Recent progress and prospect of Σ$^{\pm}$p scattering experiments

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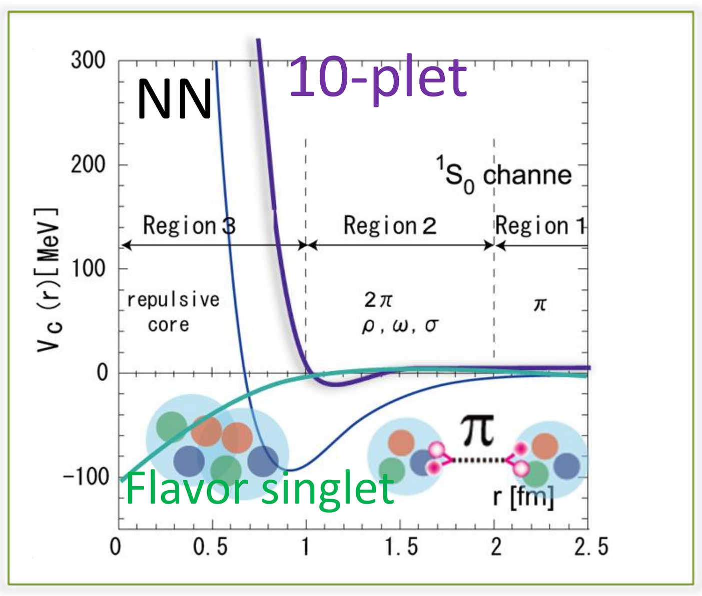
Abstract: Hyperon-proton scattering experiment is one of the most direct methods to study the hyperon-nucleon interaction, as in the case of the *NN* interaction. Although it had been experimentally difficult for a long time due to short lifetime of hyperons, we successfully performed novel high-statistics Σ$^{\pm}$*p* scattering experiment at K1.8 beamline in Hadron Experimental Facility (J-PARC E40 experiment). We derived the differential cross sections of Σ$^{\pm}$p with good precisions. Moreover, we performed phase shift analysis for Σ^{+}p channel exploiting the simple representation of the Σ^{+}*p* system with respect to the multiplets of the *BB* interaction. Now, we are considering the possibility of a further Σ$^{\pm}$p scattering experiment at K1.8 BR beamline with the new large acceptance Cylindrical Detector System.

1.Introduction

We investigate interactions between the octet baryons.

- **An extension of NN interaction**
- **Characteristic short range forces**

→ Role of quarks in B-B interaction can be understood.



Irrep: $8 \otimes 8 = \mathbf{27} \oplus 8_s \oplus \mathbf{1} \oplus \mathbf{10^*} \oplus \mathbf{10} \oplus 8_a$

27,10* : common to nuclear force

10 : strong repulsion due to quark Pauli effect

1 : attractive core (H-dibaryon?)

- **Σ^{+}p (ΣN, I=3/2) channel is suitable to investigate 10-plets.**

2.Previous studies on ΣN interaction

- **Scattering experiment is most direct methods to study two-body interaction.** However, hyperon-nucleon (YN) scattering experiment was difficult due to short lifetime of hyperon (～10^{-10} s).
  Difficulty of producing enough amount of hyperon beam
  Difficulty of detection and identification of scattering hyperon

→Data is limited for all YN channels

- **Past ΣN Scattering experiment**

Bubble chamber experiments, KEK E251[1], E289[2]
number of events was limited by detector performances (～few hundred)

- **Σ-nucleus interaction, Σ hypernuclei→only $^4_{\Sigma}$He exists[3].**

･Averaged ΣN interaction is repulsive[4].
･ΣN interaction has large isospin dependence

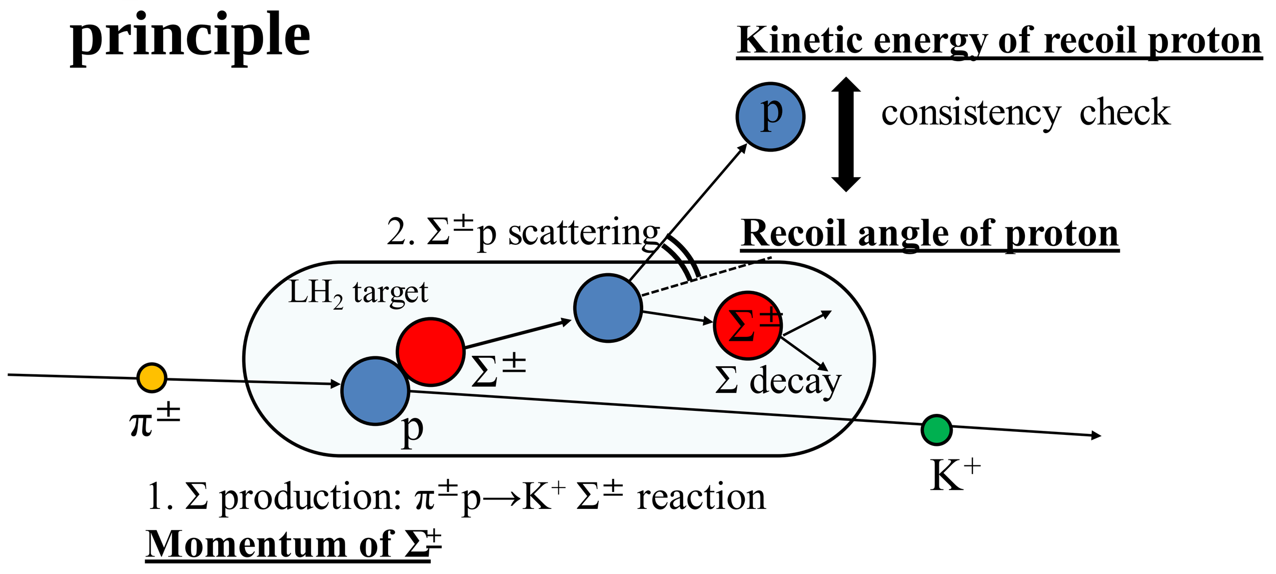
- **"Difficult" Σ$^{\pm}$p scattering experiment was needed to investigate strong repulsion of Σ^{+}p system and systematic study of ΣN interaction.**

[1] J.K. Ahn et al. Nucl. Phys. A 648 (1999) pp. 263-279.
[2] J.K. Ahn *et al.* Nucl. Phys. A 761 (2005) 41.
[3] T. Nagae *et al.* Phys. Rev. Lett. 80 (1995) 1605.
[4] H. Noumi et al., Phys. Rev. Lett. 89, 072301 (2002).

3.J-PARC E40 Experiment: Measurement of the differential cross sections of Σ$^{\pm}$p scatterings with high statistics

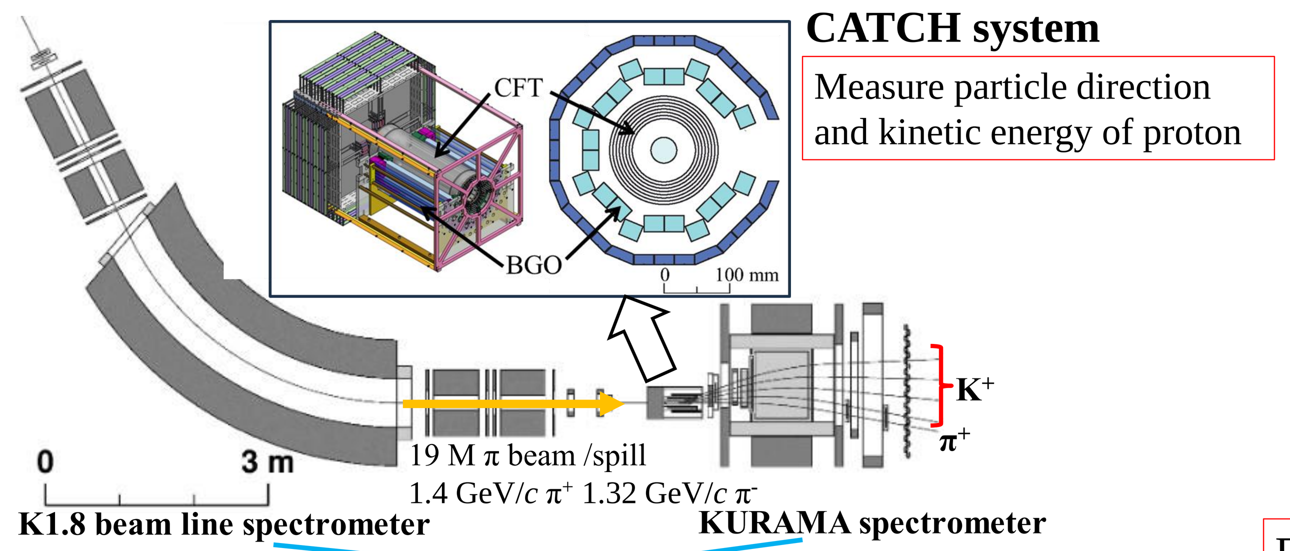
Experimental methods

principle



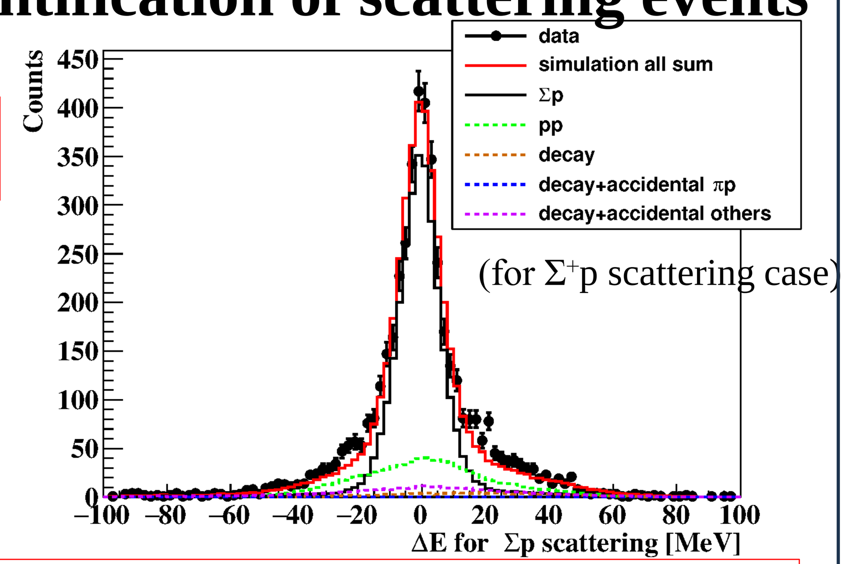
Σ production and Σ$^{\pm}$p scattering occurred in the LH$_2$ target
Σ$^{\pm}$p scattering events are identified by kinematical consistency.

Setup @HEF K1.8 beam line



Identify Σ production events & measure momentum of Σ$^{\pm}$ (**18 M Σ^{-}** events and **50 M Σ^{+}** events)

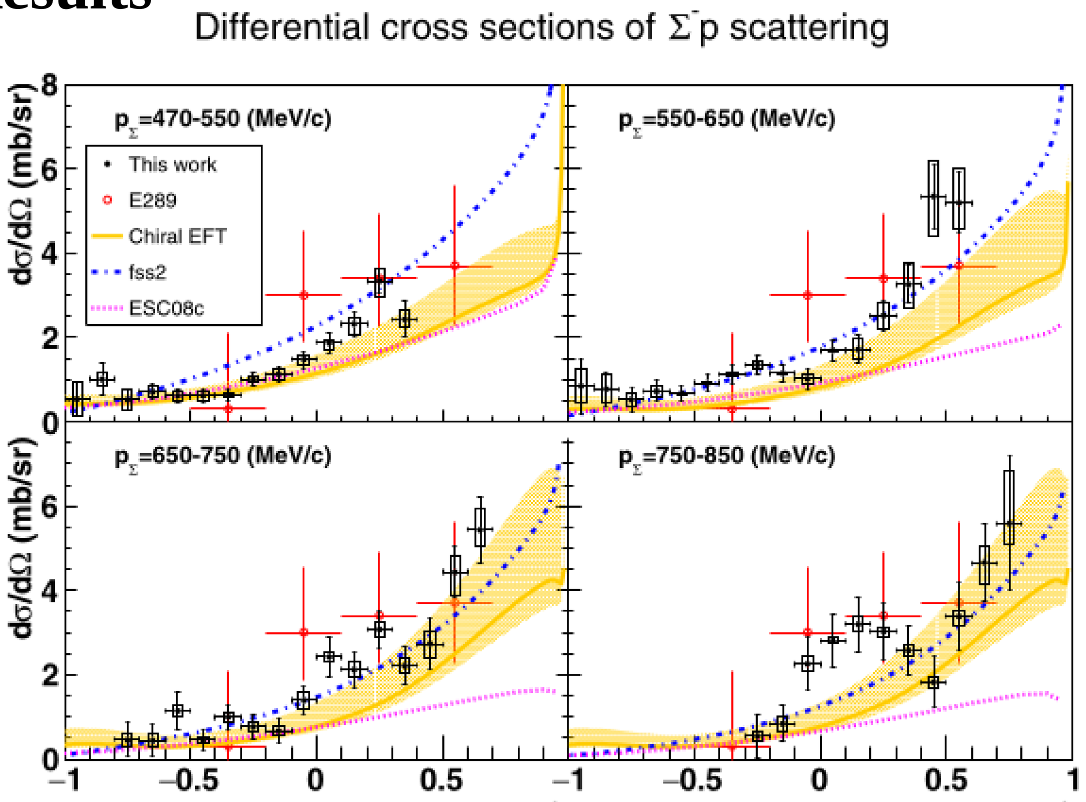
Identification of scattering events



For real Σ$^{\pm}$p scattering events, kinematical consistency ΔE distributes around 0.
4500 Σ^{-}p, 2300 Σ^{-}p→Λn, 2400 Σ^{+}p events

Results

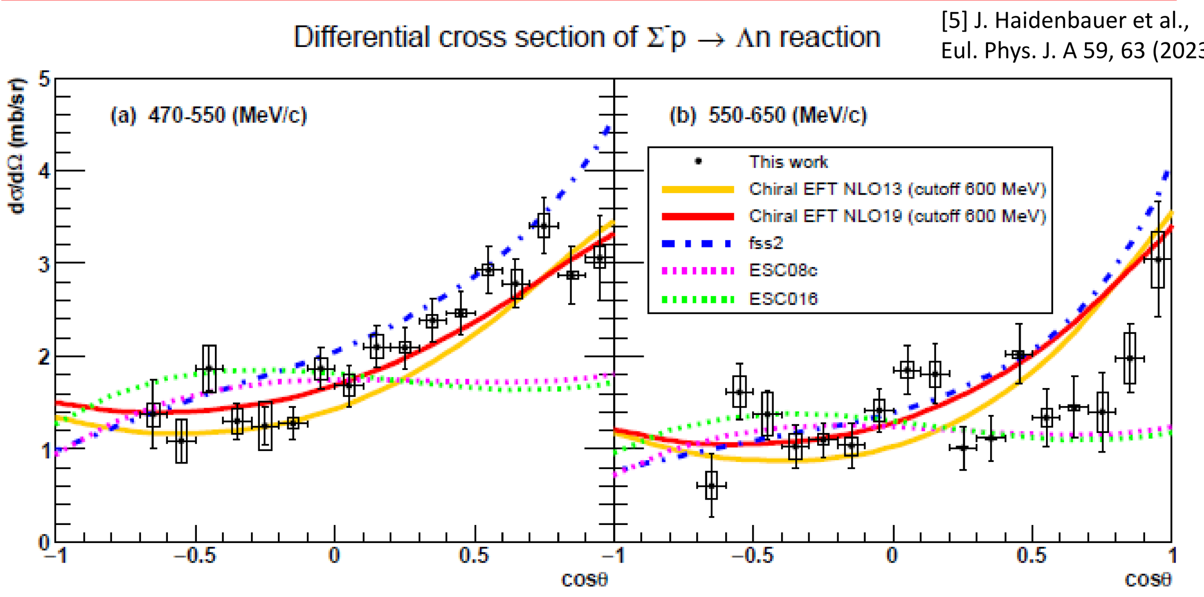
Differential cross sections of Σ^{-}p scattering



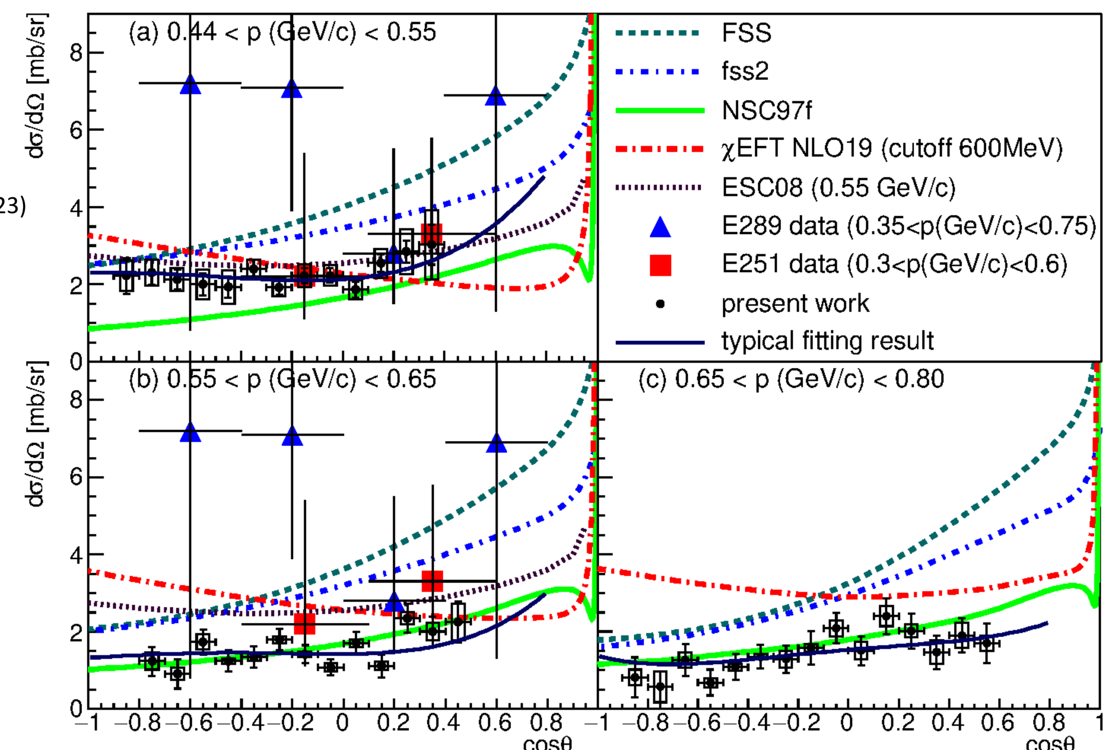
Owing to good statistics, the data quality has been significantly improved!
10-20 % error with small angular step of Δcosθ=0.1.
Reliable data for theoretical models, such as χEFT[5].

[5] J. Haidenbauer et al., Eul. Phys. J. A 59, 63 (2023)

Differential cross section of Σ^{-}p → Λn reaction



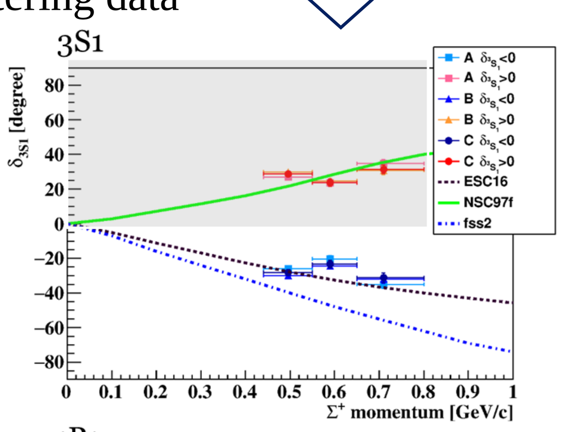
Differential cross sections of Σ^{+}p scattering



Phase shift analysis for Σ^{+}p data

Some partial waves ($^1S_0$, ^3P, $^1D_2$,…) of Σ^{+}p interaction belongs to the 27-plet of B-B interaction.
→well constrained by *pp* scattering data

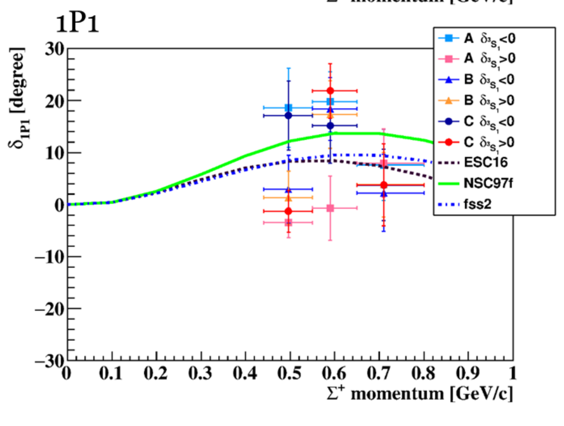
Phase shifts of $^3S_1$ and $^1P_1$ can be derived by phase-shift analysis.
contribution of ^3D is small



$^3S_1$:related to quark Pauli effect
Absolute values of phase shift are determined with error of few deg!
"The strong repulsive force" is moderate.
Direct comparison to HAL QCD result[6] can be done!

[6]H. Nemura et al., AIP Conf. Proc. **2130**, 040005 (2019).

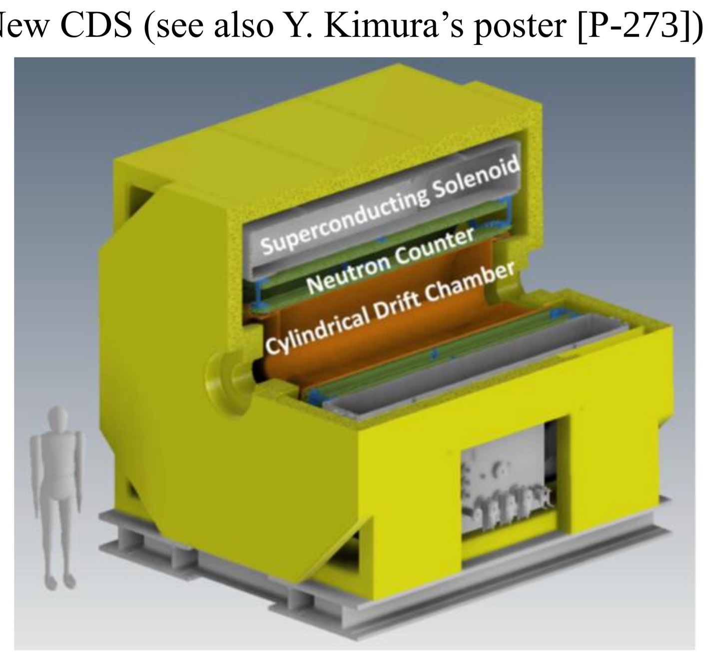
$^1P_1$
Results have large error.
Acceptance for Σ-forward angle events is important, which is limited by detection efficiency of low energy proton.



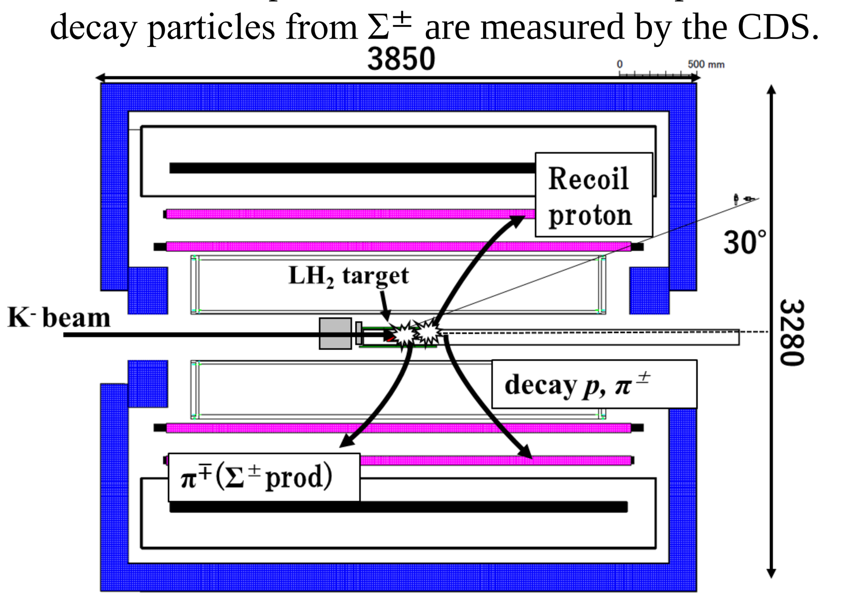
4.Possibility of new Σ$^{\pm}$p scattering experiment @K1.8 BR

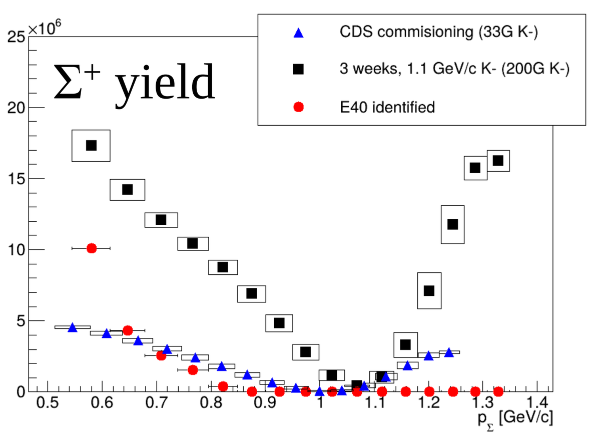
Recently, a large acceptance cylindrical detector system (CDS) is developed for systematic and sophisticated studies on kaonic nuclei at K1.8BR beamline. We are considering Σ$^{\pm}$p scattering experiments using the CDS. "Phase 1" data can be taken as the byproduct of the CDS commissioning. (～End of JFY 2026)

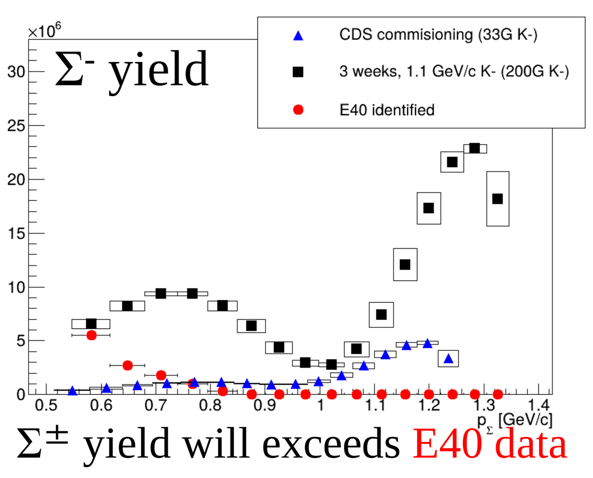
New CDS (see also Y. Kimura's poster [P-273])



Experimental concept
Pion from K$^-$+p→Σ$^{\pm}$+π$^{\mp}$ reaction, recoil proton and decay particles from Σ$^{\pm}$ are measured by the CDS.







Σ$^{\pm}$ yield will exceeds E40 data for wider momentum!

Summary

･Hyperon-nucleon scattering experiment gives us very important information for B-B interaction, especially quark Pauli effect.
･Σ$^{\pm}$p scattering experiment (J-PARC E40) was performed by 2020 Jun, few thousands of Σ$^{\pm}$p scattering events were identified.
･ We derived the differential cross sections of Σ$^{\pm}$p with good precisions. Phase shift analysis for the Σ^{+}p scattering was also performed.
･ Now, we are considering the possibility of further Σ$^{\pm}$p scattering experiment at K1.8 BR beamline.