Spectroscopic study of the $\Lambda(1405)$ resonance via the $d(K^-,n)$ reaction at J-PARC

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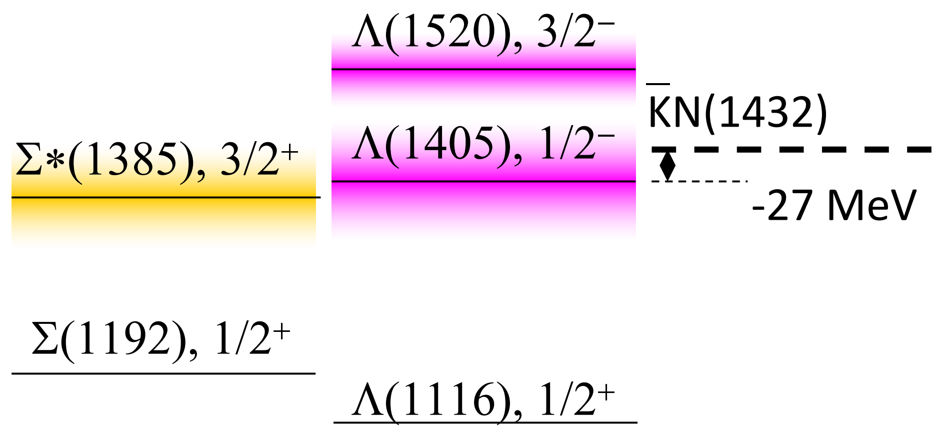
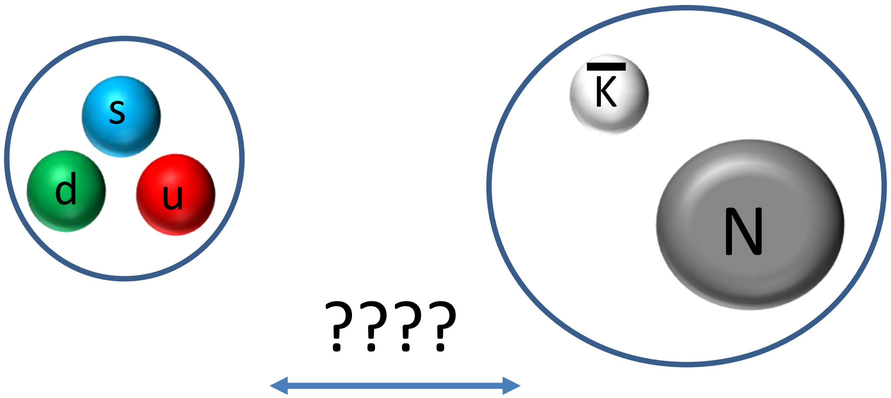
for the J-PARC E31 collaboration

Investigation of the Λ(1405)

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

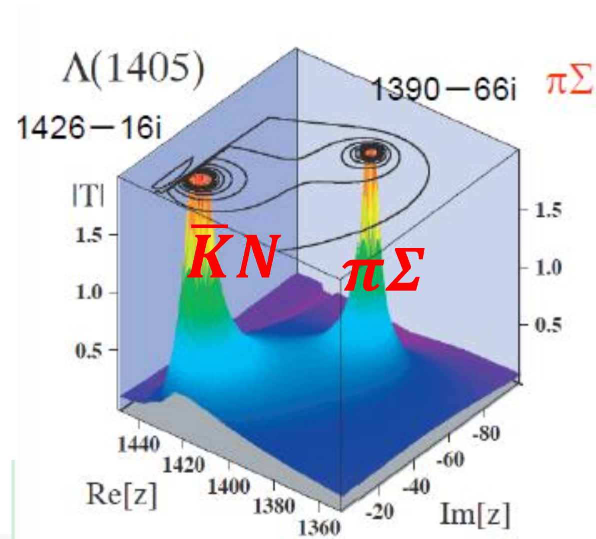




3 quark

$\bar{K}$N bound state

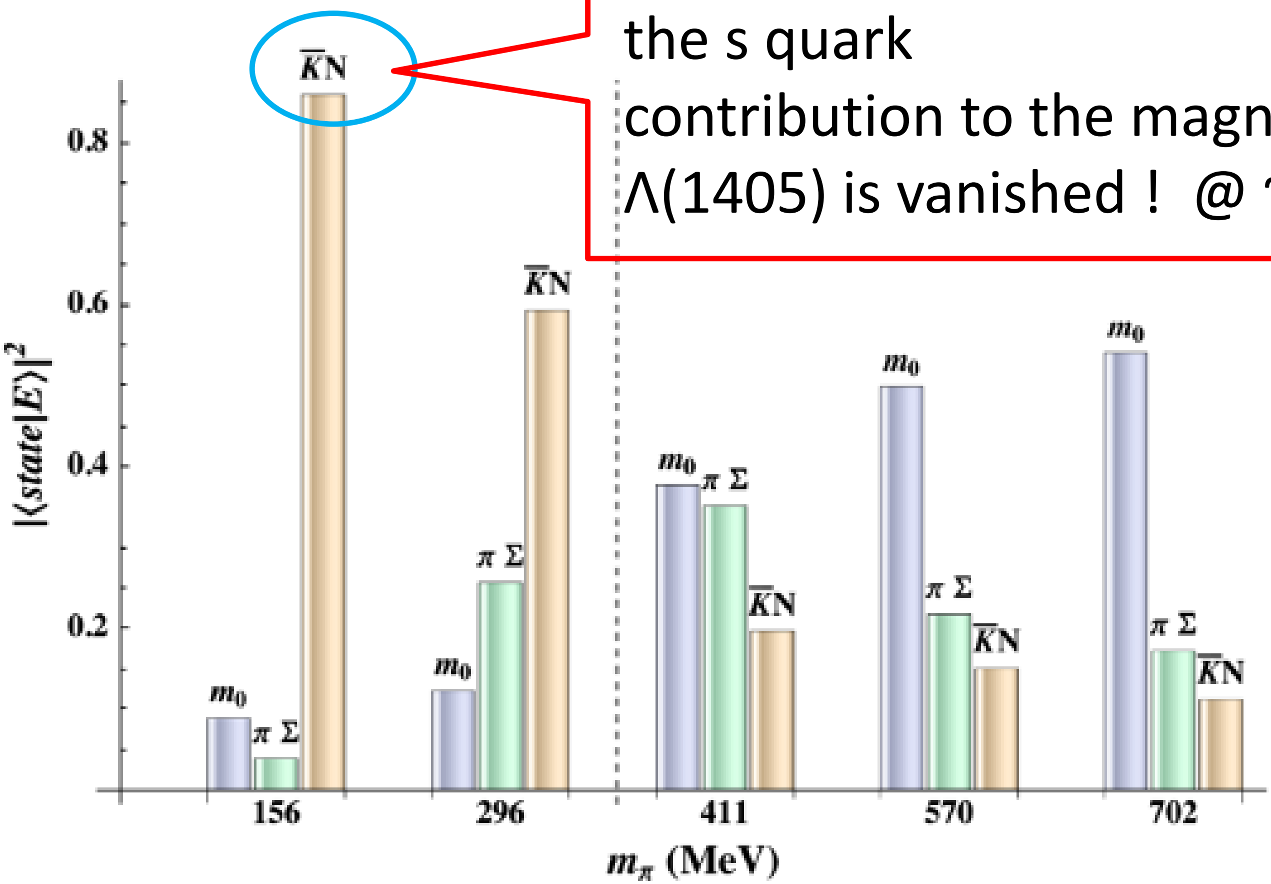
chiral unitary model:
2 pole structure of the Λ(1405)
with $\bar{K}$N, πΣ resonant states



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

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

PRL 114, 132002 (2015)

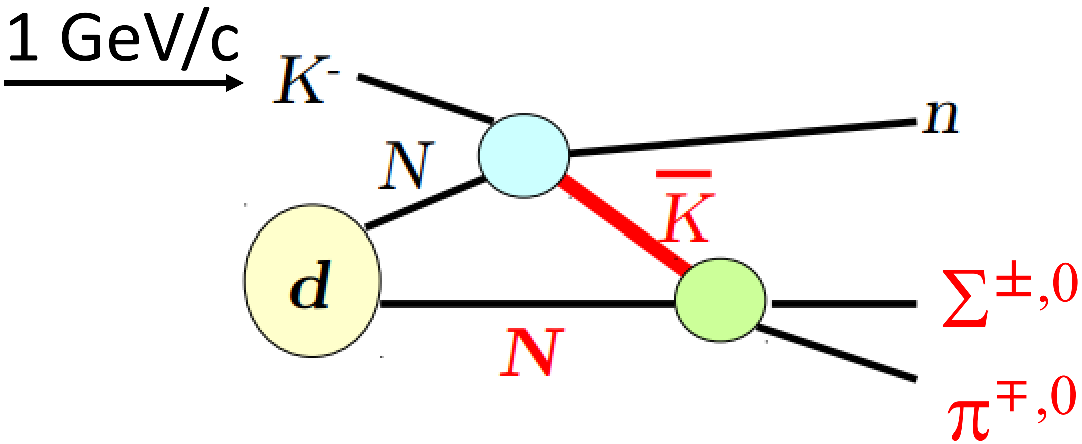


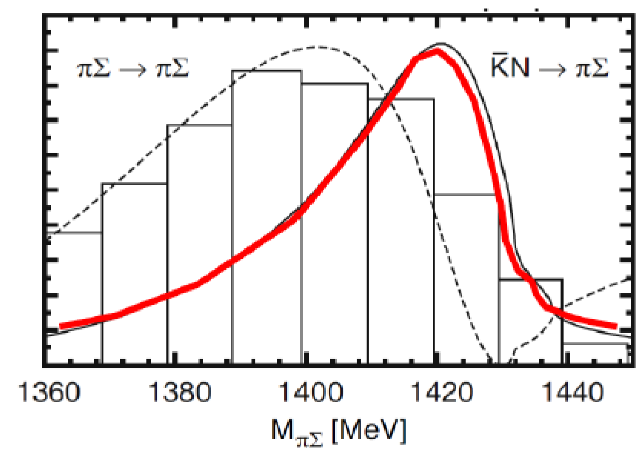
the s quark
contribution to the magnetic moment of Λ(1405) is vanished ! @ ~physical pion mass

Study of $\overline{K}N$ scattering below the $\overline{K}N$ threshold is important.

J-PARC E31 experiment

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





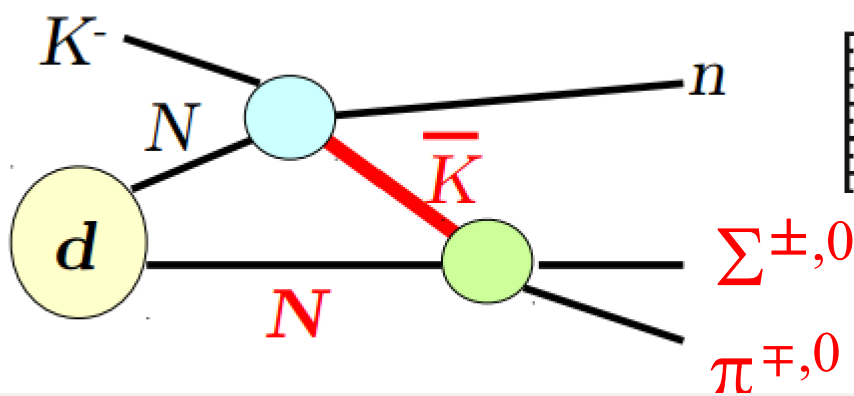
ChiralUnitary Model:
D. Jidoet al., NPA725(03)181

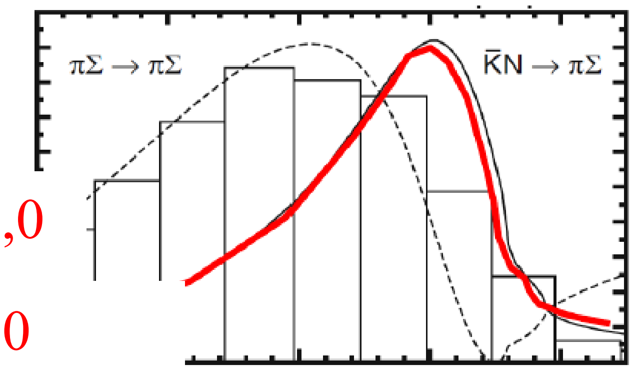
- 2 step process
- Producing Λ(1405) by virtual $\bar{K}$

J-PARC E31 experiment

measuring an $\bar{K}N \rightarrow \pi\Sigma$ scattering below the $\bar{K}N$ 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	Λ(1405) I=0 S-wave, non-resonant Σ(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	Λ(1405) (I=0, S wave) non-resonant

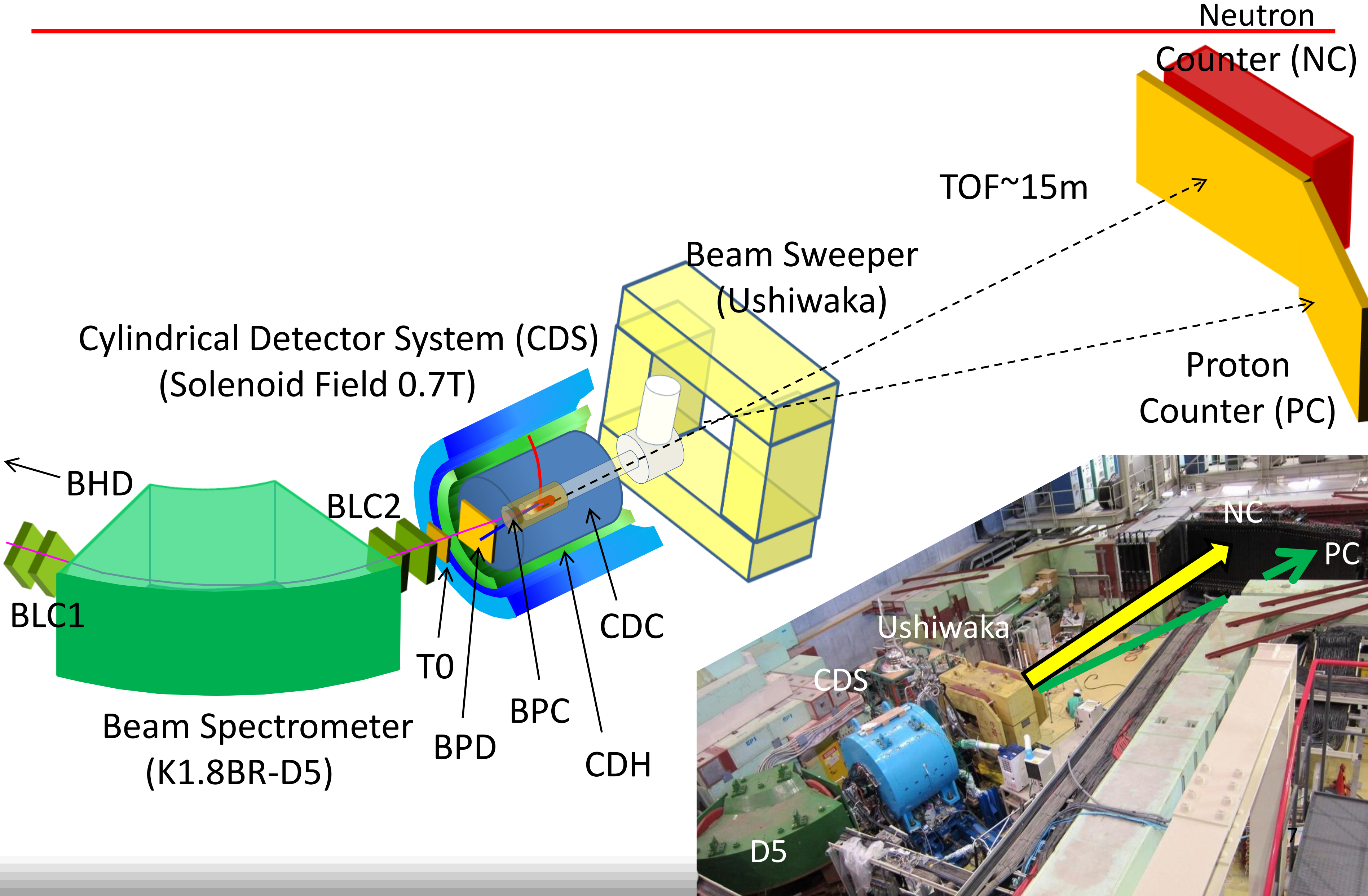
Charged mode

Neutral mode

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	33.5-51.1kW	20d	100% !!

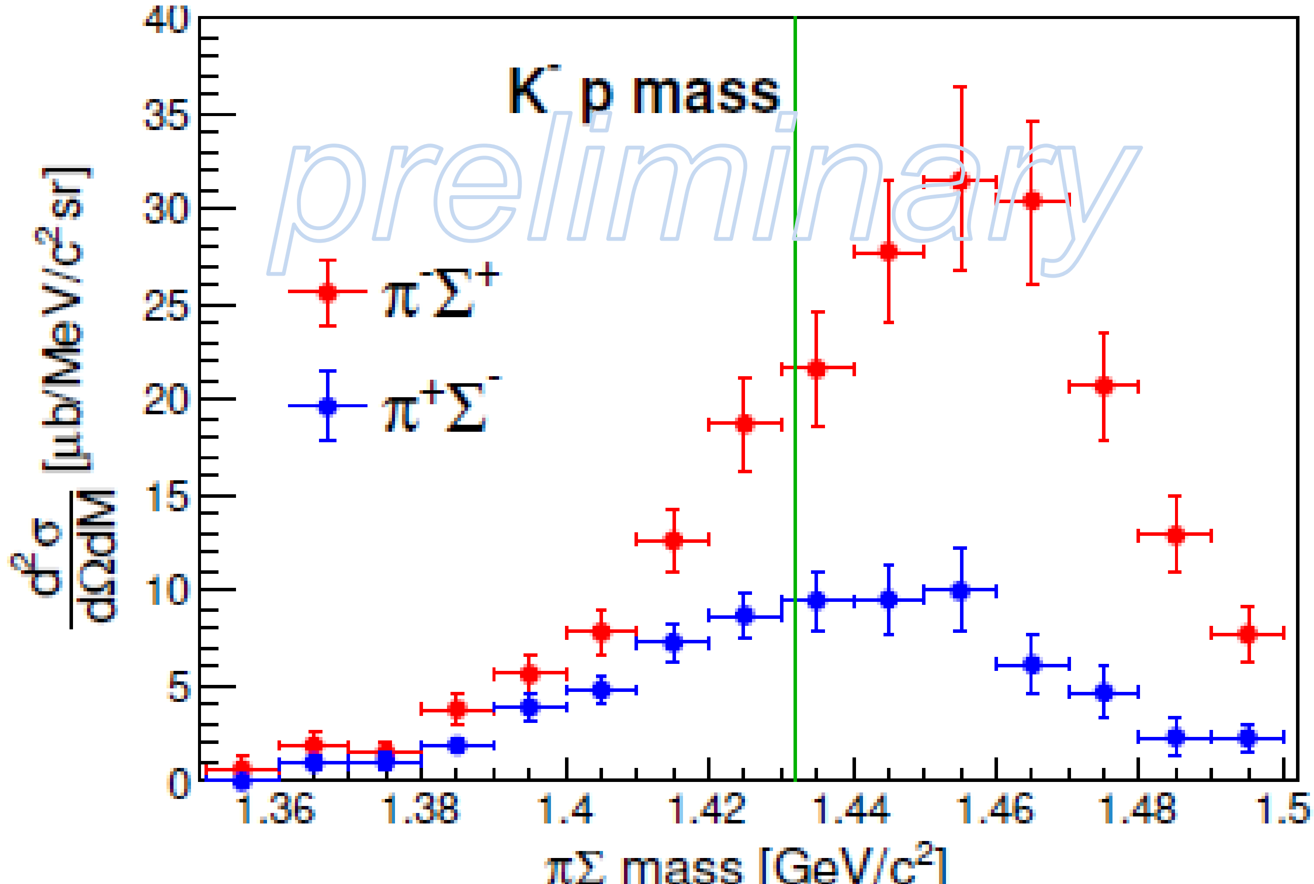
J-PARC K1.8BR beam line



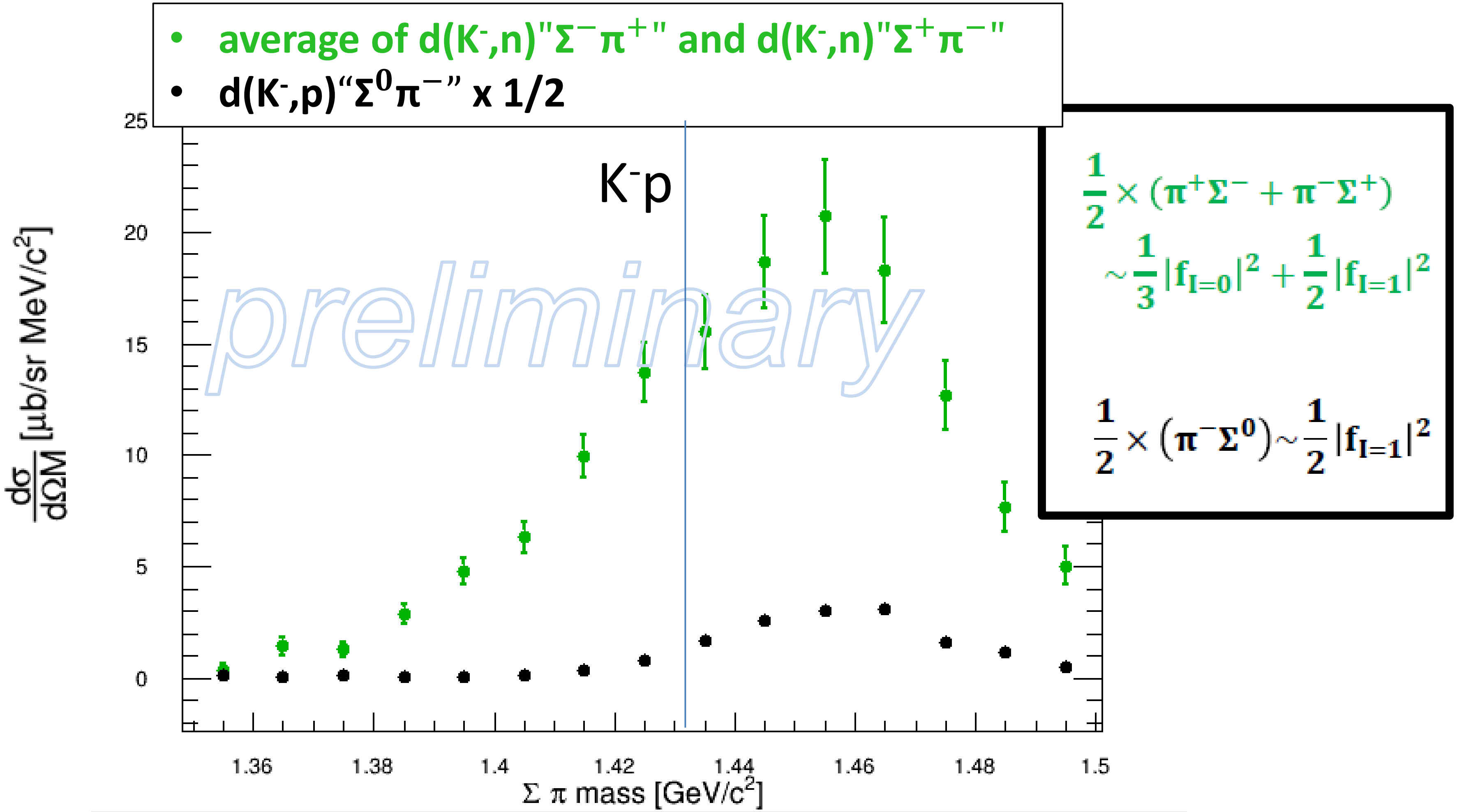
Achievement of E31-1st

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

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



I =0 dominance

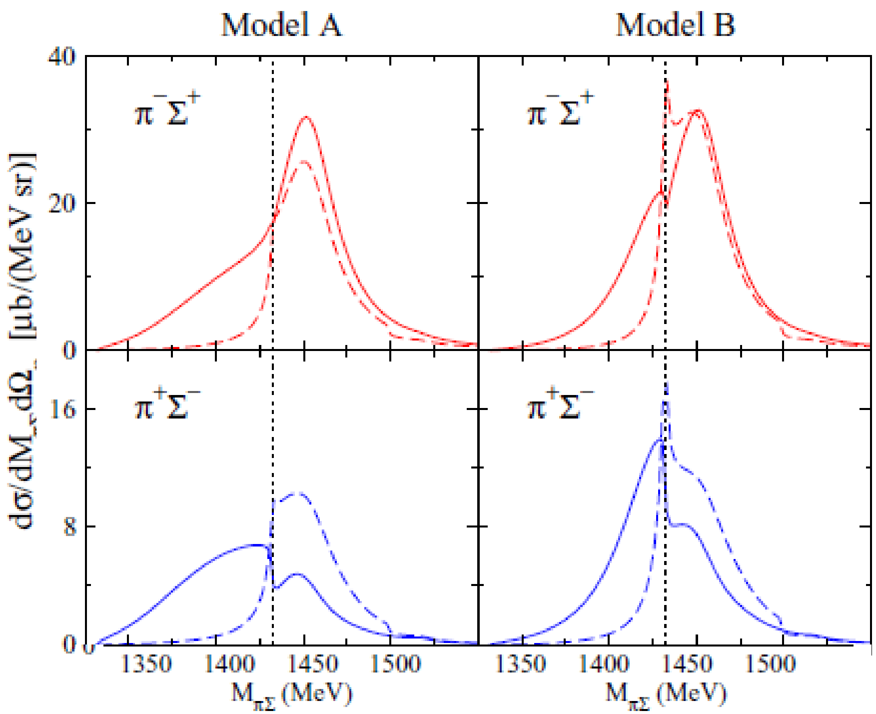


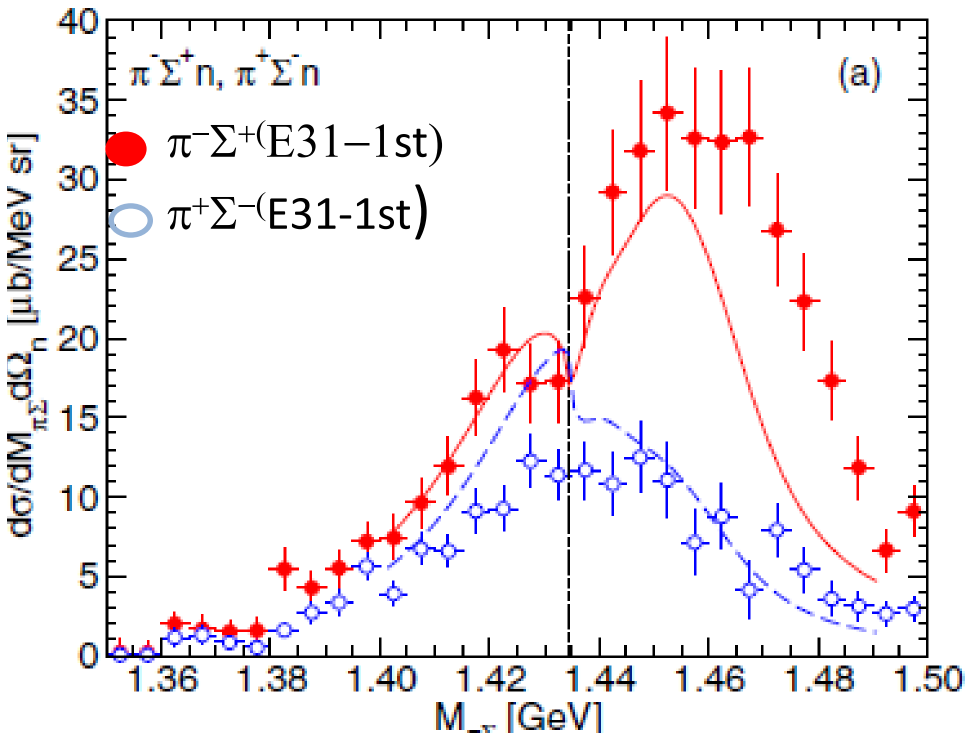
Assuming the similarity of the reaction mechanism of d(K-,n) and d(K-,p), the amplitude of I =0 in the d(K-,n) reaction is dominant below the threshold

What we learned from E31-1st

- The preliminary results of the d(K$^-$,n)"$\Sigma^-\pi^+$" and the "$\Sigma^+\pi^-$" spectra were obtained.
    - The Interference between "$\Sigma^-\pi^+$" and "$\Sigma^+\pi^-$"
  - The d(K$^-$,p)"$\Sigma^0\pi^-$" spectrum (I = 1) were obtained
    → The I = 0 amplitude is dominant below the $\bar{K}N$ threshold in the d(K$^-$,n)"$\Sigma^-\pi^+$" and "$\Sigma^+\pi^-$" spectra
- The d(K$^-$,n)"$\Sigma^0\pi^0$" spectrum (I = 0)
    - Analysis procedure was established
    - Need more statistic to discuss line shape (~25 events @ region of interests.....)

Recent theoretical development





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

-dynamical coupled-channels (DCC) model

—— Full

–·–·· w/o JP=1/2- Λ resonant amplitude

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

-studied within a Faddeev-type approach

-good agreement with data

E31 - 2nd

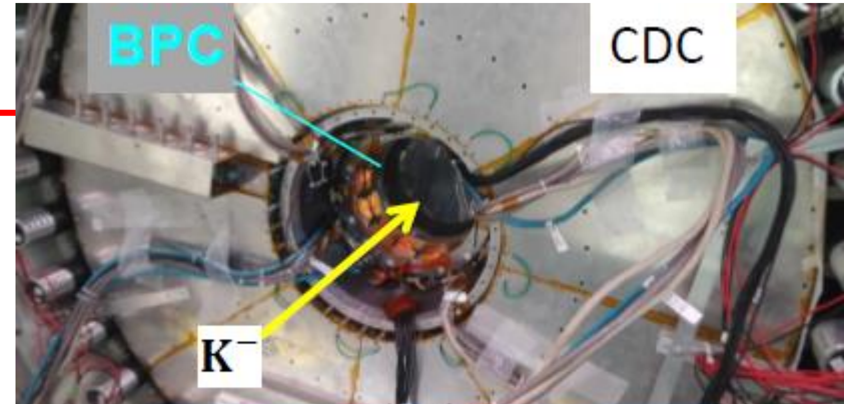
- Beam time request
- Detector Upgrade

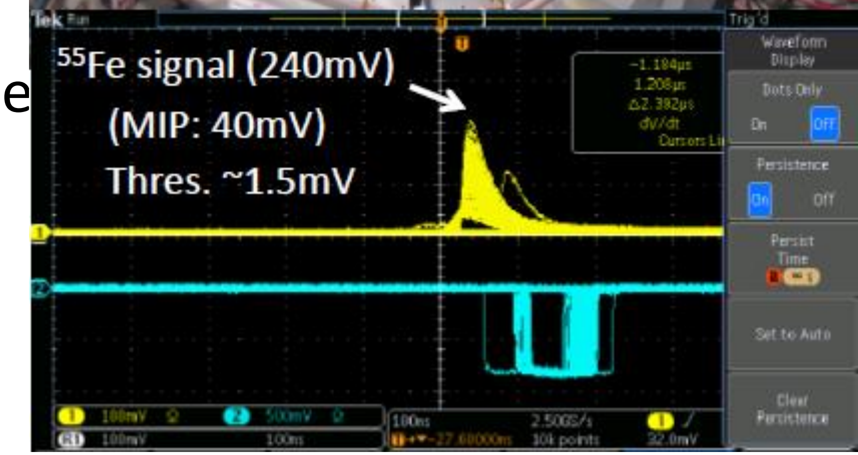
for "$\Sigma^0\pi^0$"

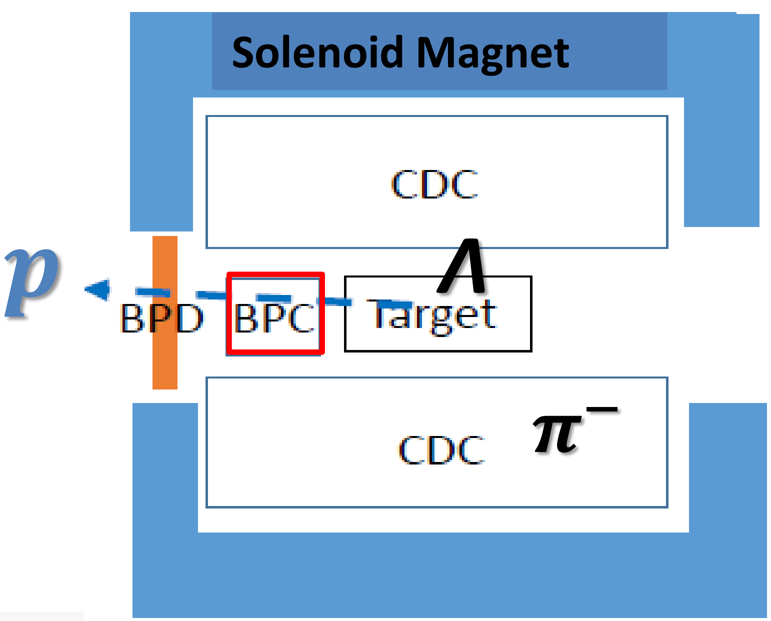
New Backward Proton Chamber (BPC)

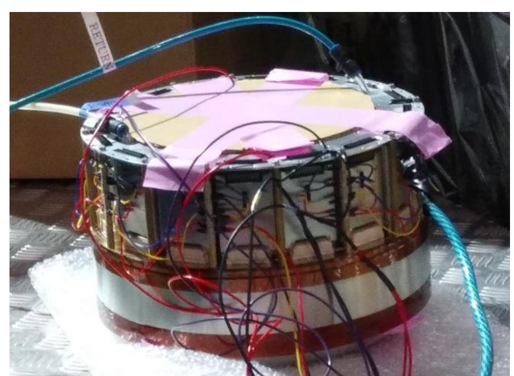
-- event vertex

-- tracking backward scattered particle









1.7 times enlarged in diameter !

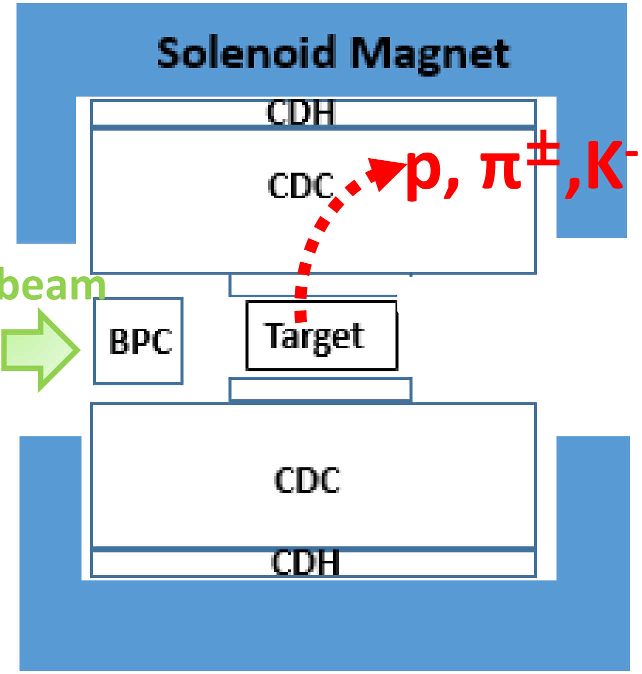
E31- 2^{nd}

- Successfully finished in Feb. 2018
- 3.92×10^{10} Kaons impacted on the deuteron target

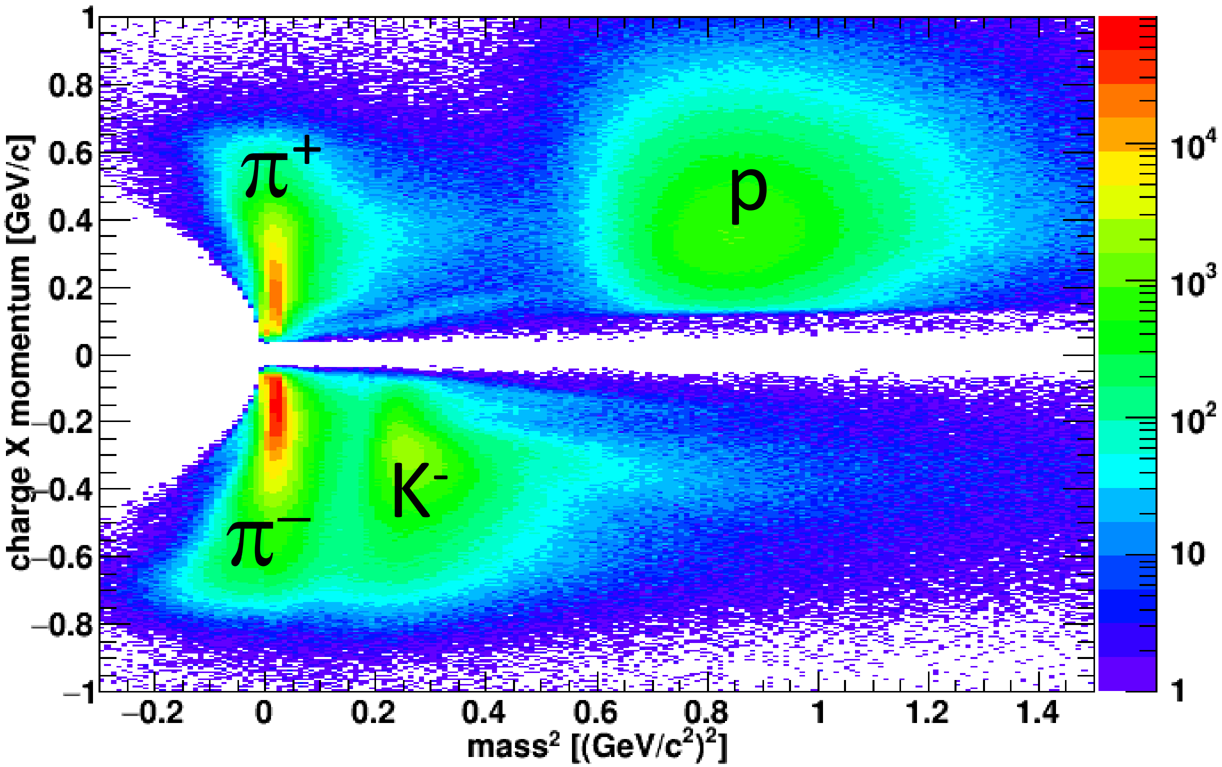
- Detector performance
- Analysis procedure
- Consistency check

Detector Performance

CDS

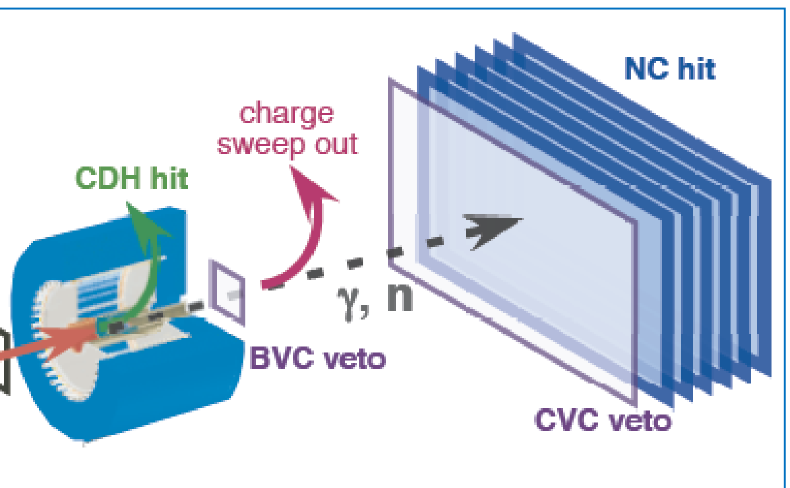


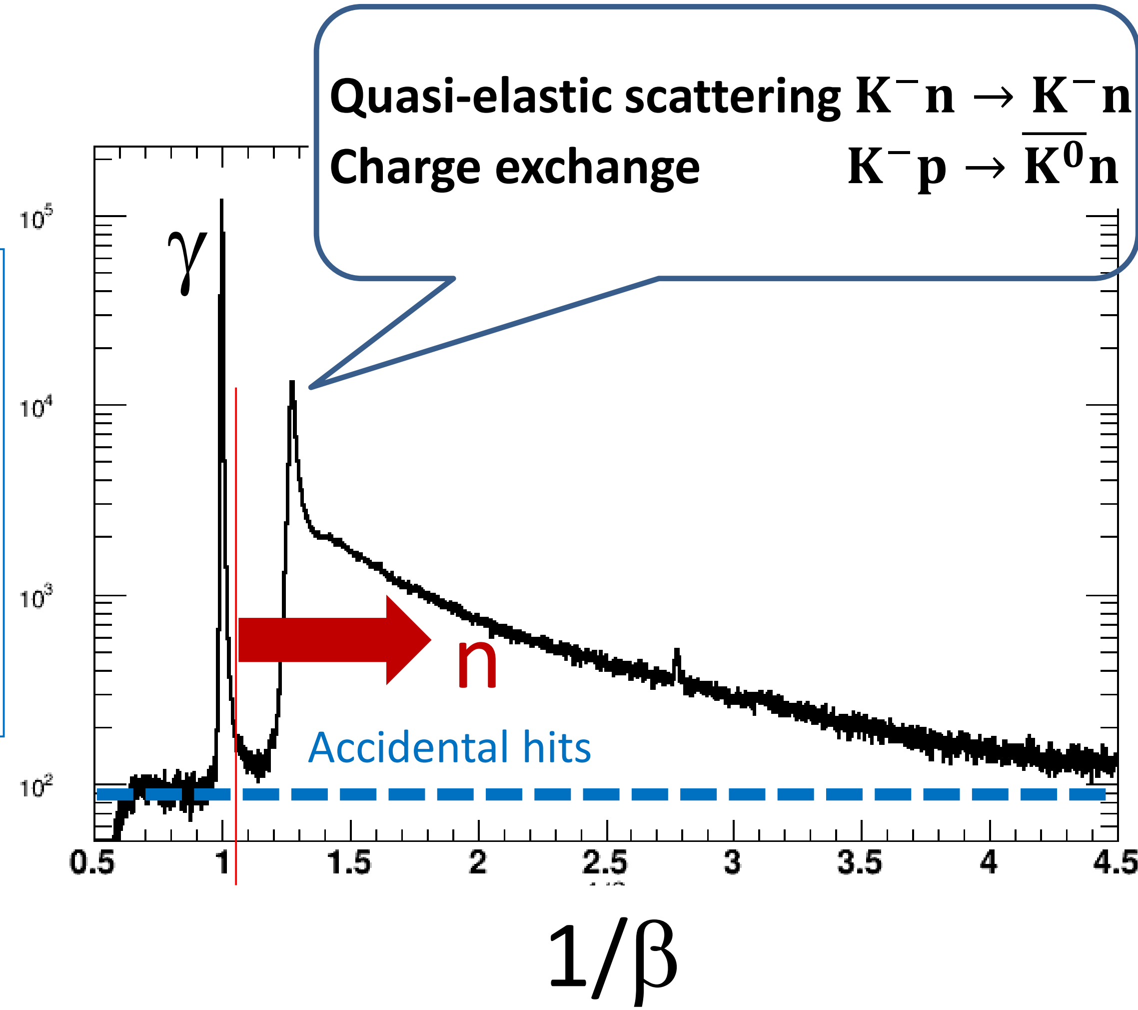
Particle ID by CDS



Detector performance

Neutron Counter (NC)

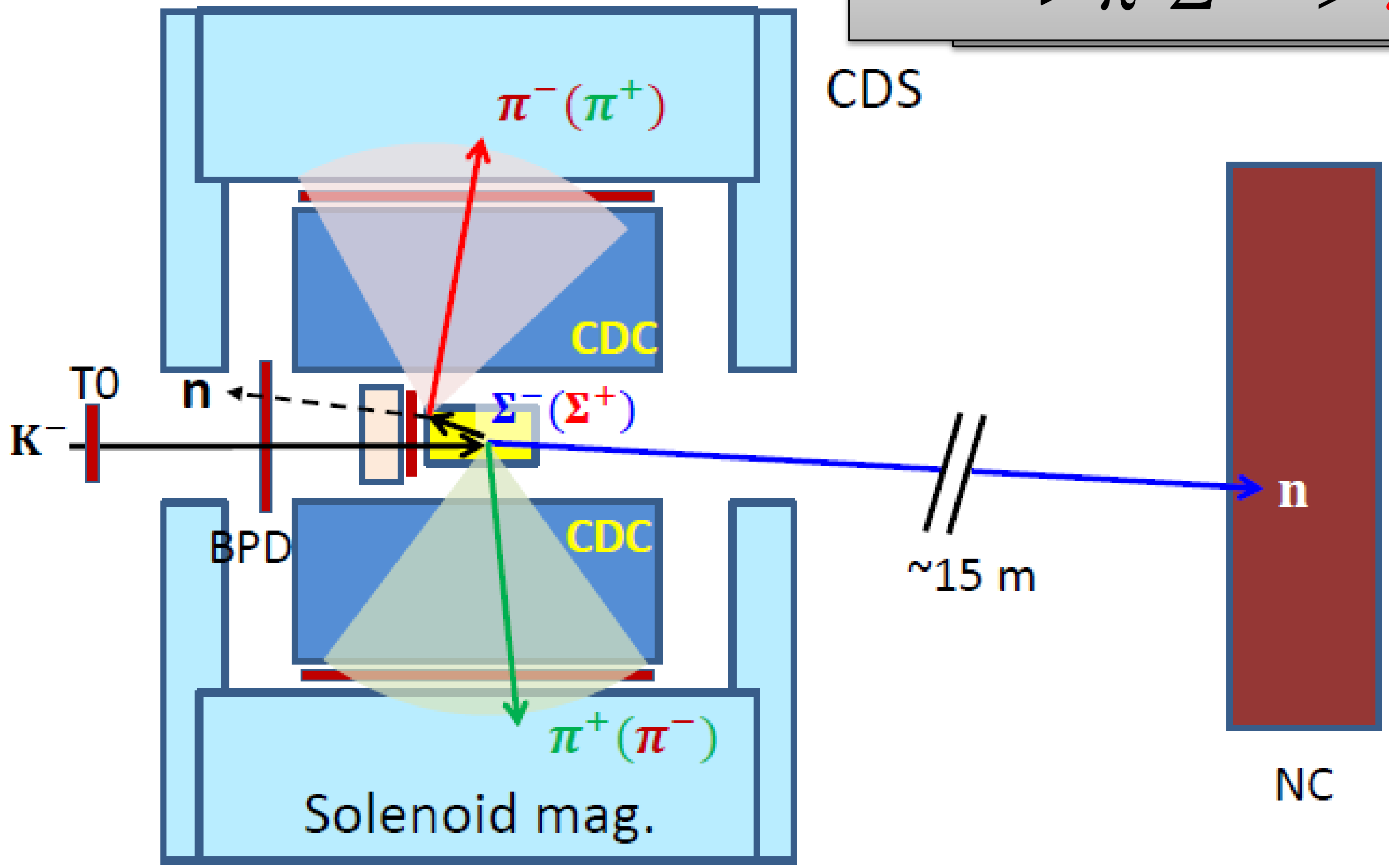




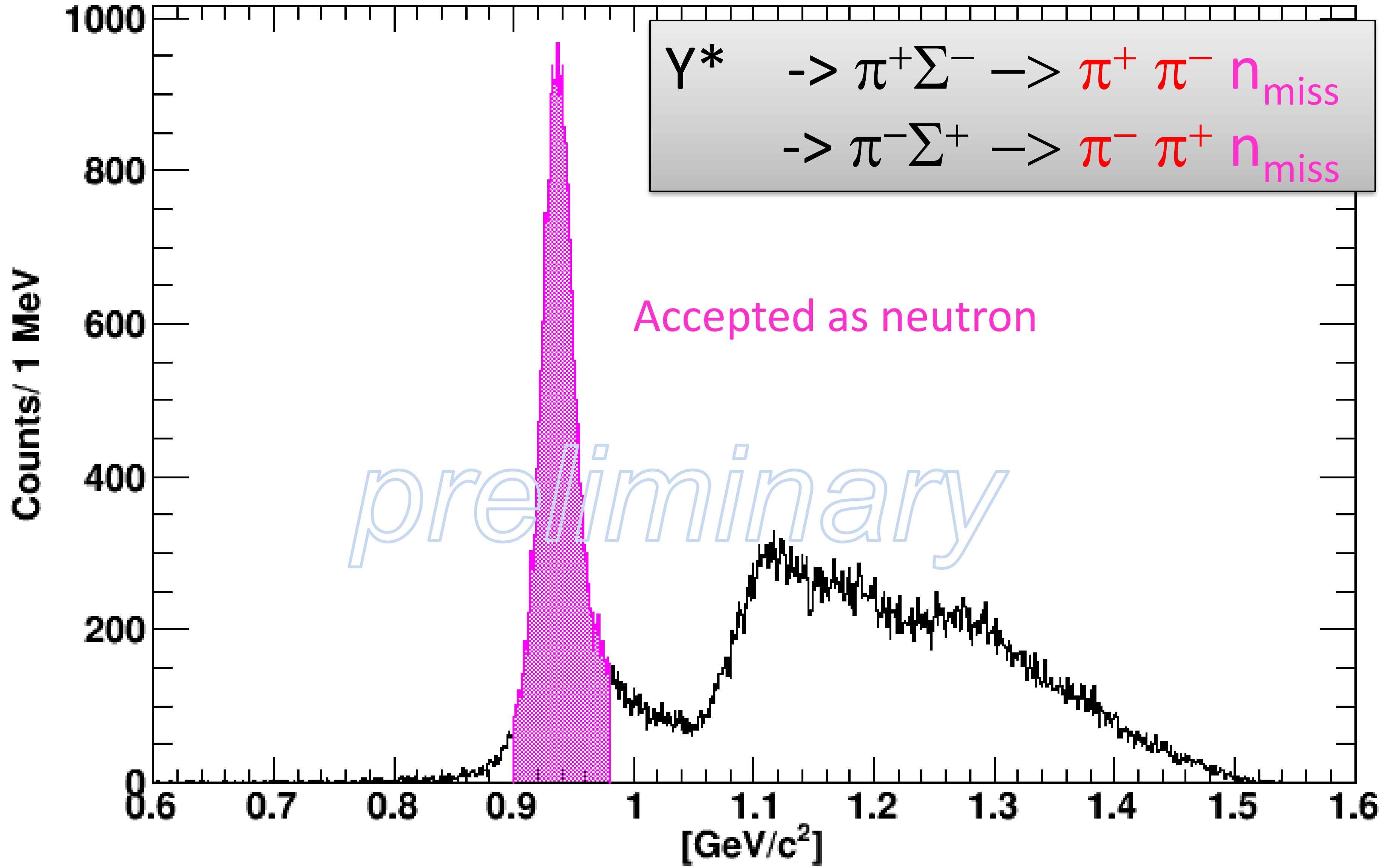
Analysis of d(K$^-$,n)X $\pi^{\mp}\Sigma^{\pm}$

Event topology

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

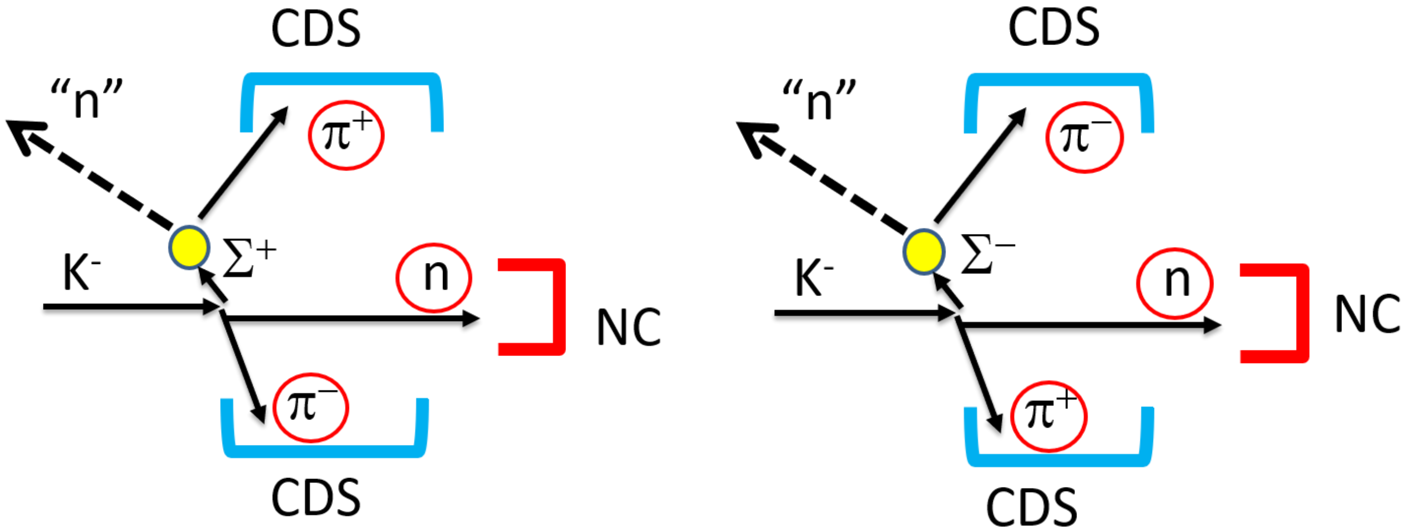


Missing mass d(K$^-$,$\pi^+\pi^-$n)"X"

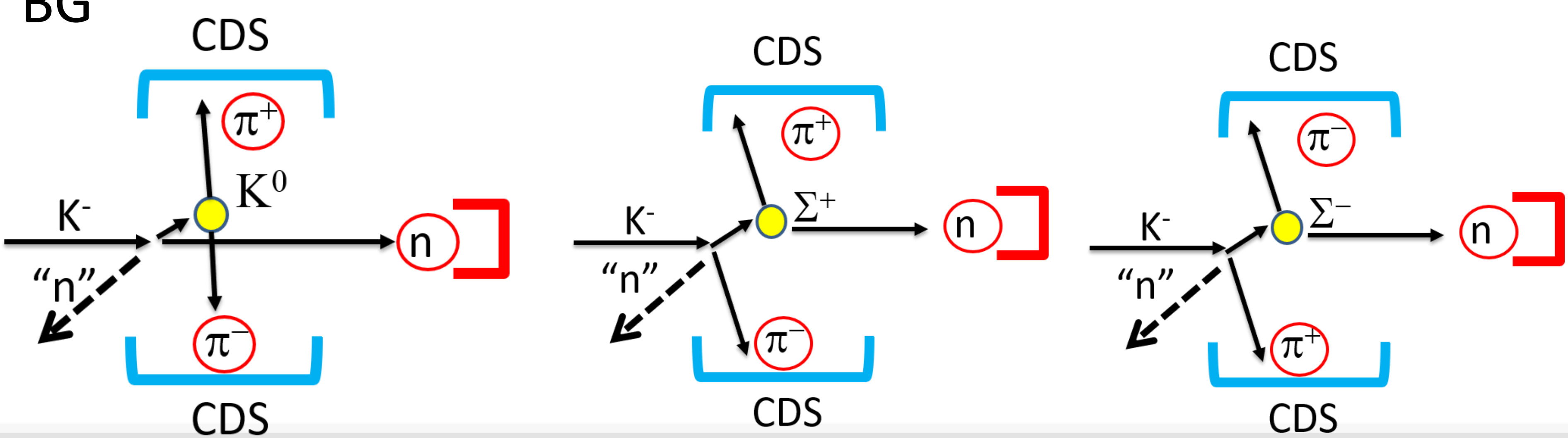


Signal/Background process

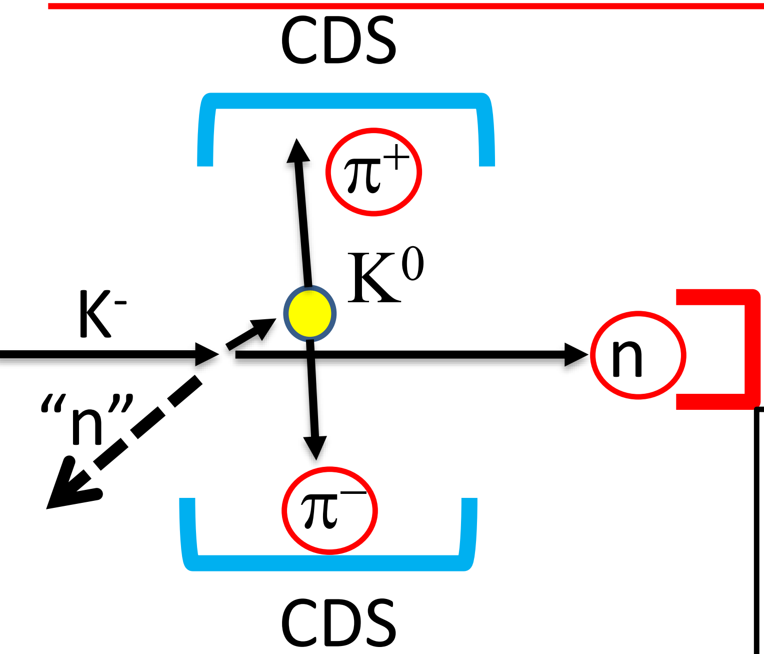
Signal

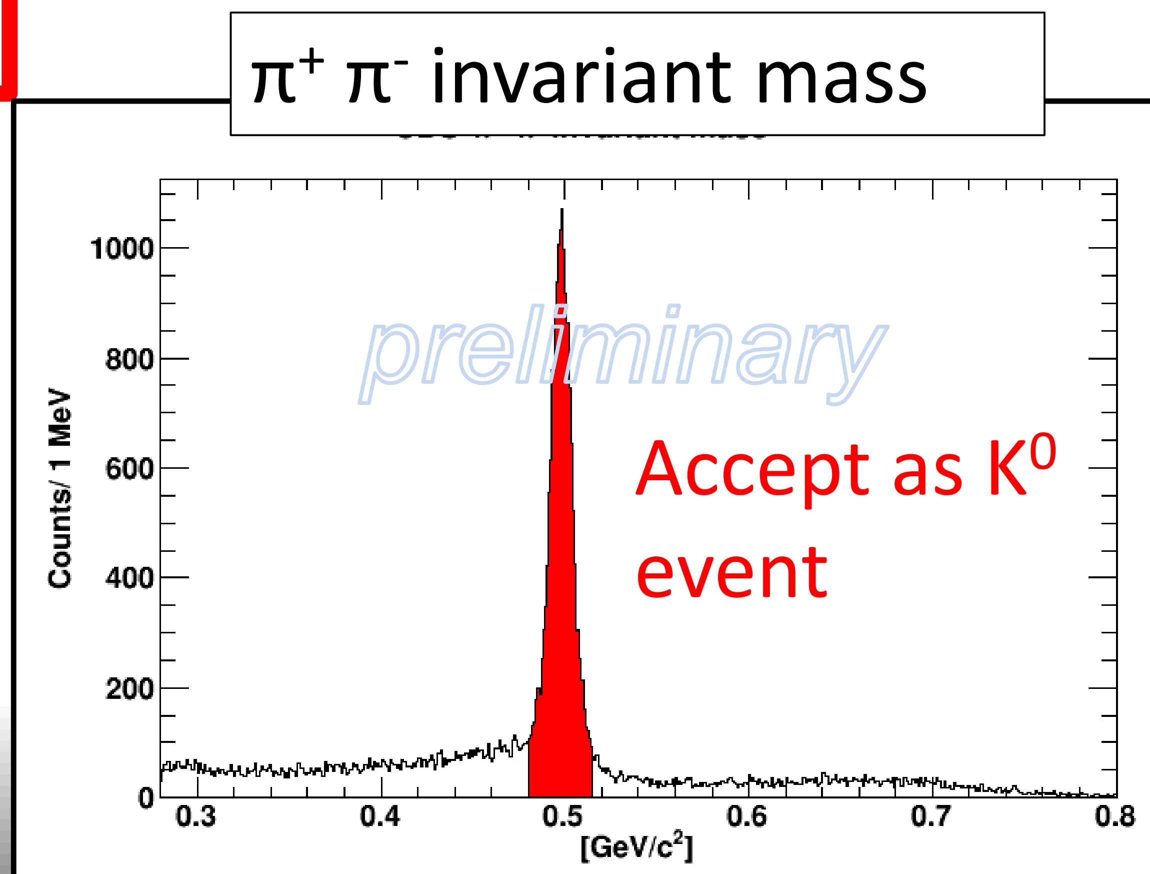


BG



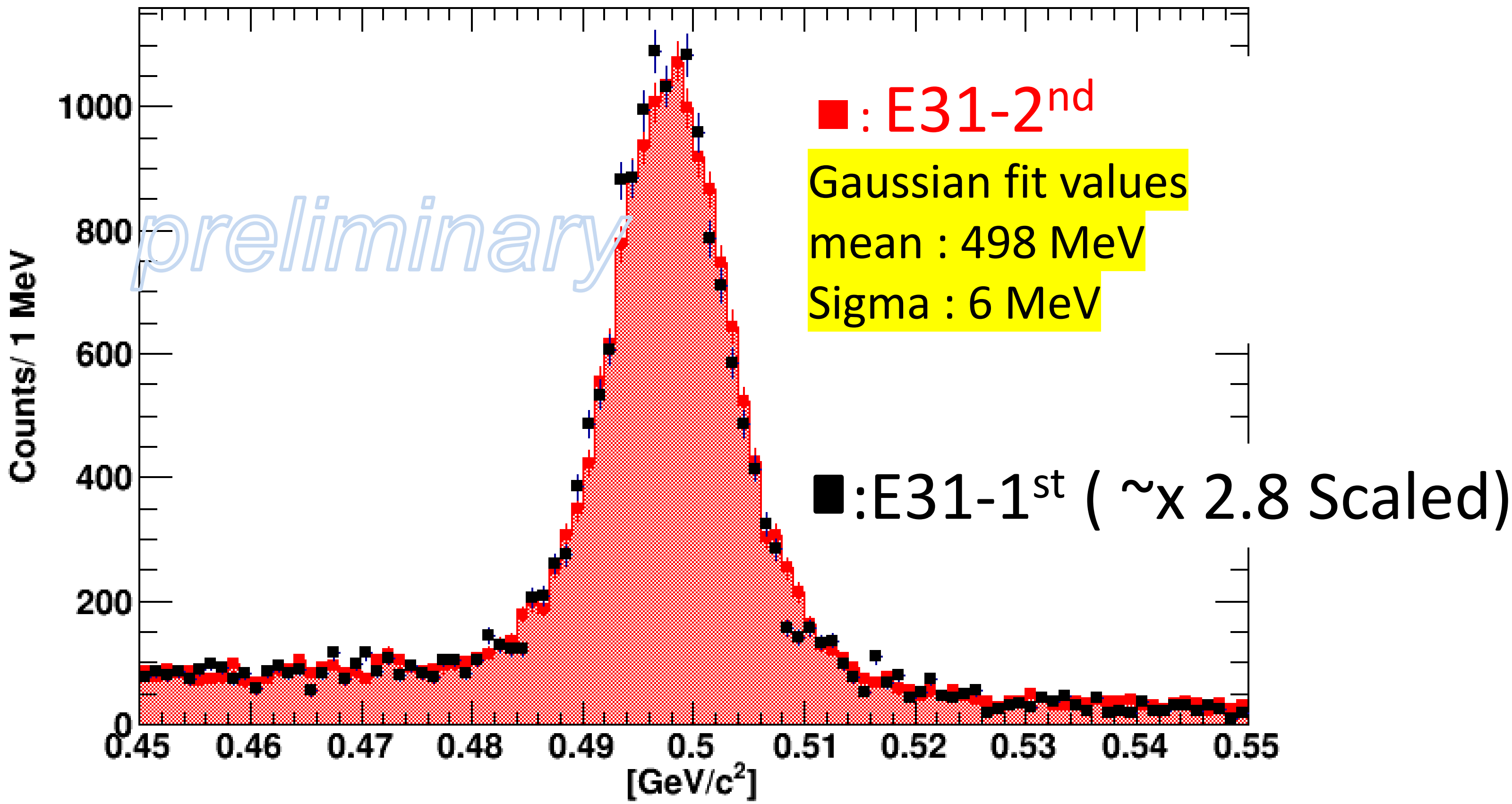
Background 1: $K^0 + n + n$



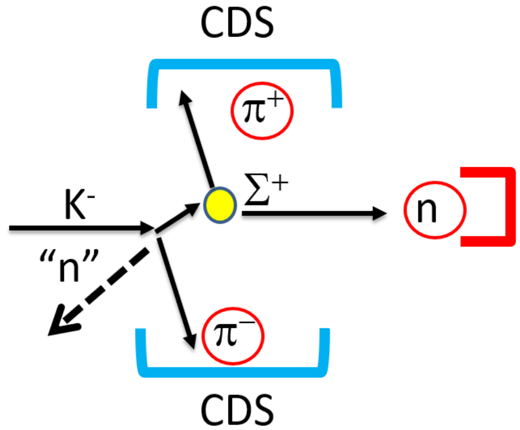


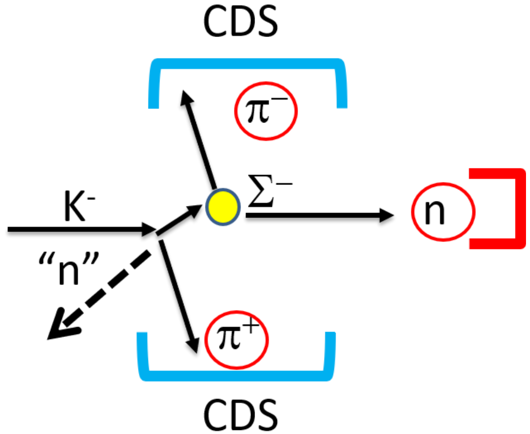
Consistency check: CDS resolution

$\pi^+ \pi^-$ invariant mass

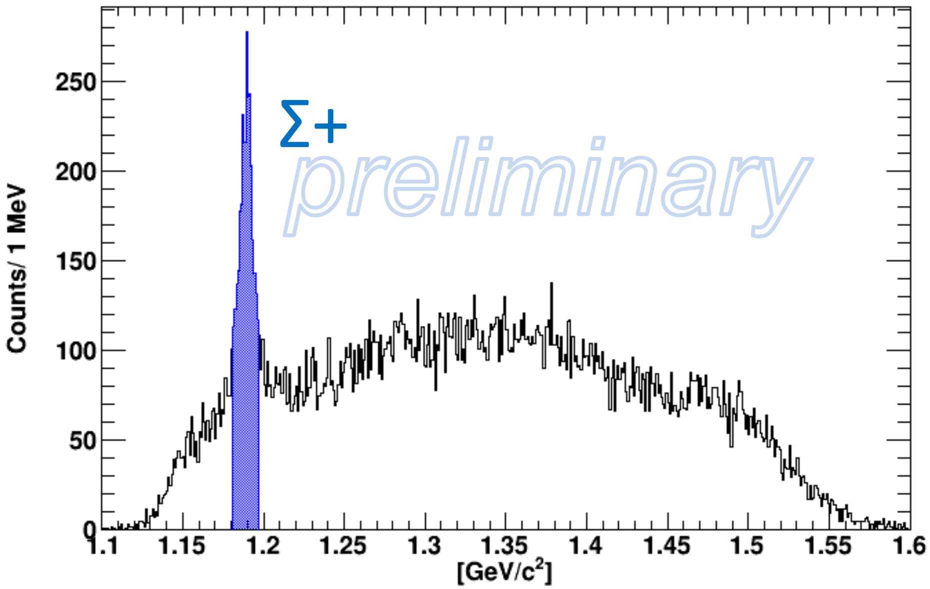


Background 2 : Forward Σ production

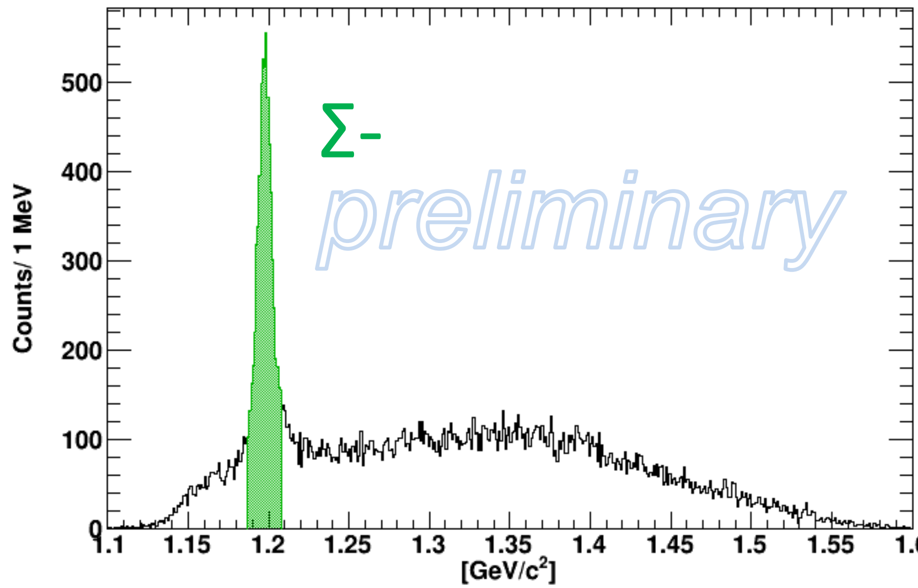




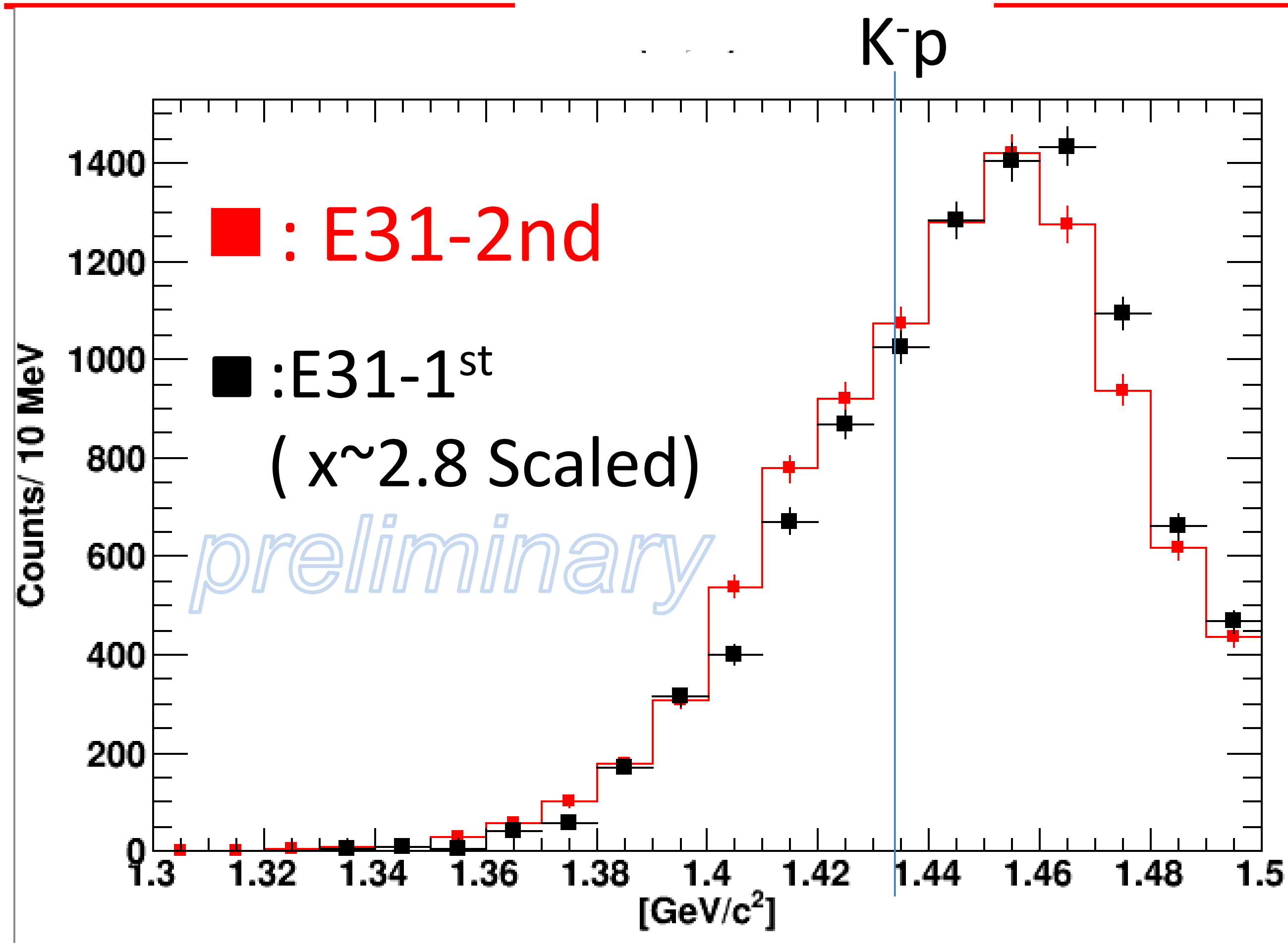
π^+ + forward n invariant mass



π^- + forward n invariant mass



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



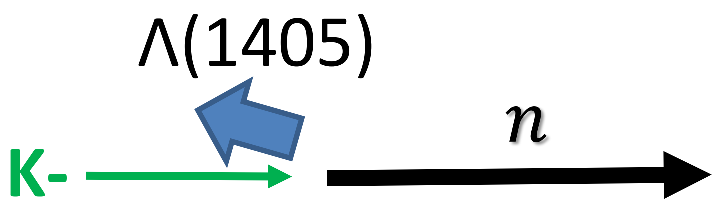
* Statistical error only

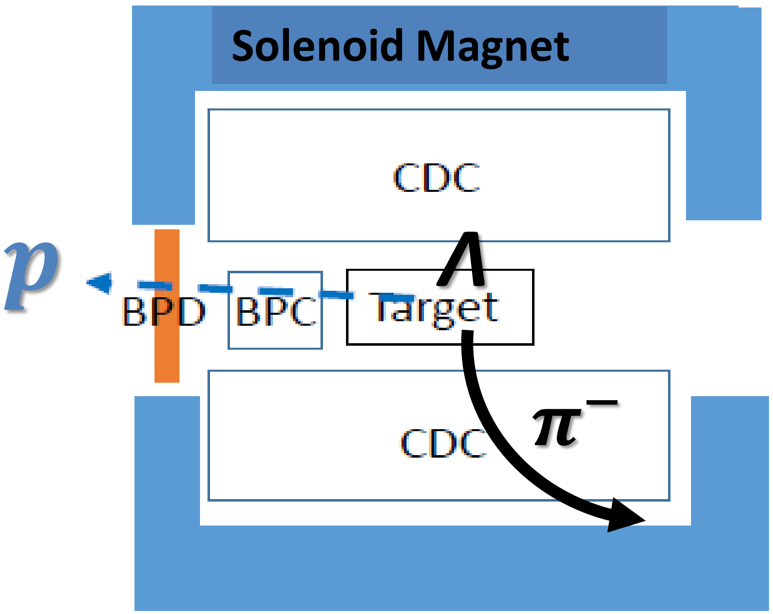
– $\pi^{+}\Sigma^{-}/\pi^{-}\Sigma^{+}$ mode separation: needs template fitting on spectra
- Acceptance to be obtained

d(K$^-$,n)"$\Sigma^0\pi^0$" Analysis

Y* -> $\pi^0\Sigma^0 \rightarrow \pi^0\gamma\Lambda \rightarrow \pi^0\gamma\, p\, \pi^-$

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

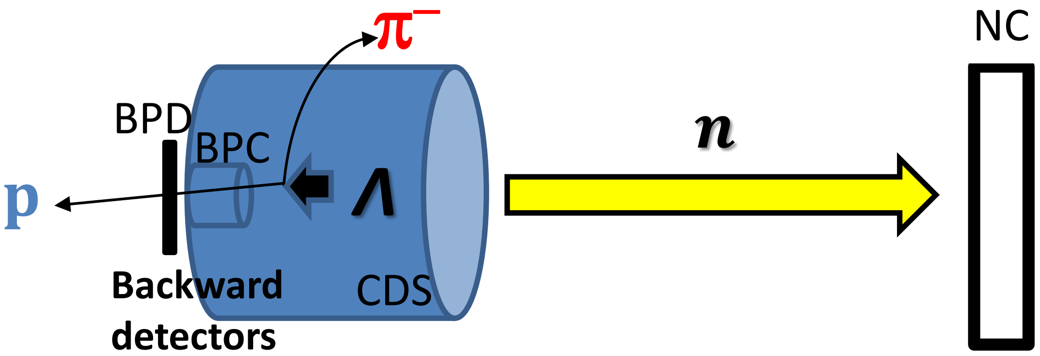




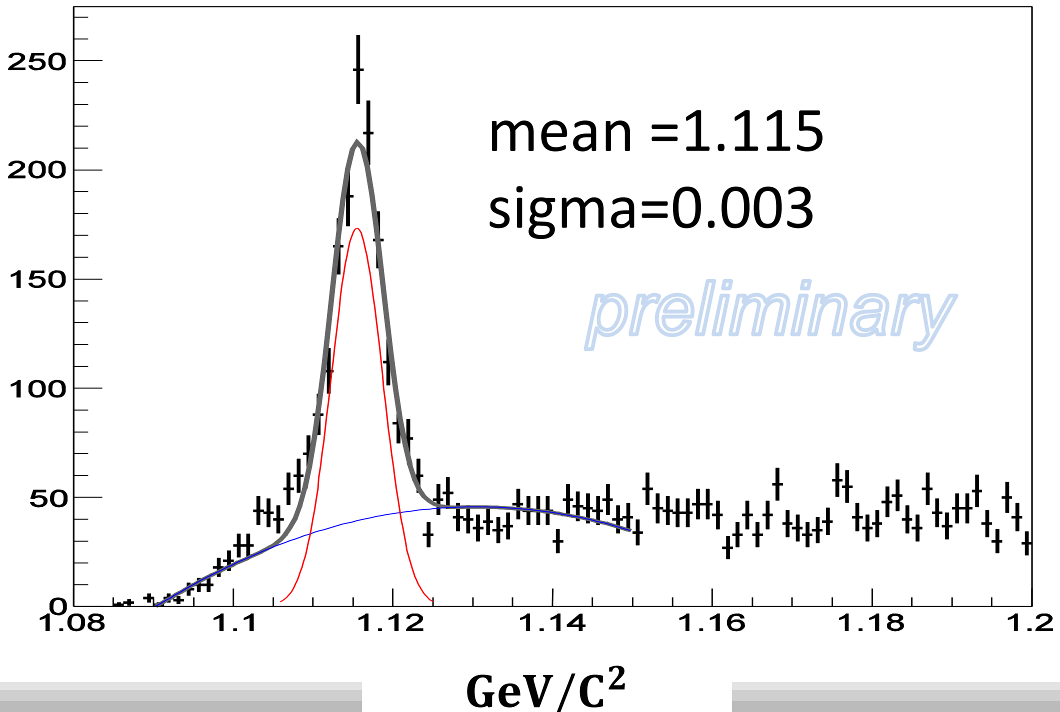
1. Reconstruction of Λ from p π^-

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

Backward Lambda reconstruction

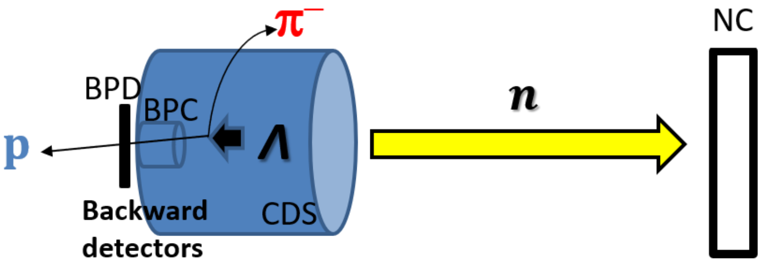


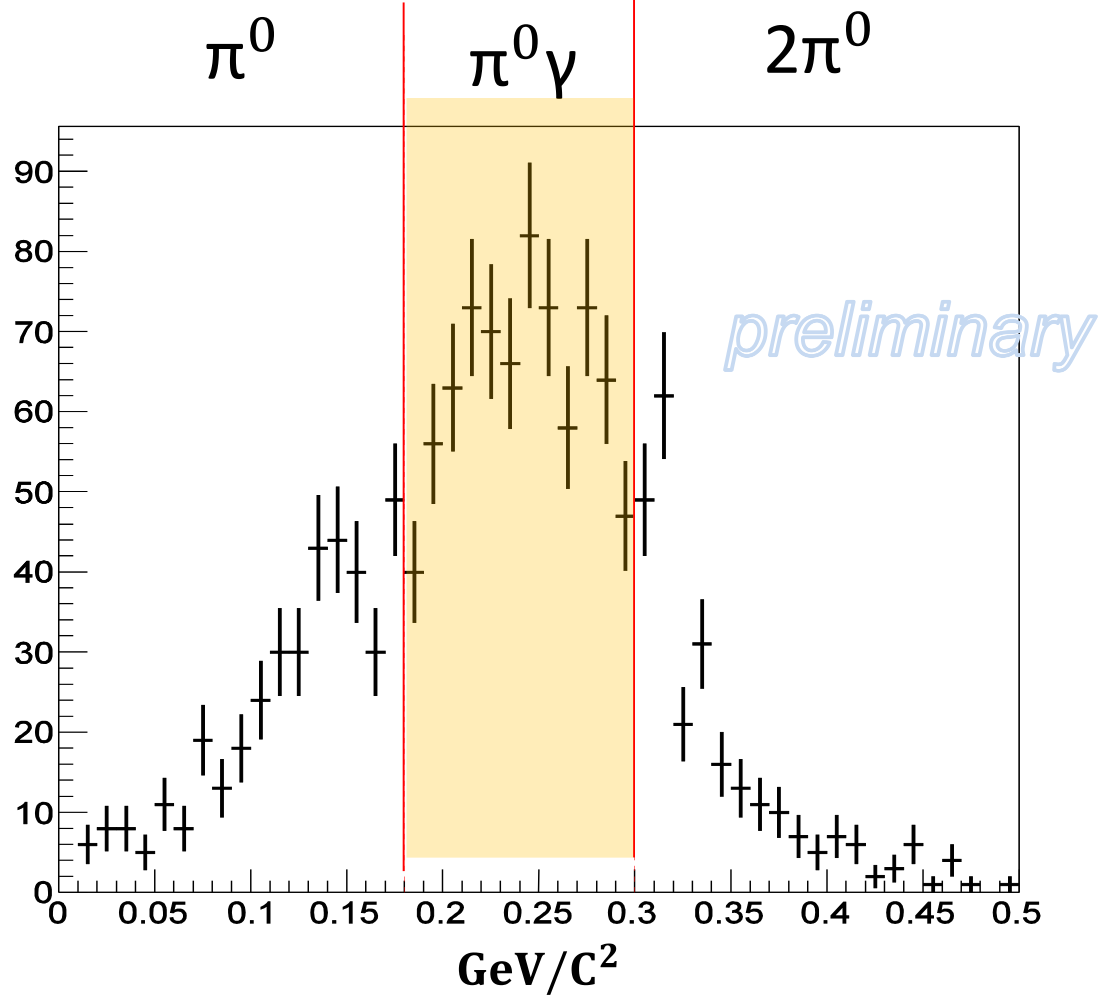
Invariant mass (π^- p)



Λ is reconstructed as designed !

d(K⁻,nΛ)"X" missing mass





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

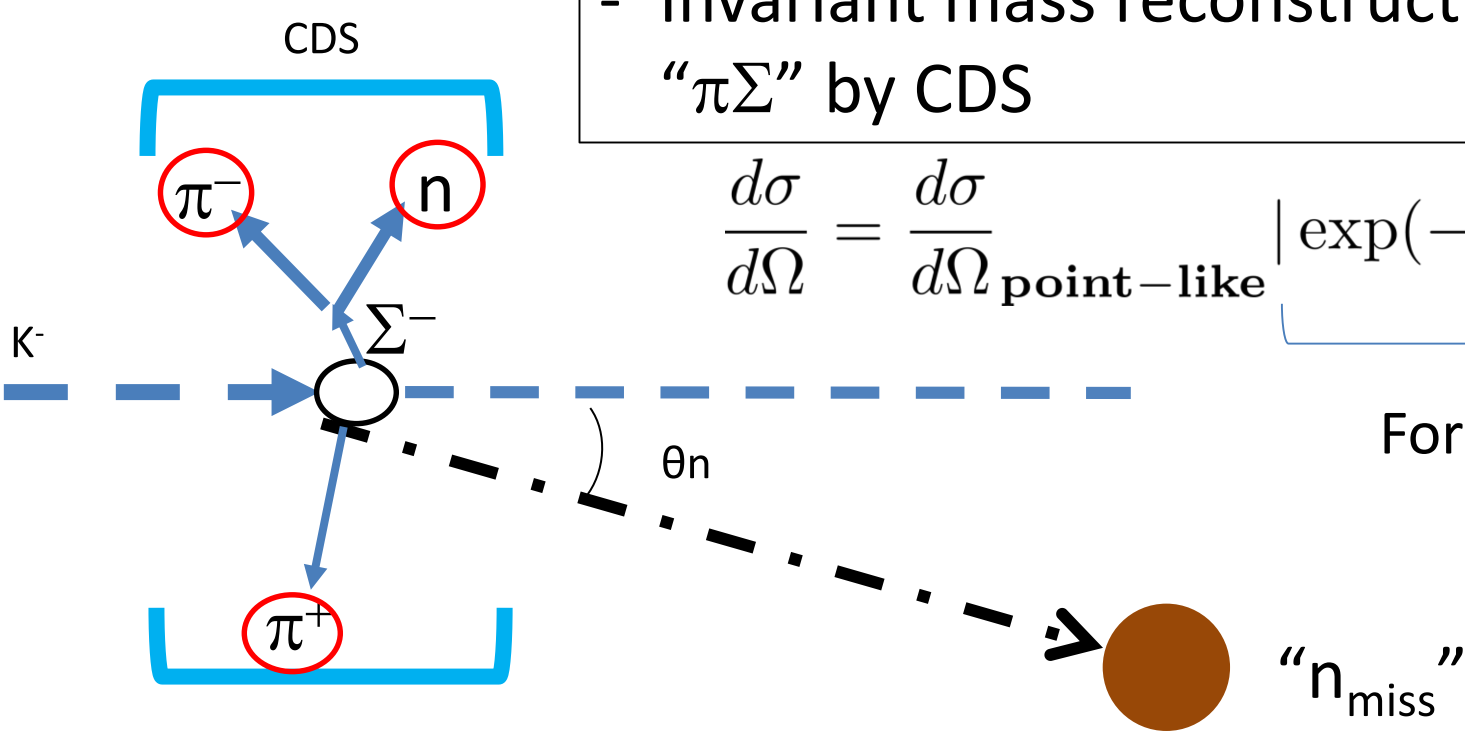
- d(K⁻,n)"$\Sigma^0\pi^0$" spectrum to be obtained

New proposed analysis – "q" dependence

Inspired by J-PARC E15 analysis Y .Sada *et al.*, PTEP 2016 (2016) no.5, 051D01

M. Iwasaki et al., arXiv:1805.12275

- Invariant mass reconstruction of "$\pi\Sigma$" by CDS



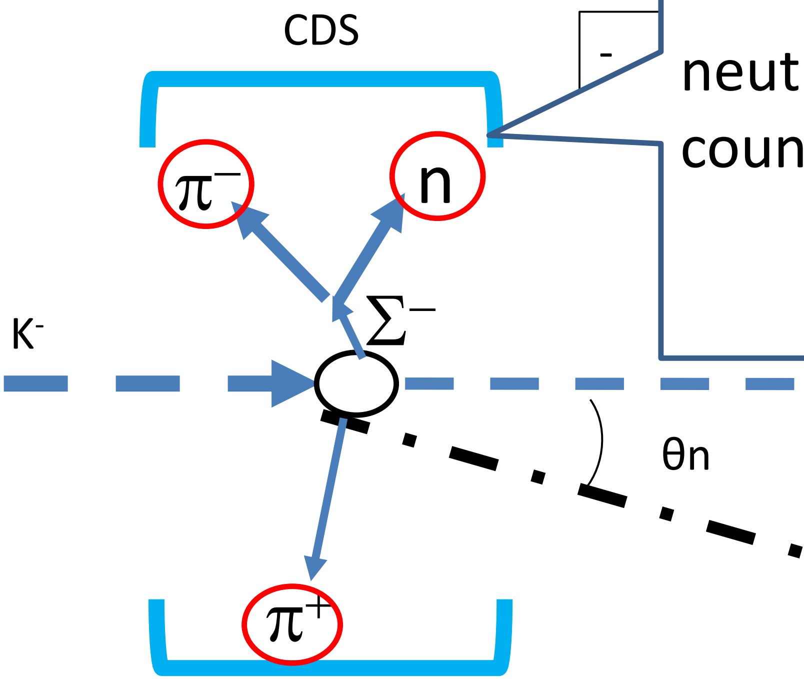
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_{\mathbf{point-like}} \underbrace{|\exp(-q^2/Q_X^2)|^2}_{\text{Form factor}}$$

Cross section vs momentum transfer "q" will be analyzed !

New proposed analysis – “q” dependence

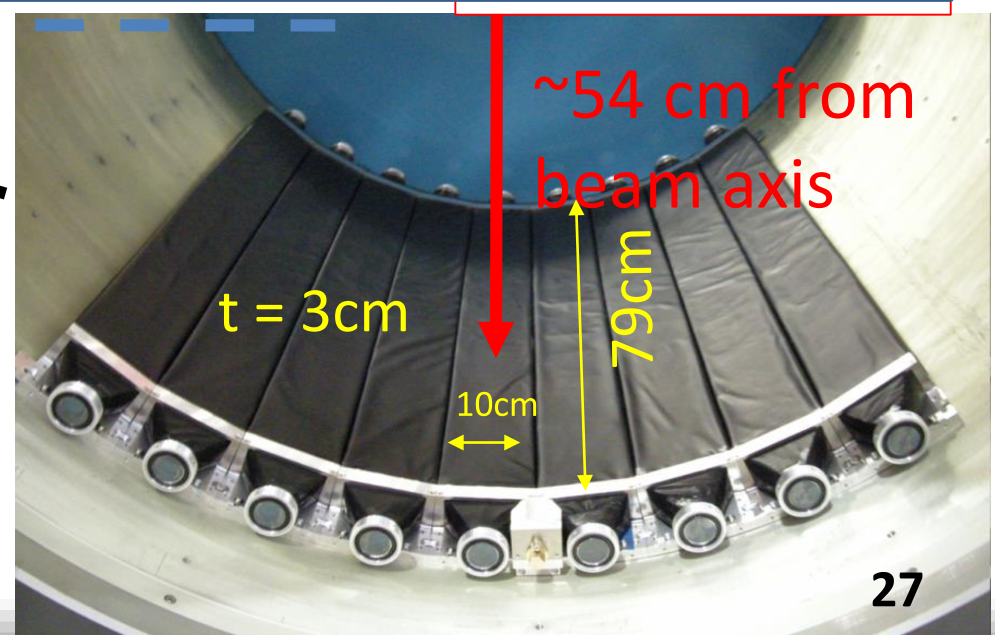
Inspired by J-PARC E15 analysis Y .Sada *et al.*, PTEP 2016 (2016) no.5, 051D01

M. Iwasaki et al., arXiv:1805.12275



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

n detection efficiency ~ 3%



Summary

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

- E31-2nd has been completed.

  -- missing mass spectra of d(K-,n)$\Sigma^-\pi^+$ and the d(K-,n)$\Sigma^+\pi^-$“ with larger statistic (~x3)

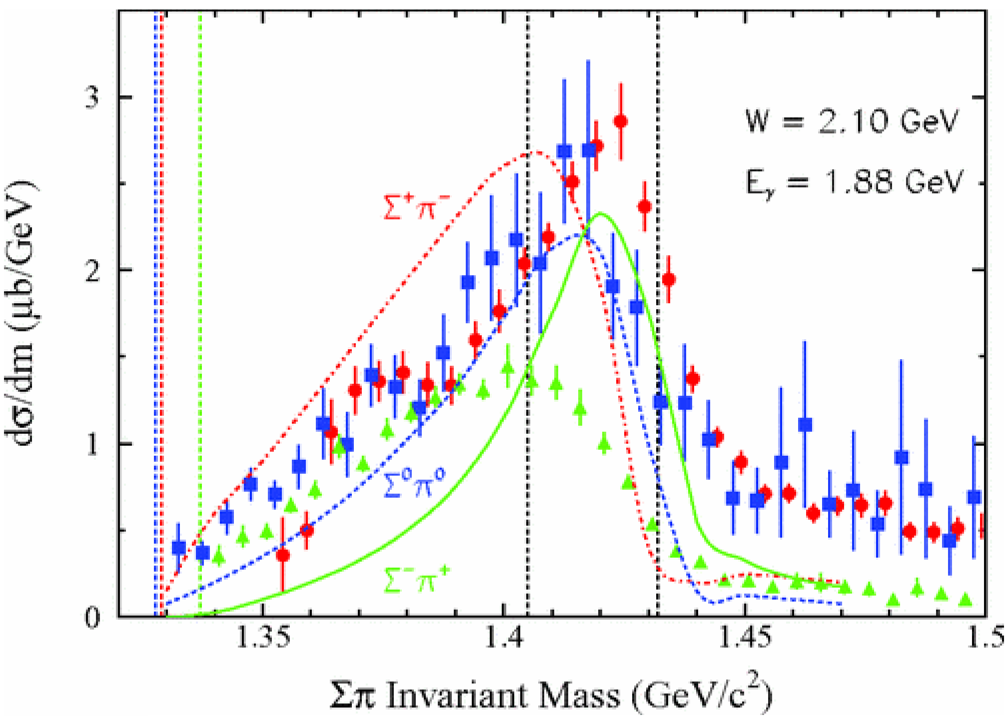
  -- line shape of missing mass spectra of d(K-,n)$\Sigma^0\pi^0$, obtained enough statistic

  -- new analysis of cross section vs momentum transfer to discuss form factor

Backup slides

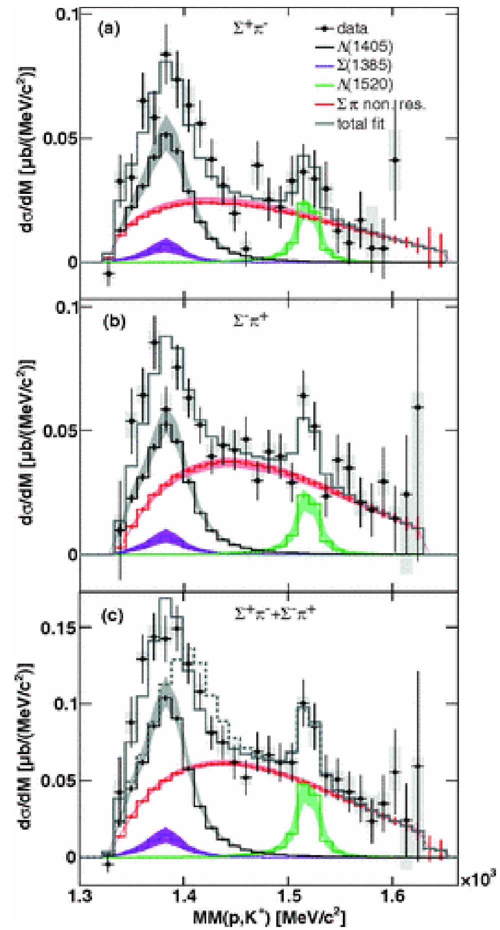
Needs Kaon induced reaction

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



CLAS collaboration: Phys Rev C87, 035206

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



HADES collaboration:
Phys Rev C87, 025201

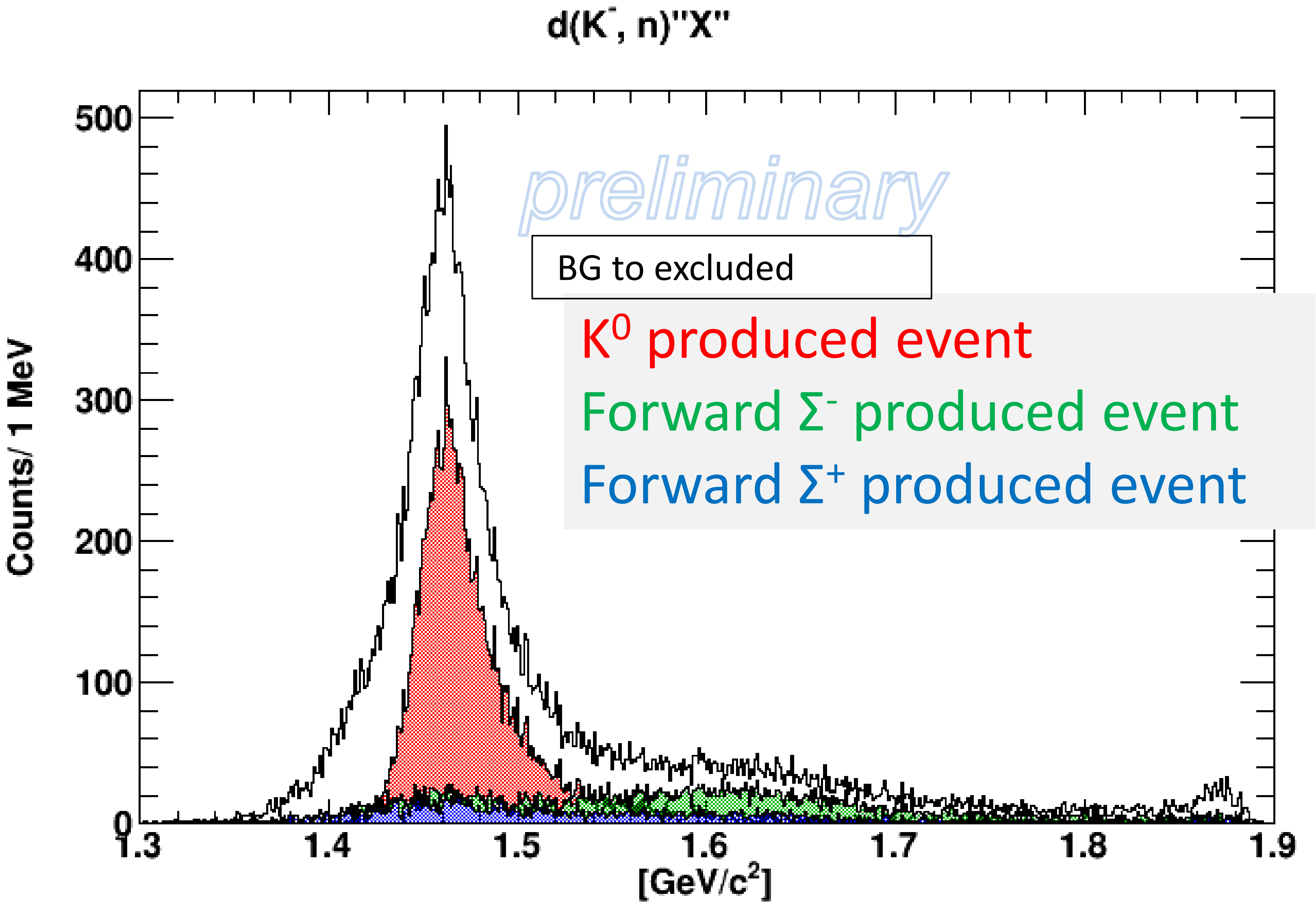
-γ/p induced experiments

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

cheating paper

- NC eff 30% by H_2 target
- 150 psec. -> d(K-,n)X spectrum 10 MeV reso.

d(K$^-$,n)"X" missing mass spectra



Detector Perfomance