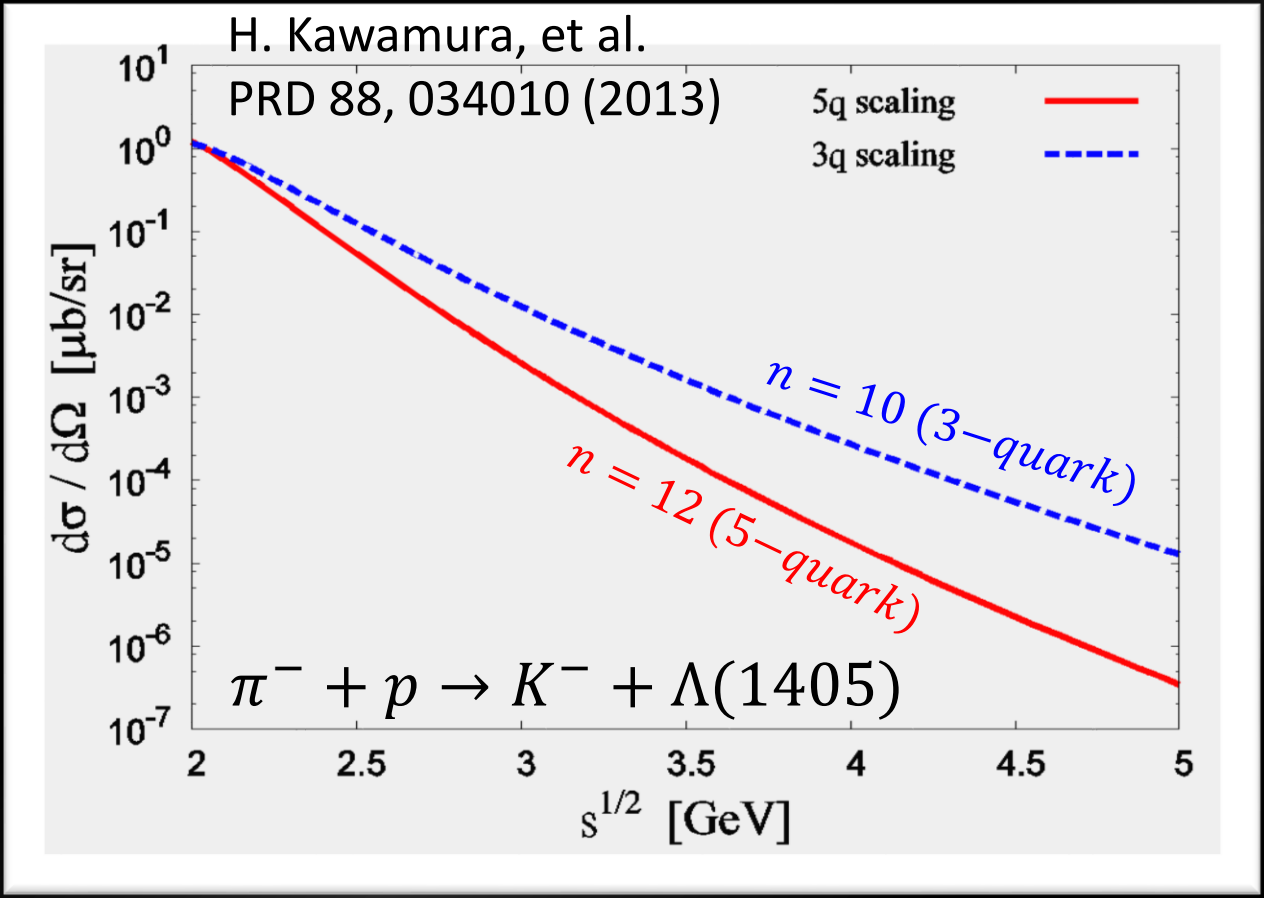




The larger b_0, the steeper angular dependence.

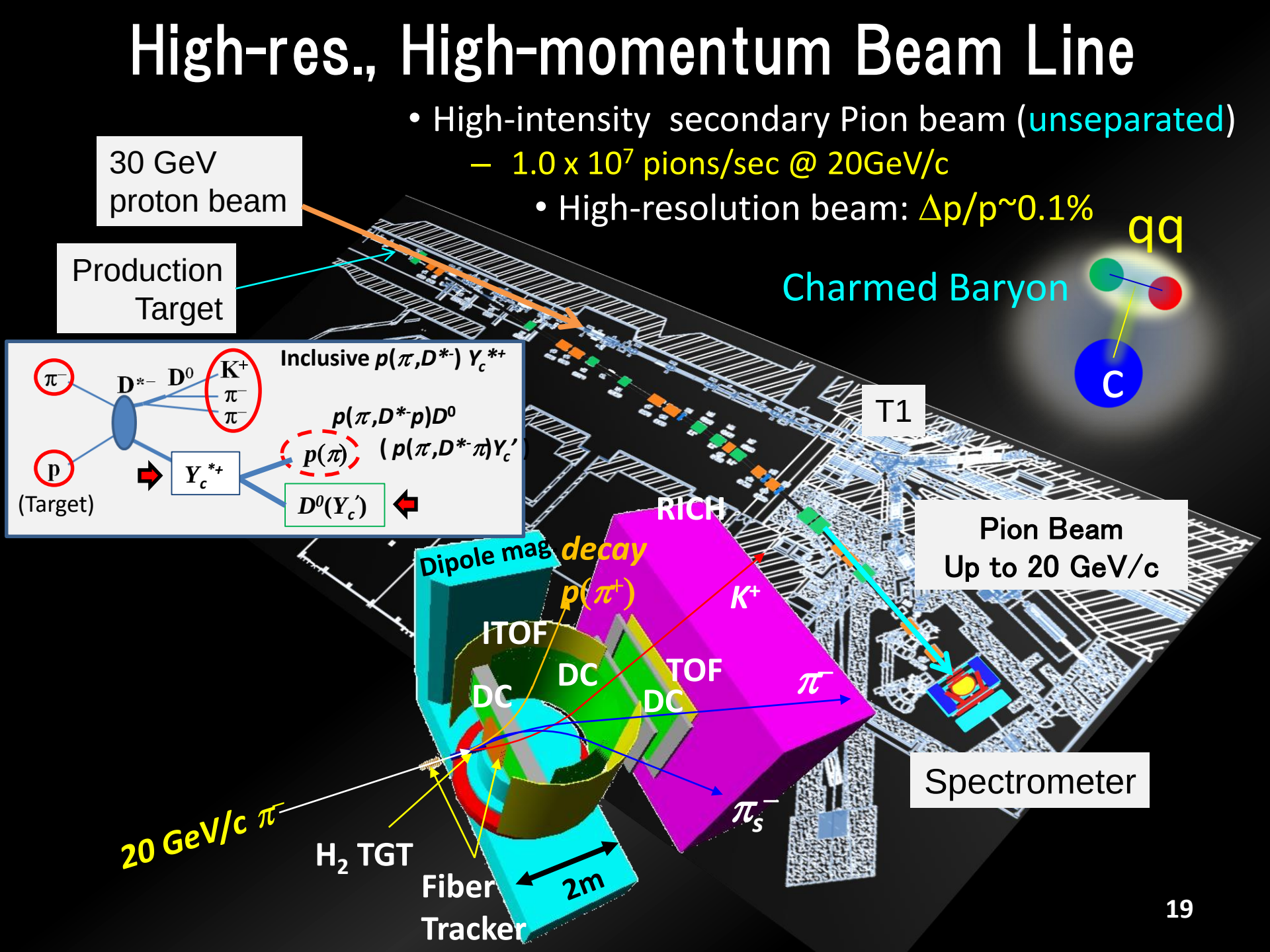
Further studies on $\Lambda(1405)$

- $\Lambda(1405)$ production in Hard process (at large *s*, *t*) :
  - quark counting rule: $d\sigma/d\Omega|_{\theta=90^o} \sim 1/s^{n-2}$



High-res., High-momentum Beam Line

- High-intensity secondary Pion beam (unseparated)
  - 1.0×10^7 pions/sec @ 20GeV/c
    - High-resolution beam: $\Delta p/p \sim 0.1\%$



In Summary

- A low-*E* K^{bar} beam is used for studying hyperon resonances below K^{bar}N threshold.
  - $d(K^-, n)X_{\pi^{\pm}\Sigma^{\mp}}$ demonstrates an *S*-wave $\bar{K}N \rightarrow \pi\Sigma$ scattering, showing the I=0 dominance.
  - A structure around the K^{bar}N threshold is observed.
  - A pole position will be determined by the spectra.
- Further studies are necessary:
  - $d(K^-, n)X_{\pi^0\Sigma^0}$ will be measured next year.
  - Meas. of Angular distribution → form factor (under consideration)
  - $\Lambda(1405)$ production in Hard process will be measuredat the high-*p* beam line at J-PARC, which may give "# of quarks" in it.