Recent progress and future prospects of hyperon nucleon scattering experiment

Koji Miwa (Tohoku Univ., KEK)

for the J-PARC E40, P86 Collaborations

HYP2022, June 27th- July 1st, 2022

Contents

- Introduction
- Σp scattering experiment (J-PARC E40)
  - Σ^-p channels (Differential cross sections)
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- Future project : Λp scattering with polarized Λ beam
- Summary

Realistic nuclear force : base for nuclear physics

Realistic Nucleon-Nucleon Potential (CD Bonn, AV18, Nijmegen I, II)

Updated based on a lot of scattering observables of NN scattering

Solid base for nuclear studies

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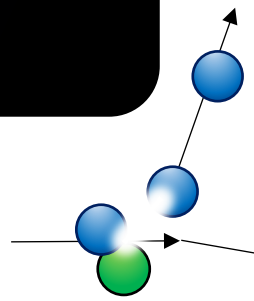
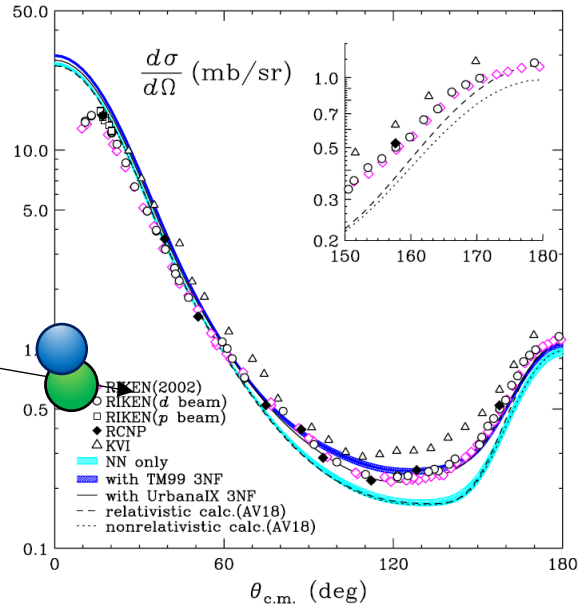


Nucleon-Deuteron scattering



K. Sekiguchi et al.
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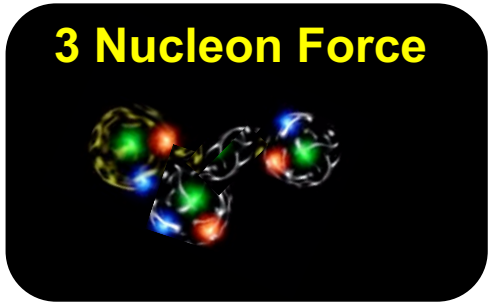

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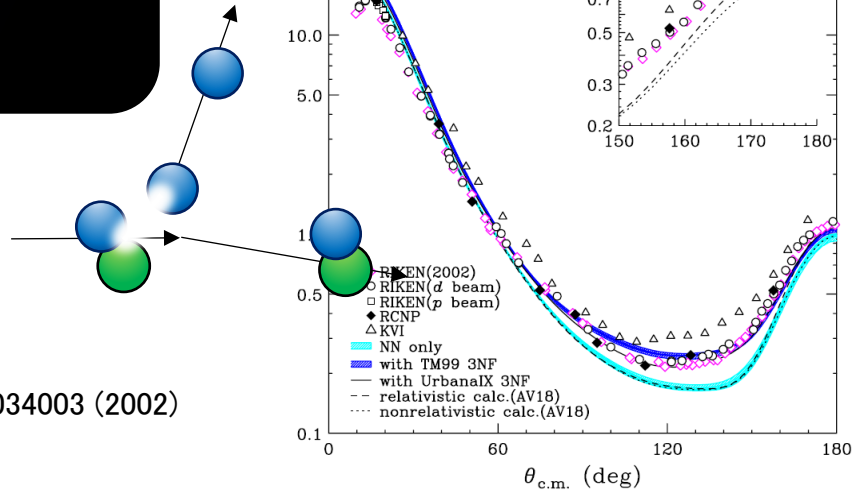

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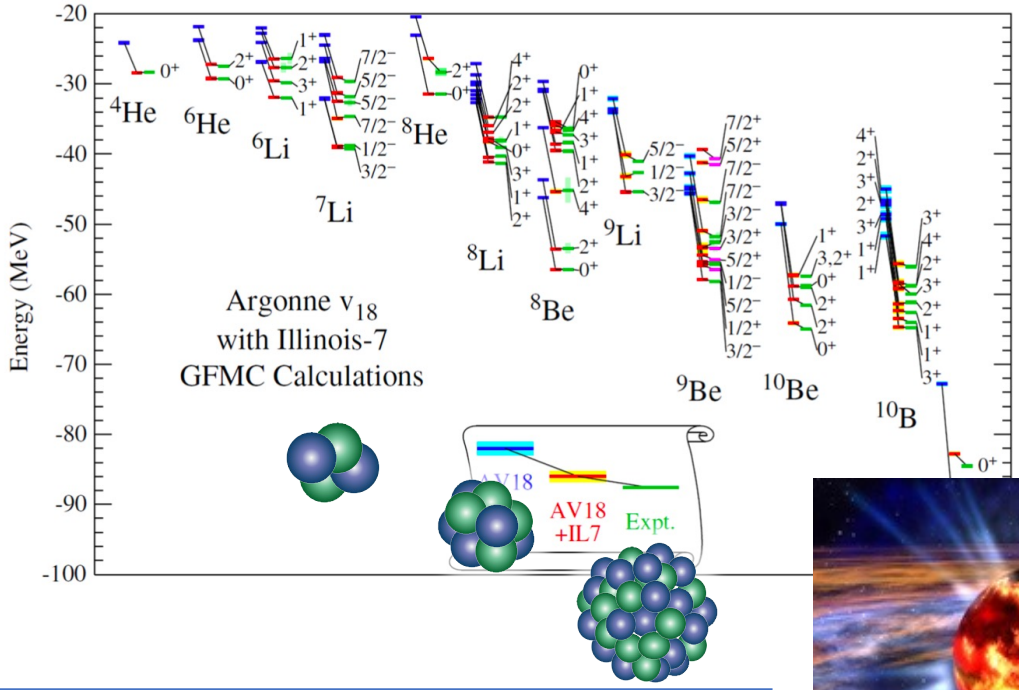
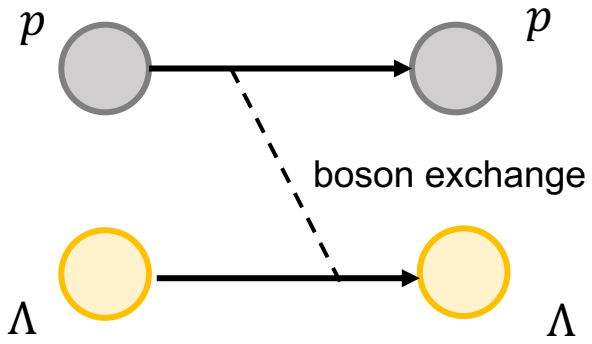


Equation of State of Nuclear Matter

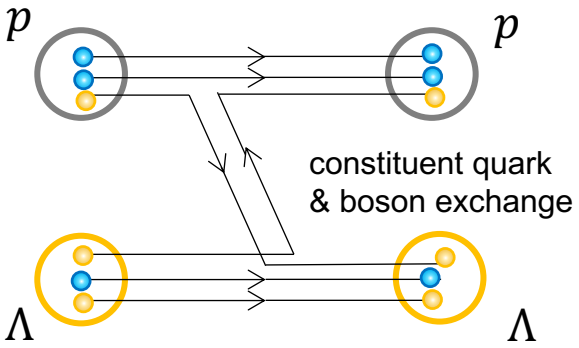
Baryon-Baryon Interaction

Boson exchange picture



Nijmegen model

Quark based model with effective QCD



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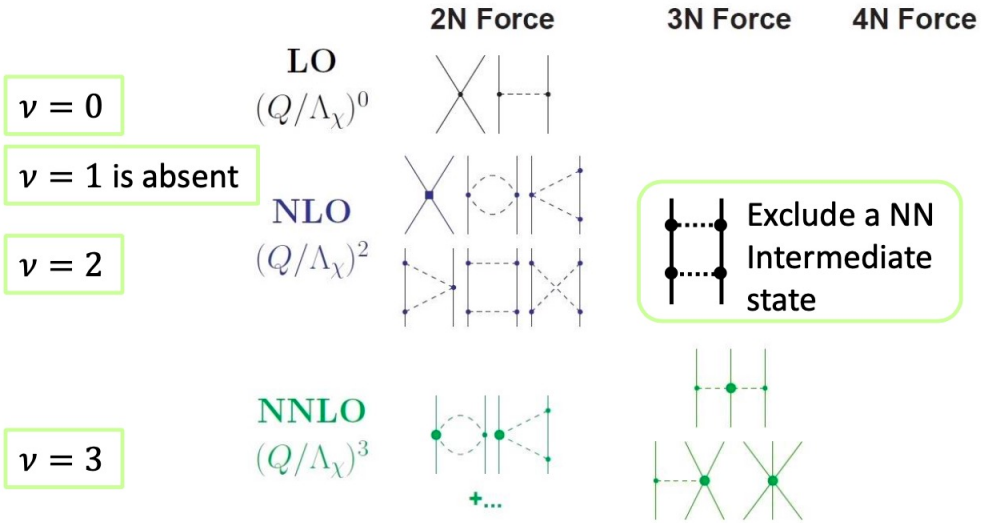
Chiral EFT



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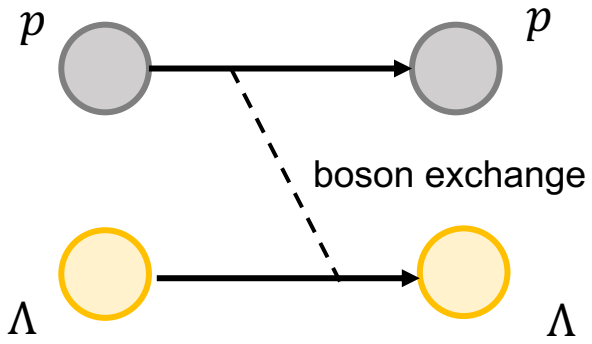

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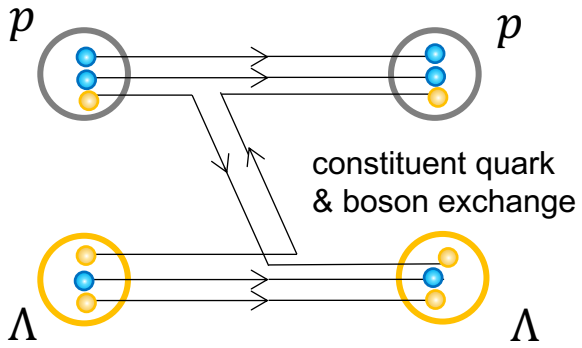

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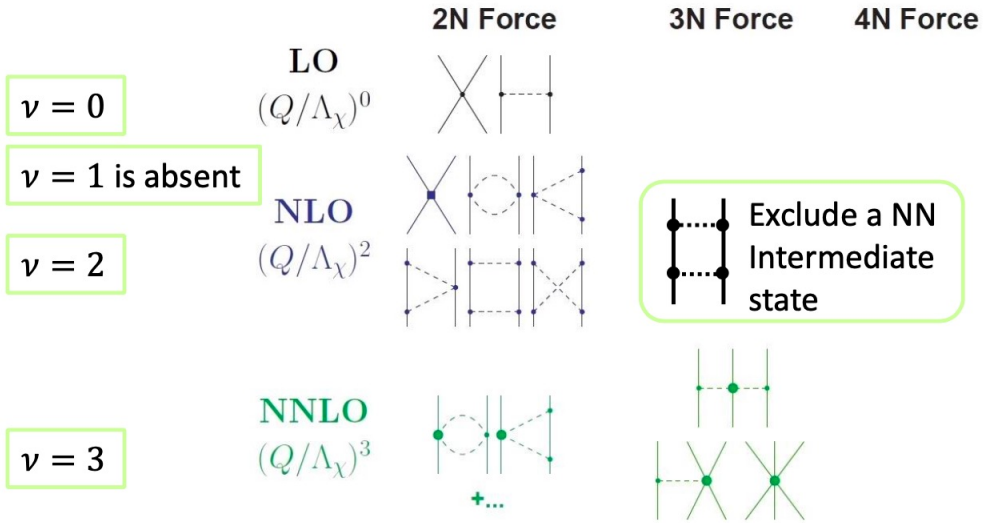

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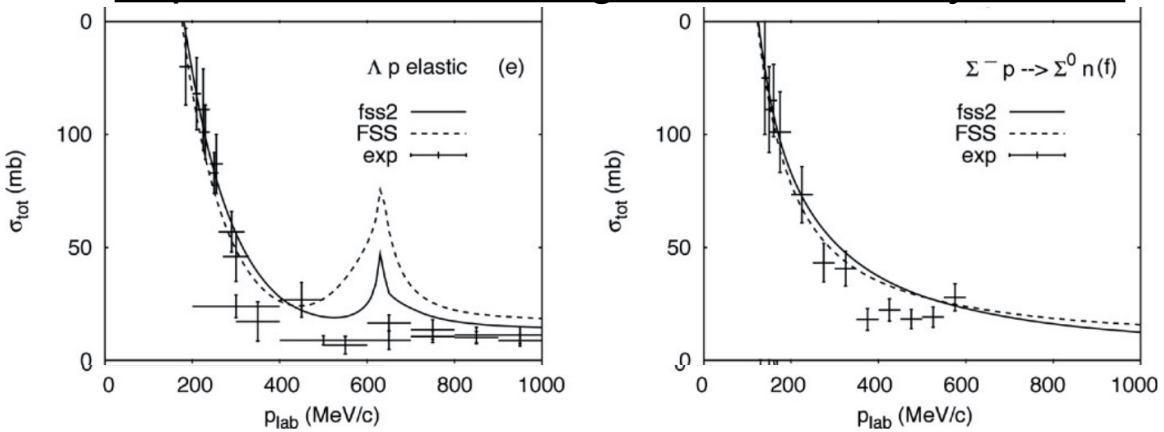

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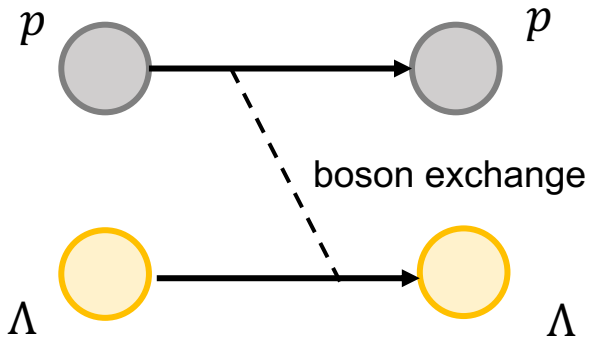

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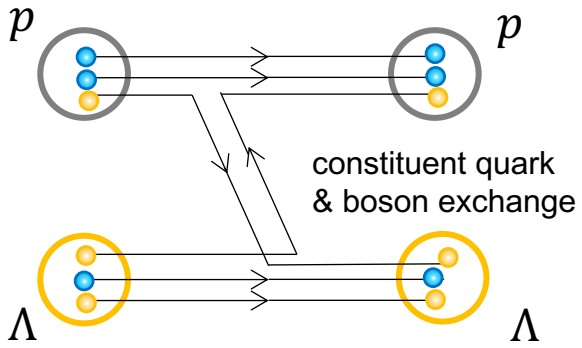

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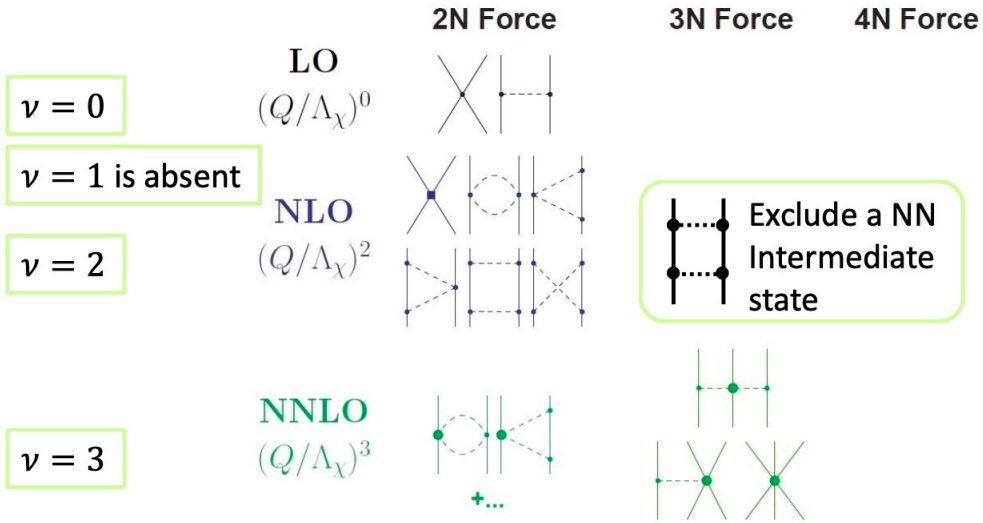

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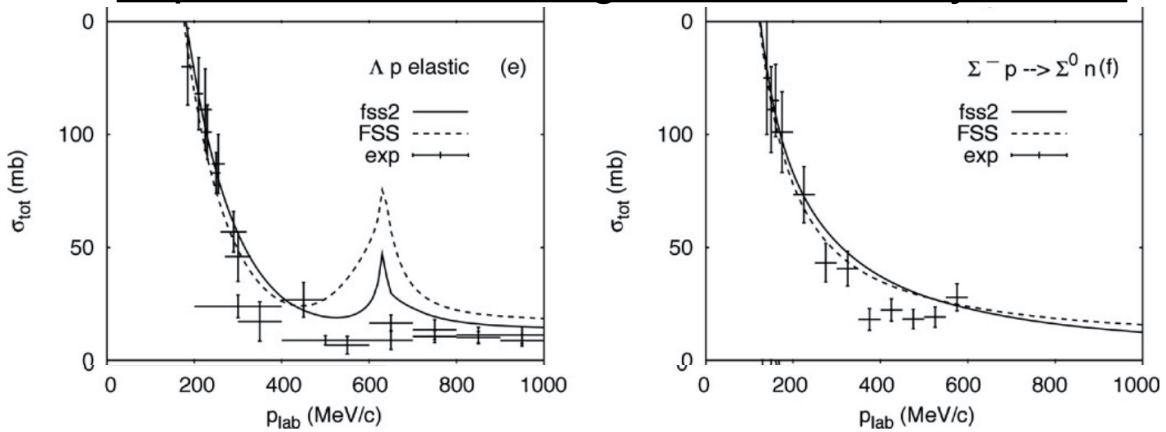

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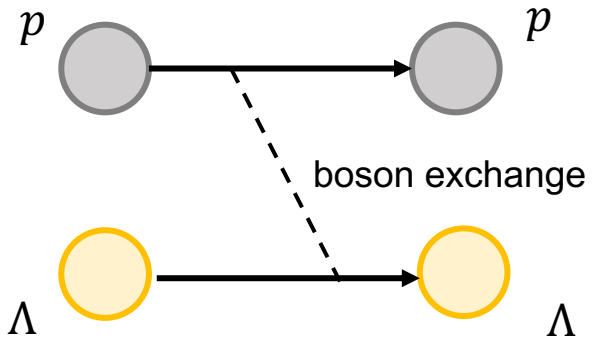

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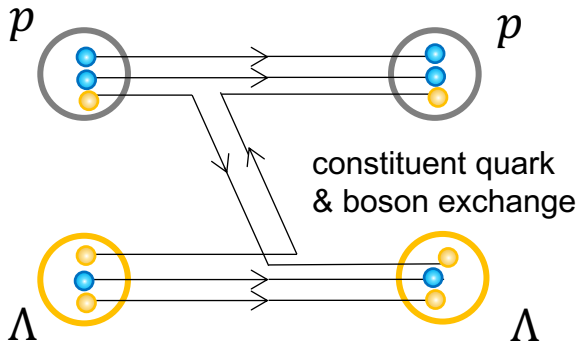

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Feed back to theories

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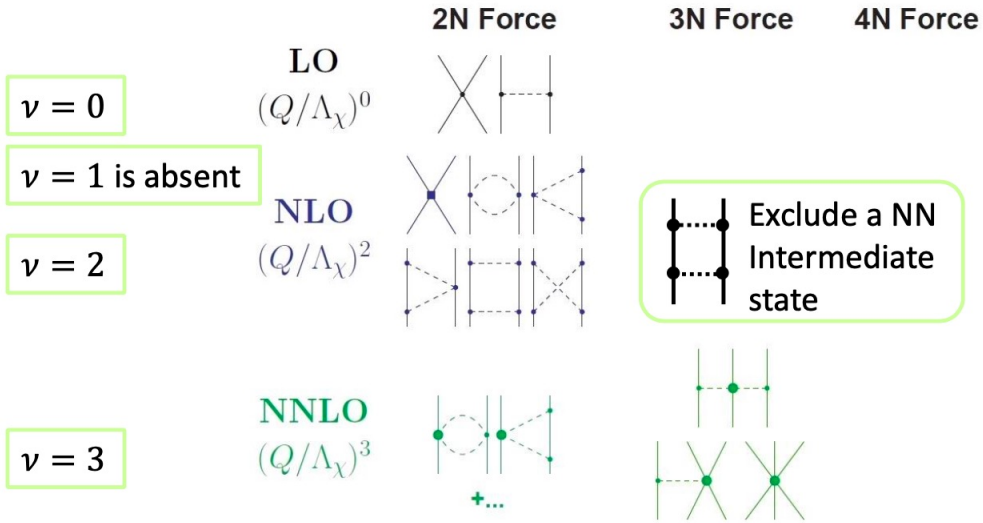

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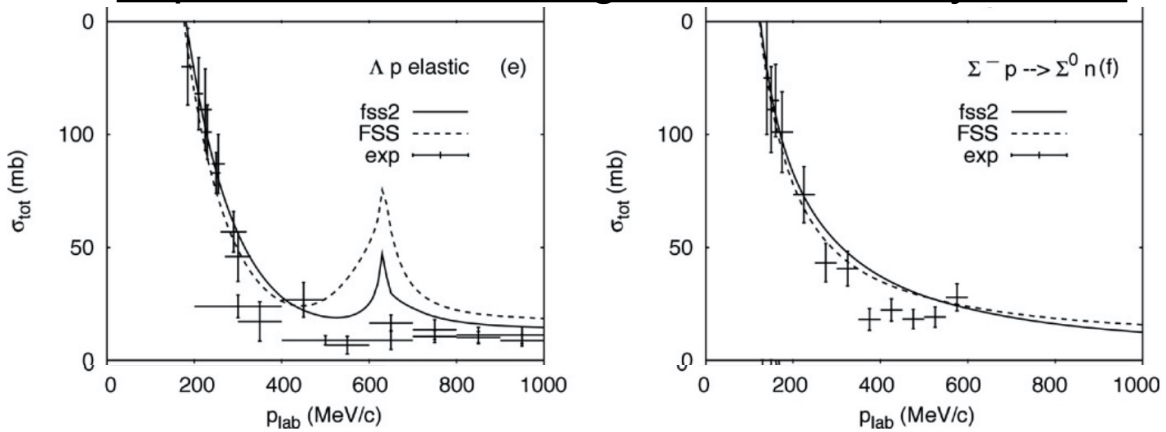

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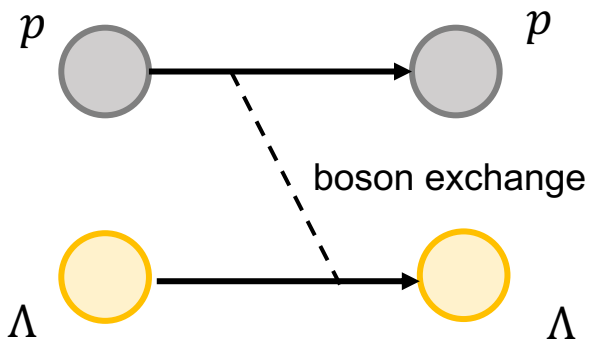

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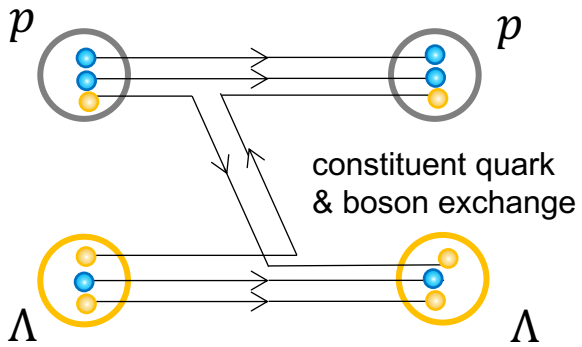

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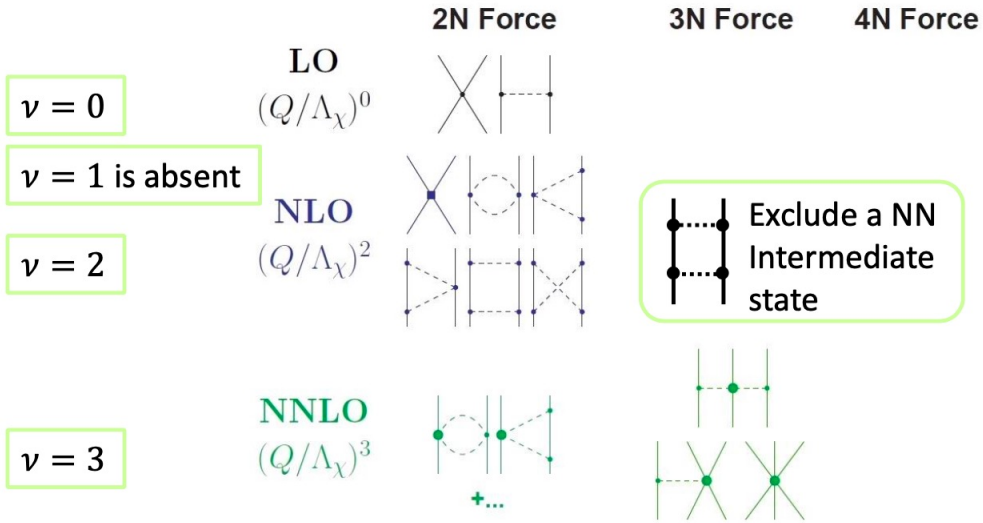

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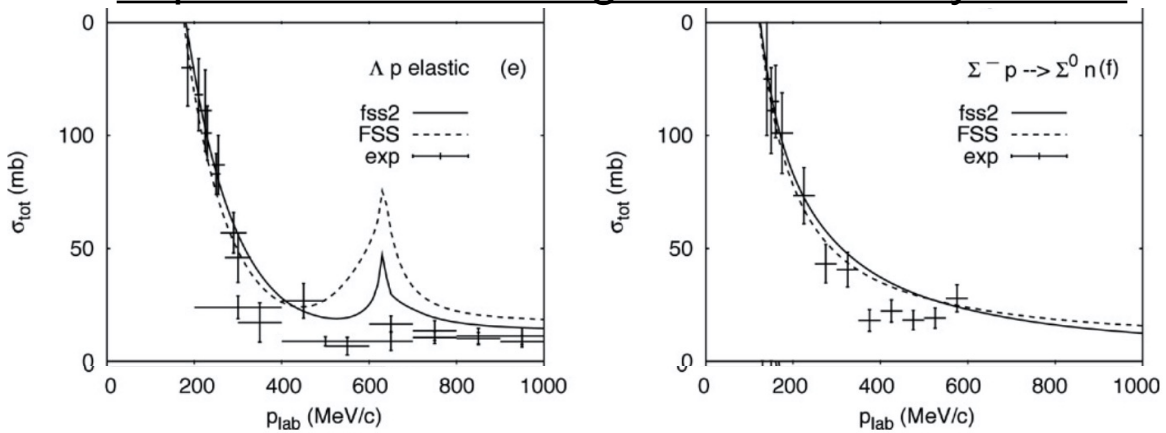
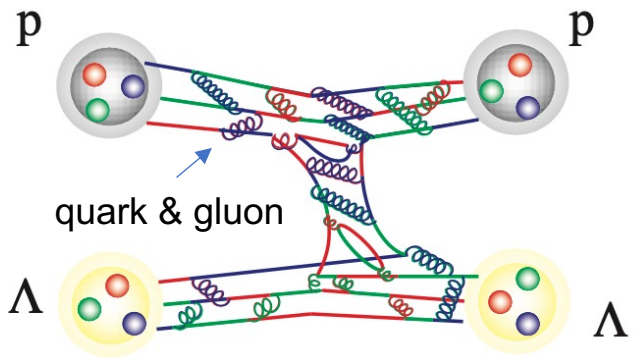


Test of theories

Quantum Chromo Dynamics (QCD)

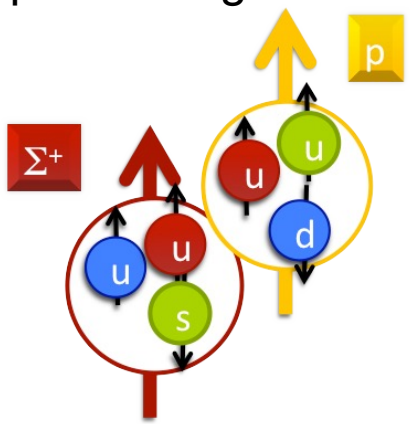


Lattice QCD

J-PARC E40 : Measurement of $d\sigma/d\Omega$ of Σp scatterings

Verification of quark Pauli repulsion

$\Sigma^+ p$ scatterng



6 quarks can stay in s state in normal case

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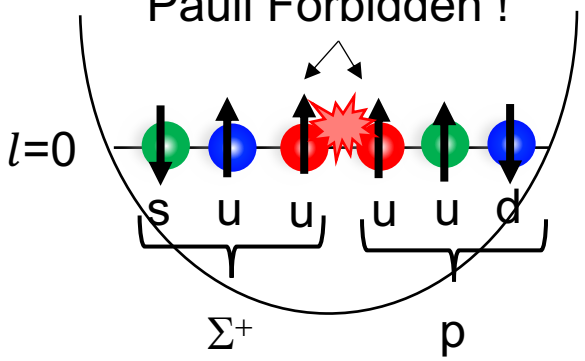

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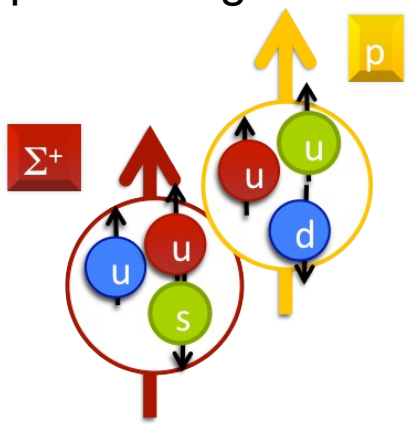

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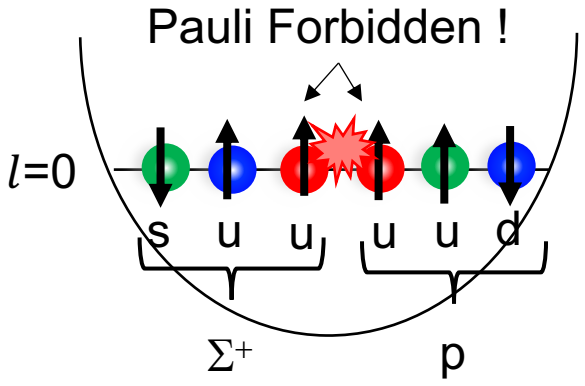

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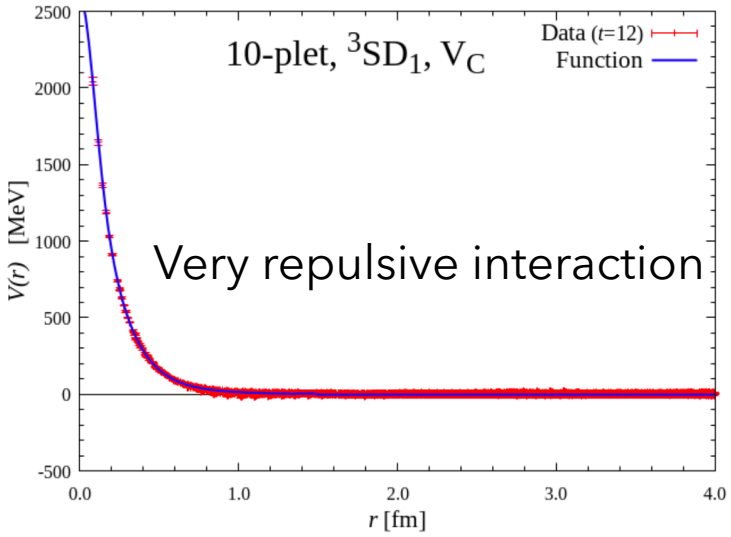

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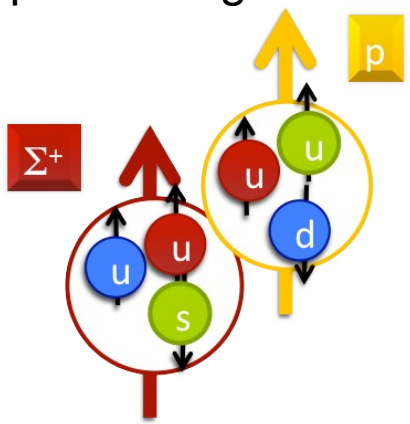

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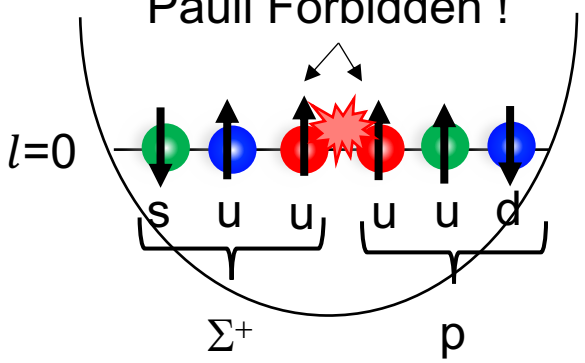

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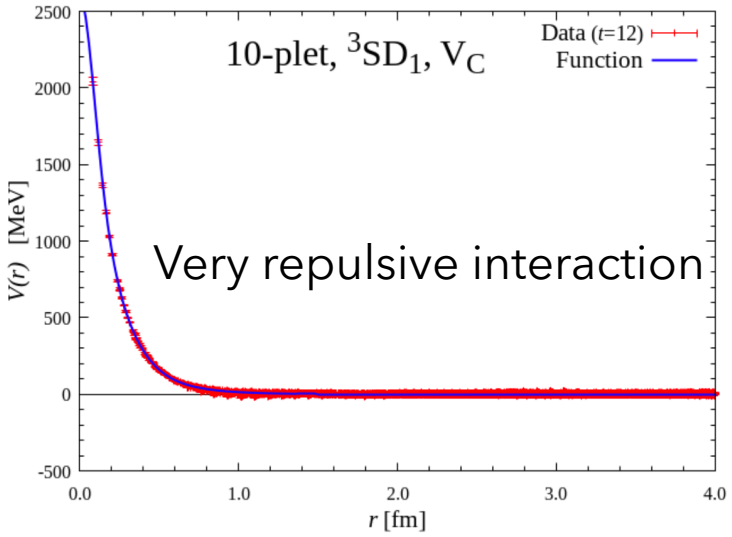

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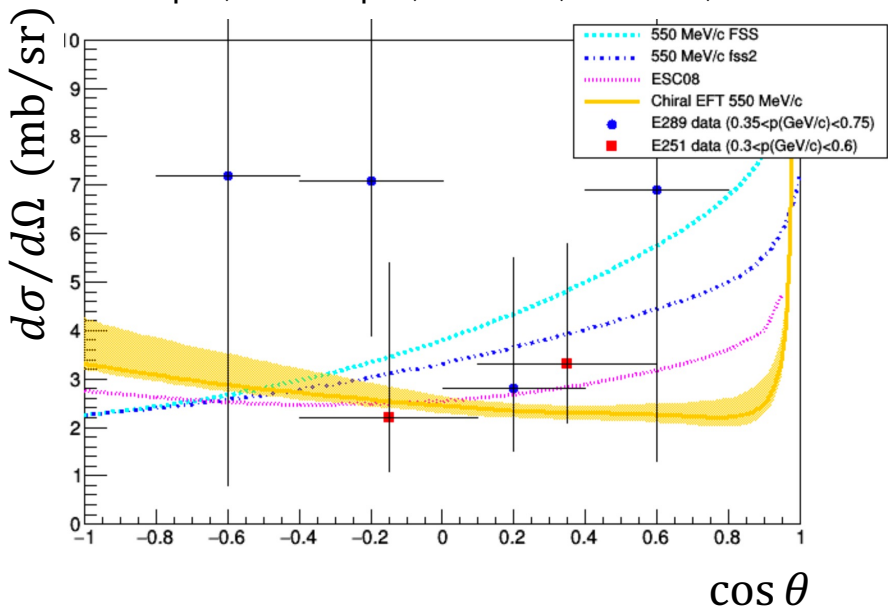

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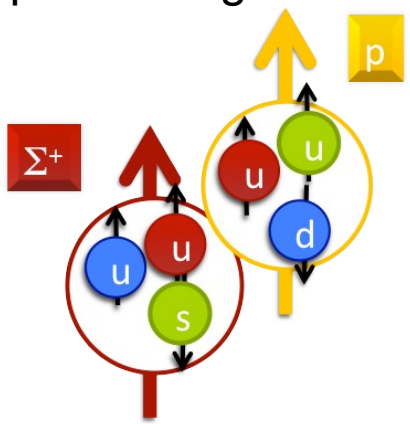

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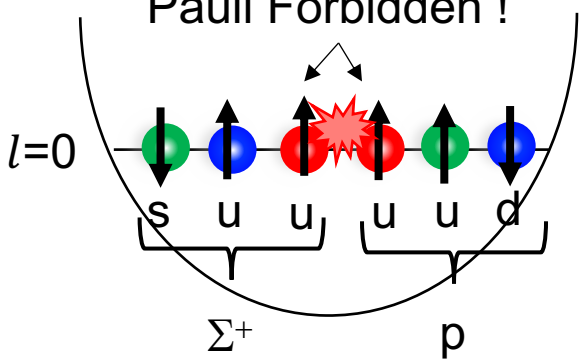

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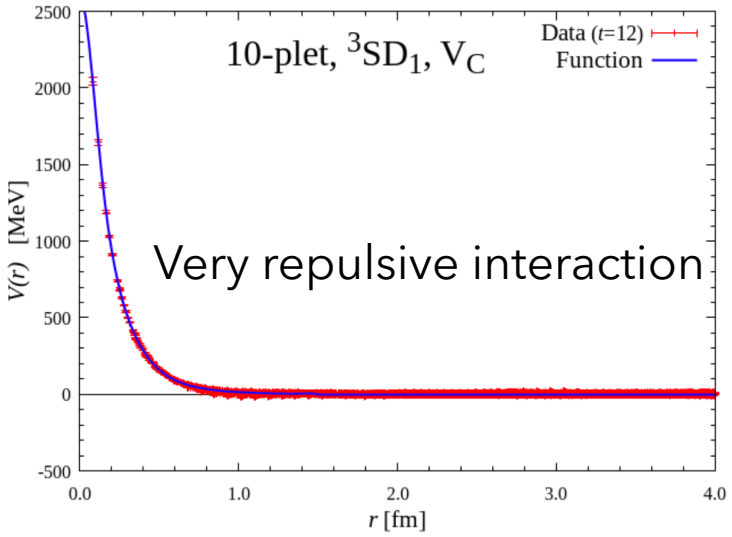

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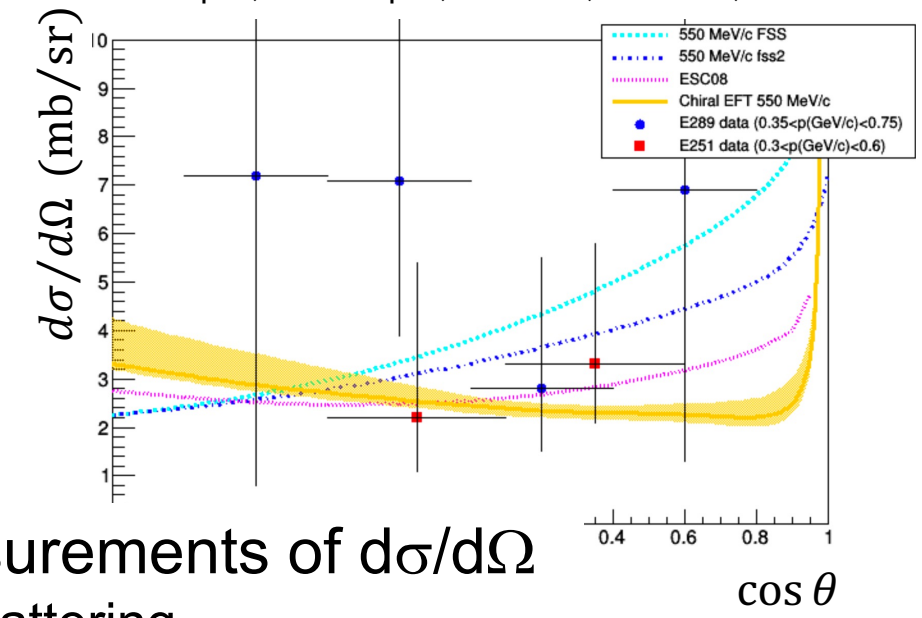

Systematic measurements of dσ/dΩ

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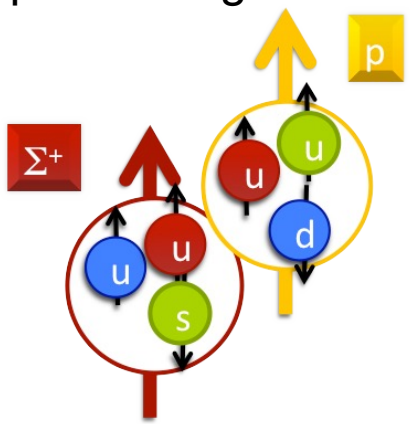

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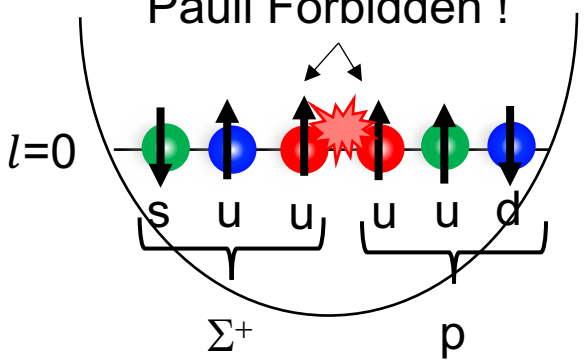

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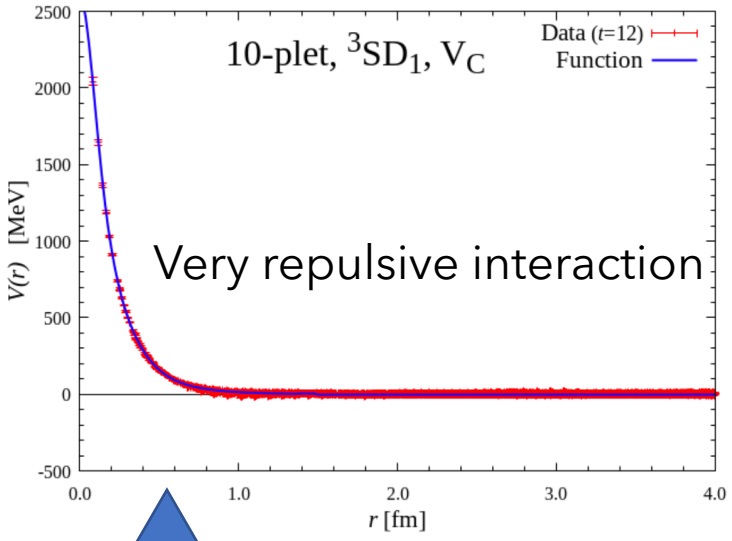

Phase-shift measurement

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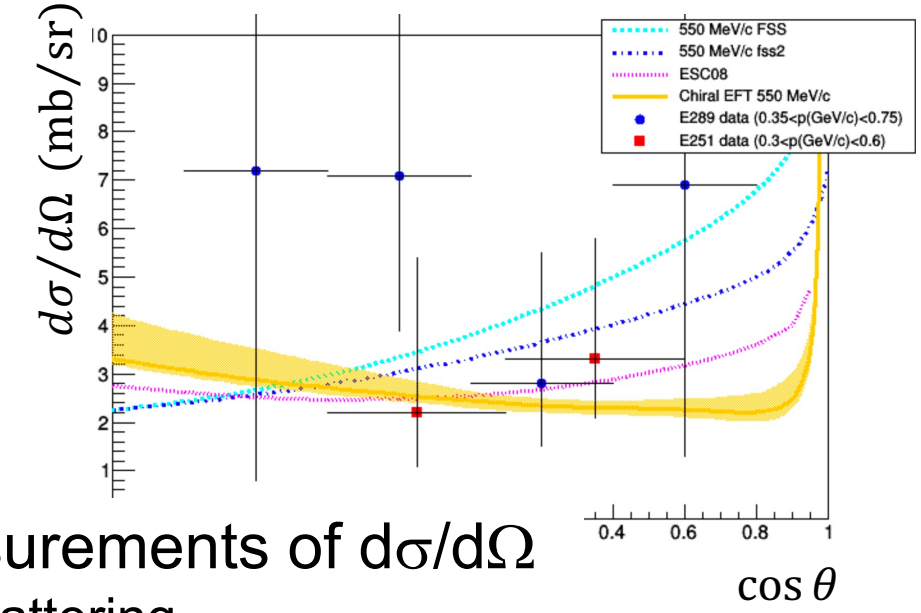

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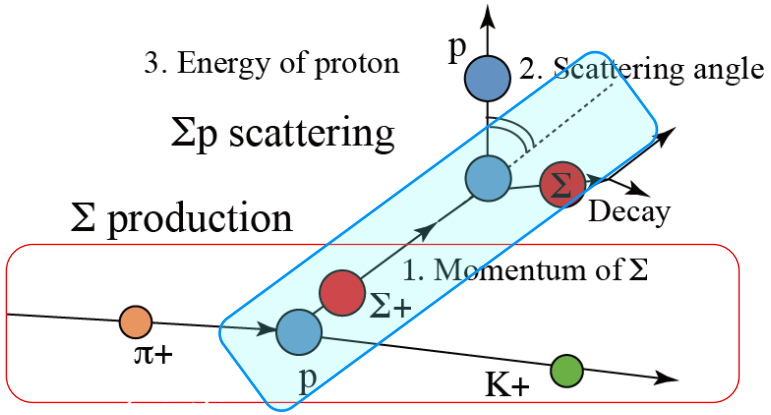
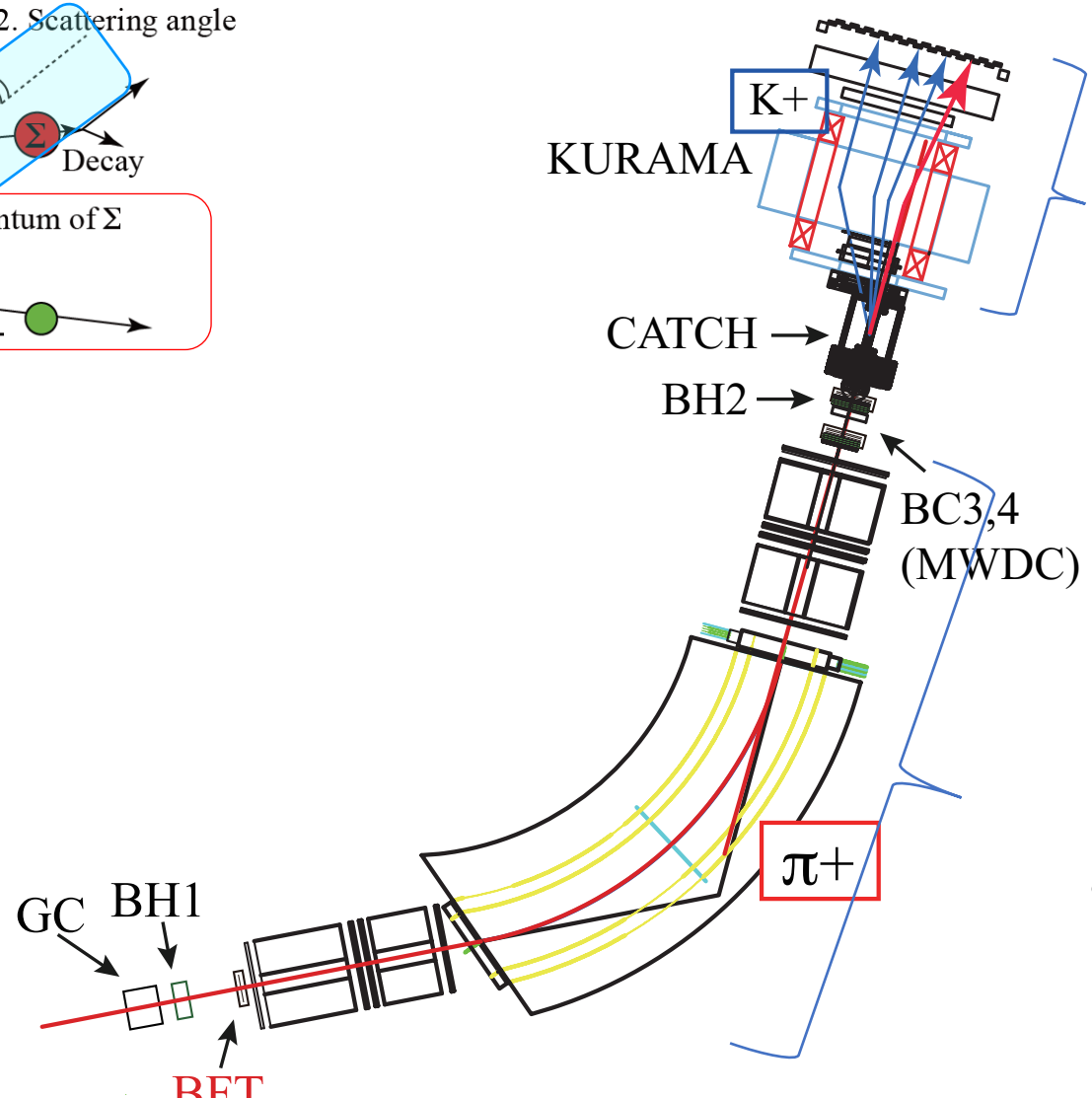
J-PARC E40 experimental setup

Two successive two-body reactions





KURAMA spectrometer
- Identification of K^+
- Momentum analysis

Momentum tagging of Σ beam

Beam-line spectrometer
- Momentum analysis of π beam

J-PARC K1.8 beam line

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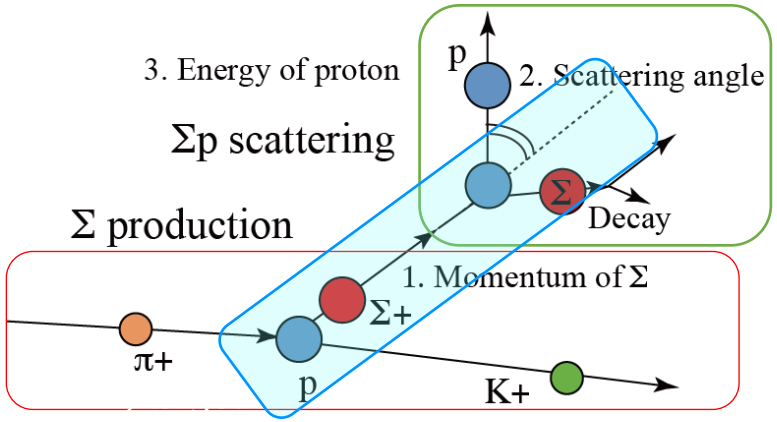
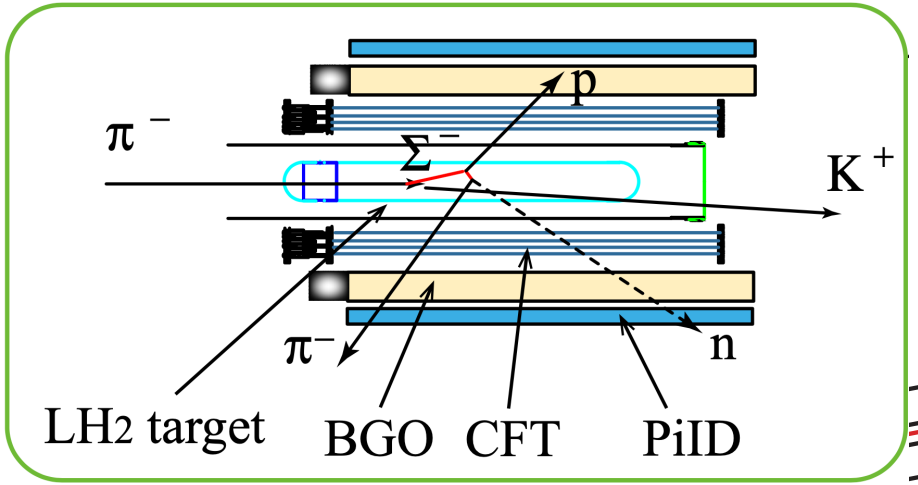
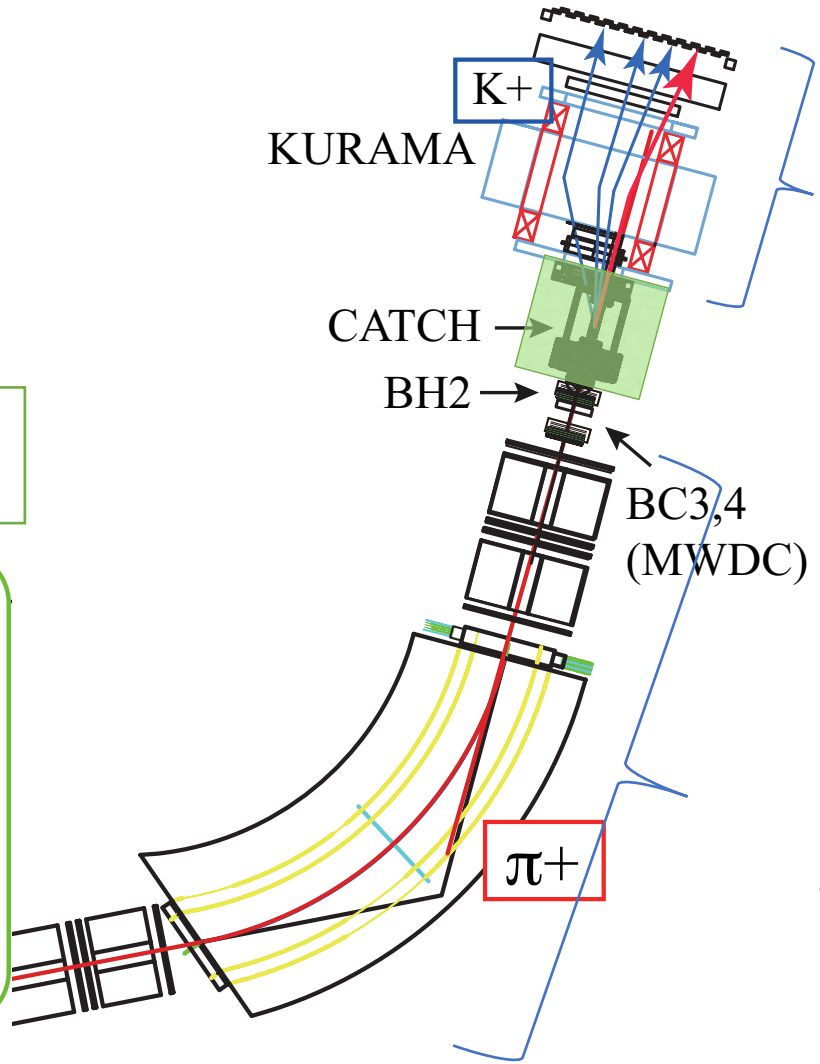


Detection of Σp scattering event by CATCH detector





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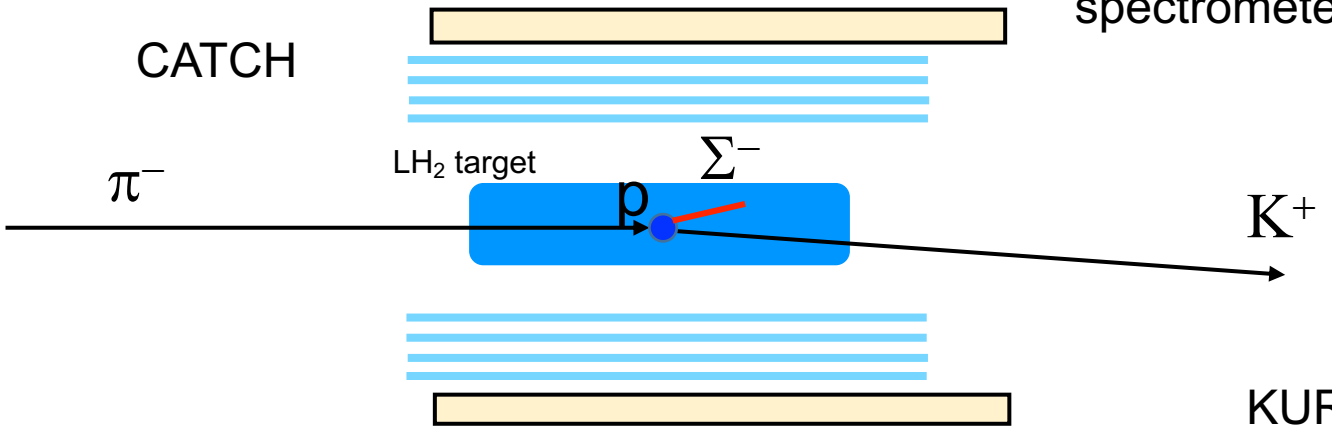
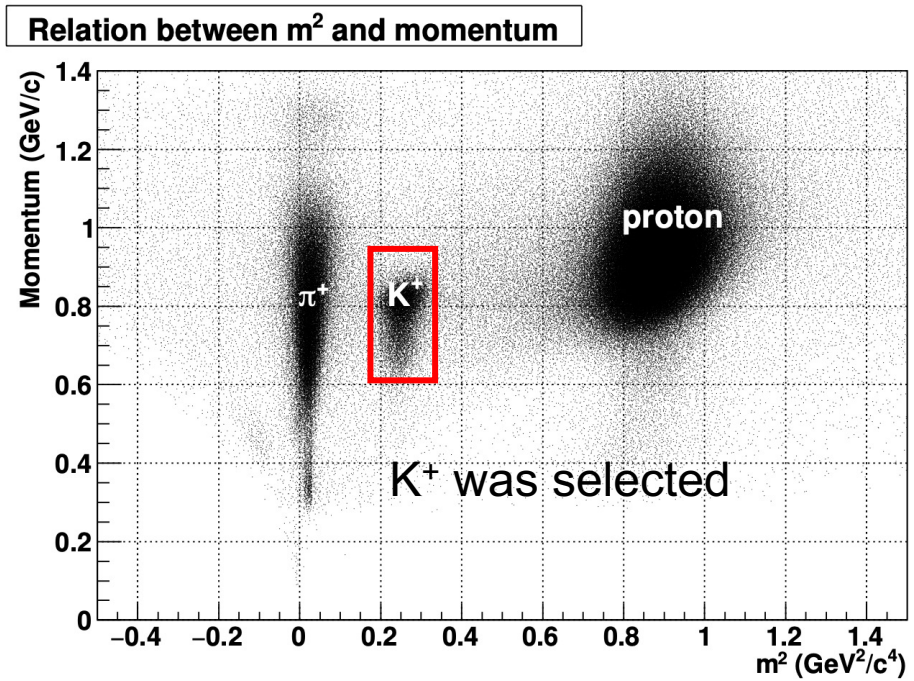


Σ beam in LH_2 target is tagged by the magnetic spectrometers

KURAMA spectrometer analysis



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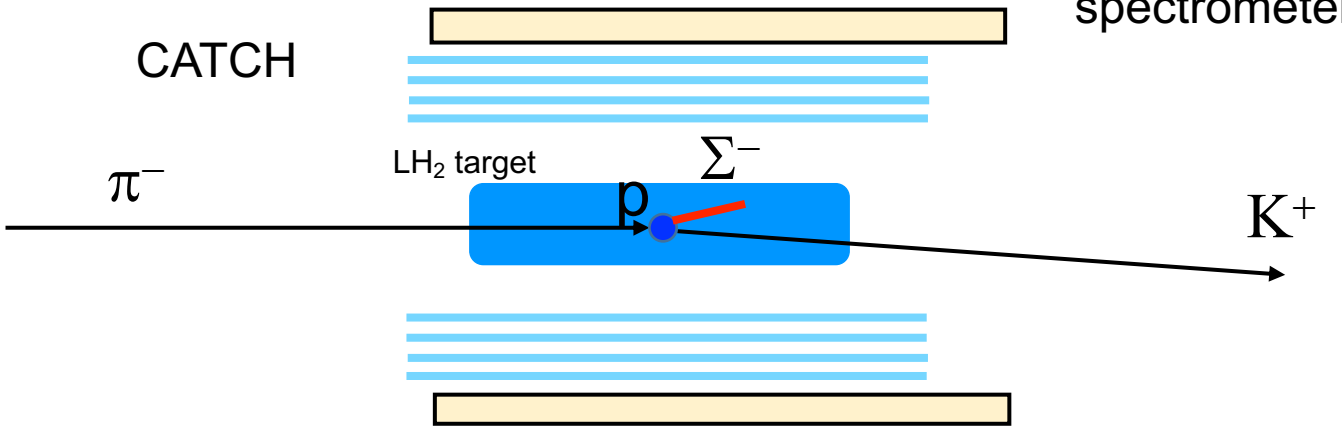
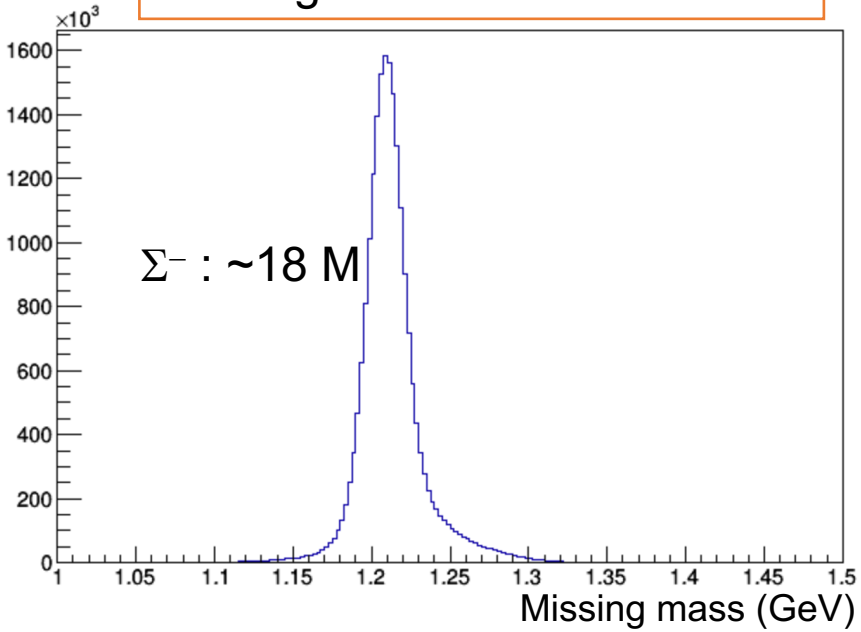
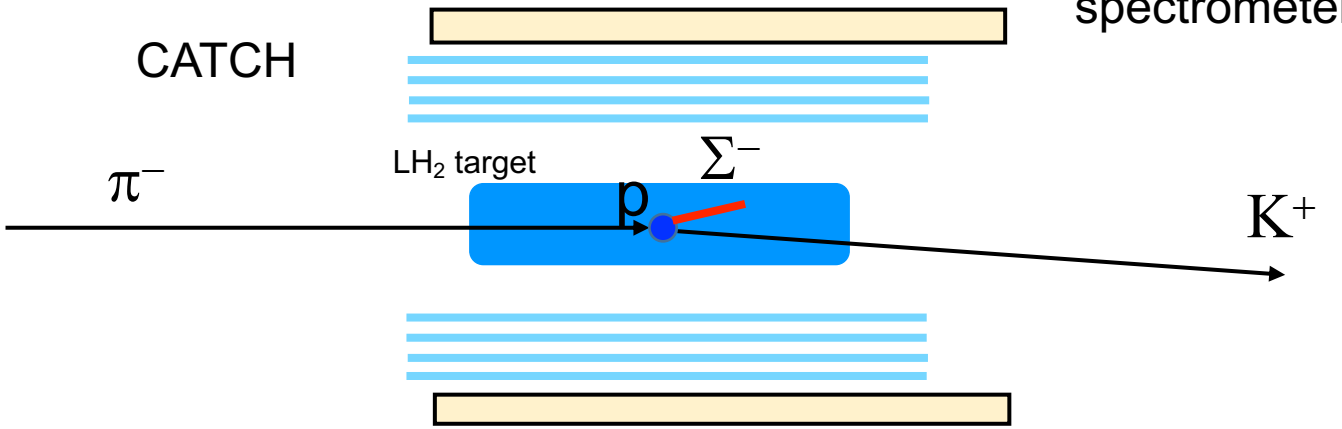


Missing mass from π^- and K^+



Σ beam identification

Σ beam in LH_2 target is tagged by the magnetic spectrometers



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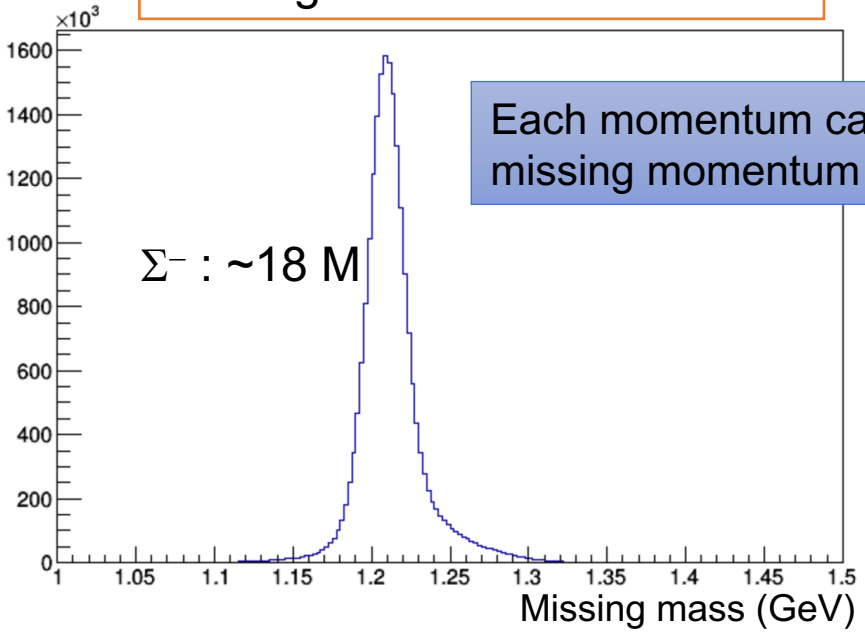
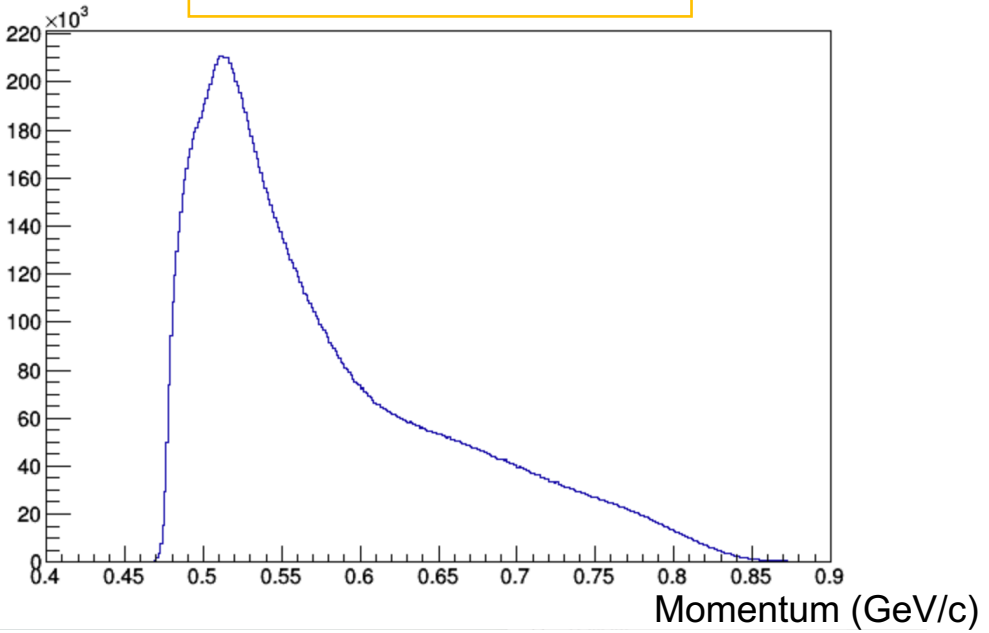


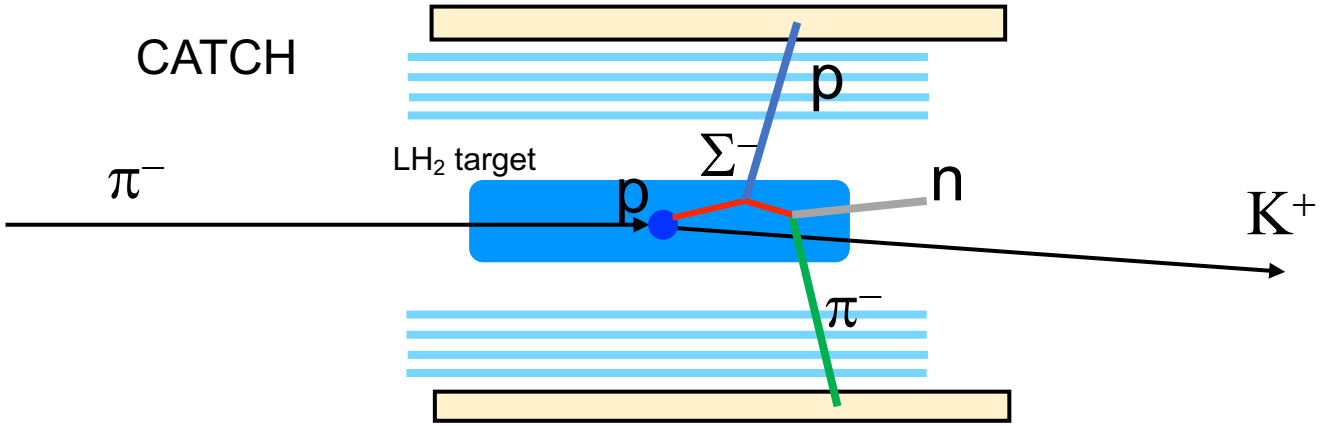
Σ^- : ~18 M

Each momentum can be reconstructed from missing momentum

Σ^- beam momentum



Recoil proton identification



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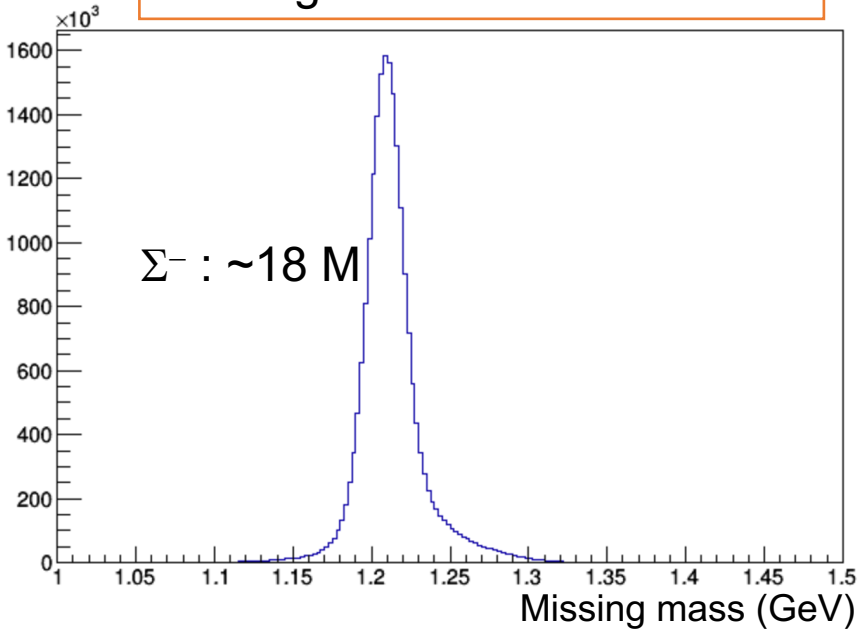

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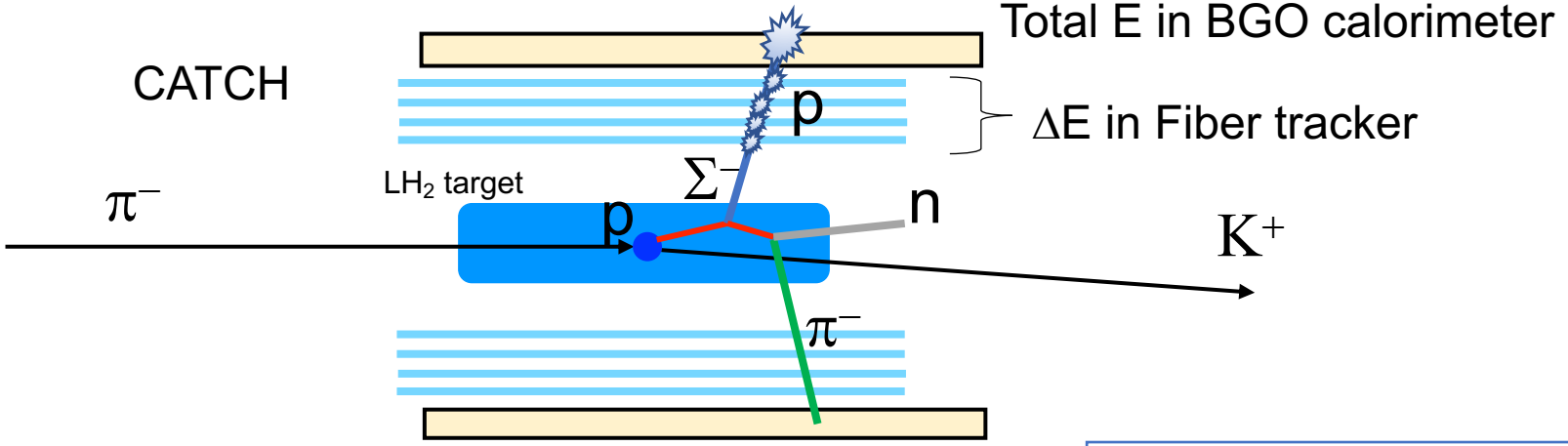

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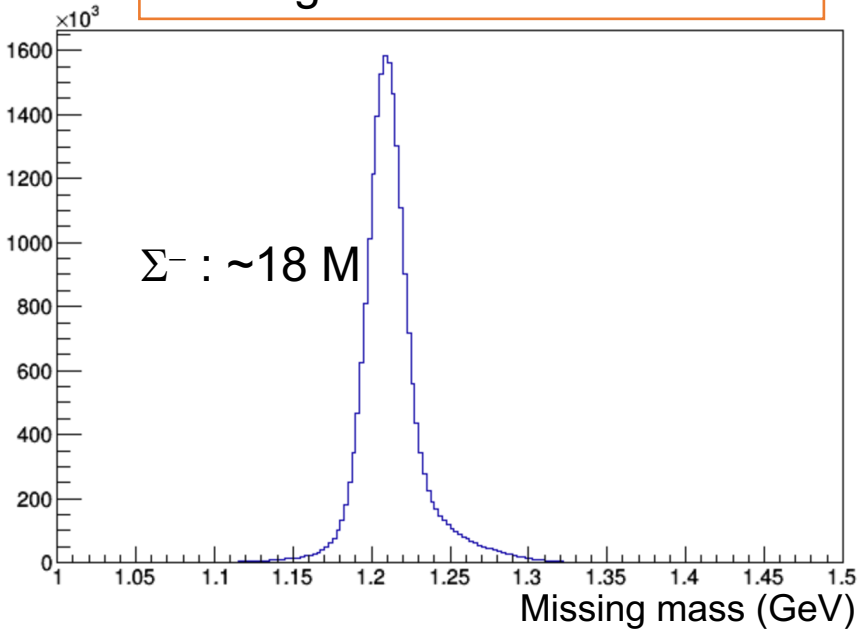
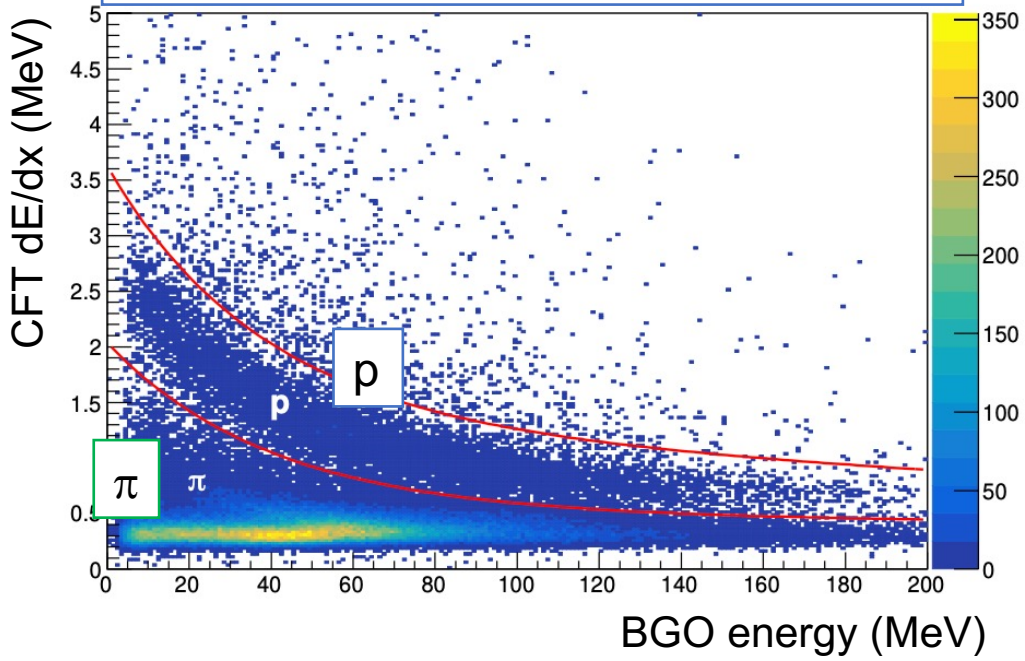


Particle ID in CATCH (ΔE-E method)



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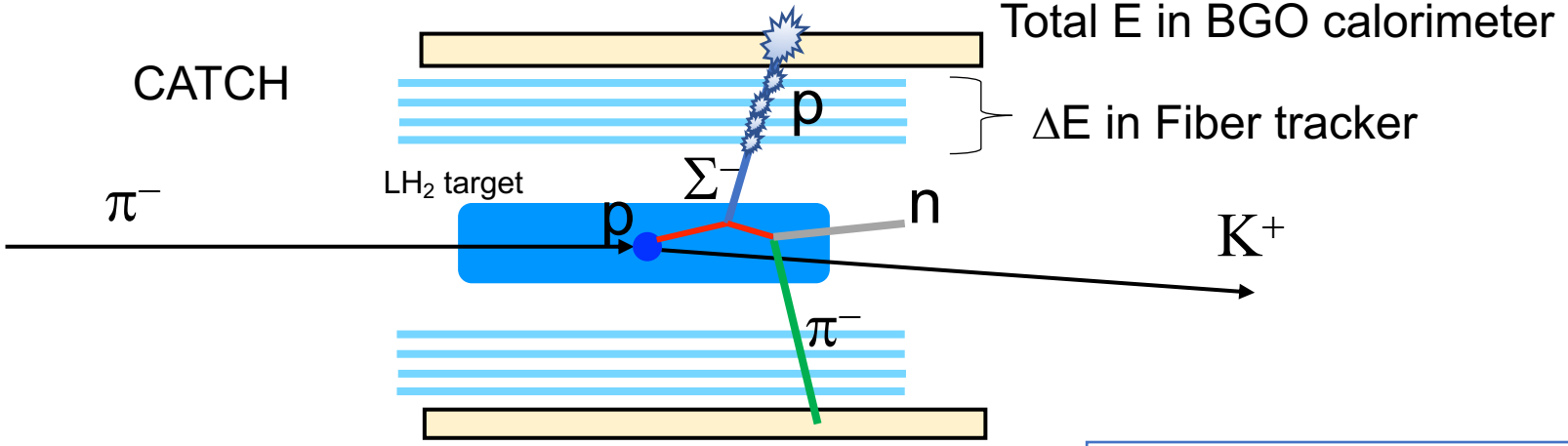

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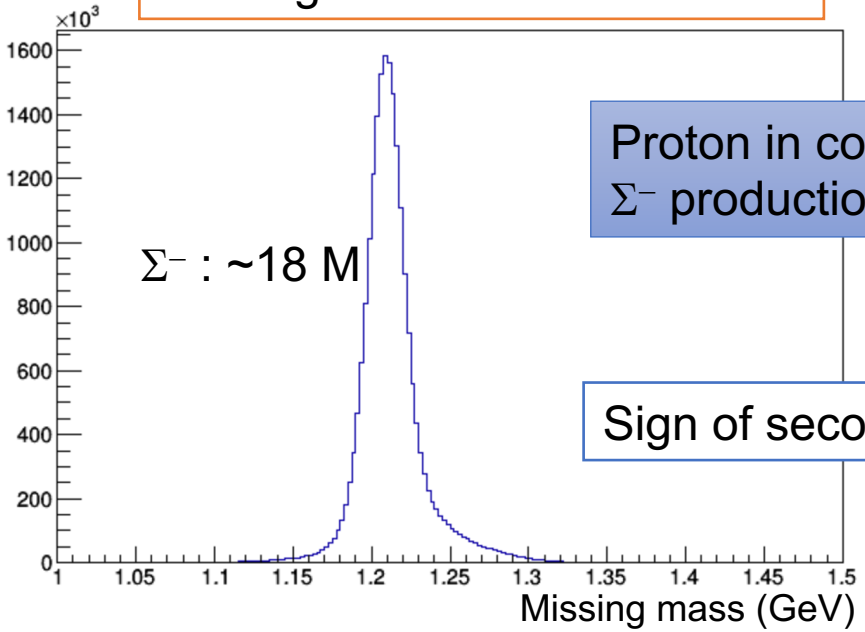
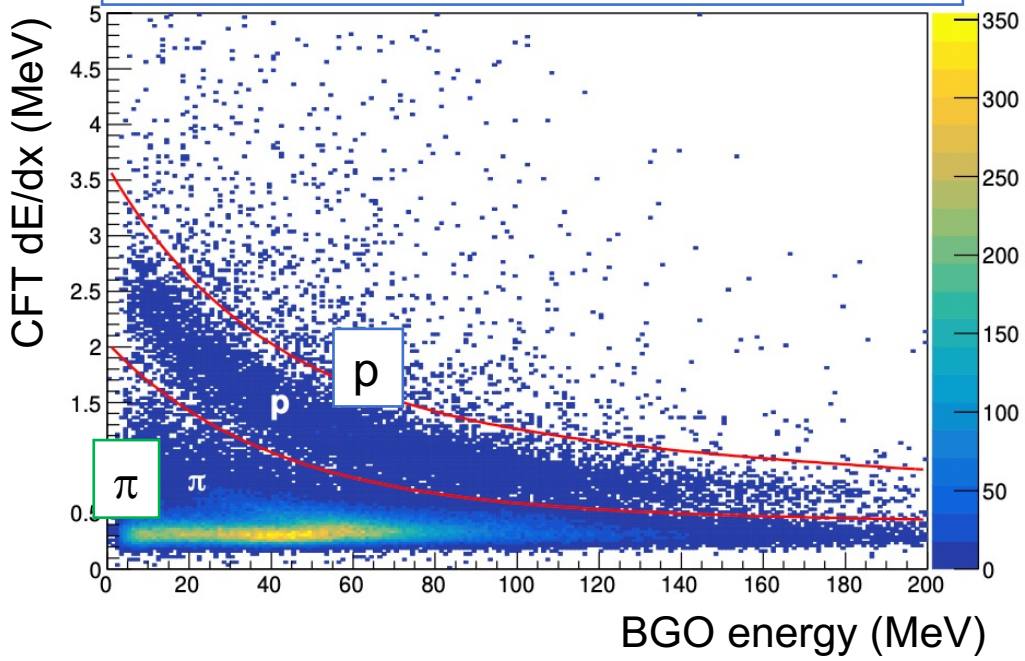


Σ^- : ~18 M

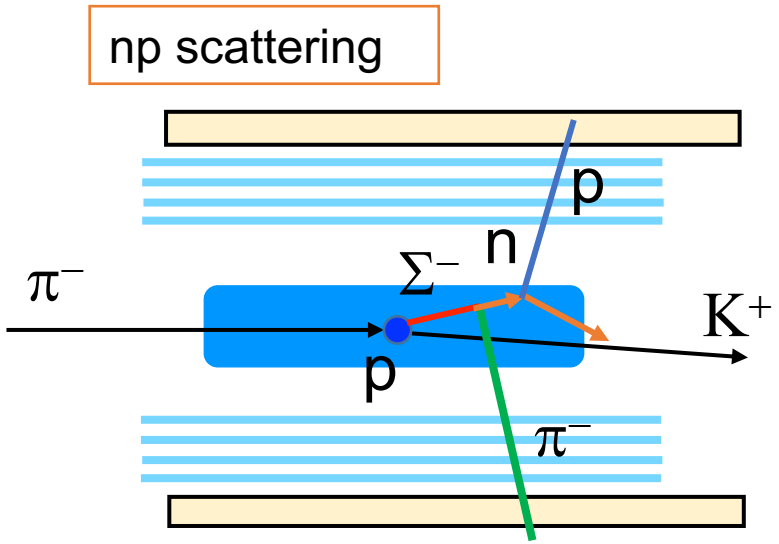
Proton in coincidence with Σ^- production

Sign of secondary reactions

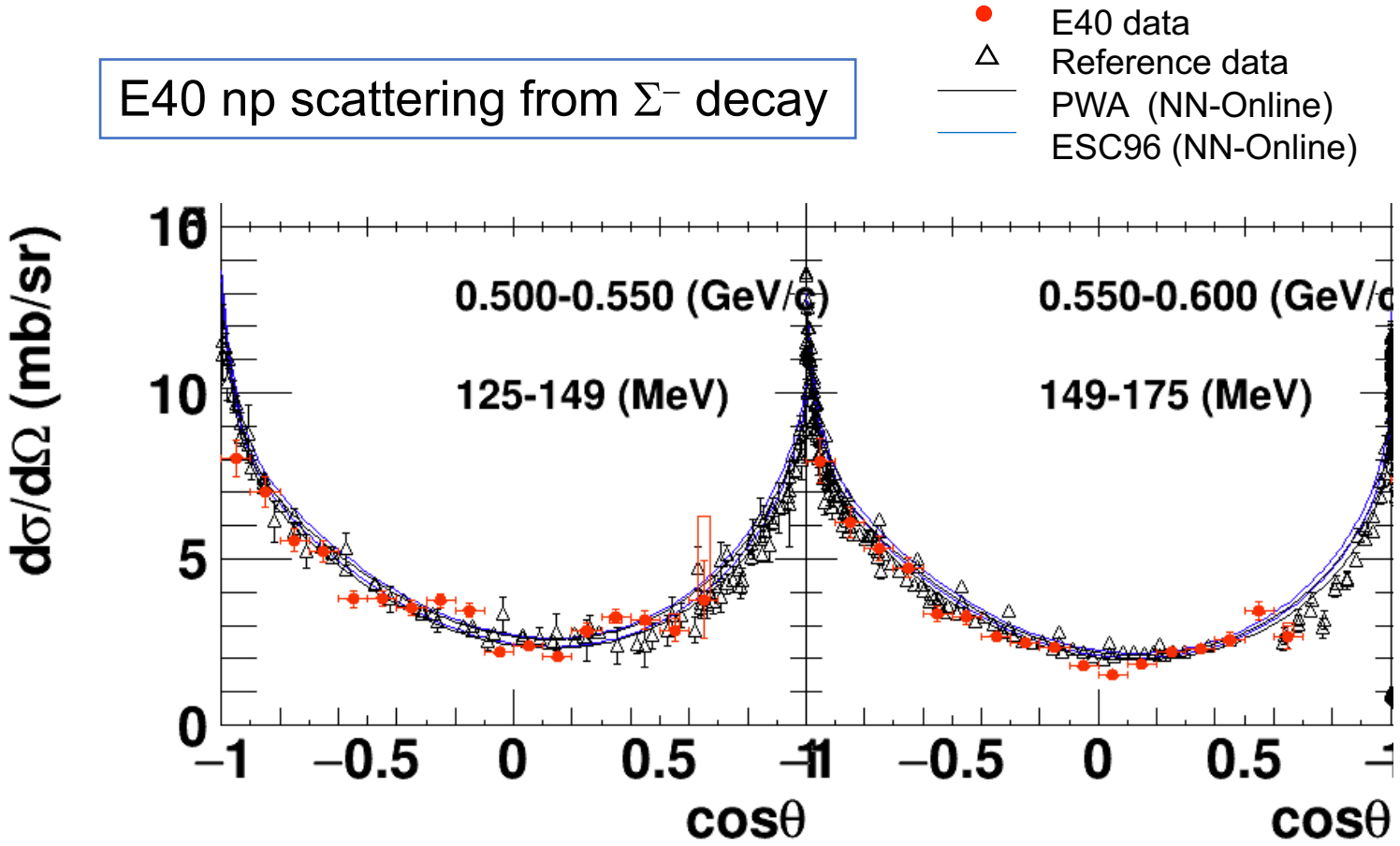
Particle ID in CATCH (ΔE-E method)



dσ/dΩ of np scattering from Σ^- decay

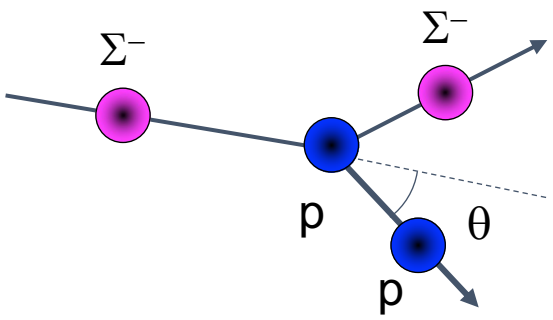


Good reaction to understand our systematics of the dσ/dΩ measuremer



The derived dσ/dΩ of np scattering are reasonable.

Kinematical identification of Σ^-p scatterings

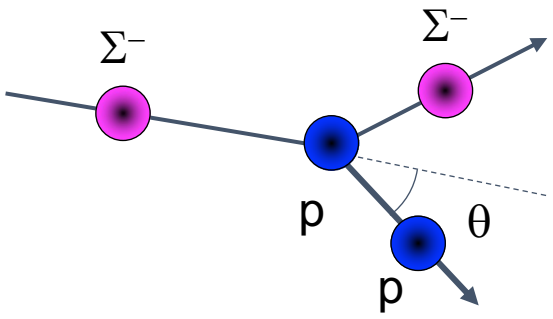


Check kinetic energy difference between

- $E_{measured}$: measured energy
- E_{calc} : calculated energy from scattering angle based on Σ^-p elastic scattering kinematics

$\Delta E(\Sigma^- p) = E_{measured} - E_{calc}$

Kinematical identification of Σ^-p scatterings



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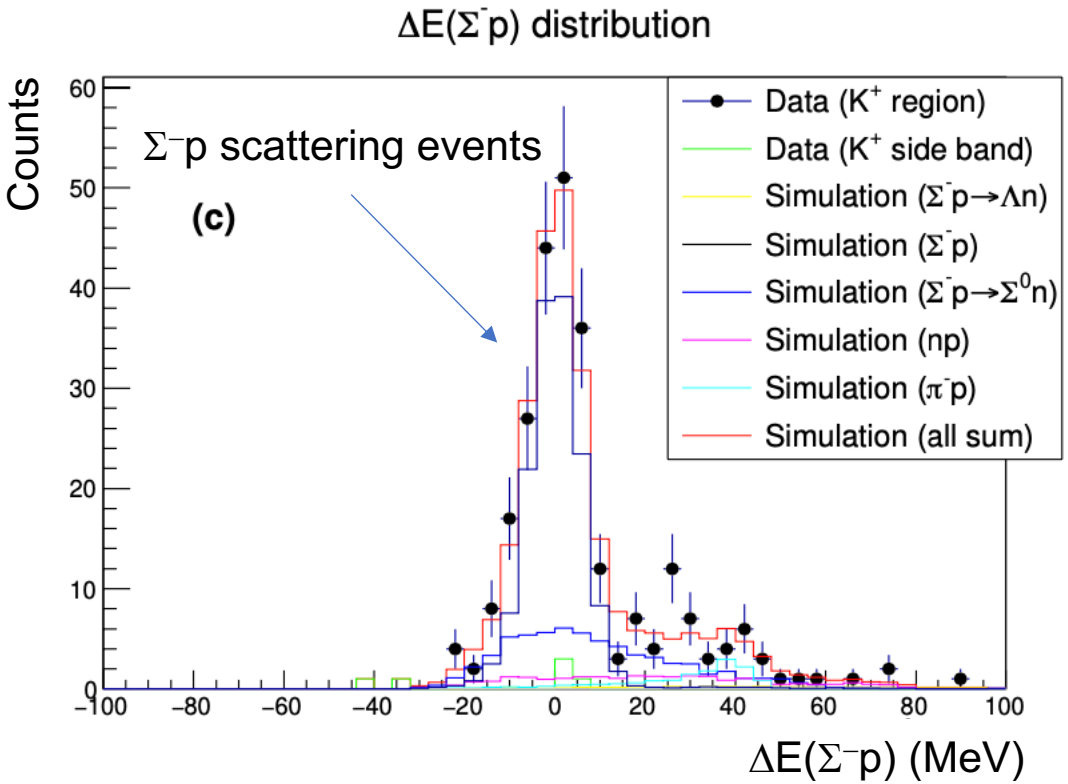

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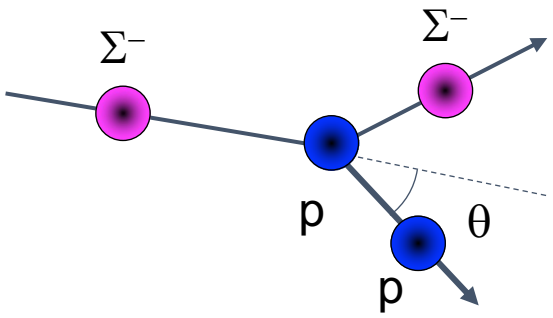

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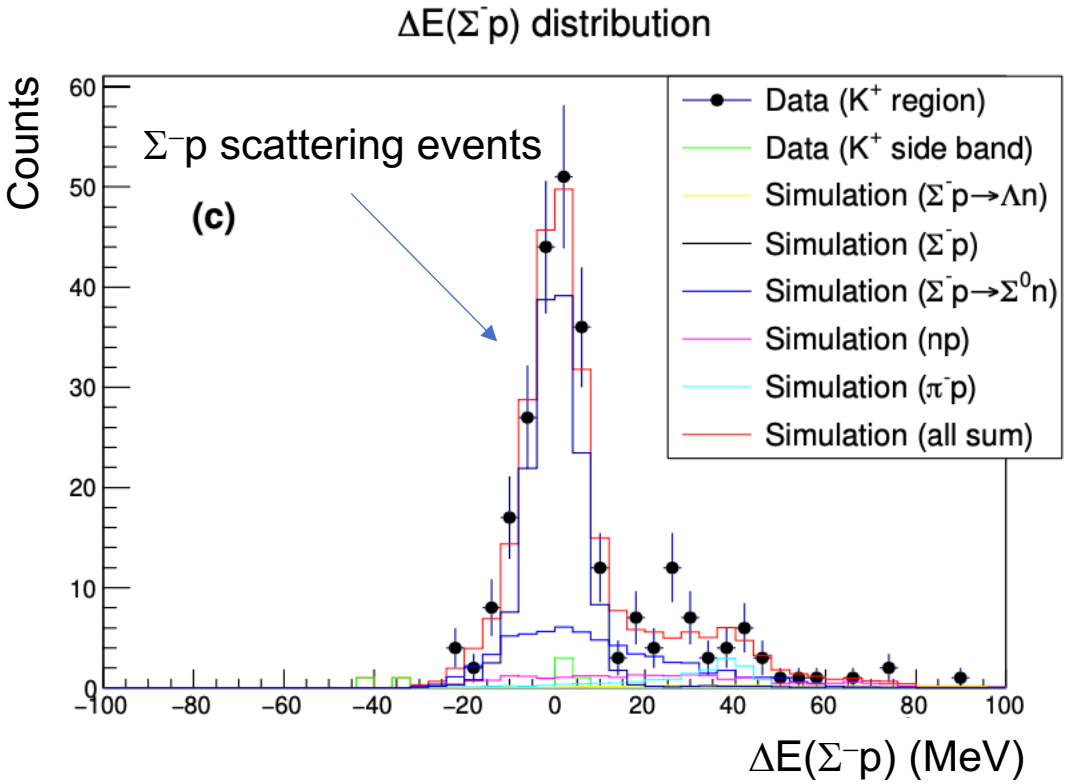
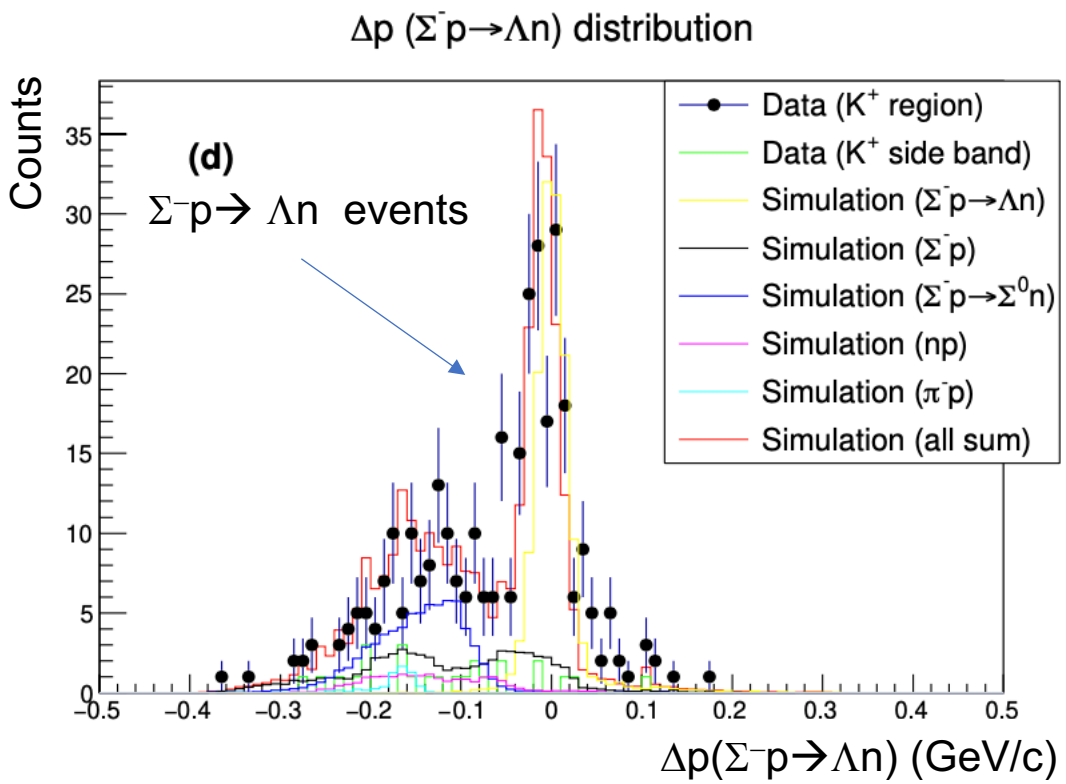
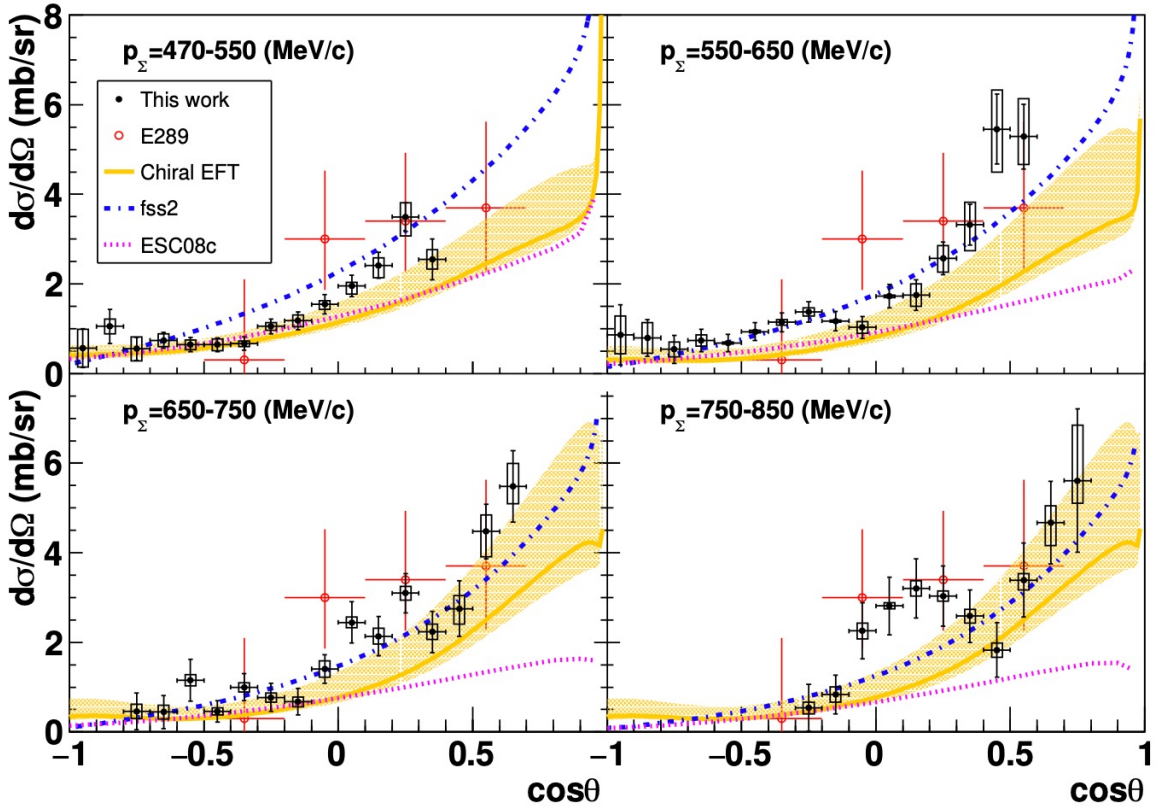




dσ/dΩ of the Σ⁻p channels

Σ⁻p elastic scattering

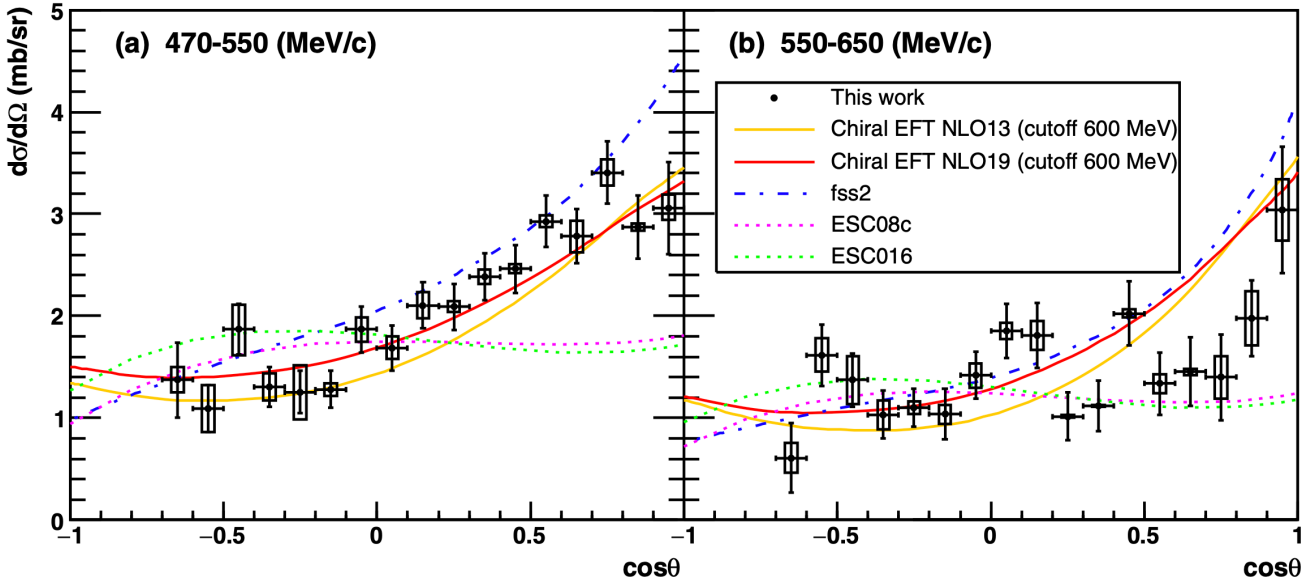
K. Miwa et al., PRC 104, 045204 (2021)



Clear forward peaking angular dependence

Σ⁻p→Λn inelastic scattering

K. Miwa et al., PRL 128, 072501 (2022)



Moderate forward peaking dependence

Comparison with theories

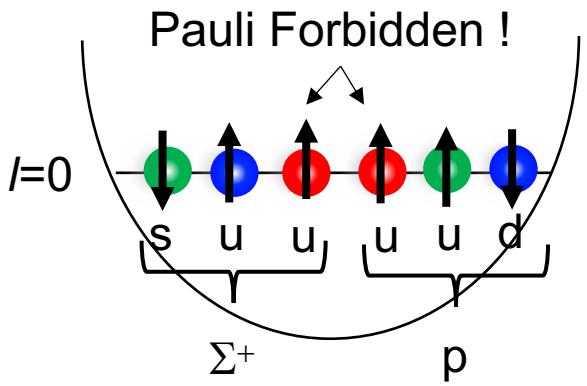
- fss2, Chiral EFT show a reasonable angular dependence.
- Nijmegen ESC models clearly underestimate the forward angle.

dσ/dΩ of Σ^+p elastic scattering

T. Nanamura et al., arXiv:2203.08393
Talk in June 30th

Σ^+p scatterng

6 quarks can stay in s state
in normal case



The more repulsive potential in $^3S_1$

→ The larger dσ/dΩ (like fss2)

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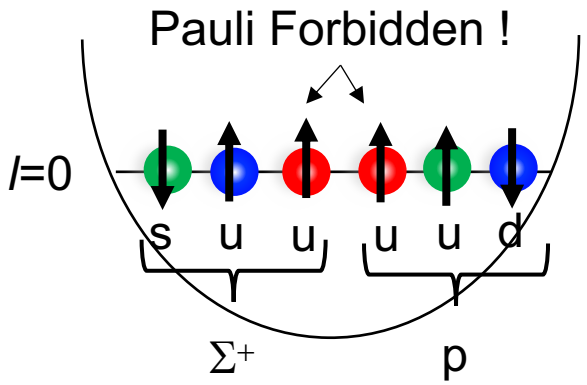

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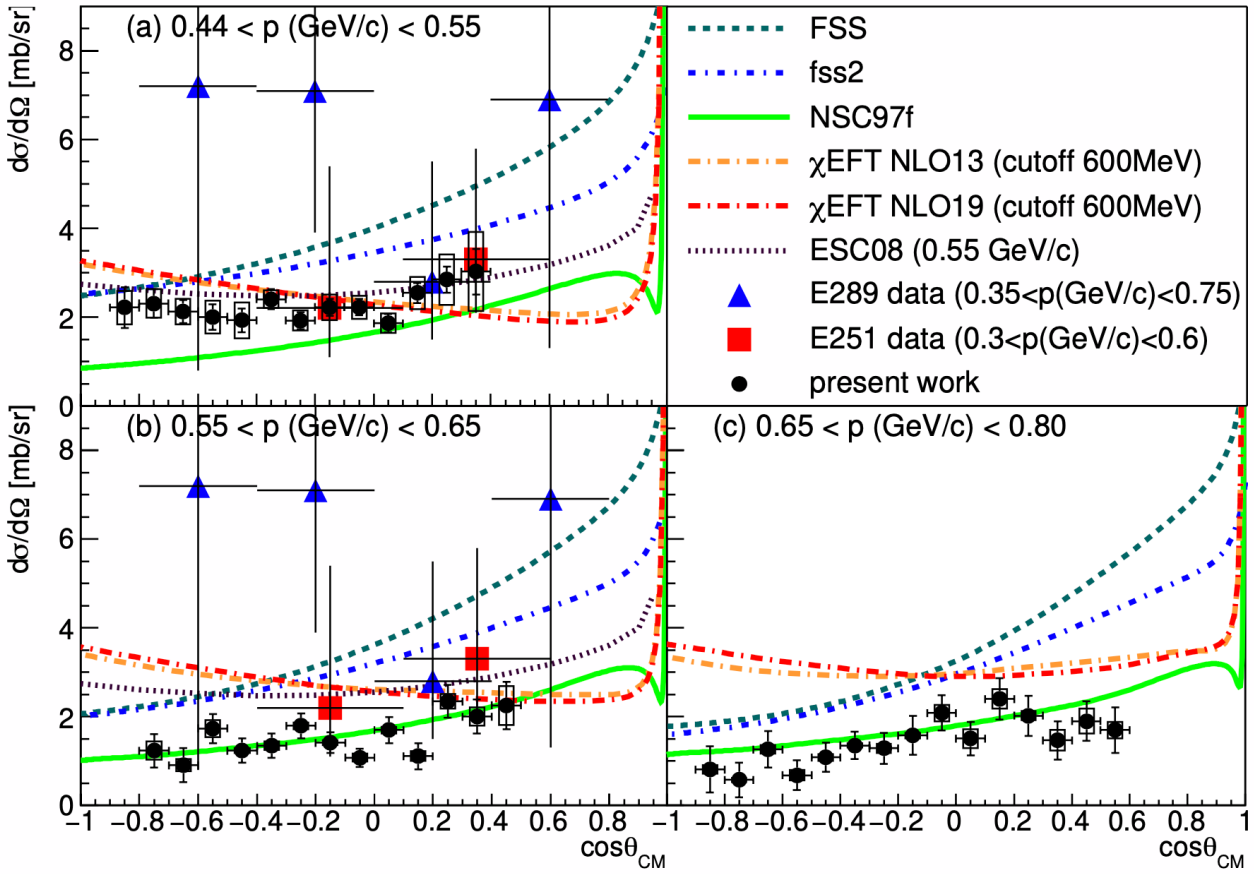

E40 data : much smaller than fss2 prediction and E289 results

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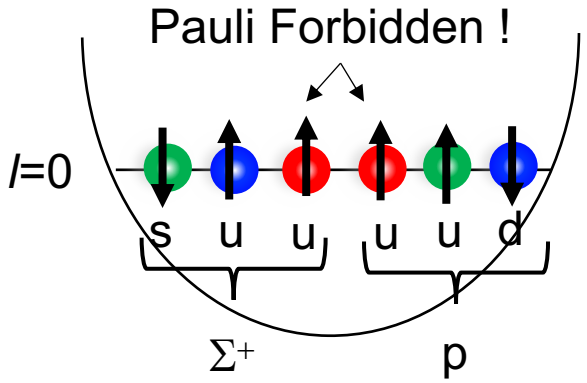

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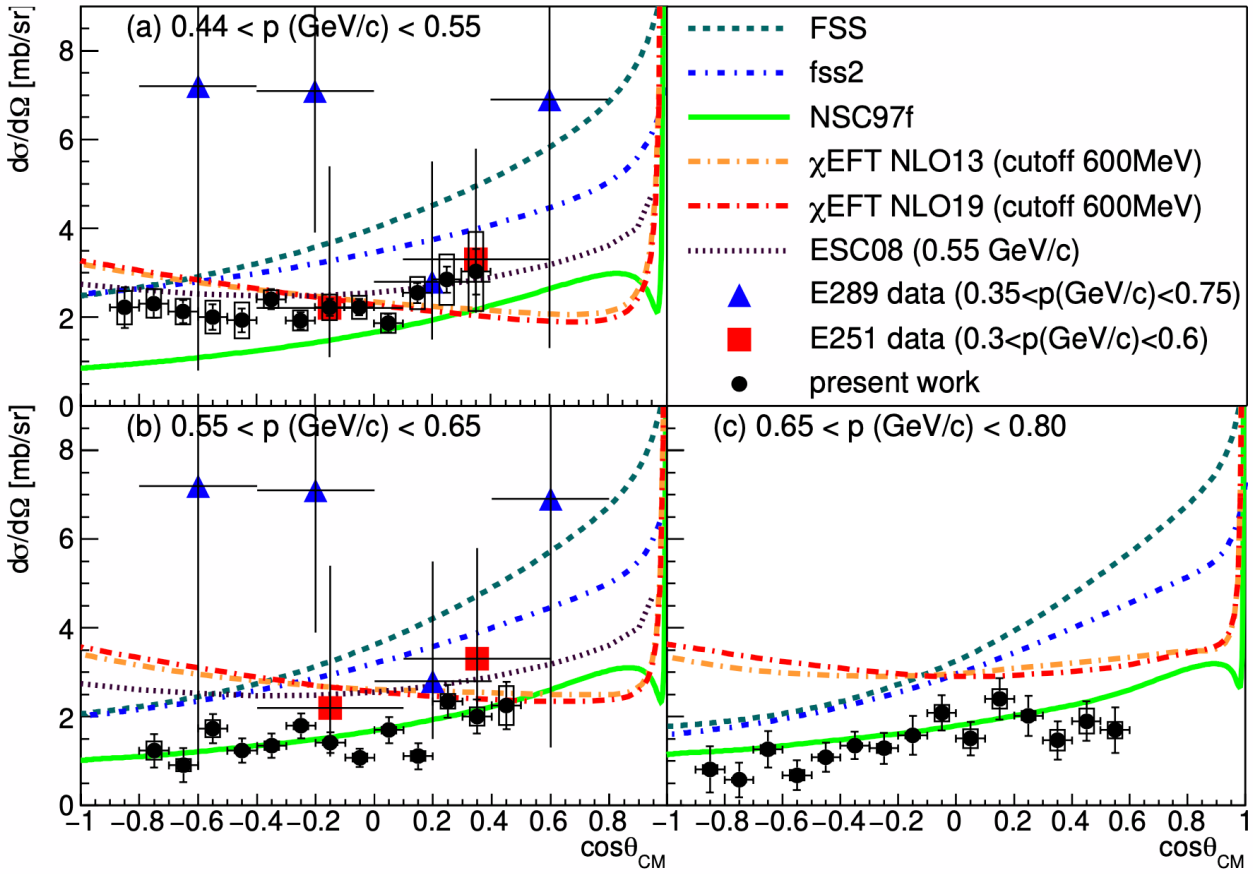


E40 data : much smaller than fss2 prediction and E289 results

Comparison with theories

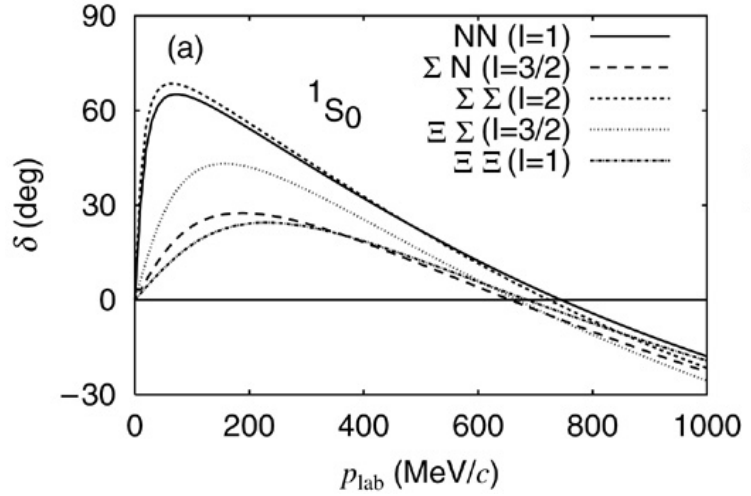
- fss2, FSS (quark model) are too large compared to data
- Chiral EFT's momentum dependence does not match with data
- Nijmegen (ESC) models are rather consistent.

Phase shift analysis

T. Nanamura et al., arXiv:2203.08393
Talk in June 30th

strangeness	BB channel (I)	^{1}Even or ^{3}Odd	^{3}Even or ^{1}Odd
0	NN($I=0$)	–	($\mathbf{10^*}$)
	NN($I=1$)	($\mathbf{27}$)	–
	$\Sigma N(I=\frac{3}{2})$	($\mathbf{27}$)	($\mathbf{10}$)

- Constrained from NN (I=1) channel
- Smaller uncertainty



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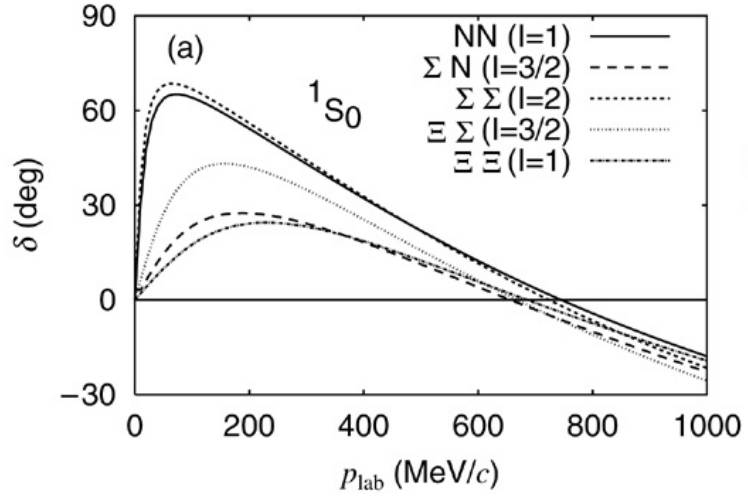

Phase shift analysis for Σ^+p $d\sigma/d\Omega$

- Two parameters : $\delta(^3S_1)$, $\delta(^1P_1)$
- Other phase shifts up to D wave :

fixed on NSC97f, ESC16, pp scat

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T. Nanamura et al., arXiv:2203.08393
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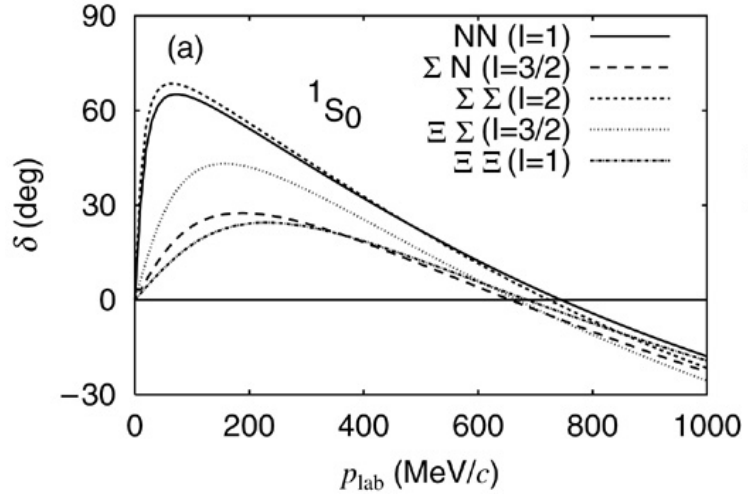

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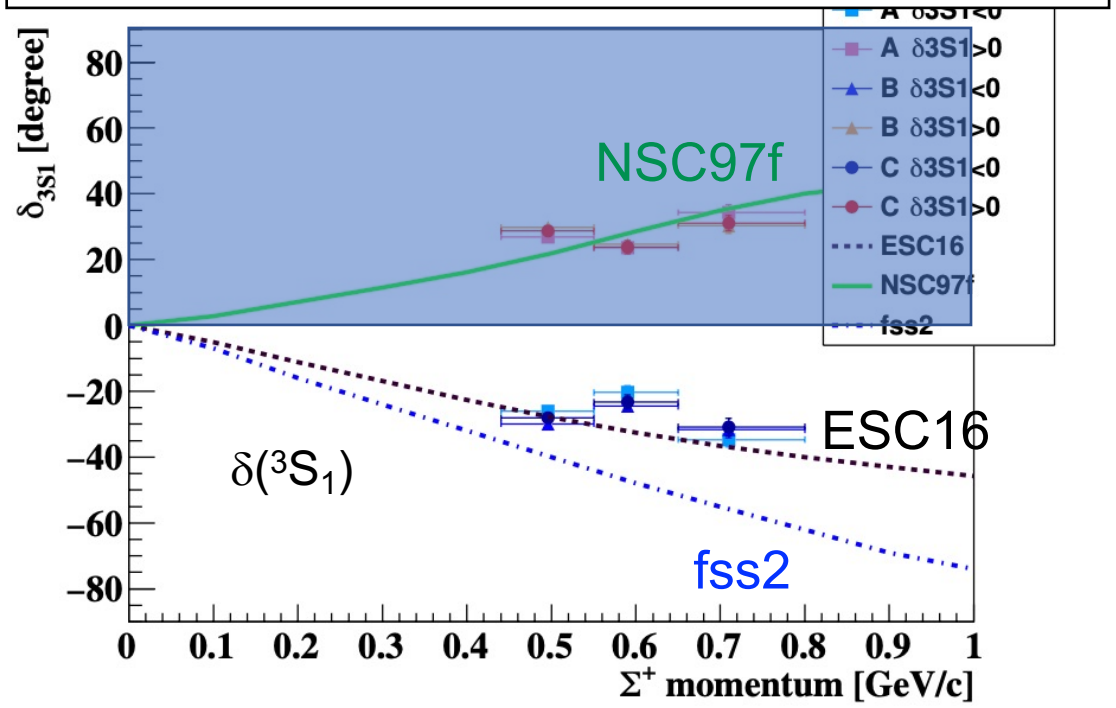
First experimental derivation of phase shift of $^3S_1$

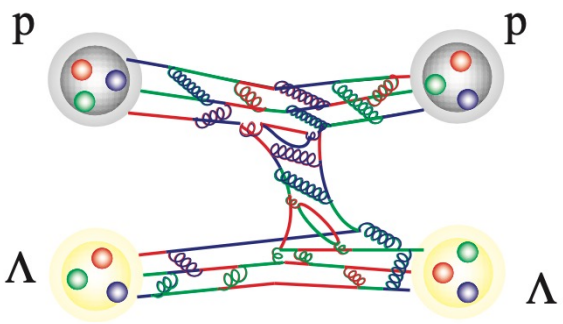


Derived phase shift suggest that **the $^3S_1$ interaction is moderately repulsive**.

Toward Λp scattering

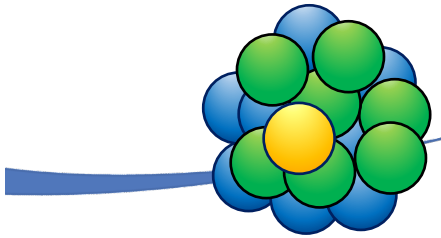
<u>Reliable ΛN two-body interaction :</u>

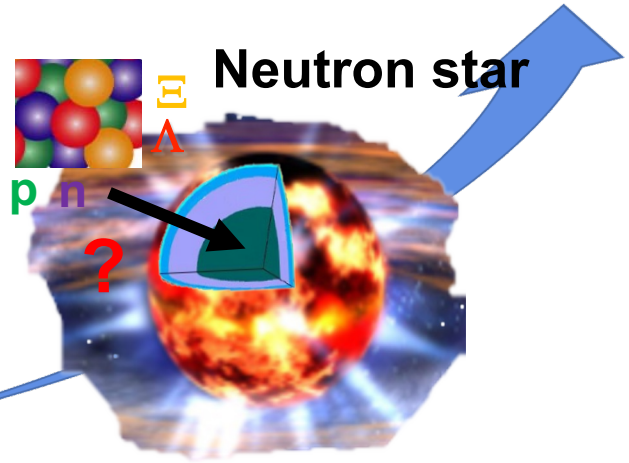
key to deepen Λ hypernuclear physics



Λ hypernuclei

key to reveal ΛNN int.





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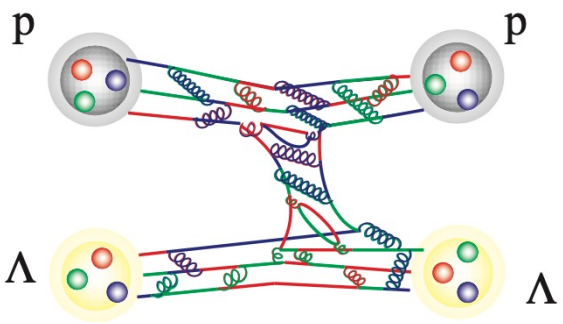

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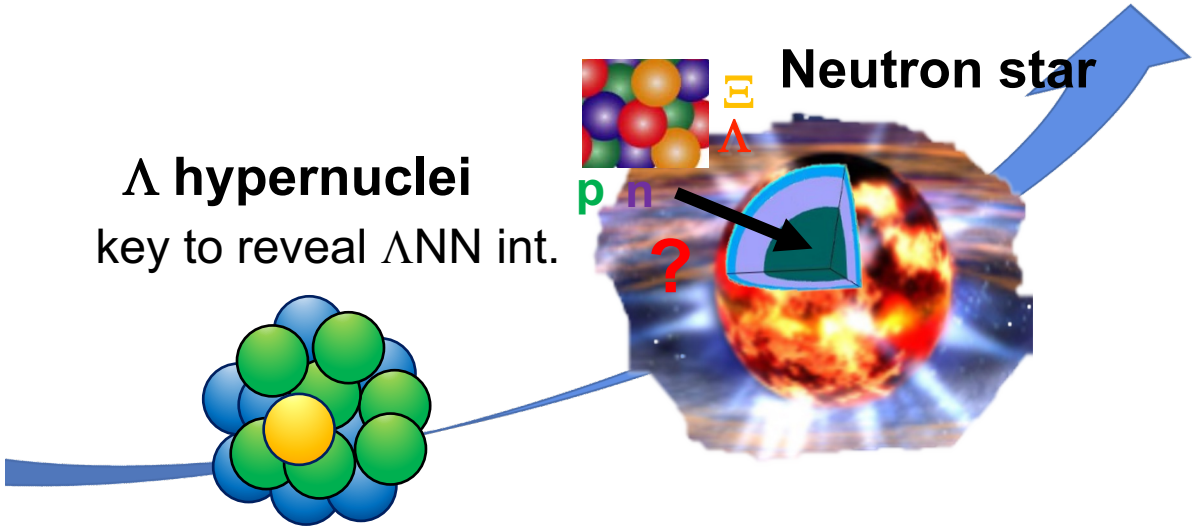
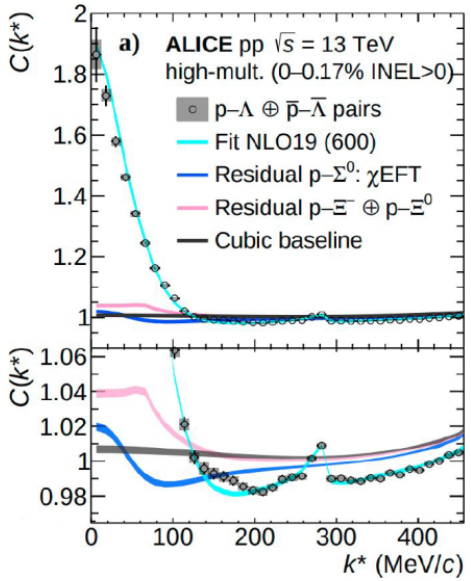
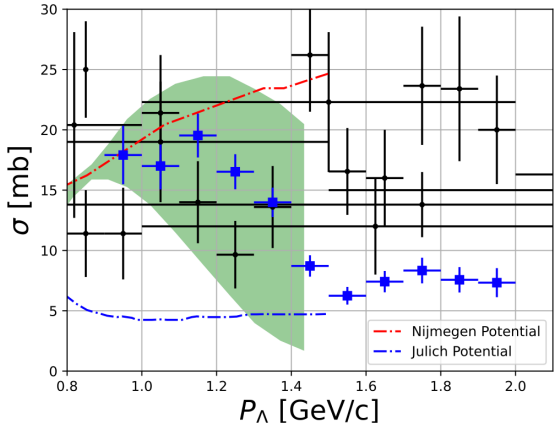


Femtoscopy from HIC



ALICE Collaboration, arXiv:2104.04427

New cross section data from Jlab CLAS



J. Rowley et al. (CLAS), Phys. Rev. Lett. 127 (2021) 272303

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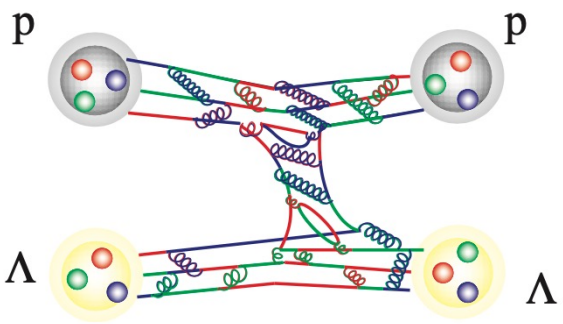

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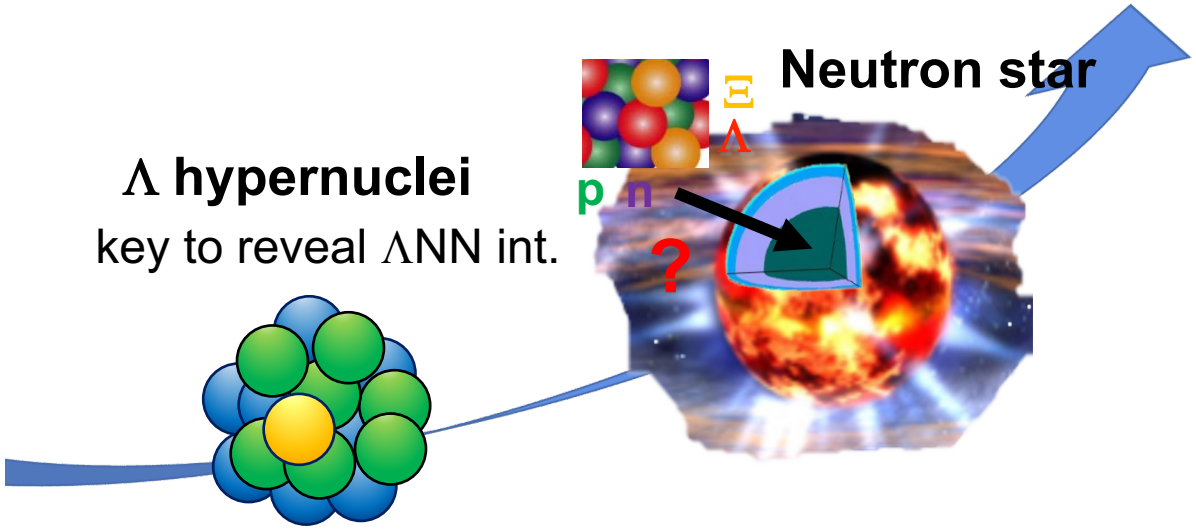

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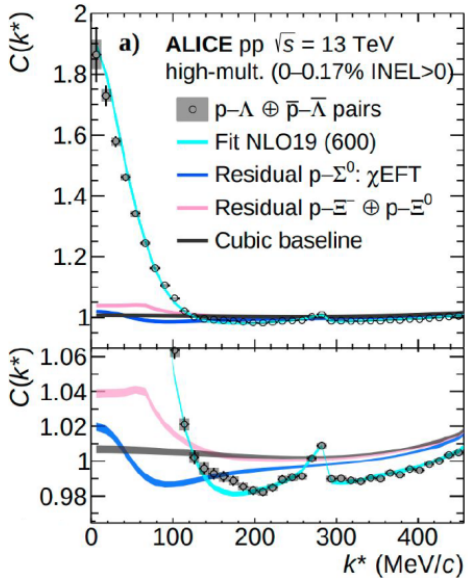

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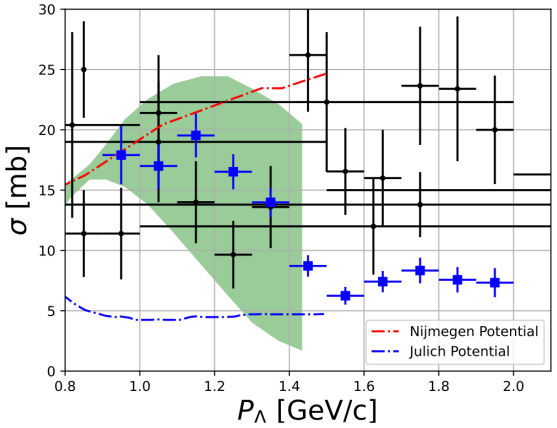
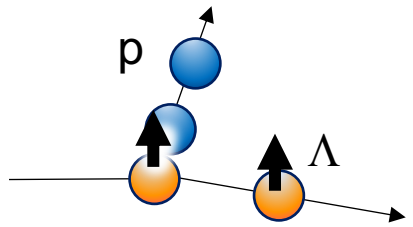


J. Rowley et al. (CLAS), Phys. Rev. Lett. 127 (2021) 272303

New project at J-PARC

Λp scattering w/ polarized Λ

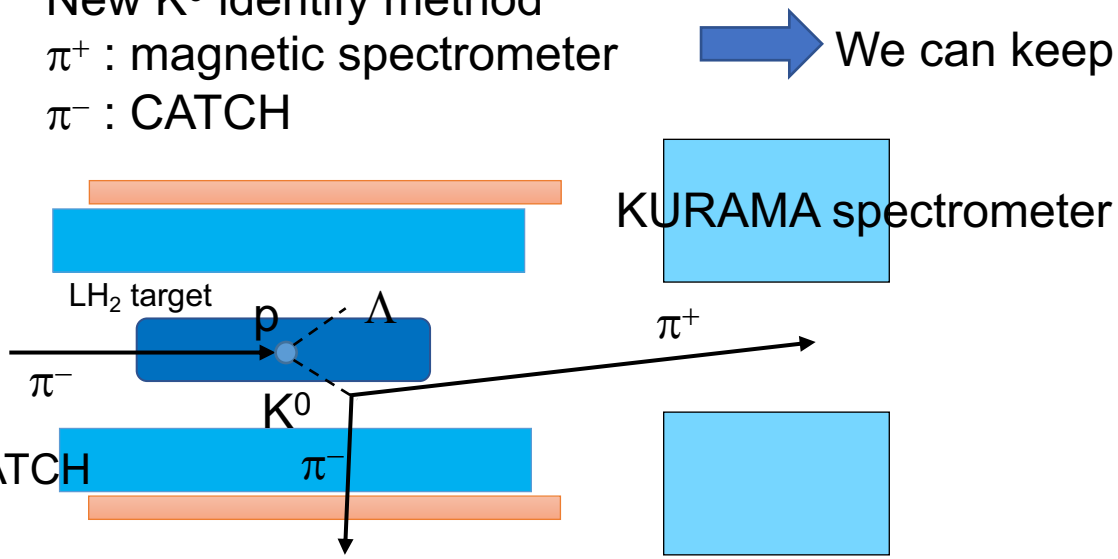


- Feasibility test w/ E40 data
- Expected results in new experiment

Feasibility study in E40 (Σp scattering)

By using by-product data in E40, we already checked feasibility of Λp scattering

New K^0 identify method
π^+ : magnetic spectrometer
π^- : CATCH



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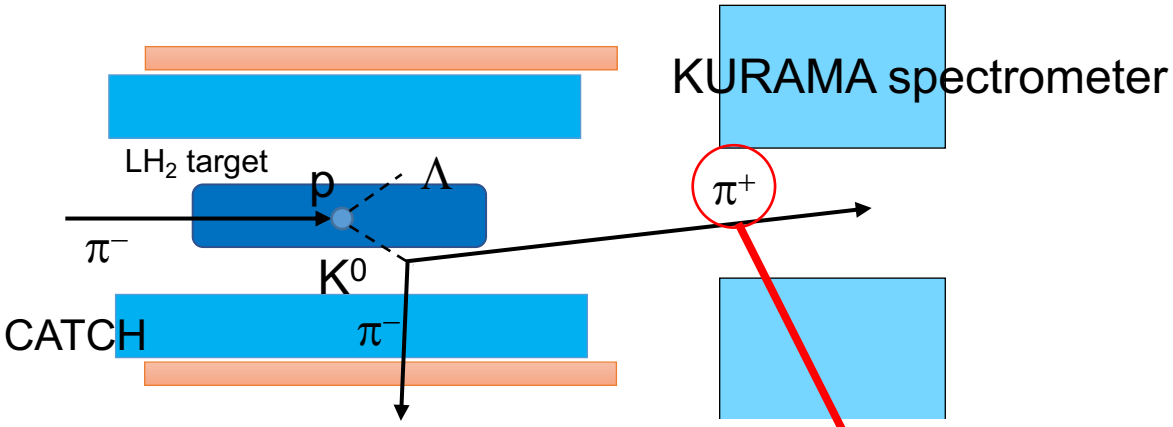

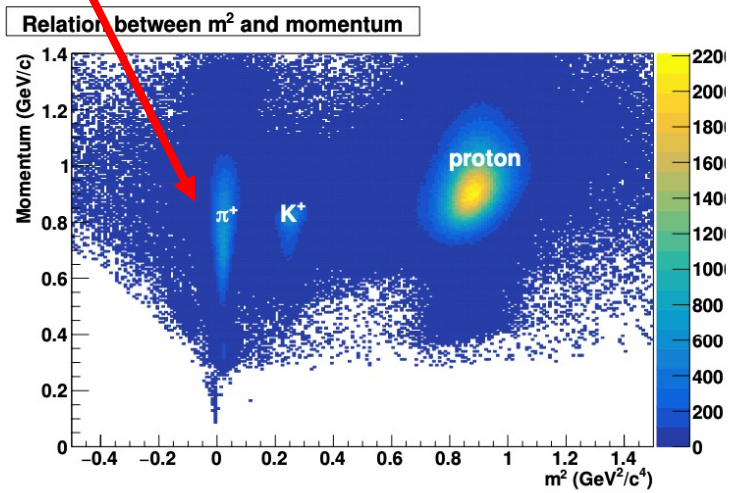

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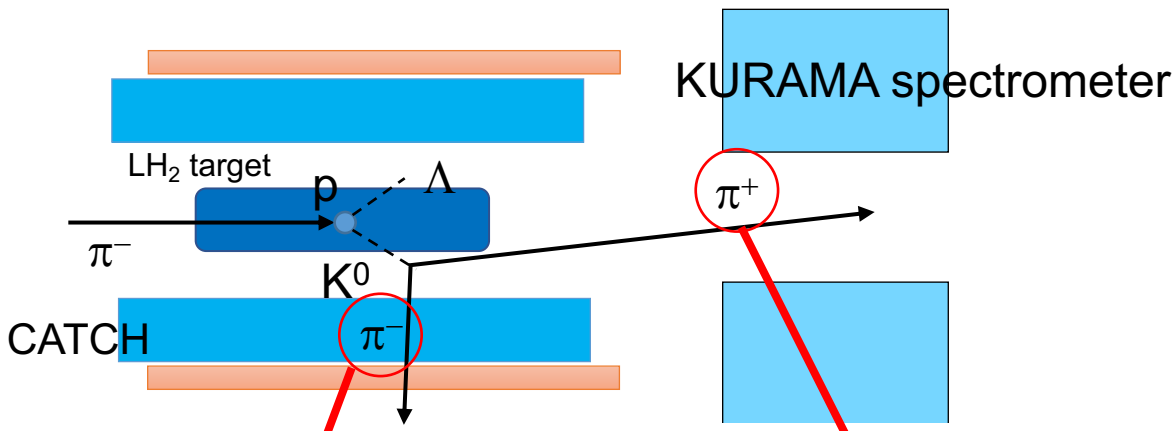
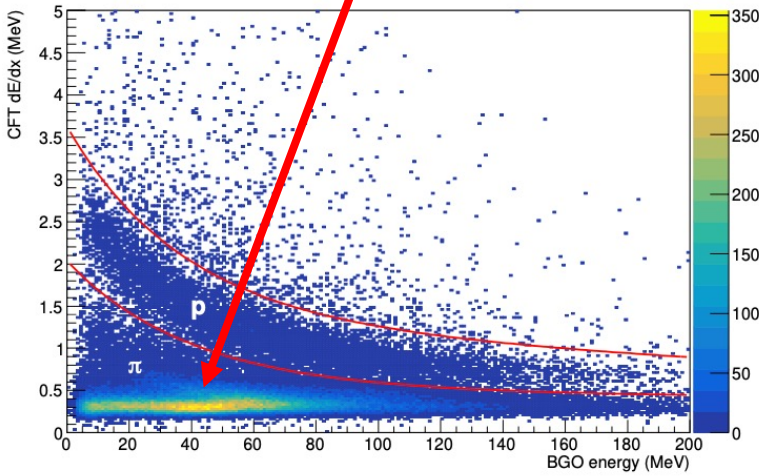
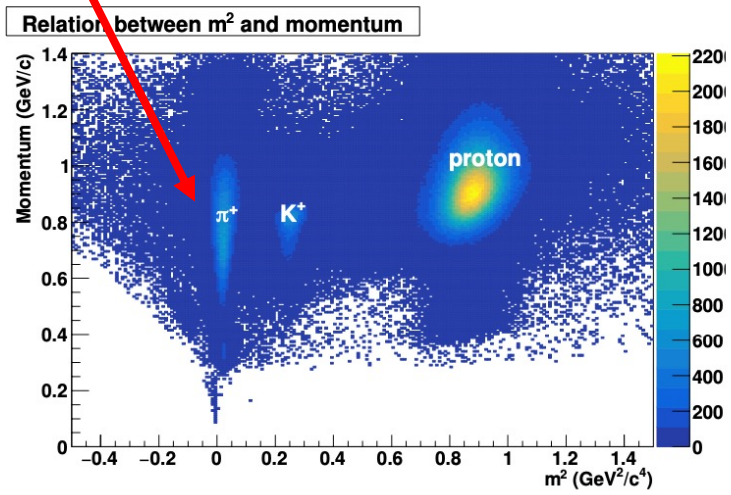


Particle ID in CATCH by ΔE-E method



Relation between m^2 and momentum

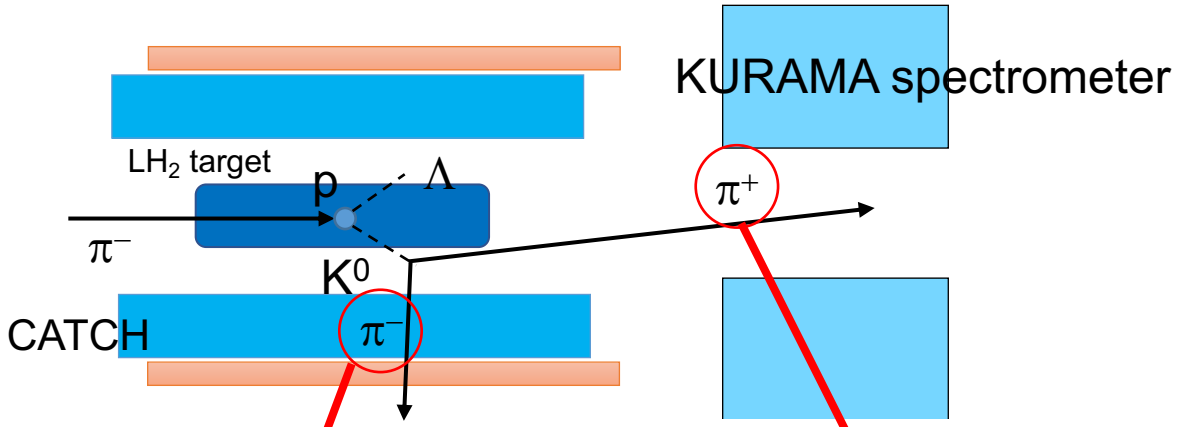


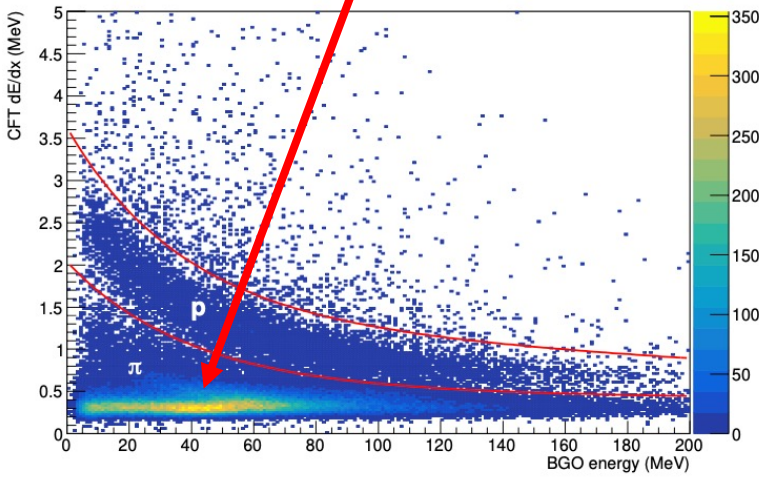
Feasibility study in E40 (Σp scattering)

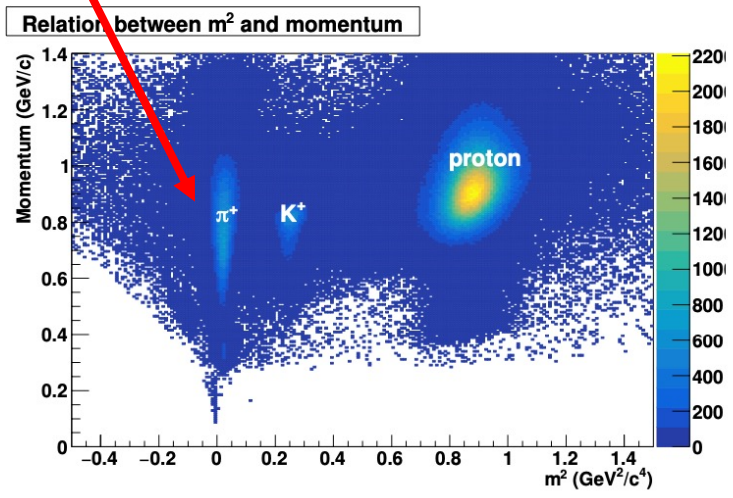
By using by-product data in E40, we already checked feasibility of Λp scattering

New K^0 identify method
π^+ : magnetic spectrometer
π^- : CATCH

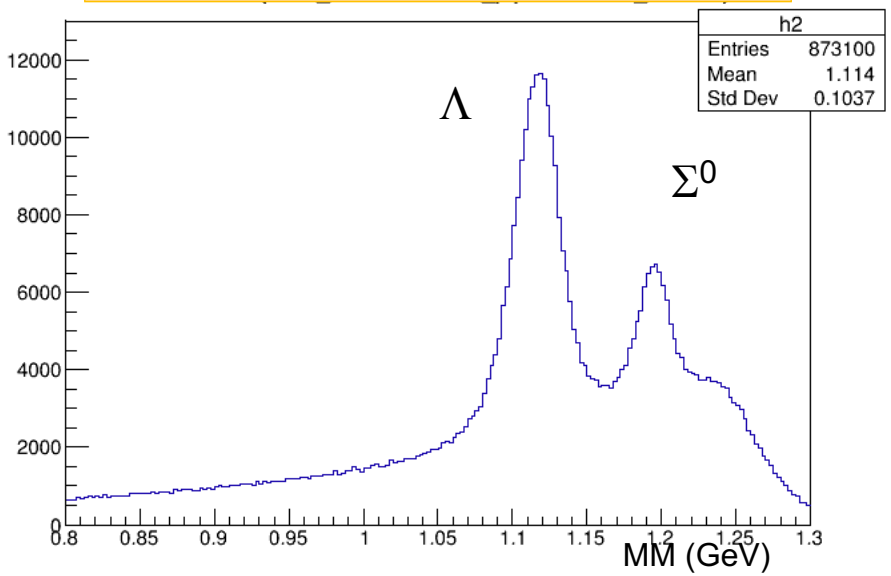
→ We can keep large acceptance for K^0







Missing mass ($\pi^- p \rightarrow K^0 X$ reaction)

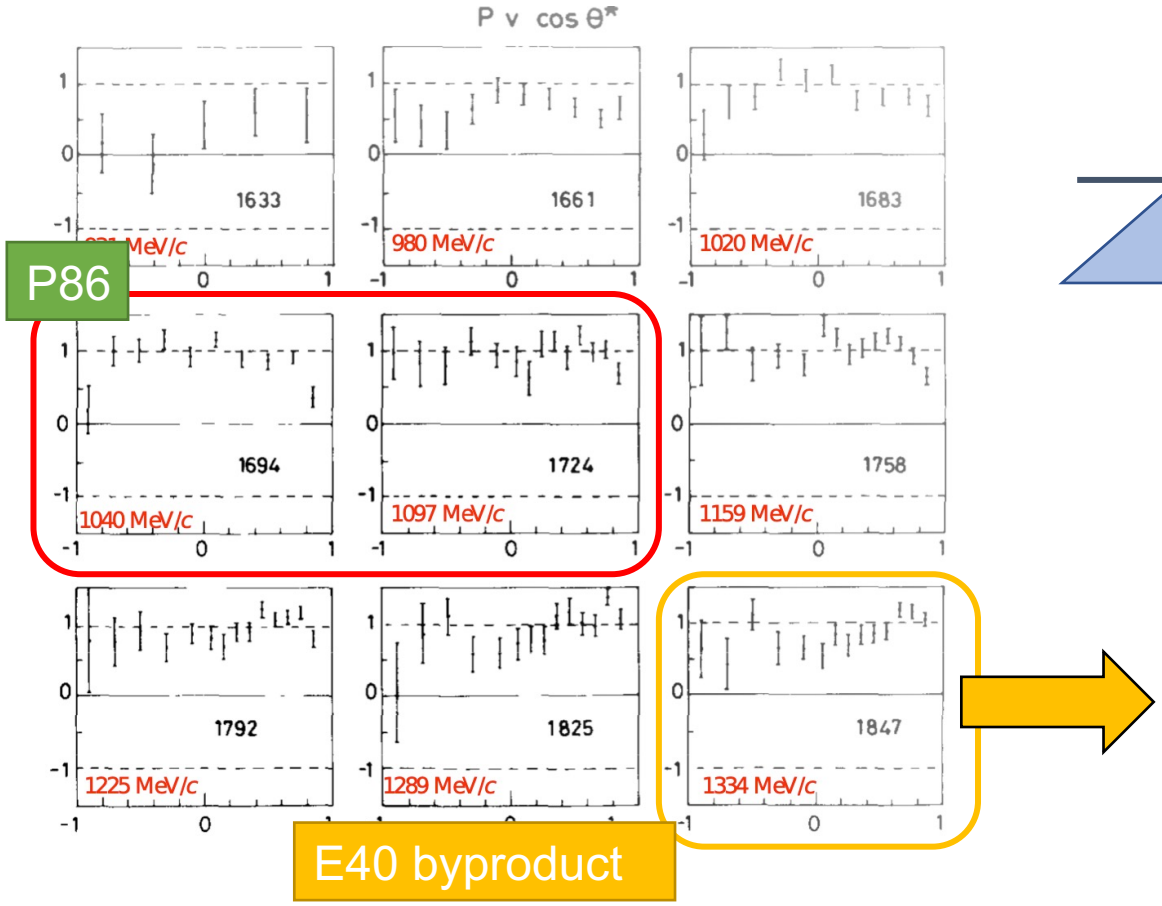


We could establish Λ production method for proton target !

Future upgrade is considered to measure π^- momentum to clean up the background

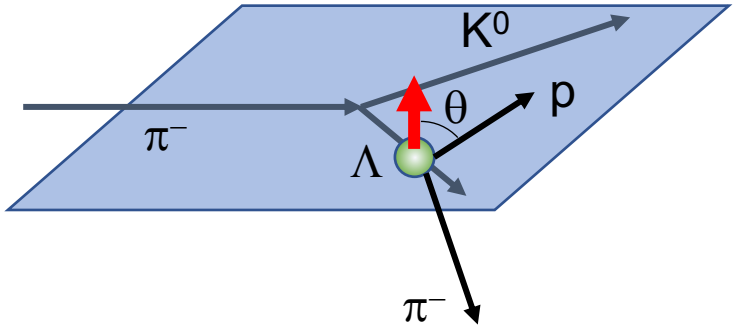
Λ polarization measurement

Past measurement by R.D. Baker et al.



Λ polarization measurement in E40

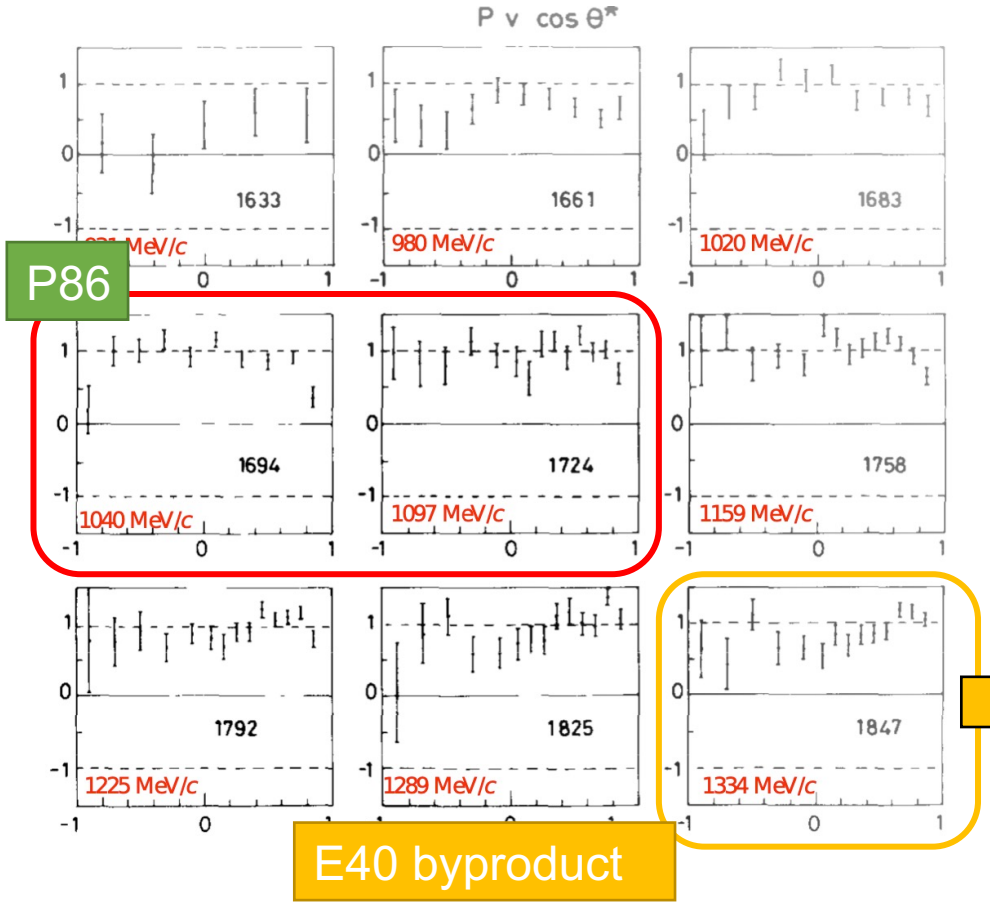
Production plane was defined event by event



Analysis by T. Sakao (Tohoku)
Talk in June 30th

Λ polarization measurement

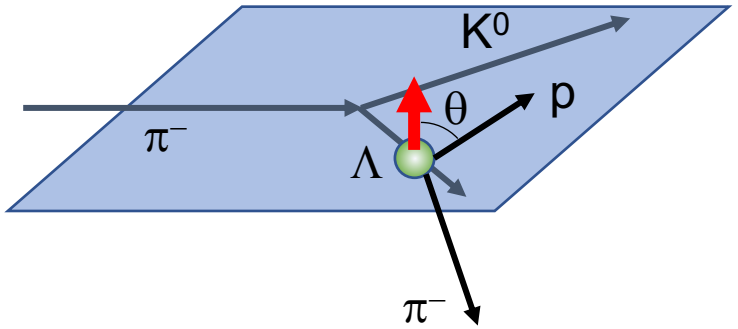
Past measurement by R.D. Baker et al.



~100% Λ polarization was confirmed

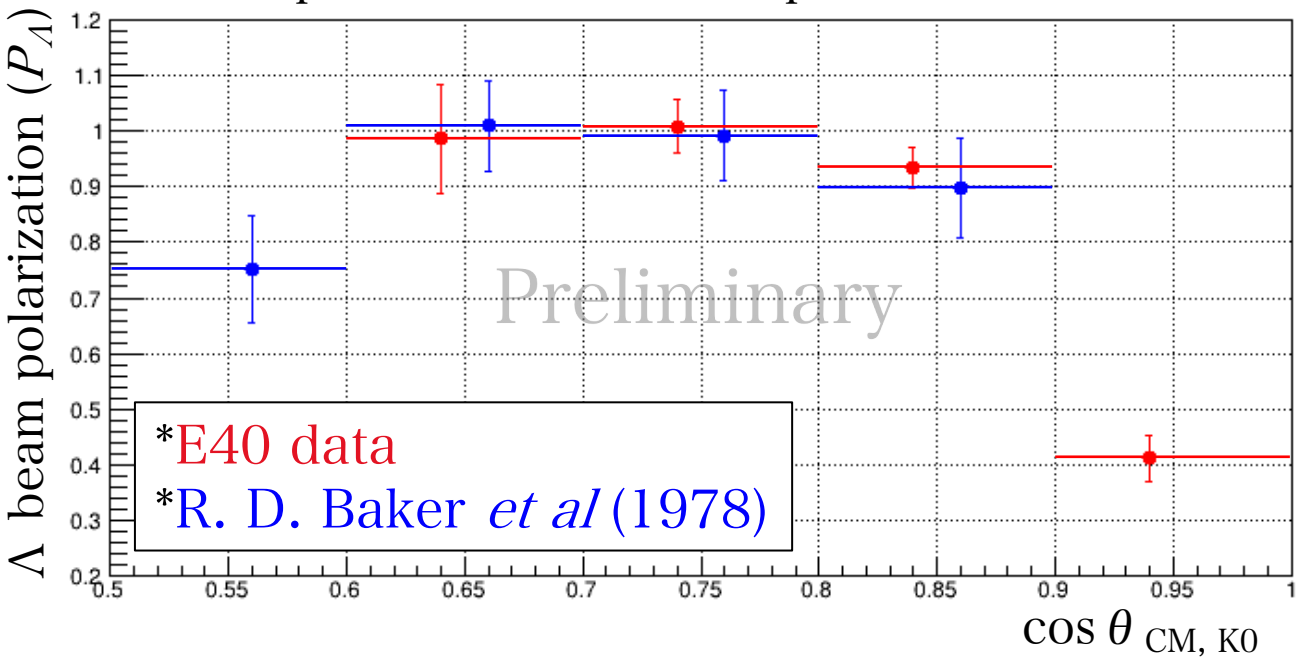
Λ polarization measurement in E40

Production plane was defined event by event



Analysis by T. Sakao (Tohoku)
Talk in June 30th

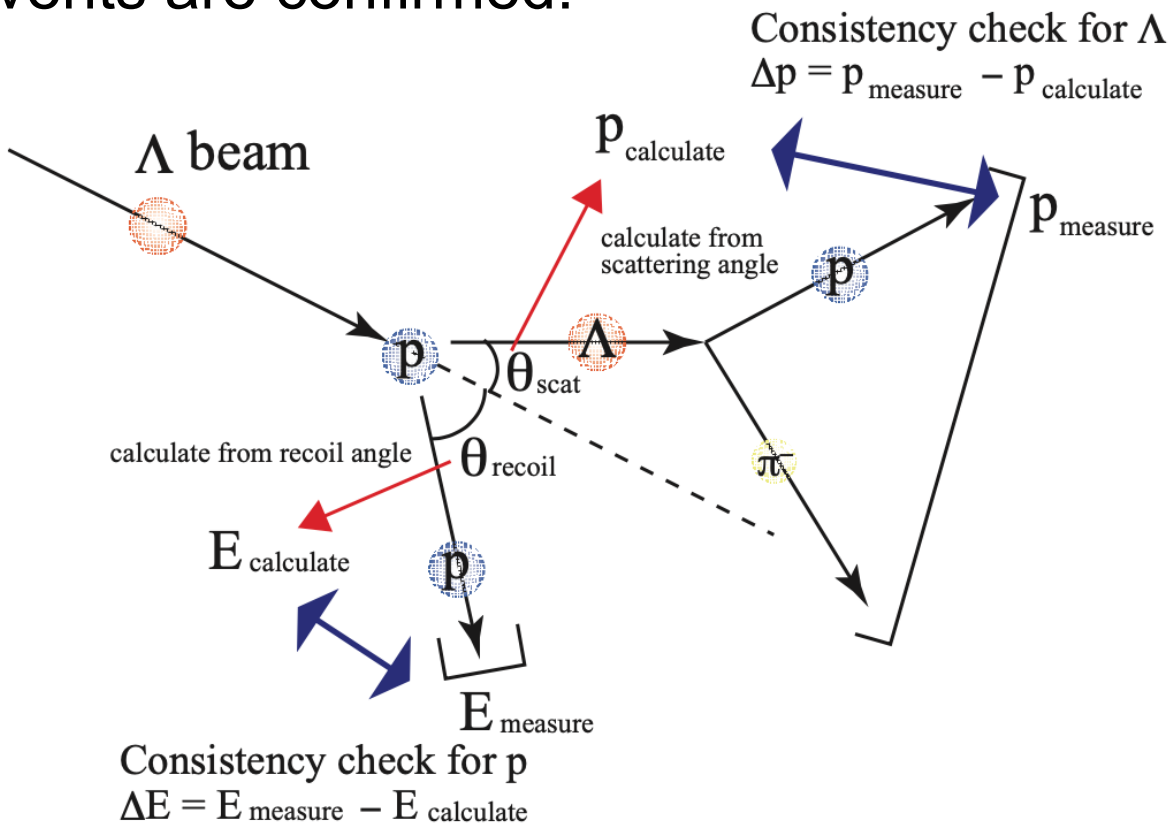
Λ polarization in the $\pi^- p \to K^0 \Lambda$ reaction



Λp scattering identification

From ~2.5x10^4 Λ beam

Λp scattering events are confirmed!



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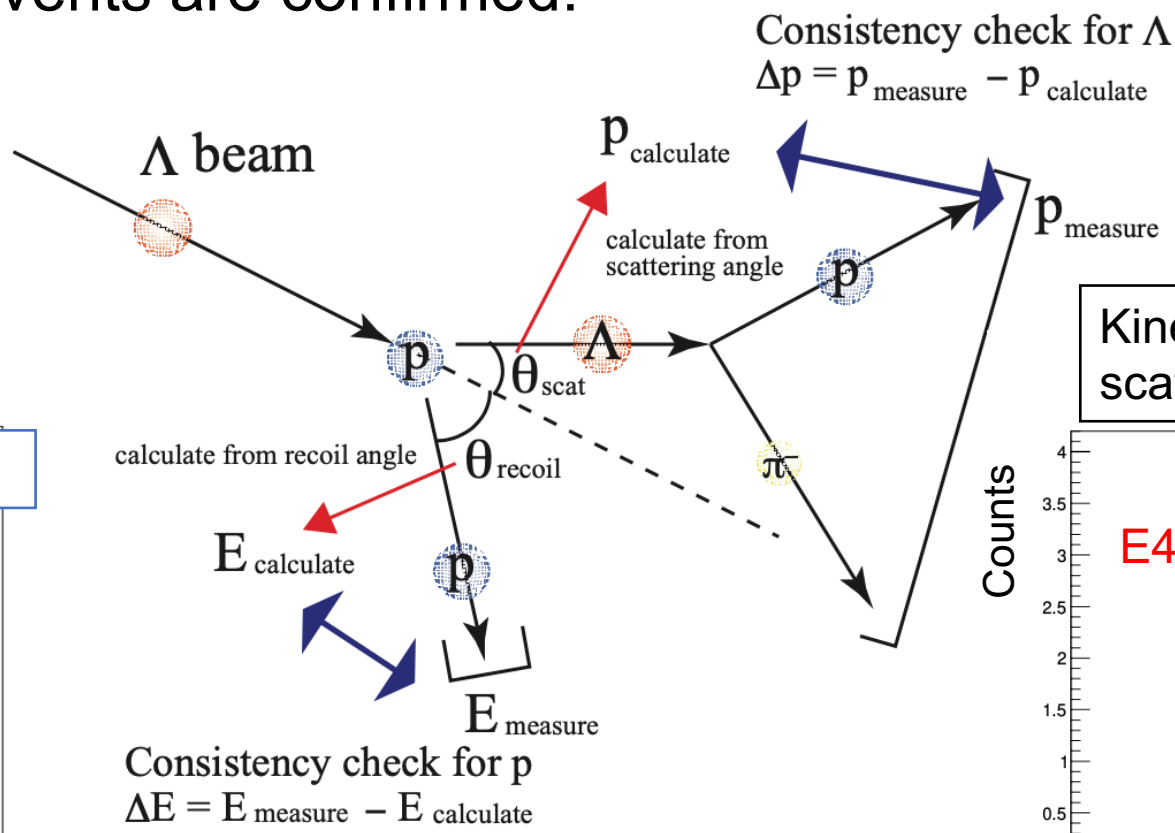
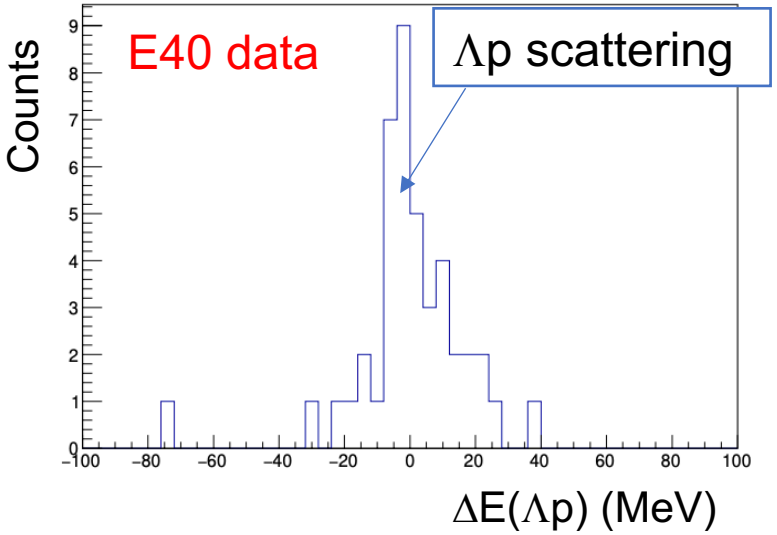
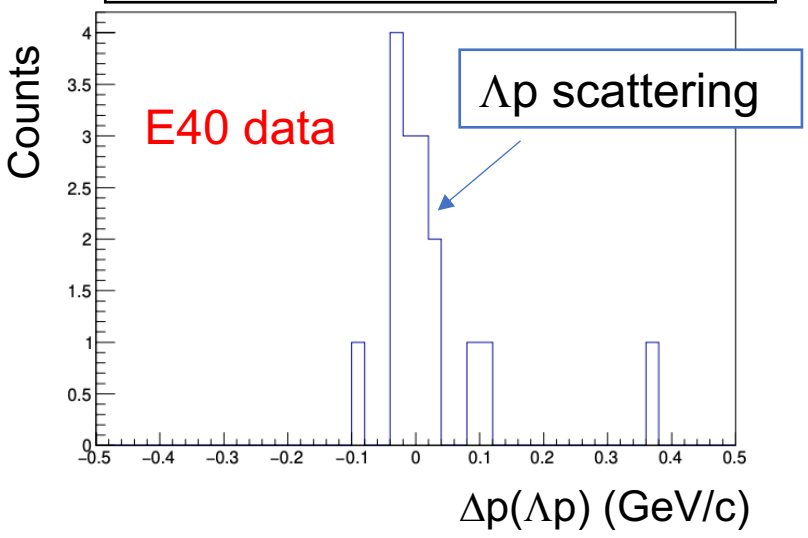


Kinematical consistency for recoil proton



Kinematical consistency for scattered Λ



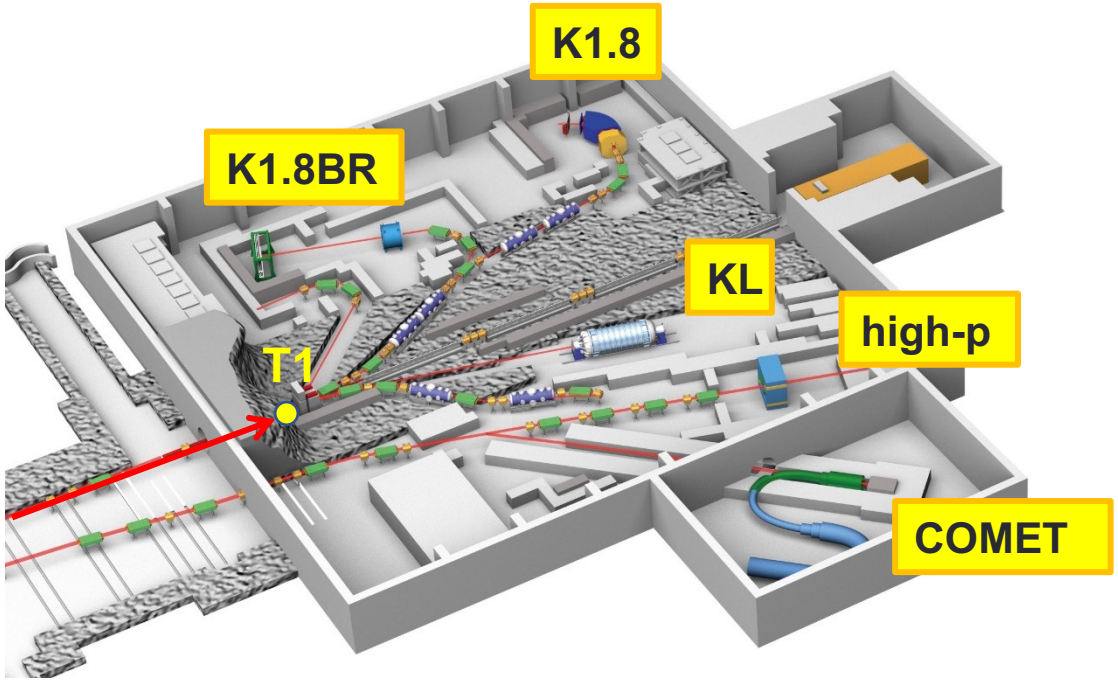
Hadron Experimental Facility Extension (HEF-EX) project

K1.8BR
(~1.0 GeV/c K^-)

K^{bar} N interaction

K1.8 (~1.8 GeV/c K^-)

BB interaction (focusing on S=-2)



high-p (30GeV primary proton beam)
π20 (20GeV/c secondary beam)

Hadron property in nuclear medium
Baryon spectroscopy

Hadron Experimental Facility Extension (HEF-EX) project

K1.8BR
(~1.0 GeV/c K^-)

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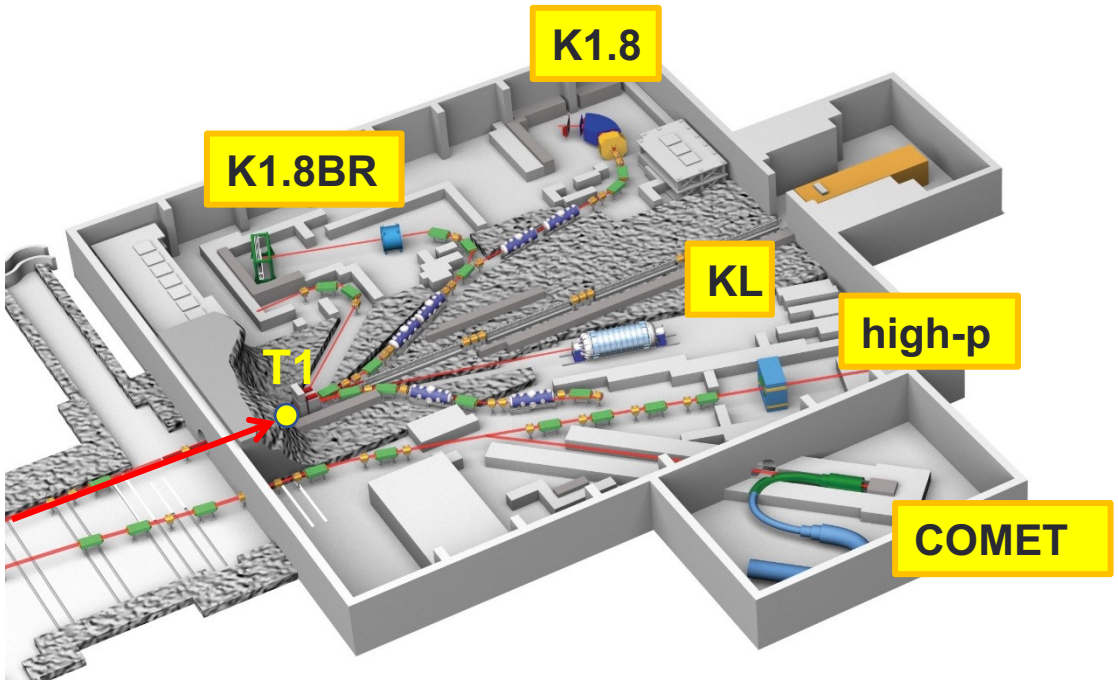


high-p (30GeV primary proton beam)
π20 (20GeV/c secondary beam)

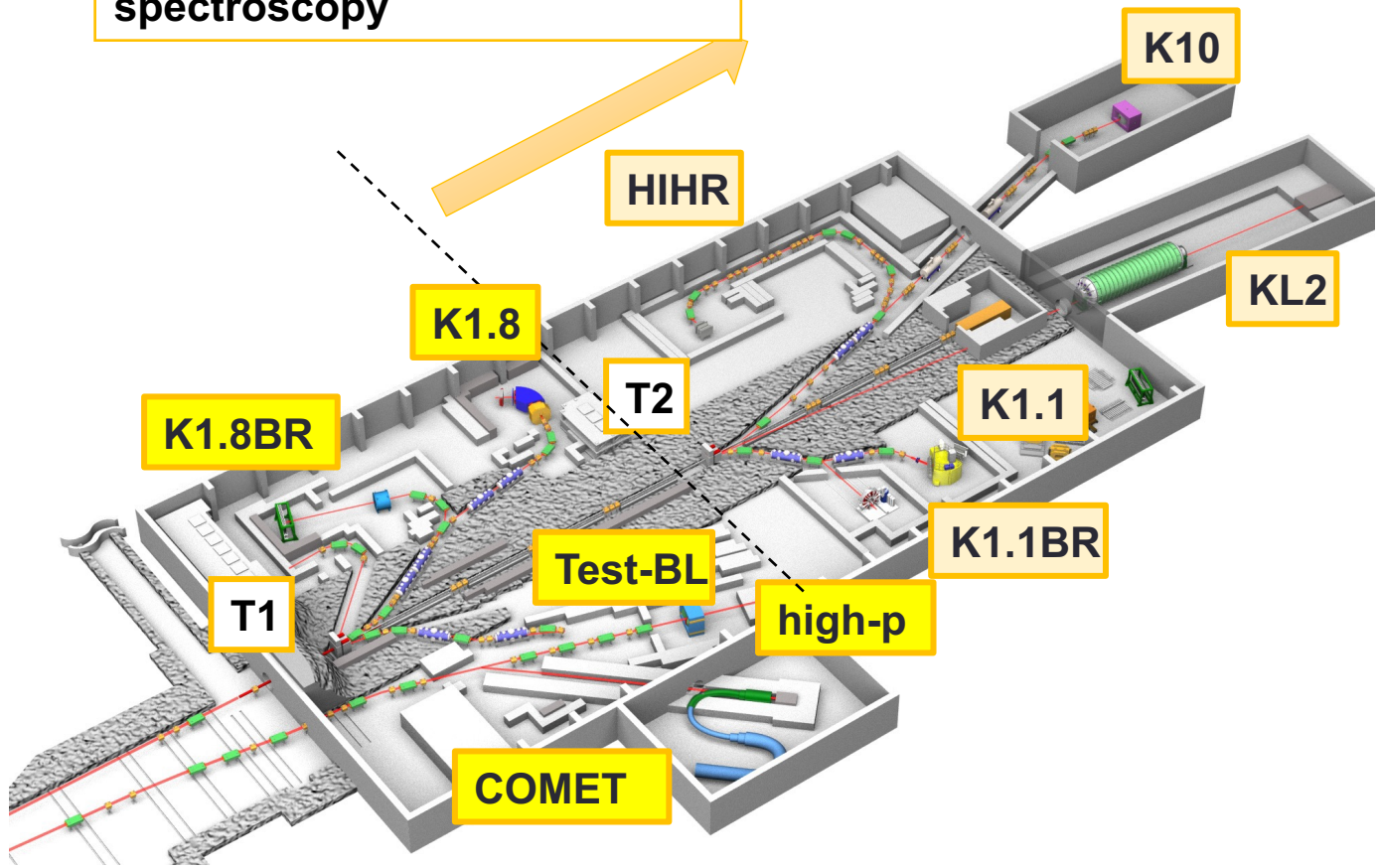
Hadron property in nuclear medium
Baryon spectroscopy

HIHR (~2 GeV/c π)

Ultra precise Λ hypernucler spectroscopy

K10 (~10 GeV/c K^-)

Ω baryon spectroscopy



K1.1BR (~0.8 GeV/c π/K)

Physics using a low energy Kaon

K1.1 (~1.2 GeV/c π/K)

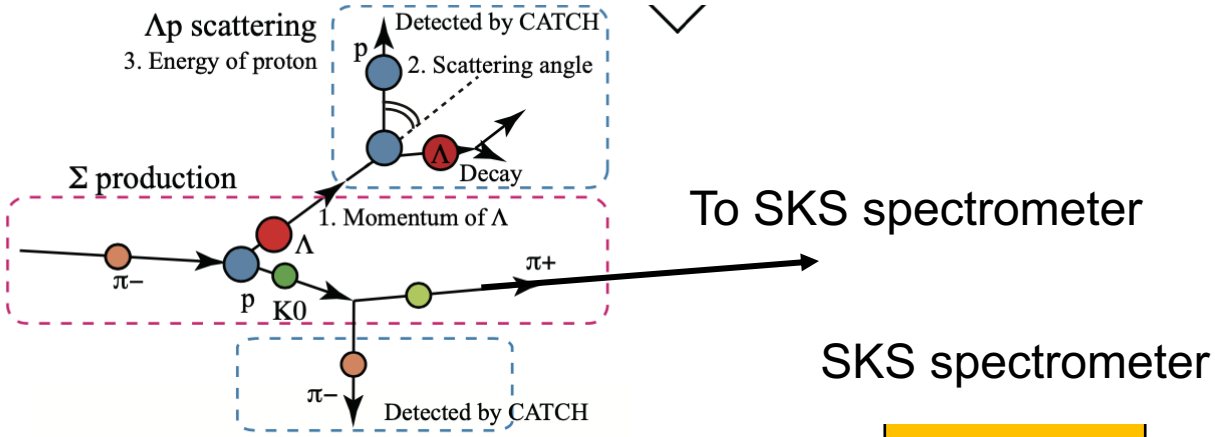
BB interaction (focusing on S=-1)

Perform physics not accessible in the present hadron hall
Perform physics programs in parallel with twice more beam lines

Λp scattering experiment with polarized Λ beam

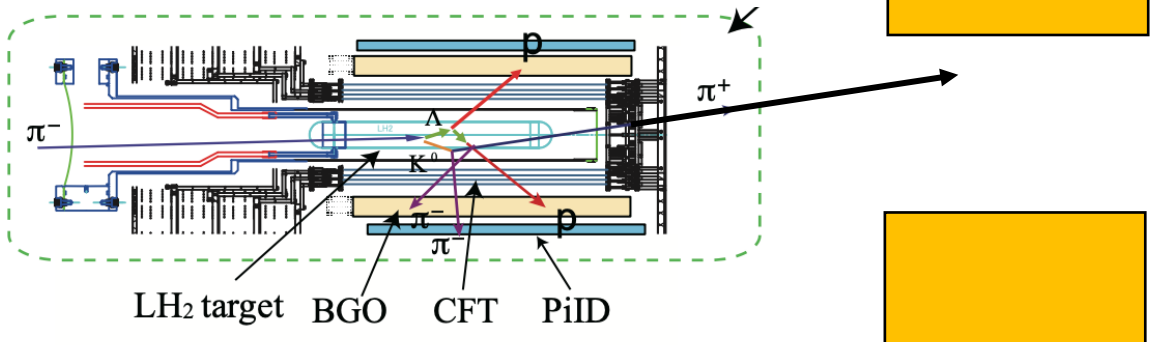
Λ beam identification

Tagged by $\pi^- p \rightarrow K^0 \Lambda$ reaction at p=1.05 GeV/c



To SKS spectrometer

SKS spectrometer

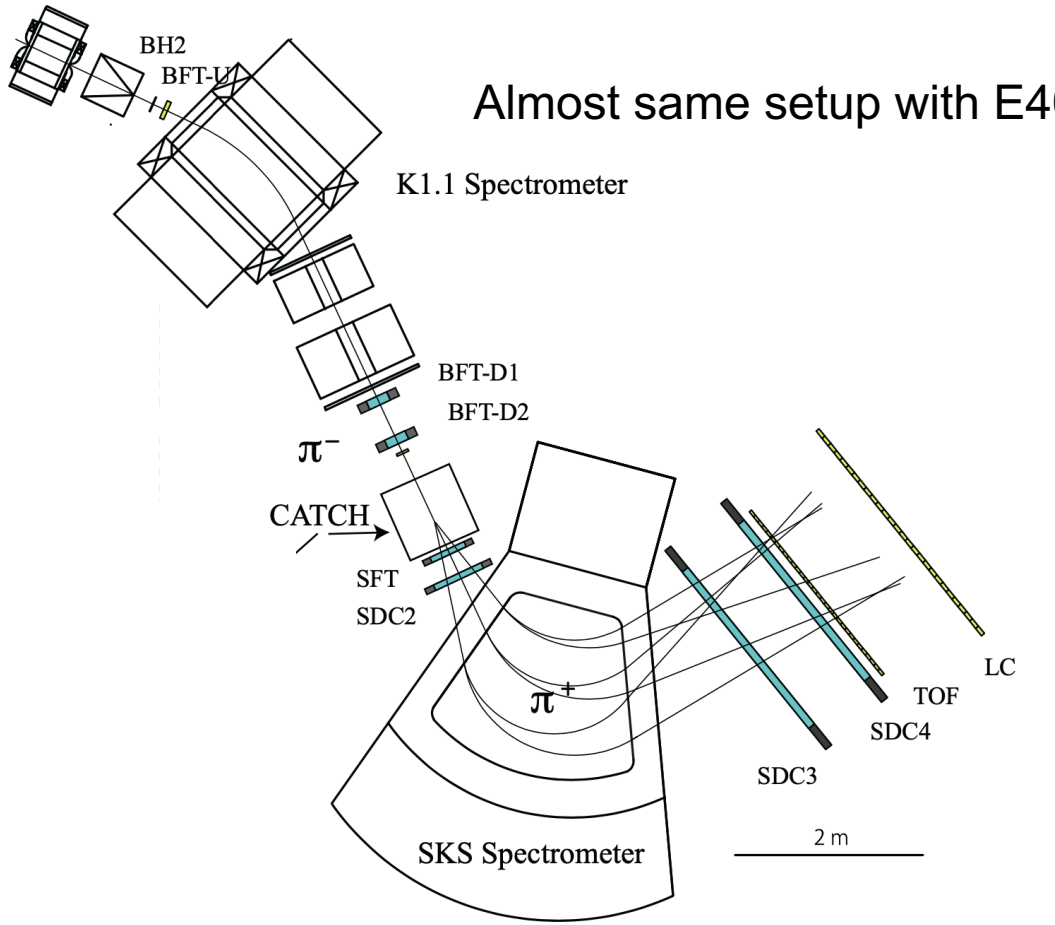


Λp scattering identification

Detected by CATCH

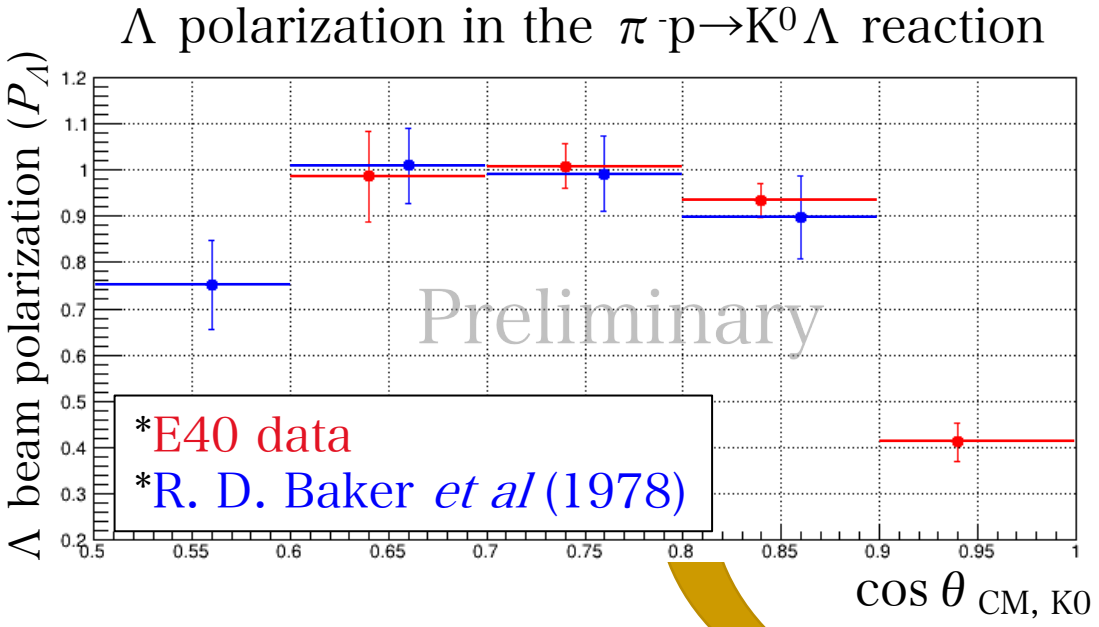
J-PARC P86 (J-PARC EX project)
at K1.1 beam line

Almost same setup with E40



Λp scattering experiment with polarized Λ beam

High spin polarization of Λ



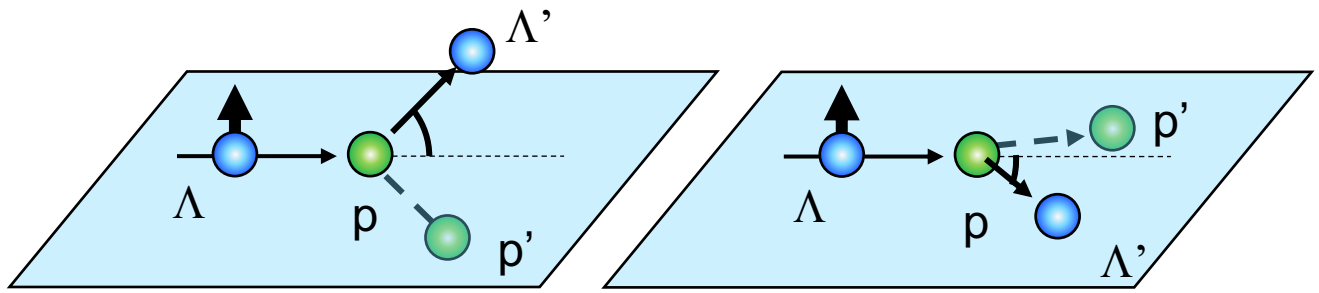
Realize spin observable measurement

Analyzing power

Left/Right asymmetry of Λp scattering

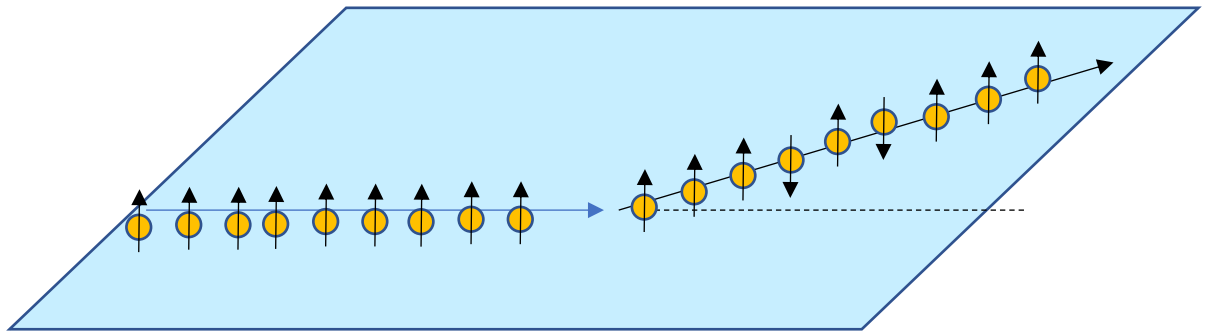
Left scattered event

Right scattered event



Depolarization (D_y^y)

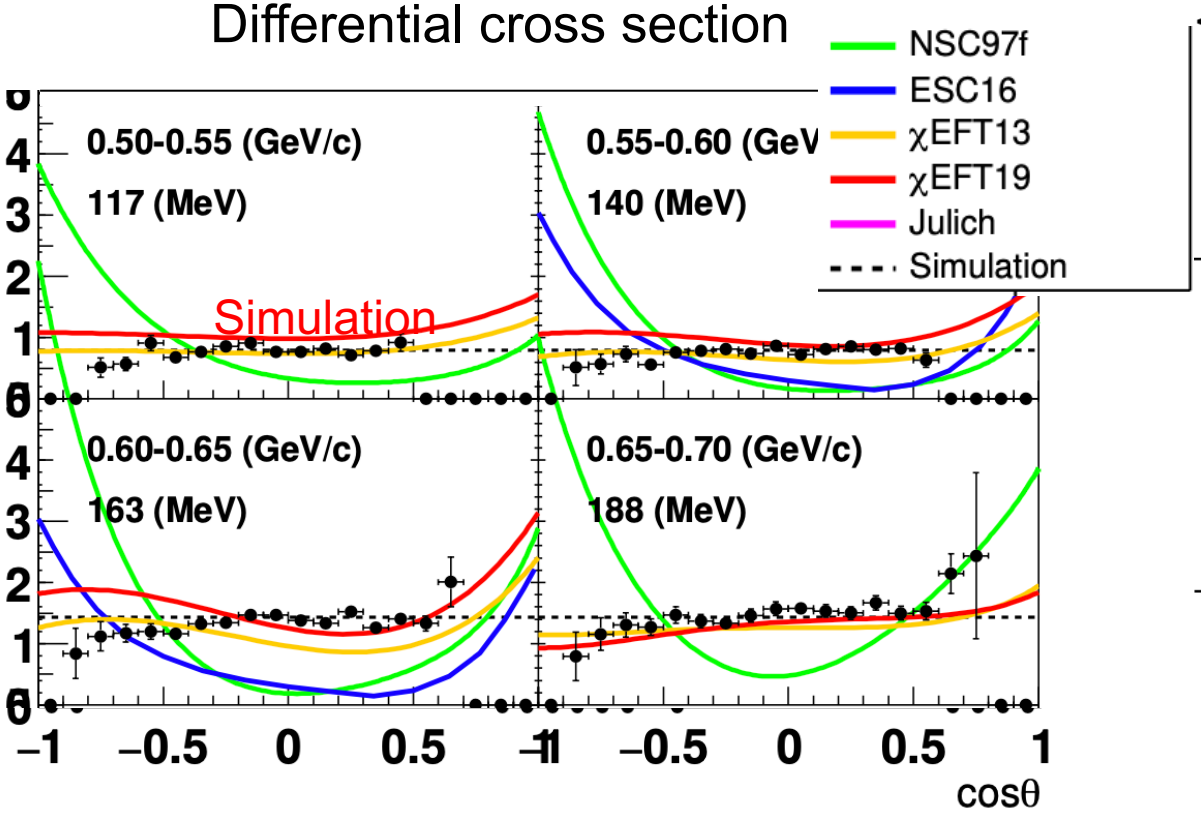
Change the spin polarization after the Λp scattering



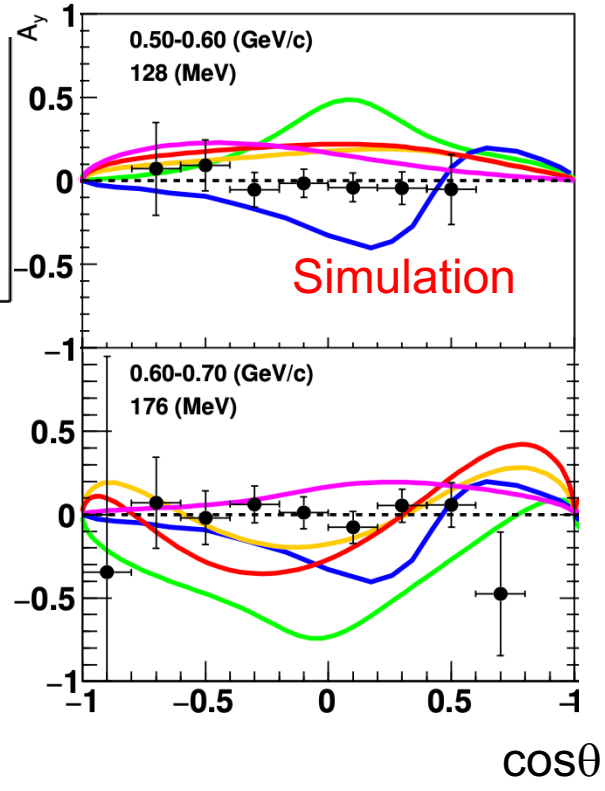
dσ/dΩ and Spin observables in Λp scattering

J-PARC P86 (J-PARC EX project) at K1.1 beam line

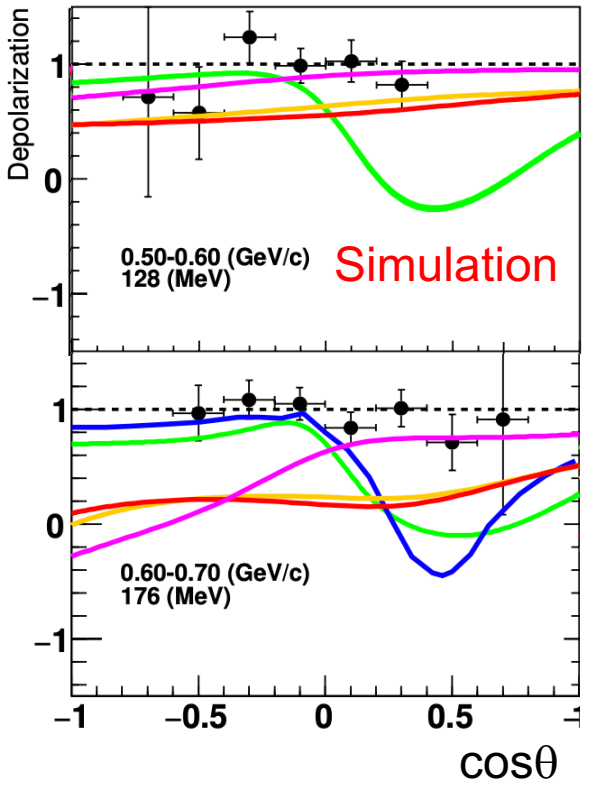
Differential cross section



Analyzing power



Depolarization (D_y^y)



No differential observables of Λp scattering SO FAR

Simulated results w/ 10^8 Λ

--> Large uncertainty in P-wave and higher-wave interaction.

Theoretical prediction shows quite different angular dependence in dσ/dΩ, A_y and D_y^y

These new scattering data become essential constraint to determine spin-dependent ΛN interaction

Summary

- BB interactions are important to understand
  - Generalized meson-exchange picture with (broken) $SU_F(3)$ symmetry
  - Role of quarks at the short range
  - Dynamics of nuclear system with hyperon (hypernuclei, neutron star) as its basic interaction
- YN scattering experiment gets possible!
- Systematic measurements of Σp scattering at J-PARC
  - $d\sigma/d\Omega$ for Σ^+p, Σ^-p, $\Sigma^-p \rightarrow \Lambda n$ scatterings with ~10% level accuracy for fine angular pitch ($d\cos\theta=0.1$)
  - Momentum dependence of Σ^+p $\delta(^3S_1)$ channel was derived (–20 ~ −30 degrees)
- Future project to measure $d\sigma/d\Omega$ and spin observables of Λp scattering w/ polarized Λ beam
  - These measurements are important to reinforce the current ΛN interaction for deepening hypernuclear physics.

We hope our data become important inputs to improve theoretical models

E40 Collaborators

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