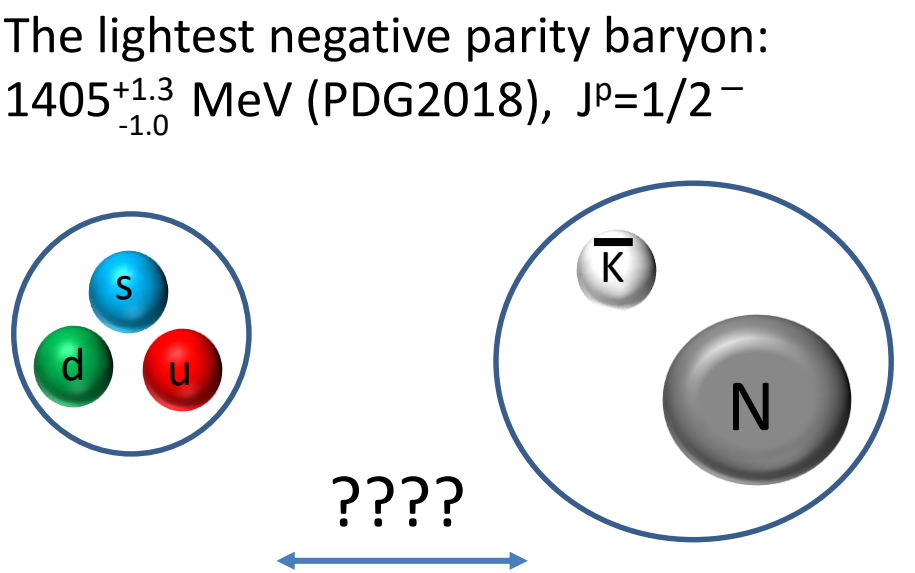
E31:
Λ(1405) from d(K^-,n) reaction

Hidemitsu Asano (RIKEN)

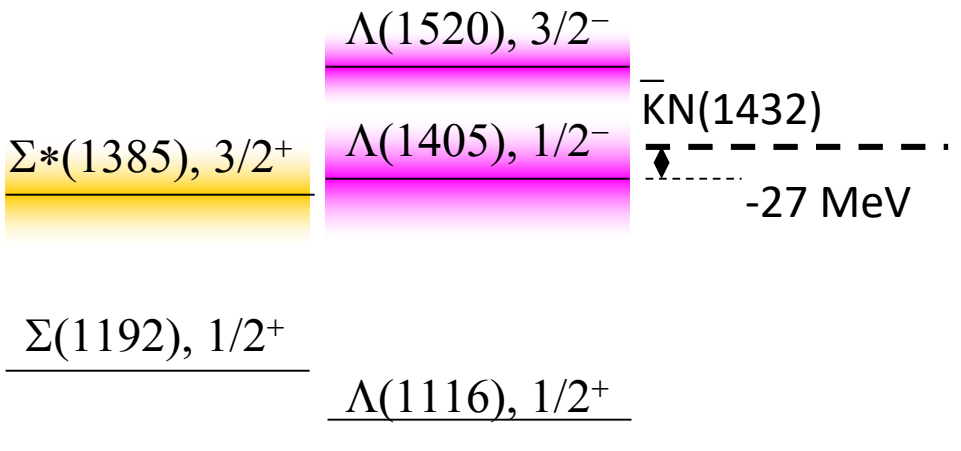
for the J-PARC E31 collaboration

Investigation of the Λ(1405)

The lightest negative parity baryon:
$1405^{+1.3}_{-1.0}$ MeV (PDG2018), $J^p=1/2^-$

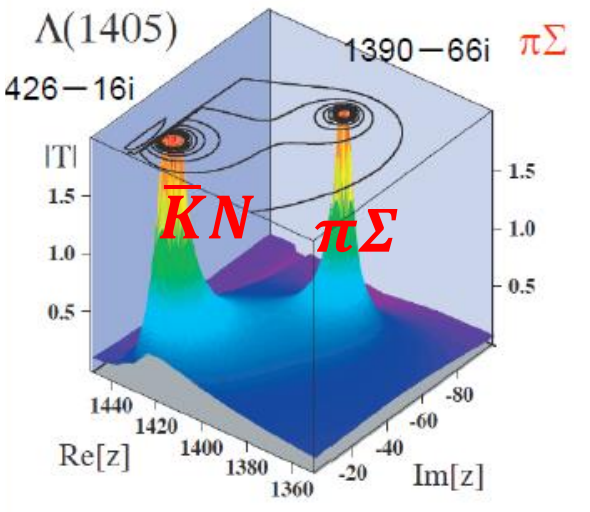


3 quark ⟷ $\bar{K}N$ bound state



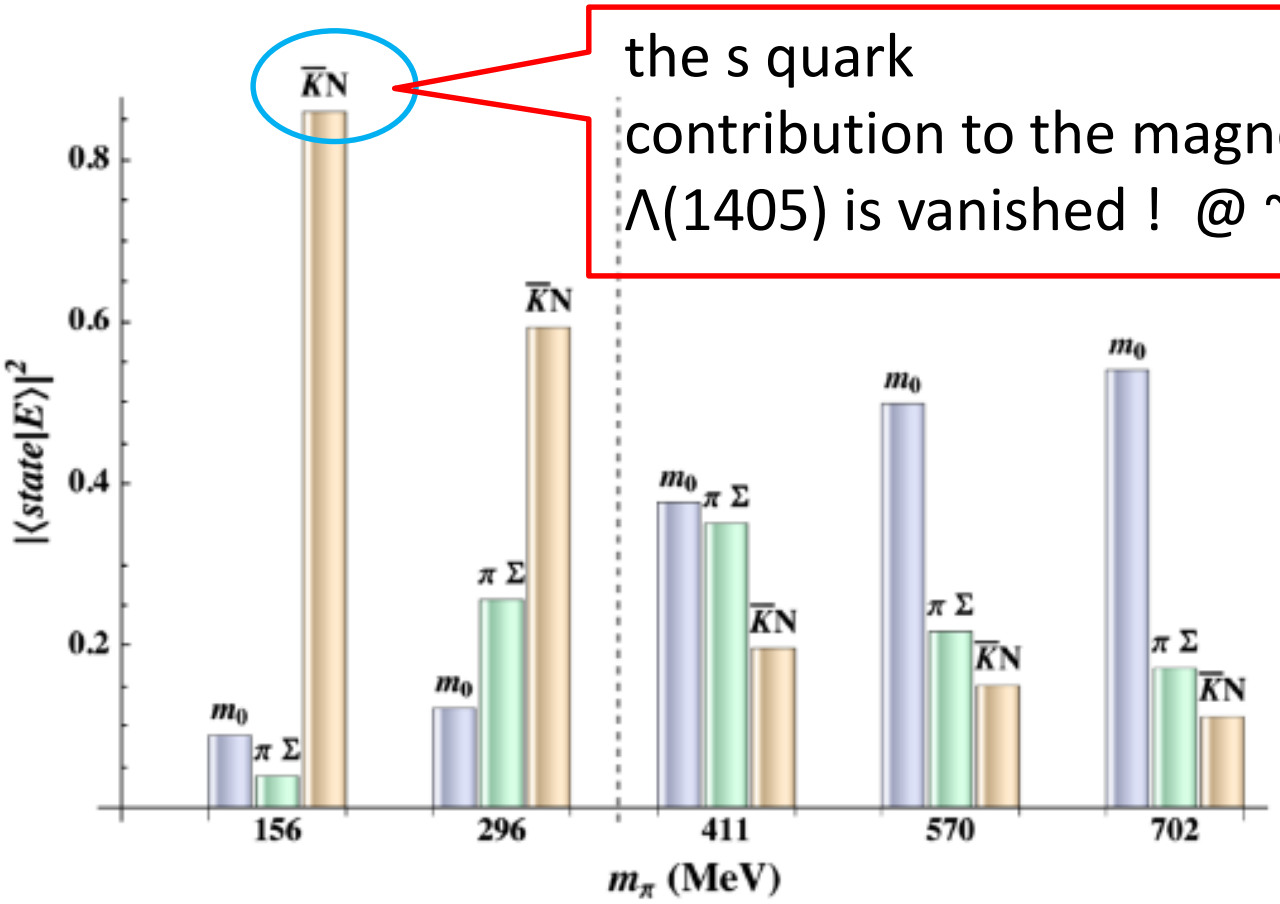
chiral unitary model:
2 pole structure of the Λ(1405)
with $\bar{K}N$, $\pi\Sigma$ resonant states

T.Hyodo and W.Weise,
Phys.RevC77,035204(2008)



Lattice QCD Evidence that the Λ(1405) Resonance is an $\bar{K}N$ molecule

PRL 114, 132002 (2015)



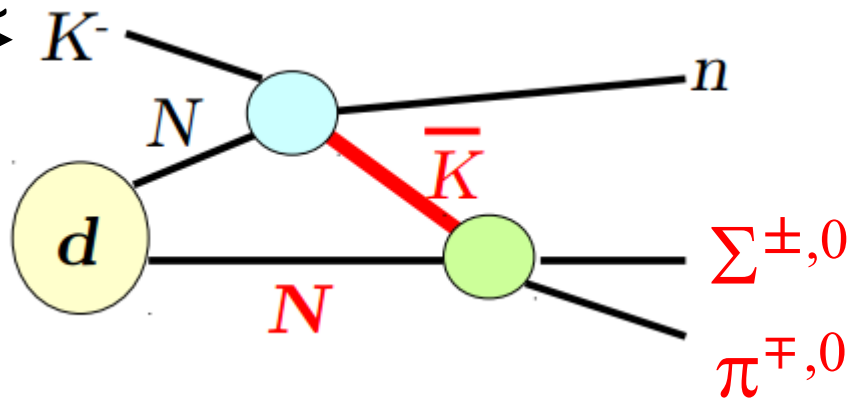
the s quark
contribution to the magnetic moment of Λ(1405) is vanished ! @ ~physical pion mass

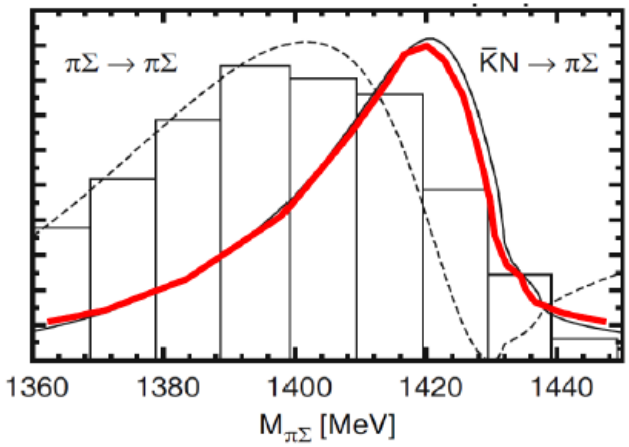
Experimental Study of $\bar{K}N$ scattering below the $\bar{K}N$ threshold !!

J-PARC E31 experiment

measuring an $\overline{K}N \to \pi\Sigma$ scattering below the $\overline{K}N$ threshold in the $d(K^-,n)\pi\Sigma$ reactions

1 GeV/c





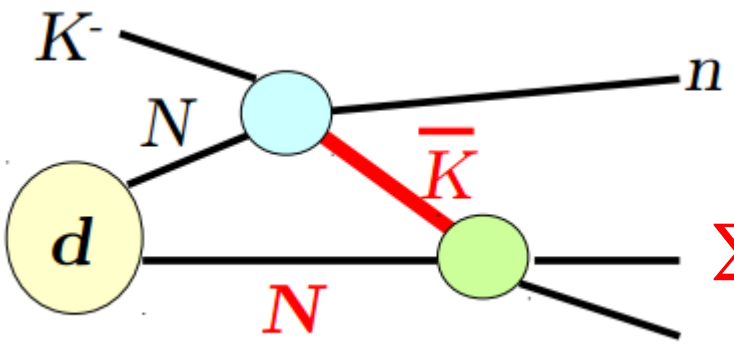
ChiralUnitary Model:
D. Jidoet al., NPA725(03)181

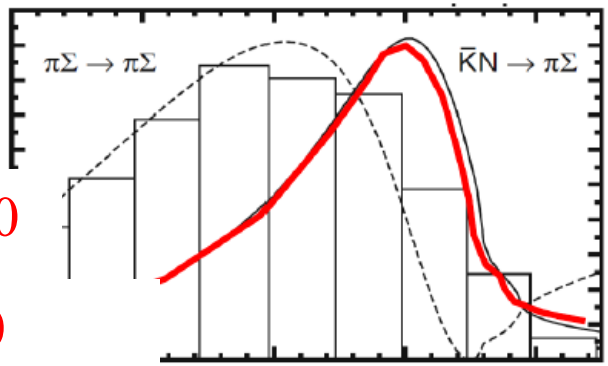
- 2 step process
- Producing Λ(1405) by virtual $\overline{K}$

J-PARC E31 experiment

measuring an $\overline{K}N \to \pi\Sigma$ scattering below the $\overline{K}N$ threshold in the d(K^-,n)$\pi\Sigma$ reactions

1 GeV/c





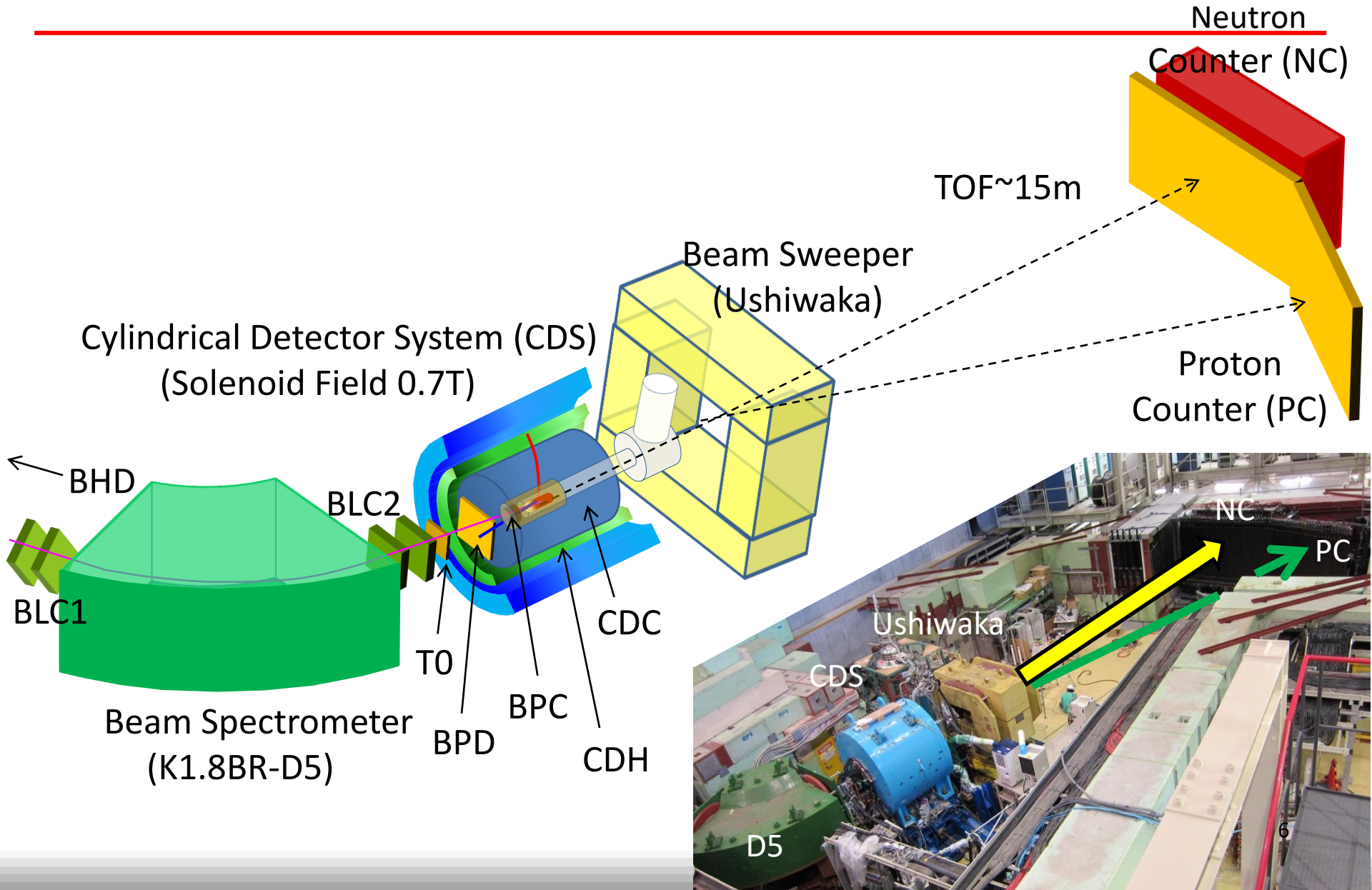
Identifying all final states to decompose the I=0 and I = 1 amplitude

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

Charged mode

Neutral mode

E31 setup at the J-PARC K1.8BR beam line



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	Jan.- Feb. 2018	51.1kW	21.5d	100% !!

Analysis topics

- Missing mass spectrum of
  - d(K-,n) $\pi^{\pm}\Sigma^{\mp}$ --- K.Inoue
  - d(K-,n) $\pi^{0}\Sigma^{0}$ --- S.Kawasaki

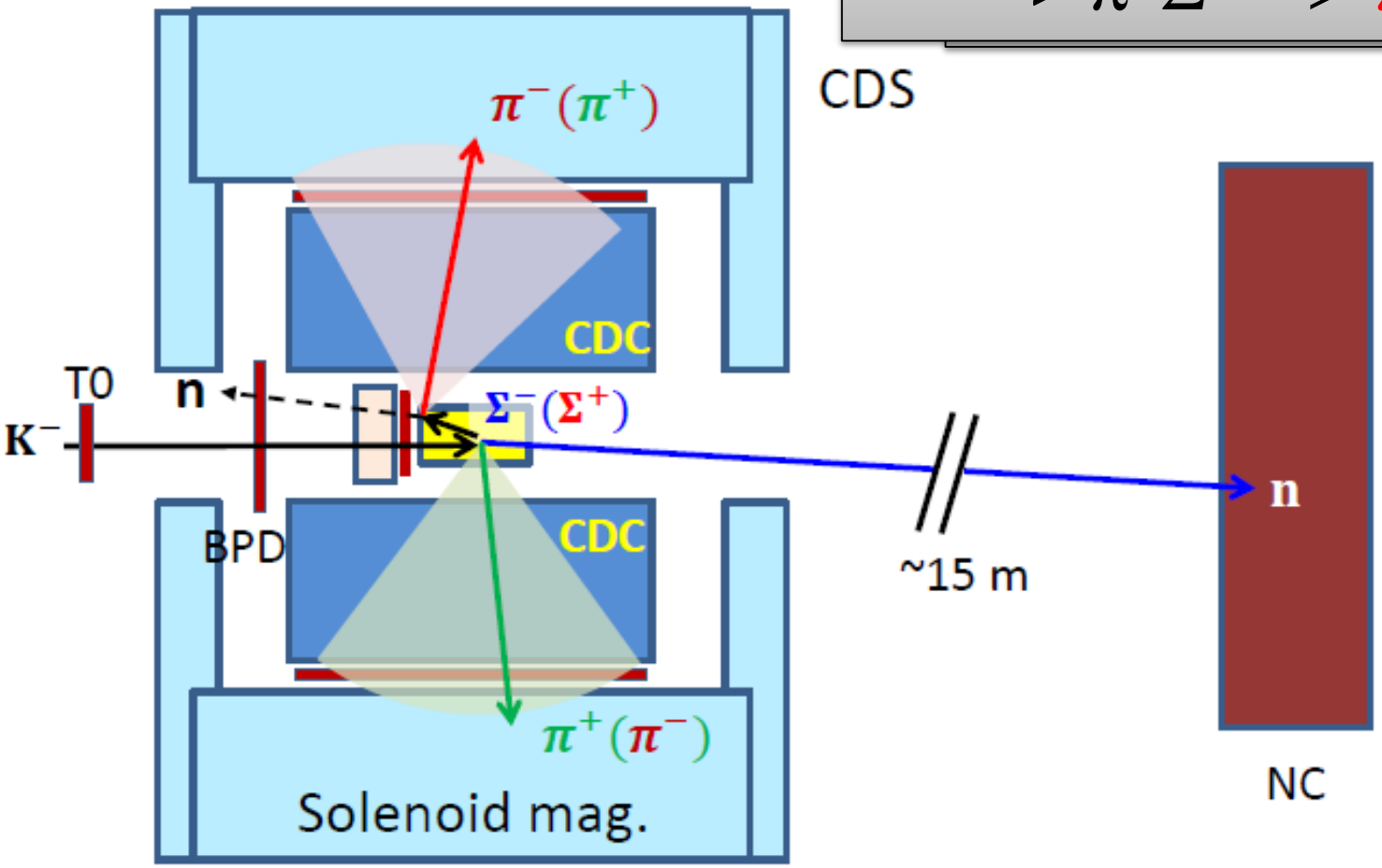
- Invariant mass spectra of
  - d(K-,n) $\pi^{\pm}\Sigma^{\mp}$ vs mom. transfer --- HA

Analysis of d(K⁻,n)"X" $\pi^{\mp}\Sigma^{\pm}$

Event topology

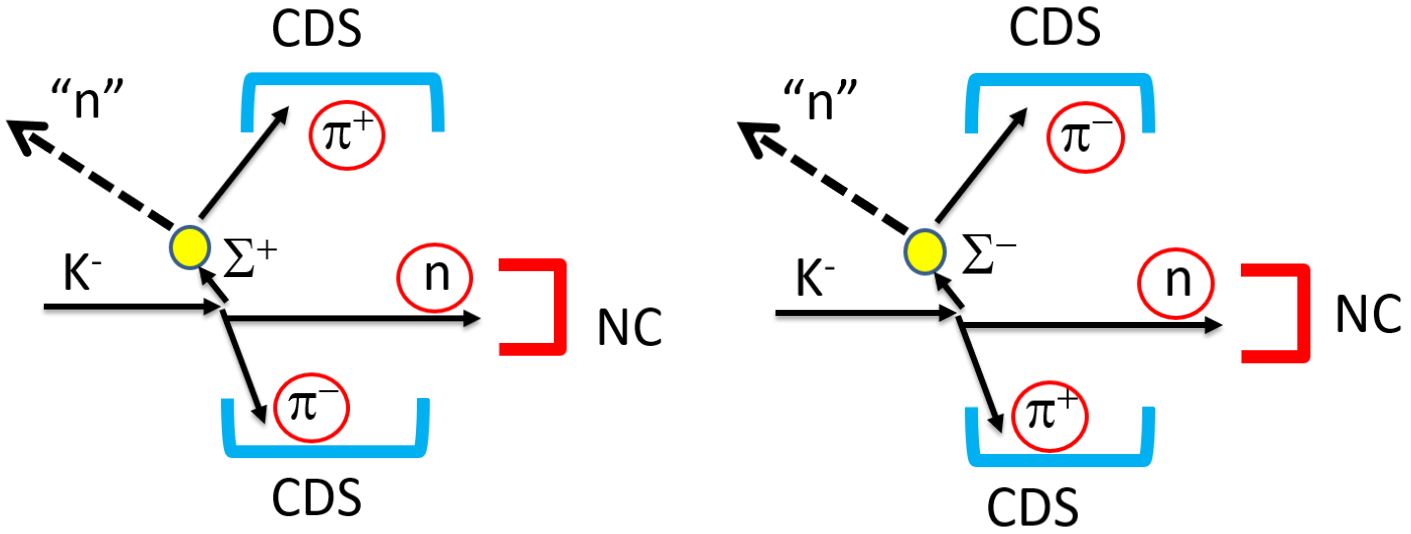
Y* -> $\pi^+\Sigma^-$ –> π^+ π^- n_{miss}

-> $\pi^-\Sigma^+$ –> π^- π^+ n_{miss}

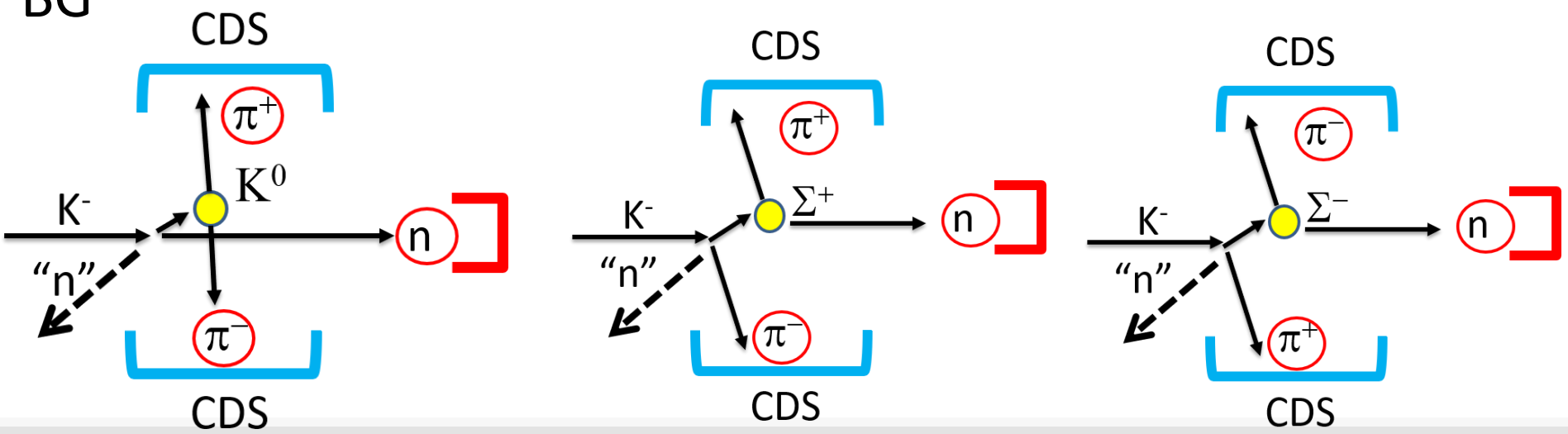


Signal/Background process

Signal

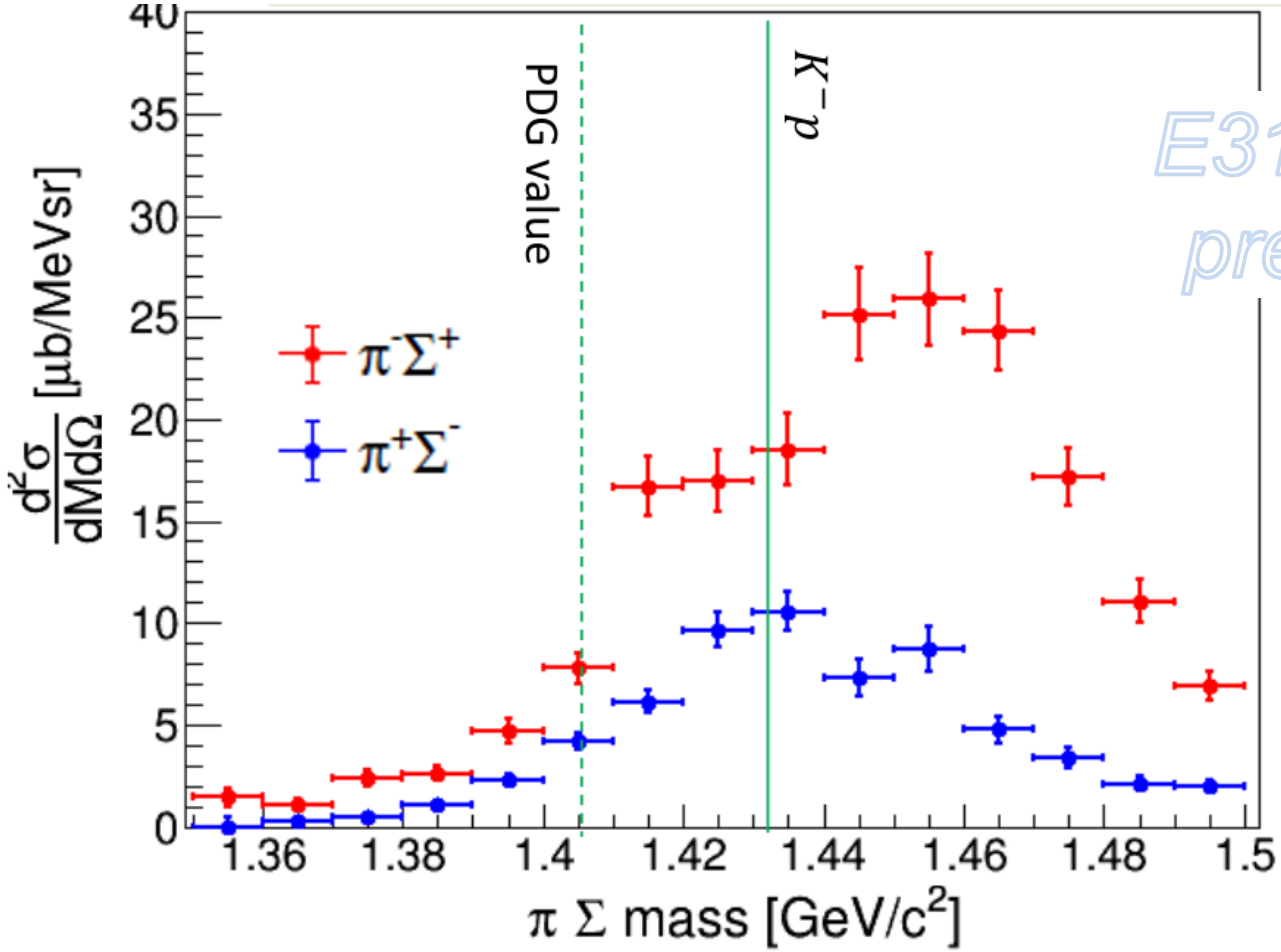


BG



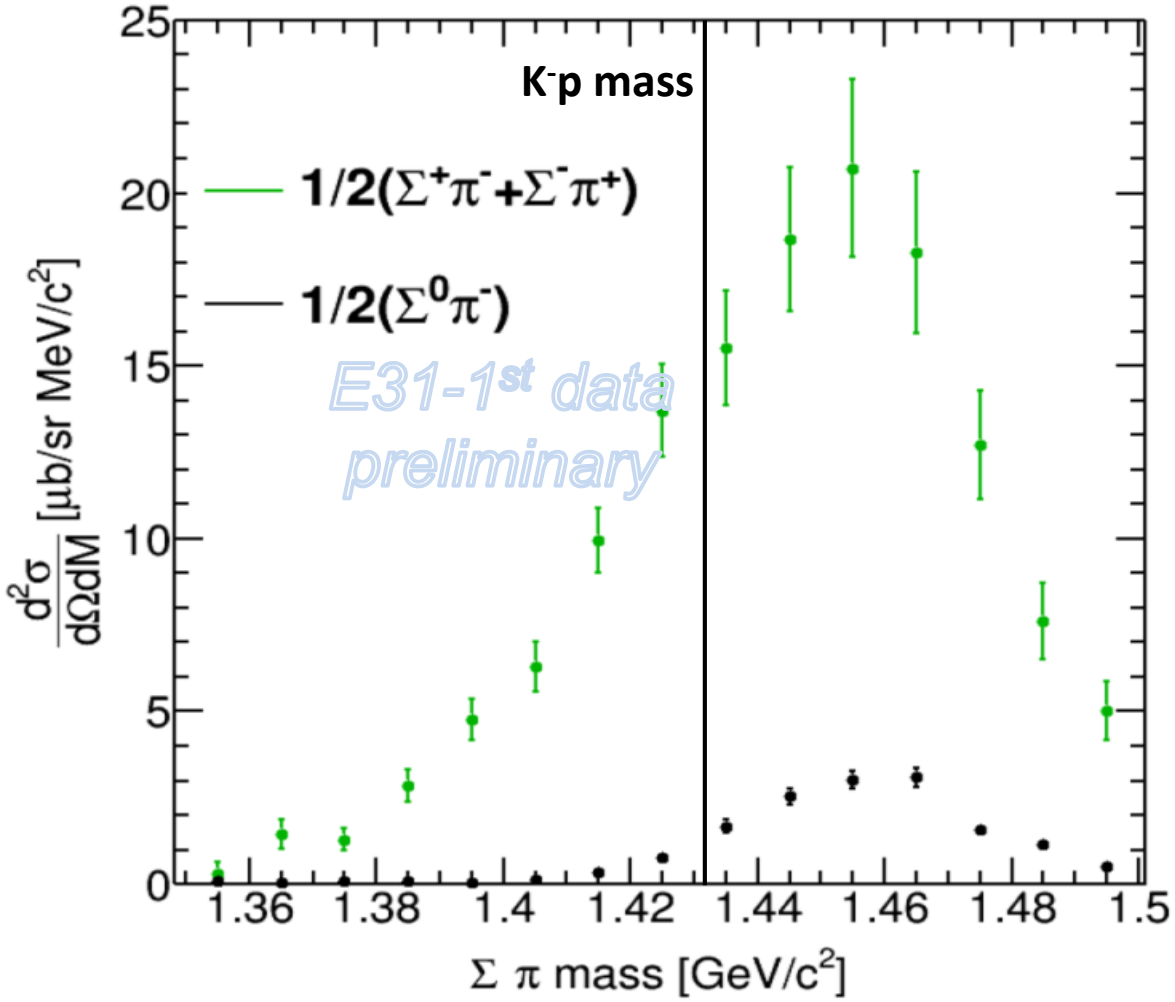
$\pi^+\Sigma^-/\pi^-\Sigma^+$ missing mass spectra

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



E31-2nd data
preliminary

Dominance of I=0 amp.



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

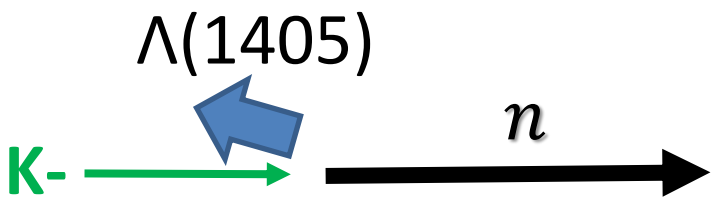
$$\frac{1}{2}\times(\pi^{-}\Sigma^{0}) \sim \frac{1}{2}|f_{I=1}|^{2}$$

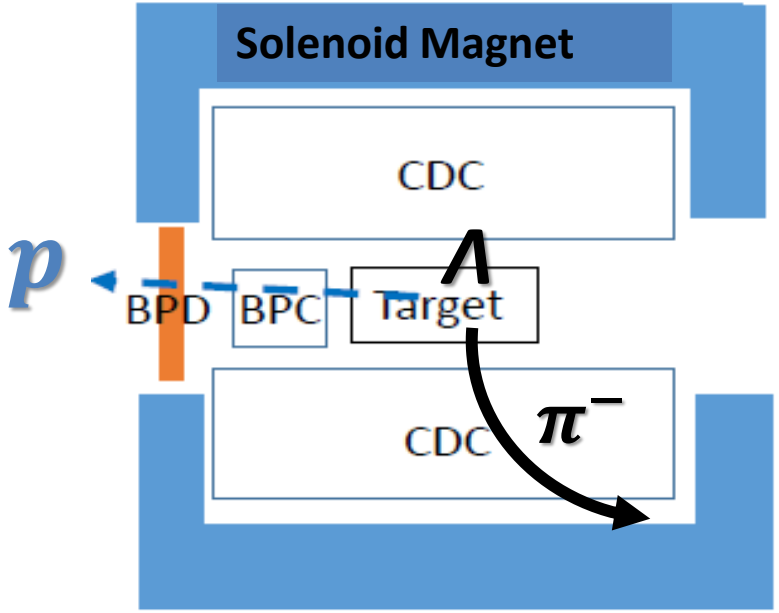
Assuming the similarity of the reaction mechanism of d(K-,n) and d(K-,p), the amplitude of I =0 in the d(K-,n) reaction is dominant below the threshold

d(K⁻,n)"$\Sigma^0\pi^0$" Analysis

Y* -> $\pi^0\Sigma^0$ –> $\pi^0\gamma\Lambda$–>$\pi^0\gamma$ *p* π^-

Λ(1405) is recoiled at a backward angle. The decay proton is detected by backward detectors

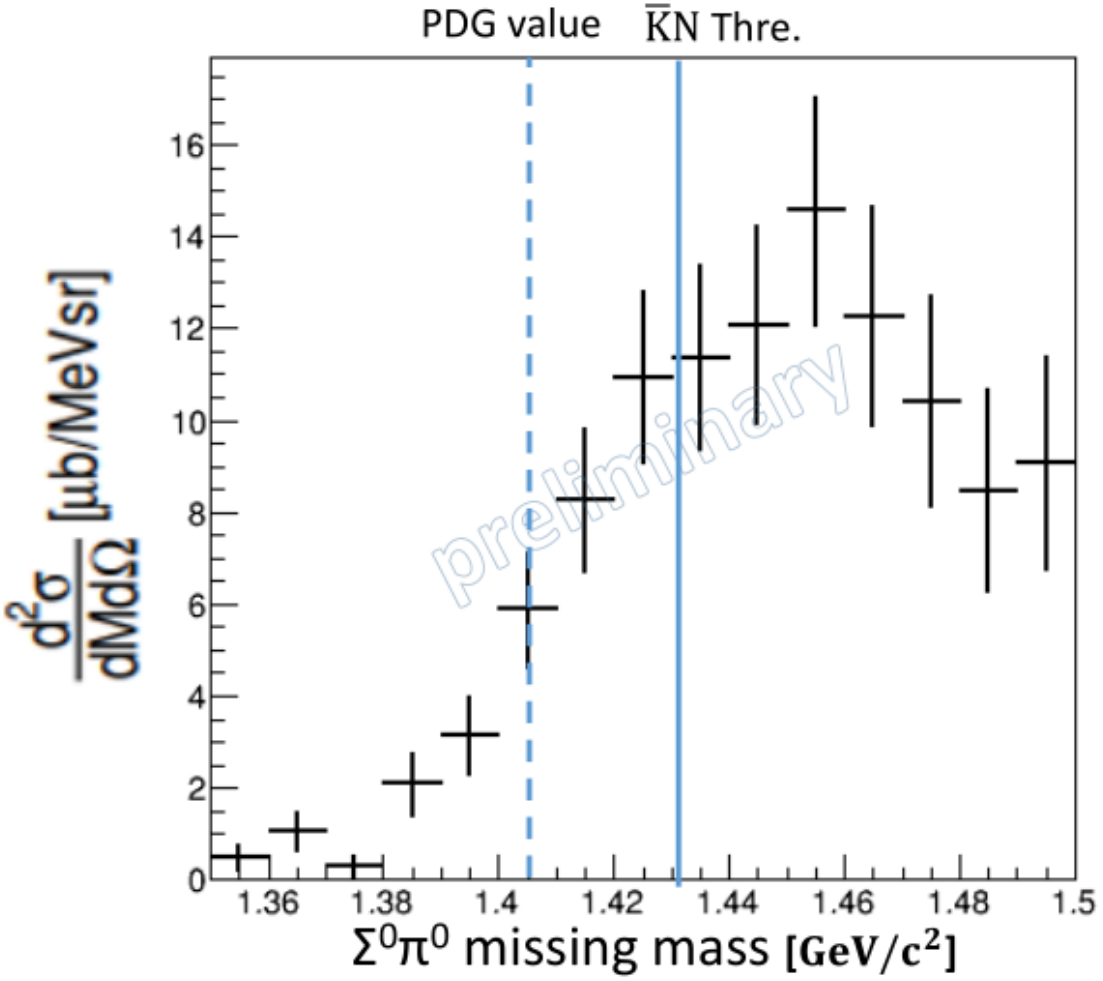




1. Reconstruction of Λ from p π^-

2. Separate "Λ $\pi^0\gamma$" events from $\Lambda\pi^0$ and $\Lambda\pi^0\pi^0$ by d(K^-,"n Λ")"X" missing mass analysis

Cross Section of $d(K^-,n)\Sigma^0\pi^0$

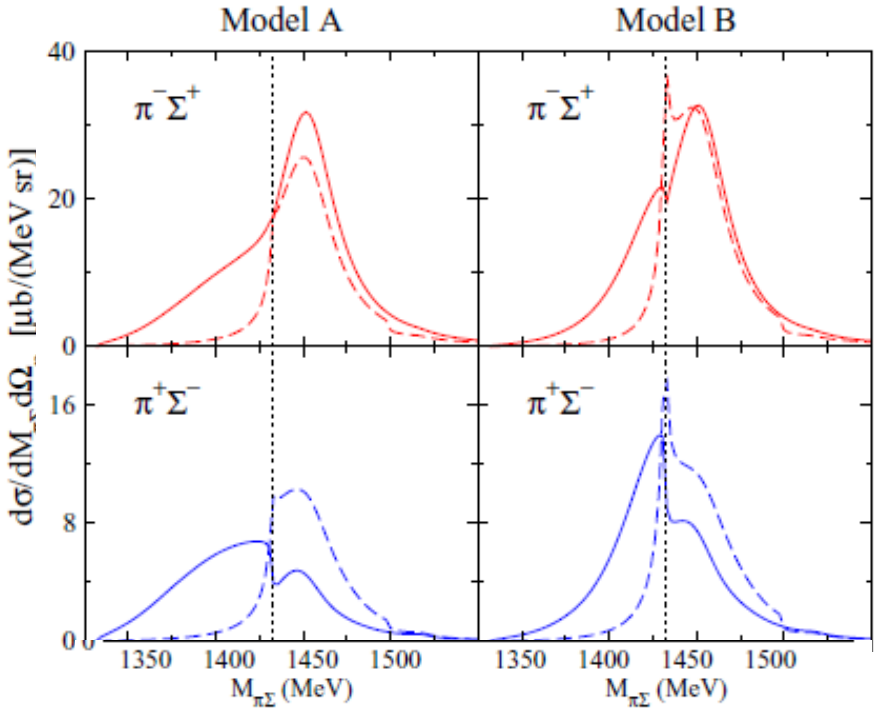


$$\frac{d\sigma}{d\Omega}(\pi^0\Sigma^0) \sim \frac{1}{3}|f_{I=0}|^2$$

Pure I=0 component

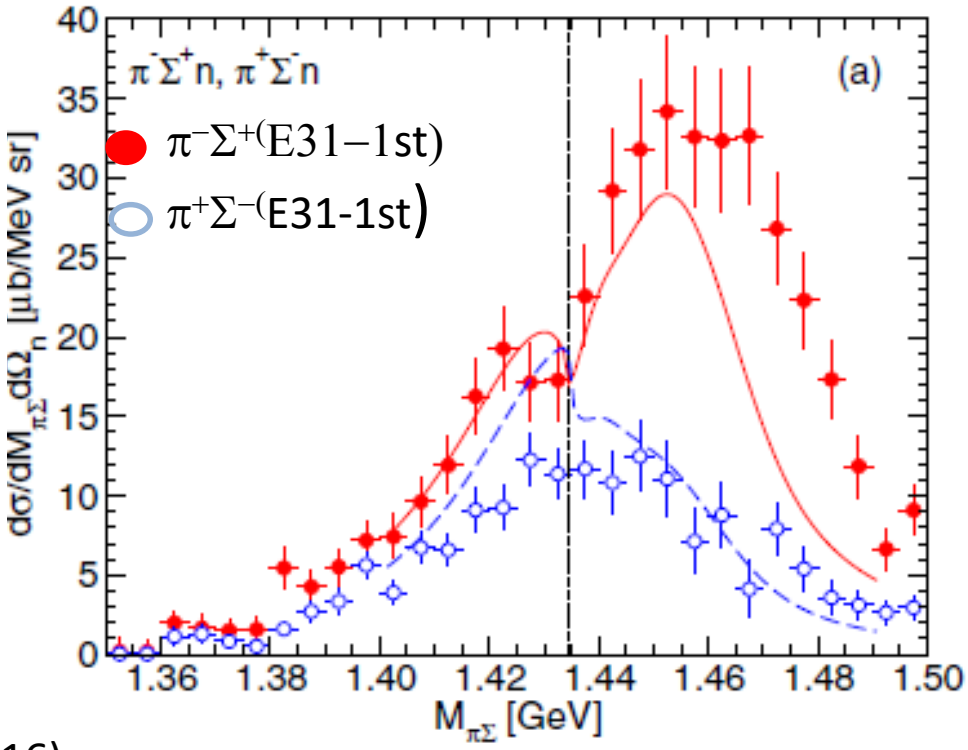
Trying to extract pole positions related to Λ(1405)

Recent theoretical development



H. Kamano et al., Phys. Rev. C **94**, 065205 (2016)

-Two step reaction process
-dynamical coupled-channels (DCC) model

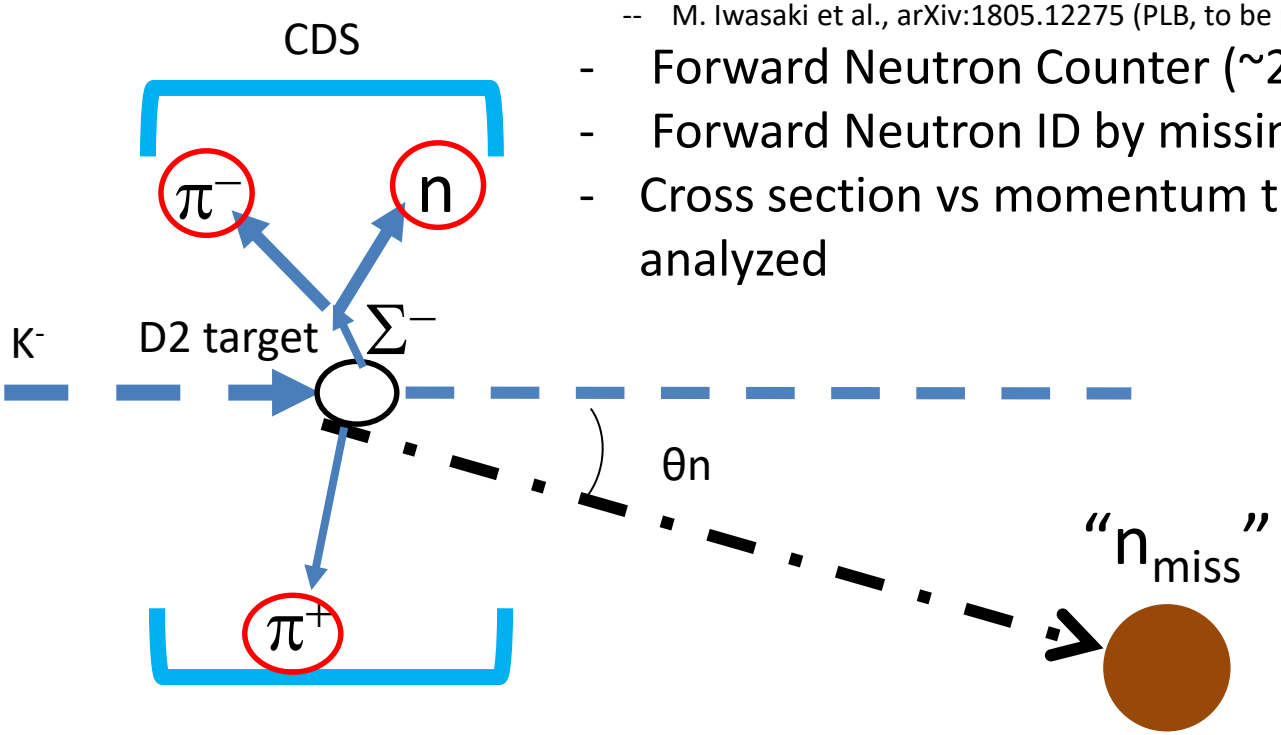


K. Miyagawa et al.,Phys. Rev. C **97**, 055209 (2018)

-studied within a Faddeev-type approach
-good agreement with data

Invariant mass $\pi^{\pm}\Sigma^{\mp}$ vs "q" analysis

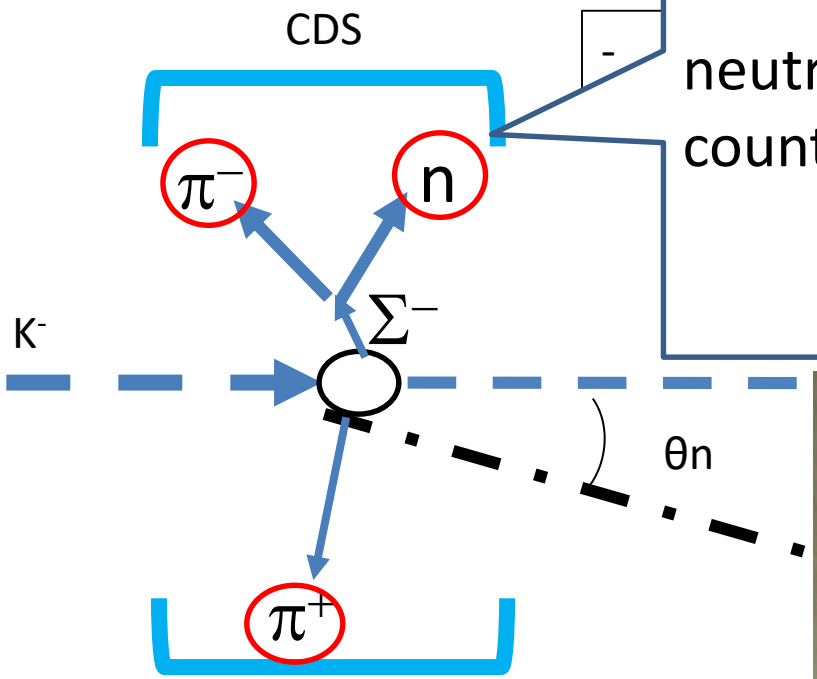
- Inspired by J-PARC E15 analysis
  - -- Y .Sada *et al.,* PTEP 2016 (2016) no.5, 051D01
  - -- M. Iwasaki et al., arXiv:1805.12275 (PLB, to be published)
- Forward Neutron Counter (~20 msr) is not used
- Forward Neutron ID by missing mass
- Cross section vs momentum transfer "q" is being analyzed



Reaction Form factor

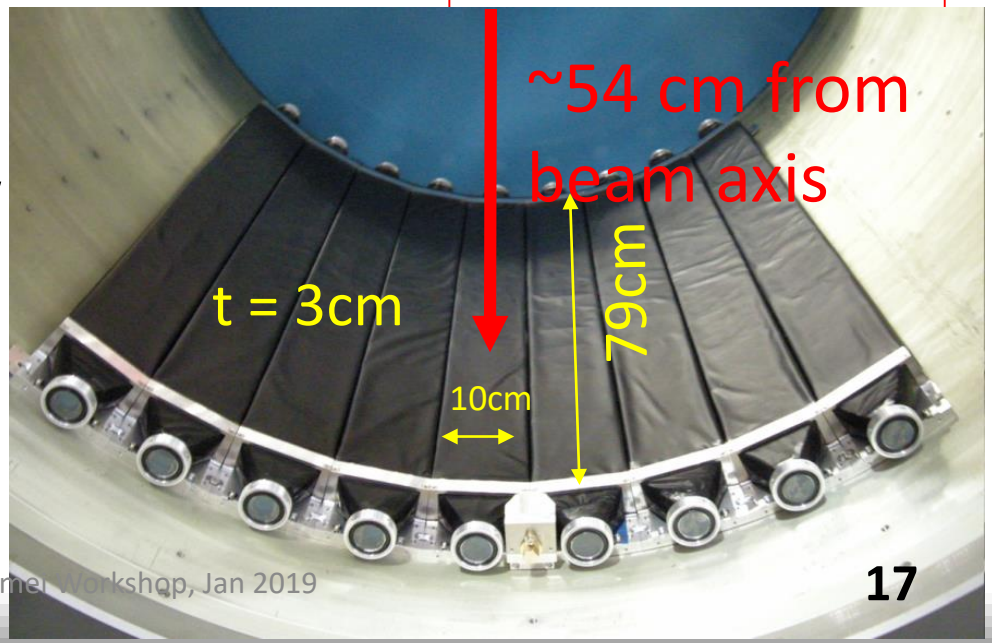
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_{\mathbf{point-like}} \left| \exp(-q^2/Q_X^2) \right|^2$$

Invariant mass $\pi^{\pm}\Sigma^{\mp}$ vs "q" analysis

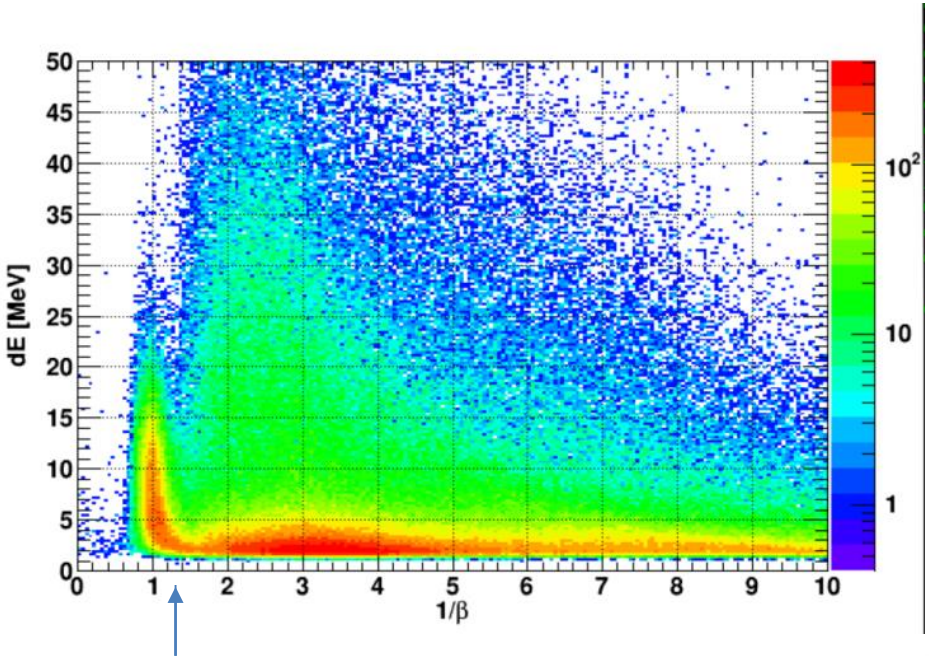


neutron detection with thin scintillation counters (t=3cm)

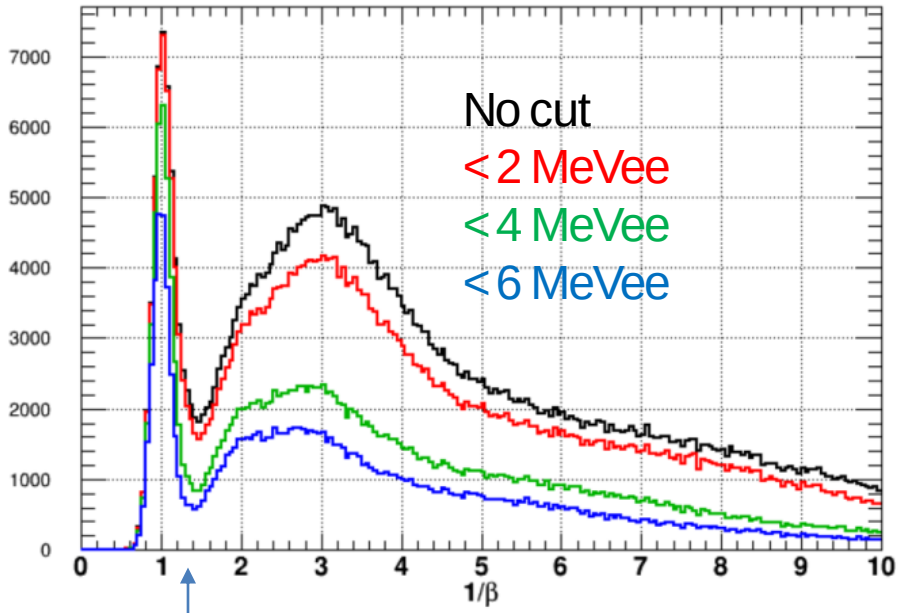
n detection efficiency ~ 3%



Neutron ID by CDS



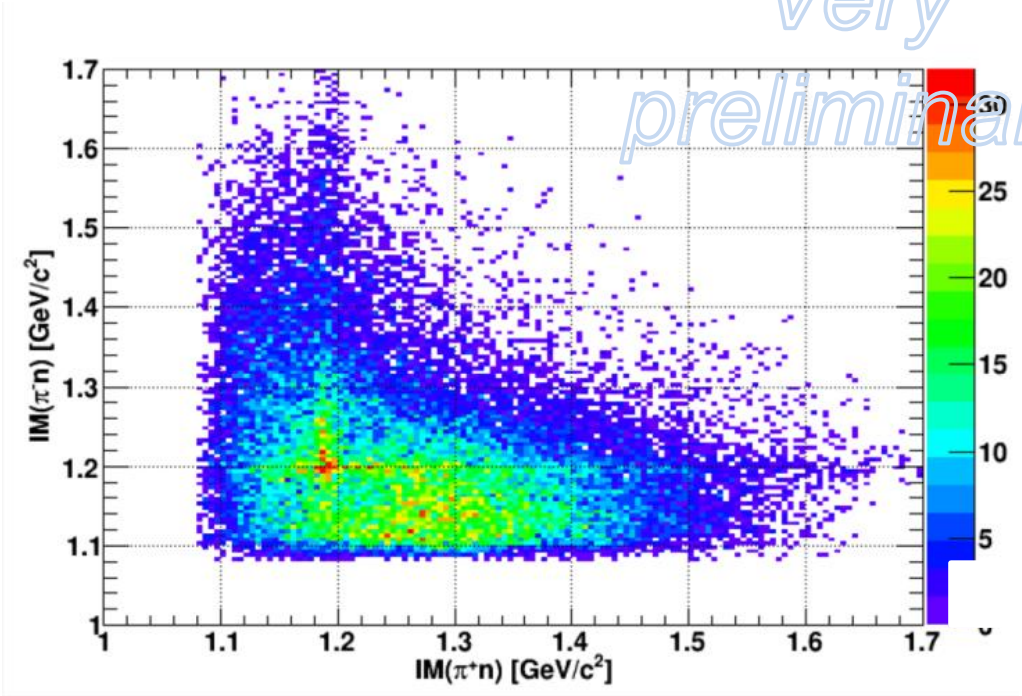
1.372 < 1/beta (P_n < 1.GeV/c)

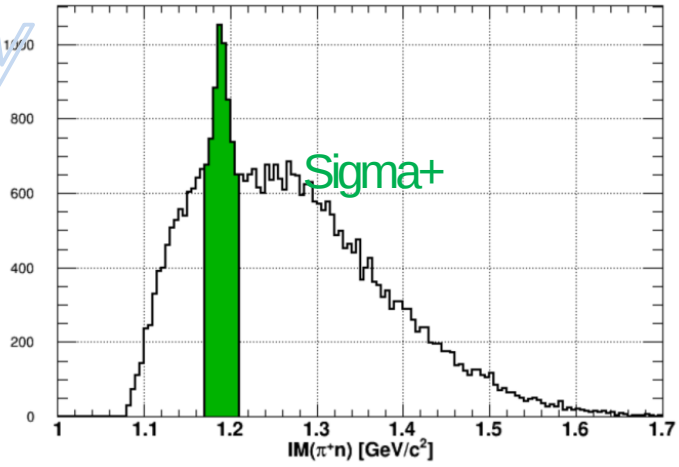


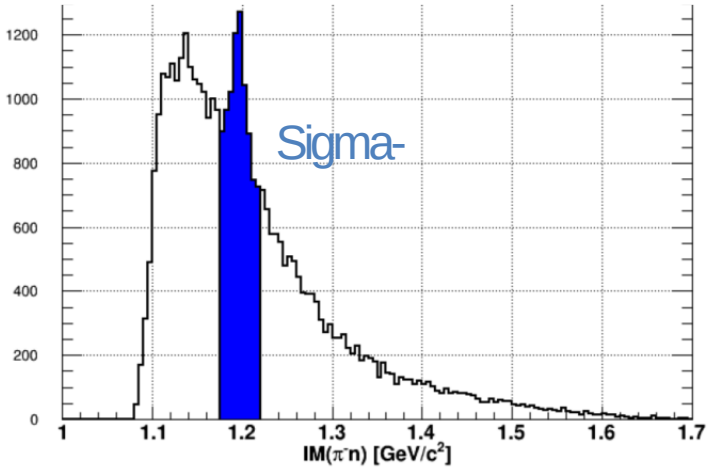
1.372 < 1/beta (P_n < 1.GeV/c)

- 1/beta vs Energy deposit in CDS of Neutral particle.
- Charge veto by the inner Cylindrical Drift Chamber (CDC)

Σ^+/Σ^- selection by πn_{cds}

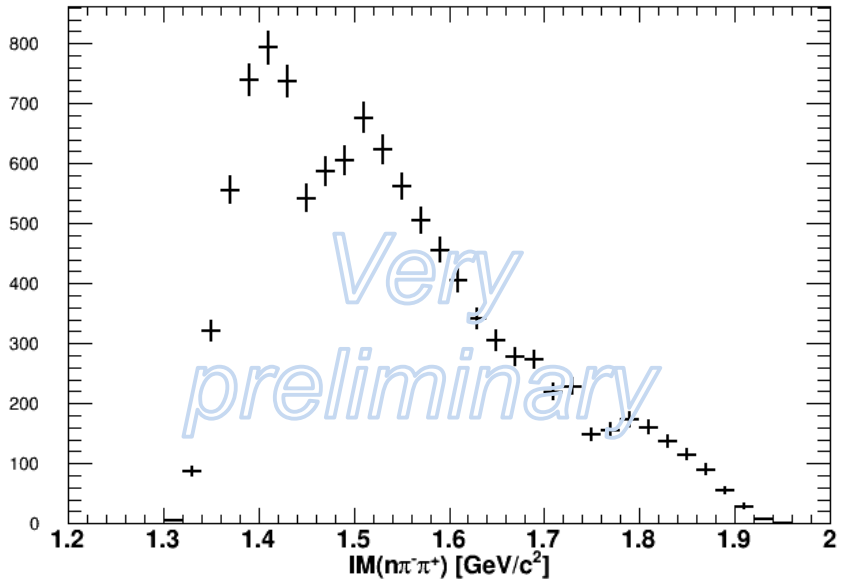


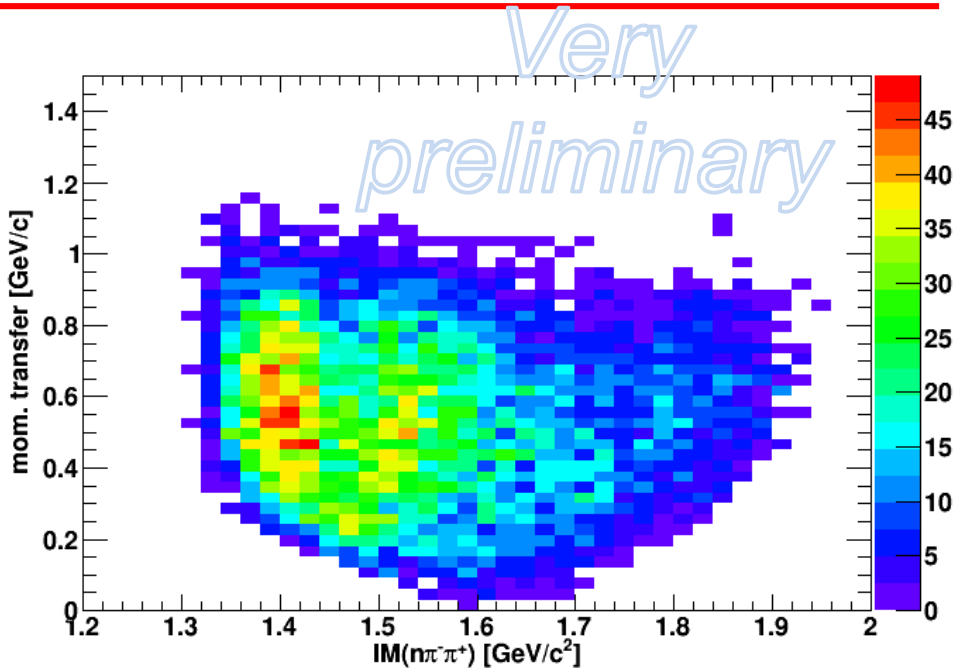




-IM(π^+n) and IM(π^-n)

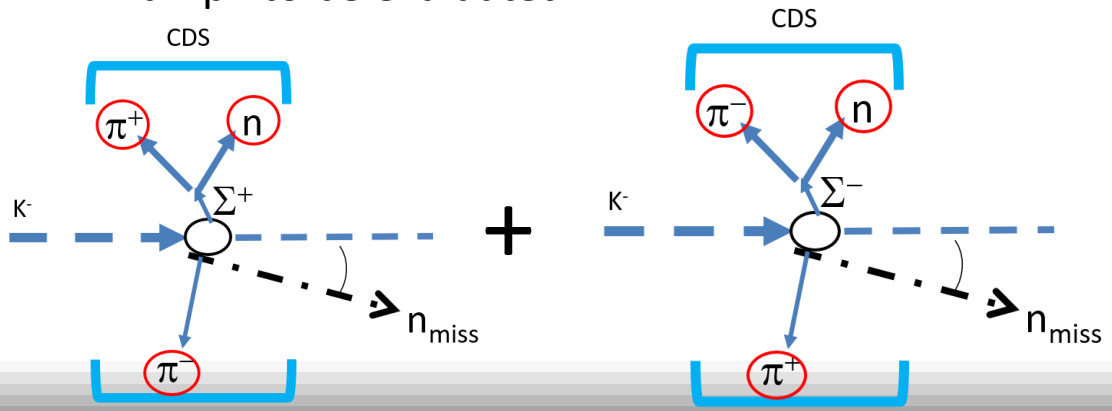
Invariant mass of $(\pi^+\Sigma^-/\pi^-\Sigma^+)$





- Λ(1405) peak is observed
- I=1 amp. to be evaluated.

Momentum transfer q = $|\mathbf{q}_{nmiss} - \mathbf{q}_K|$



Summary

- Data analysis of the E31-2nd Run is in progress.

  -- 39.2 G kaons impacted on the deuteron target

- missing mass spectra of $\pi^{\pm}\Sigma^{\mp}$ and $\pi^{0}\Sigma^{0}$ by the kaon induced reaction on deuteron are obtained for the first time

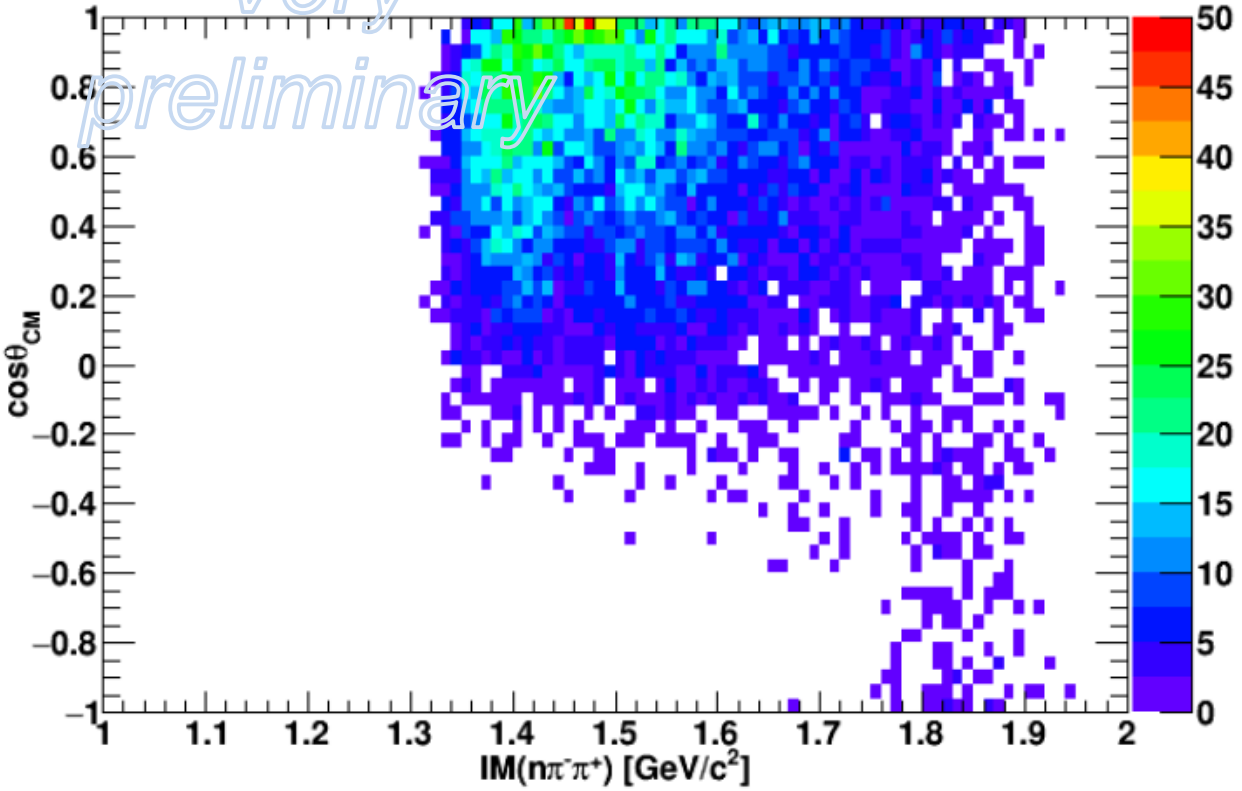
  -- Pole position of $\Lambda(1405)$ will be extracted by theoretical model fits

- New analysis of Invariant mass of $\pi^{\pm}\Sigma^{\mp}$ and q-dependence is feasible.

  -- $\Lambda(1405)$ peak is observed

  -- I=1 amplitude ($\Sigma(1385)^{0}$-> $\pi^{\pm}\Sigma^{\mp}$) to be evaluated

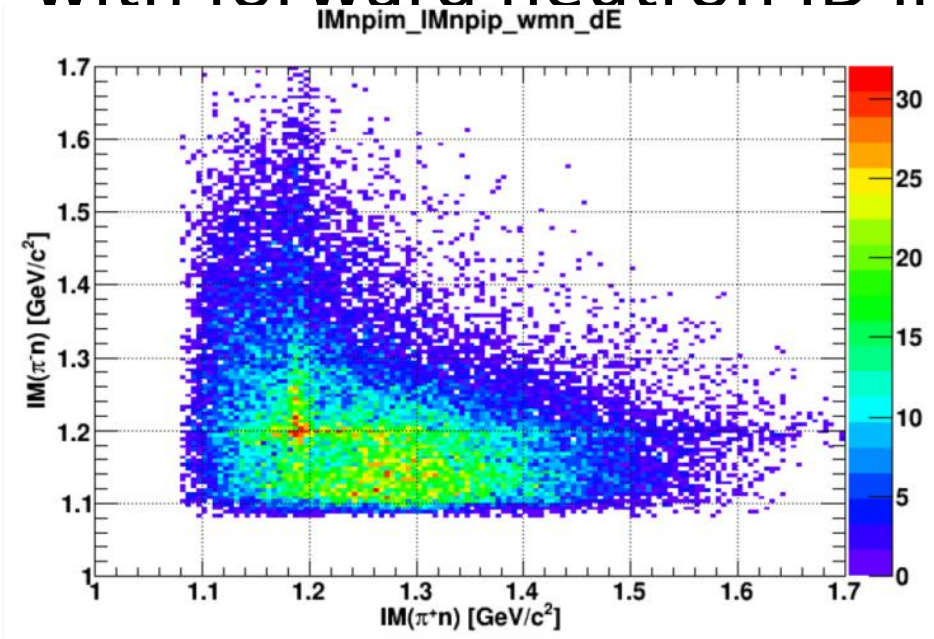
IM ($\pi^+\Sigma^-/\pi^-\Sigma^+$) vs cosθn

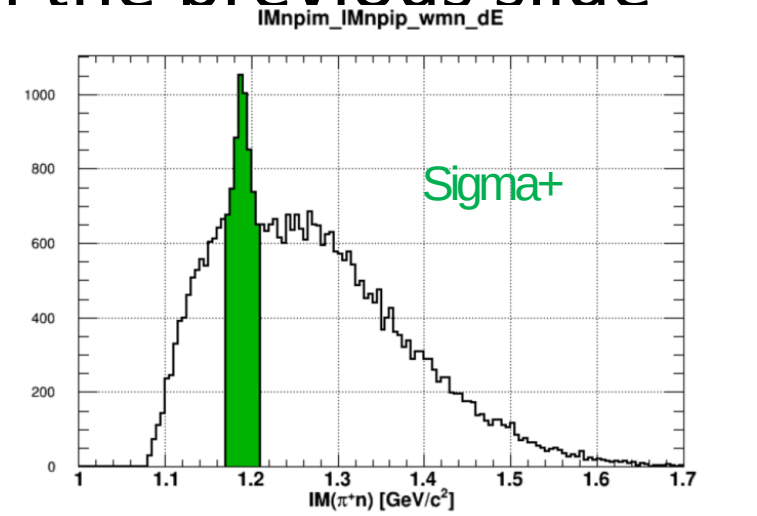


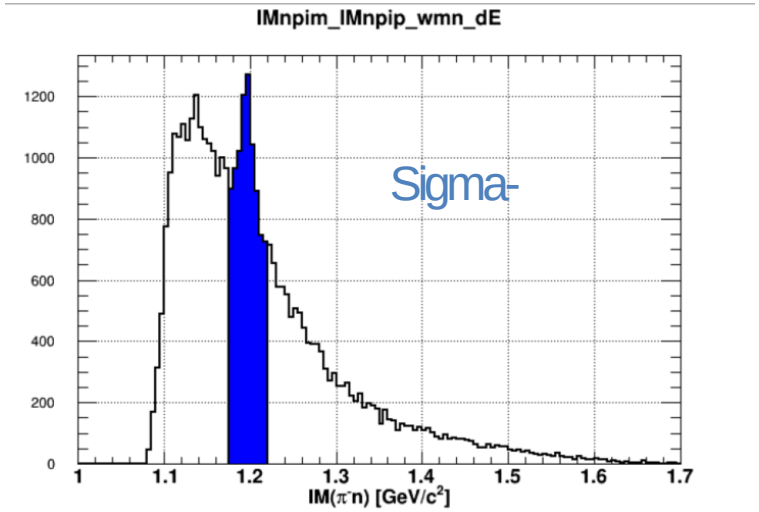
$$\frac{d^2\sigma_X}{dM_{\Sigma\pi}dq} \propto \rho_3(\Sigma\pi n) \times \frac{(\Gamma_{\Lambda(1405)}/2)^2}{(M_{\Sigma\pi} - M_{\Lambda(1405)})^2 + (\Gamma_{\Lambda(1405)}/2)^2} \times |\exp(-q^2/2Q^2_{\Lambda(1405)})|^2,$$

Σ^+/Σ^- selection by πn_{cds}

-with forward neutron ID in the previous slide

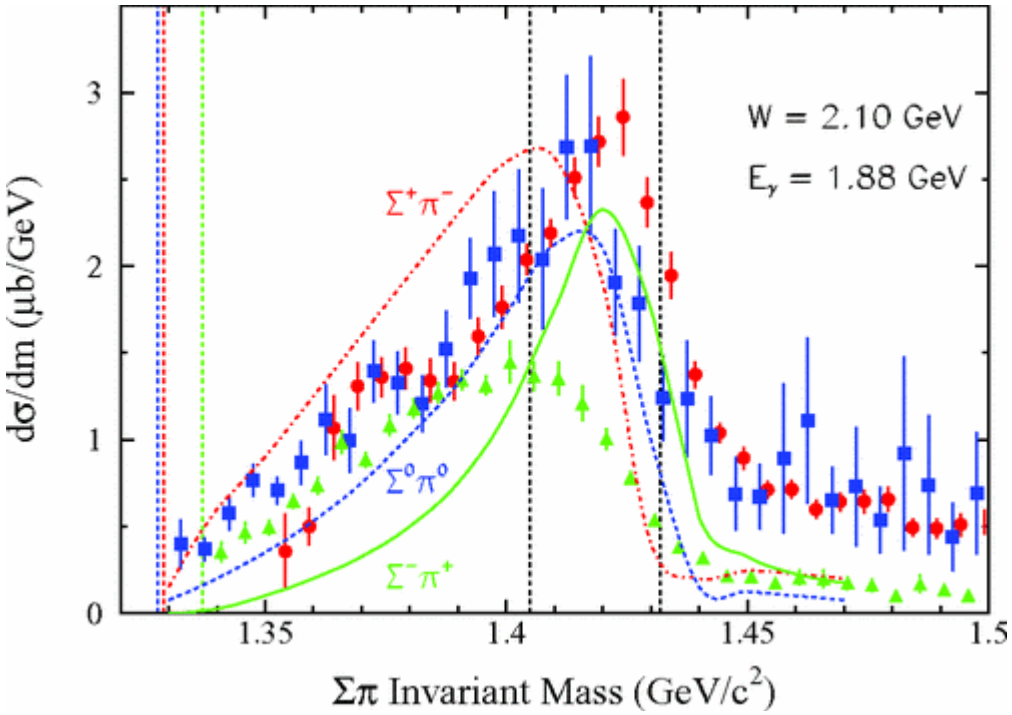






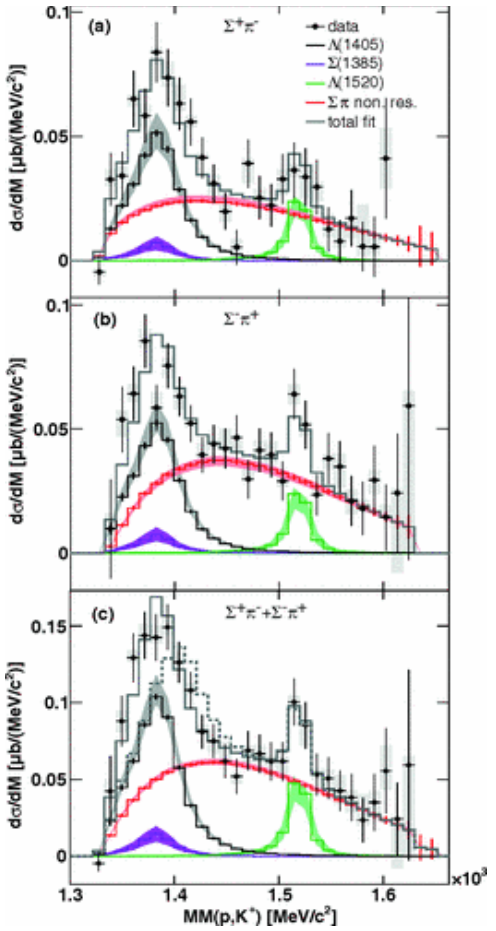
Needs Kaon induced reaction

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



CLAS collaboration: Phys Rev C87, 035206

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

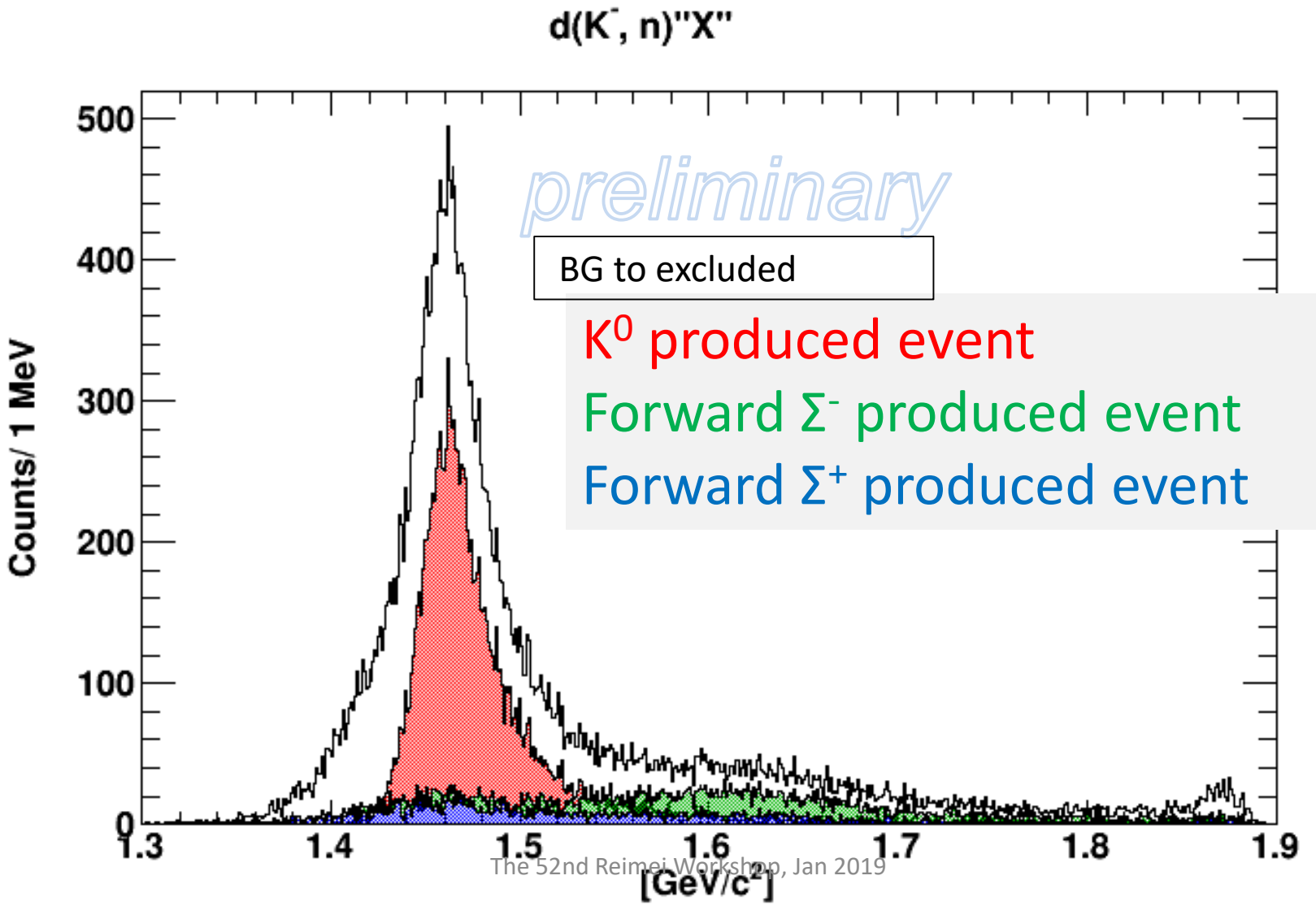


HADES collaboration:
Phys Rev C87, 025201

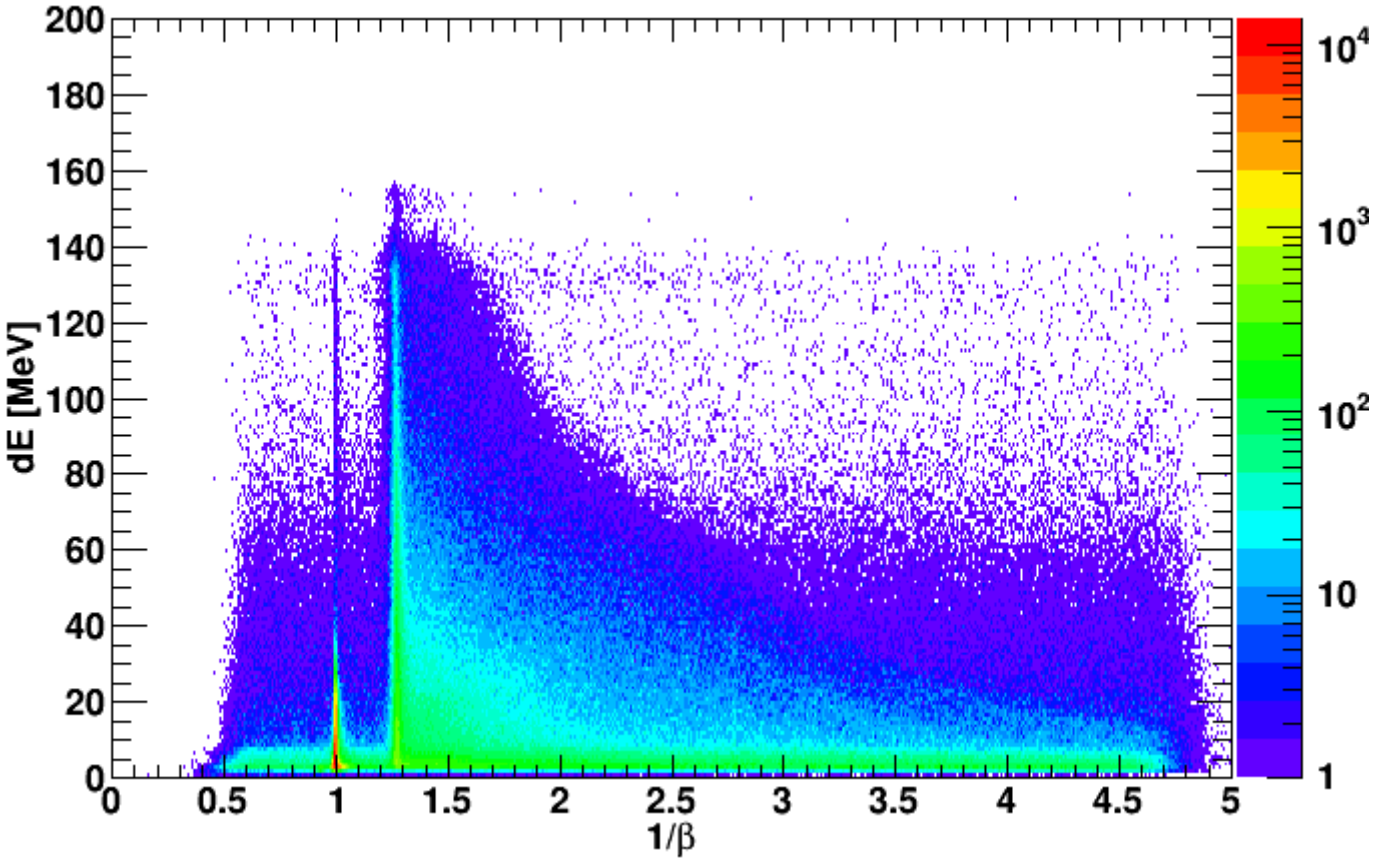
- γ/p induced experiments

How these spectra couple to the KbarN pole or the pole is still controversial.

d(K⁻,n)"X" missing mass spectra

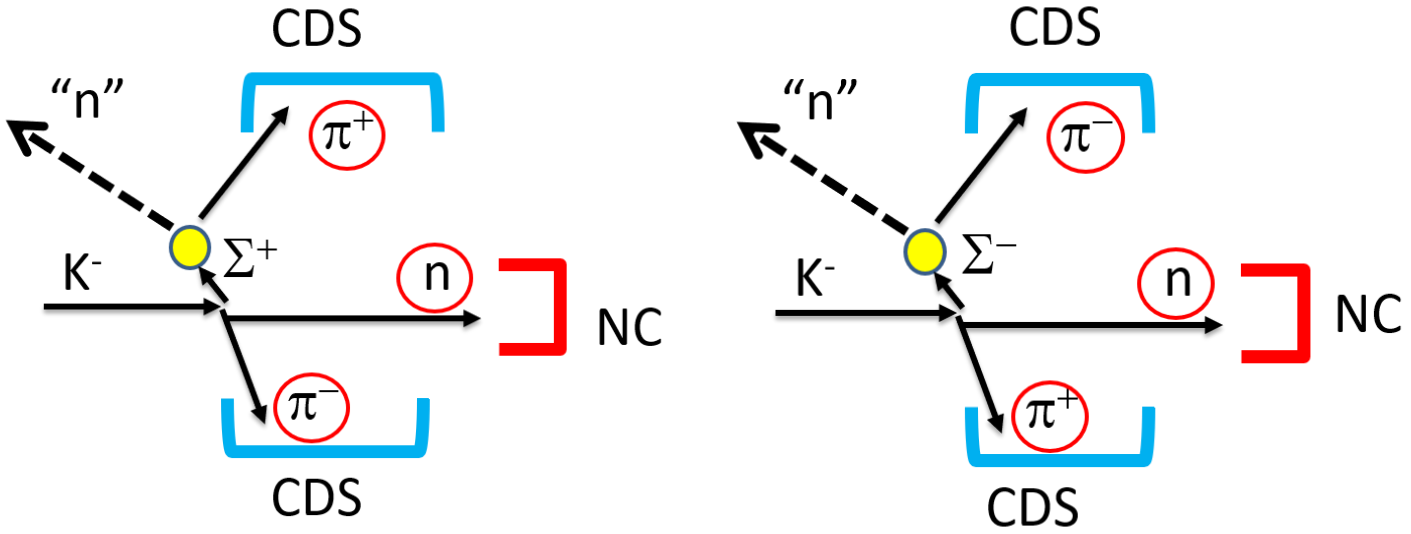


Detector Performance



Signal/Background process

Signal



BG