

# Current and future programs to study the $\Lambda N$ interaction from scattering experiments

Koji Miwa (Tohoku Univ., KEK IPNS, RIKEN)  
on behalf of J-PARC E40, E86, HYPN collaboration



the 62<sup>nd</sup> International Winter Meeting on Nuclear Physics in Bormio, Italy  
Jan. 19<sup>th</sup> – 23<sup>rd</sup> , 2026



# Contents

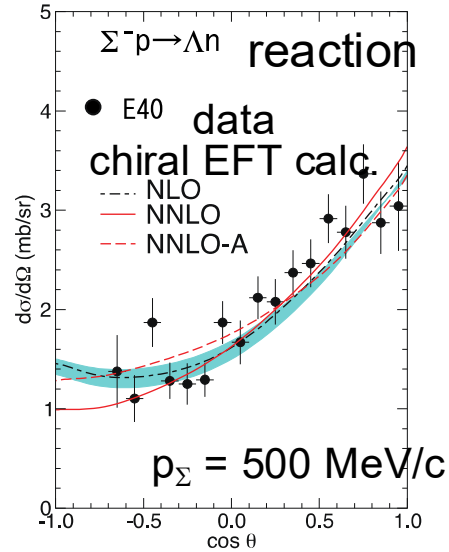
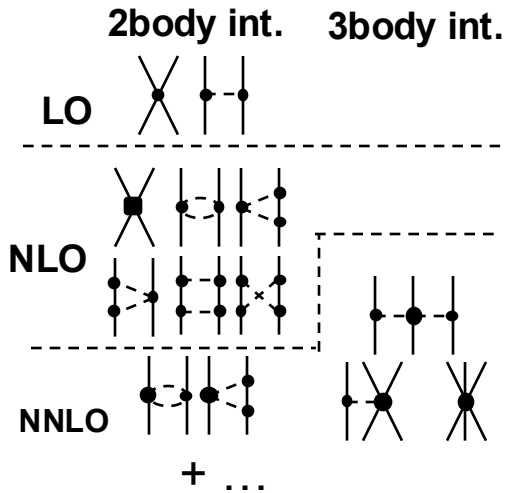
- Recent progress of baryon-baryon interaction study
- Brief summary of  $\Sigma p$  scattering experiment (J-PARC E40)
- Collaborative research regarding the two-body  $\Lambda N$ ,  $\Sigma N$  interactions
  - Scattering, Cusp, Lattice QCD
- New project of  $\Lambda p$  scattering experiment at SPring-8
- Summary



# Progress of theory & experiment of BB int. study

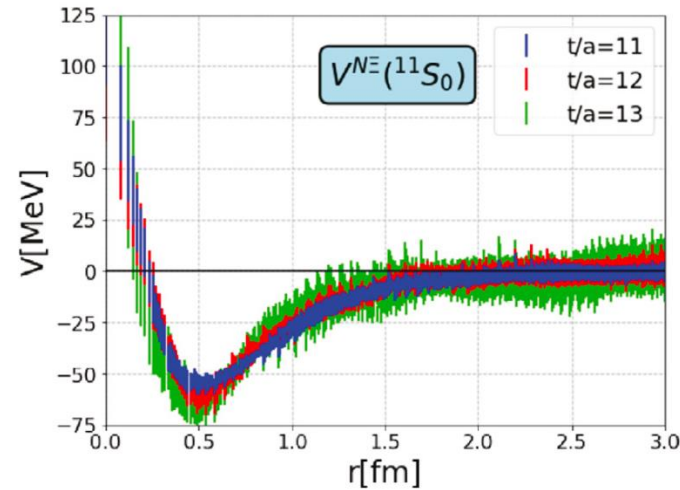
## Theoretical progress

### Hyperon-Nucleon int. w/ chiral effective field theory (J. Haidenbauer et al.)



### Hyperon potential by Lattice QCD

BB interaction at almost physical point for multi-strangeness sector



K. Sasaki et al.,  
Nucl. Phys. A 998  
(2020) 121737

## Improving accuracy w/ our new data

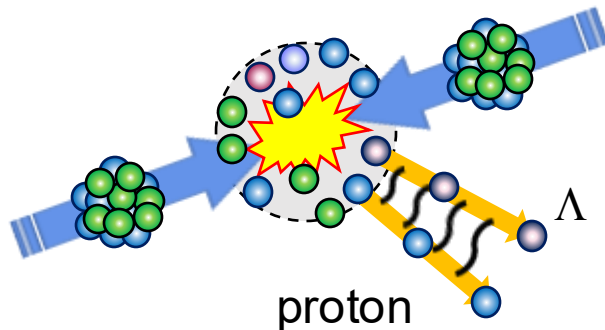
## Experimental progress

### BB interaction from femtoscopy

$$c(k^*) = \int S(r^*) |\Psi(\vec{k}^*, \vec{r}^*)|^2 d^3r^*$$

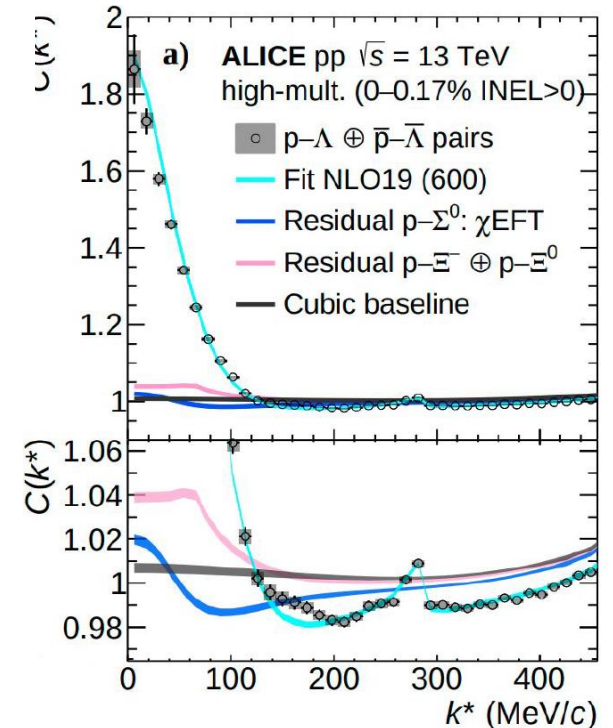
Fix source size ( $S(r^*)$ )  $\rightarrow$

Study interaction from wave function ( $\Psi(\vec{k}^*, \vec{r}^*)$ )



ALICE Collaboration,  
Phys. Lett. B 833  
(2022) 137272

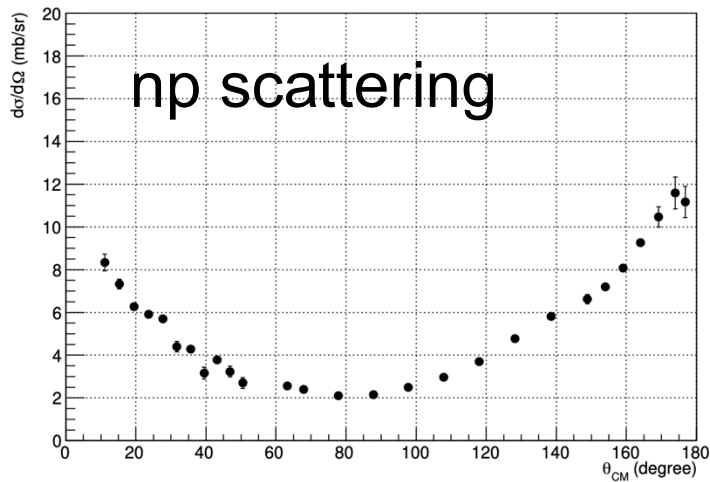
### Particle correlation between $\Lambda$ and p



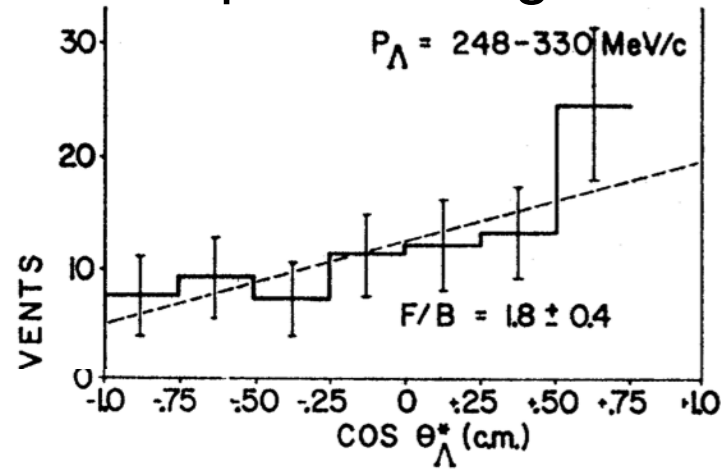
# NN scattering and hyperon-nucleon (YN) scattering

Clearly there is a big difference in data quality between NN and YN scatterings

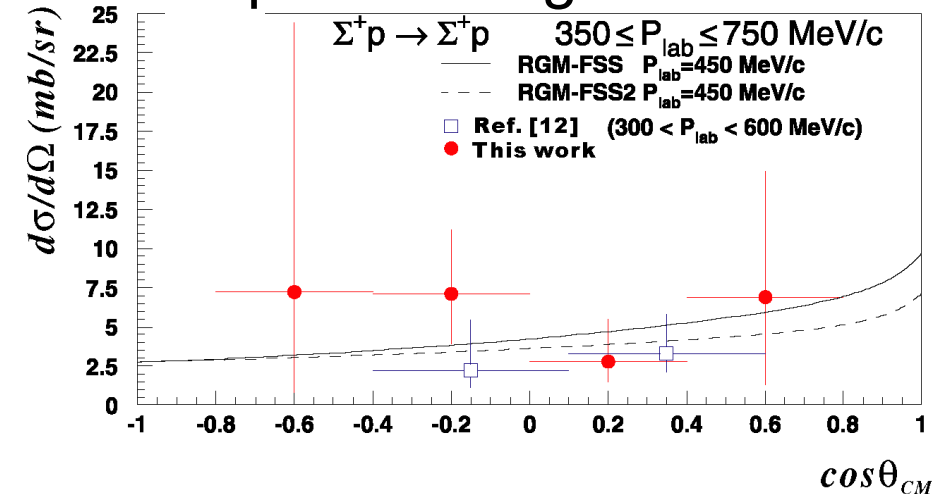
np scattering differential cross section



$\Lambda p$  scattering



$\Sigma^+ p$  scattering

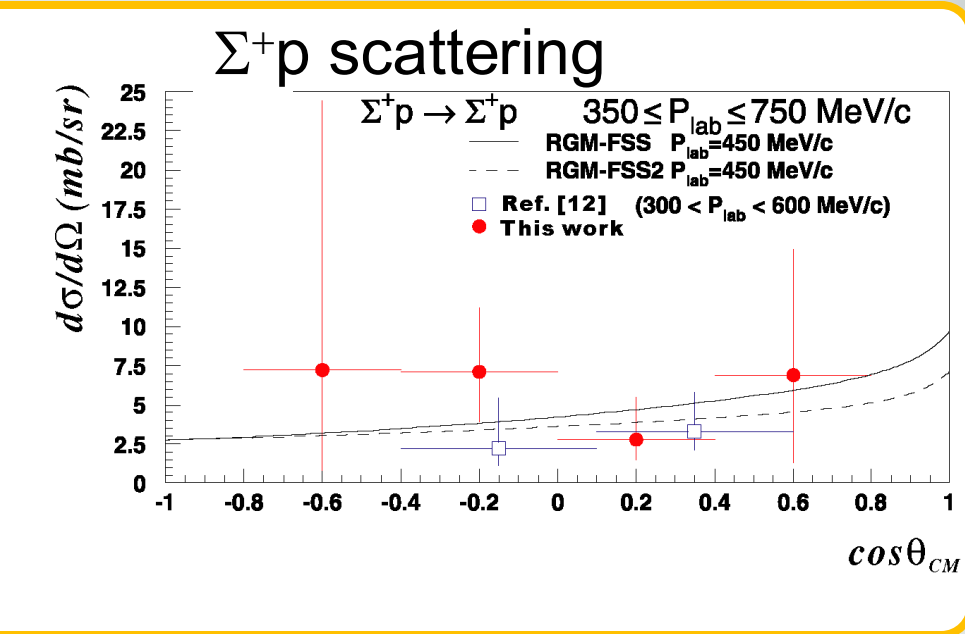
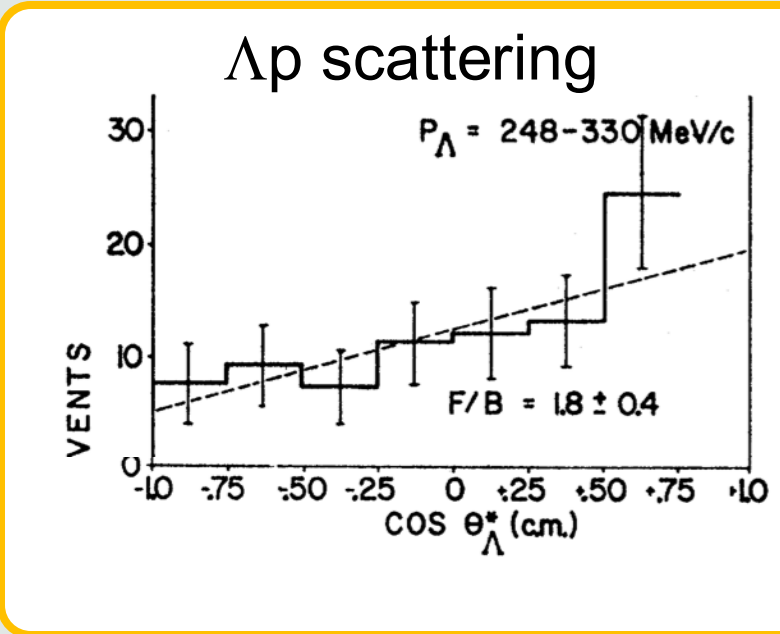
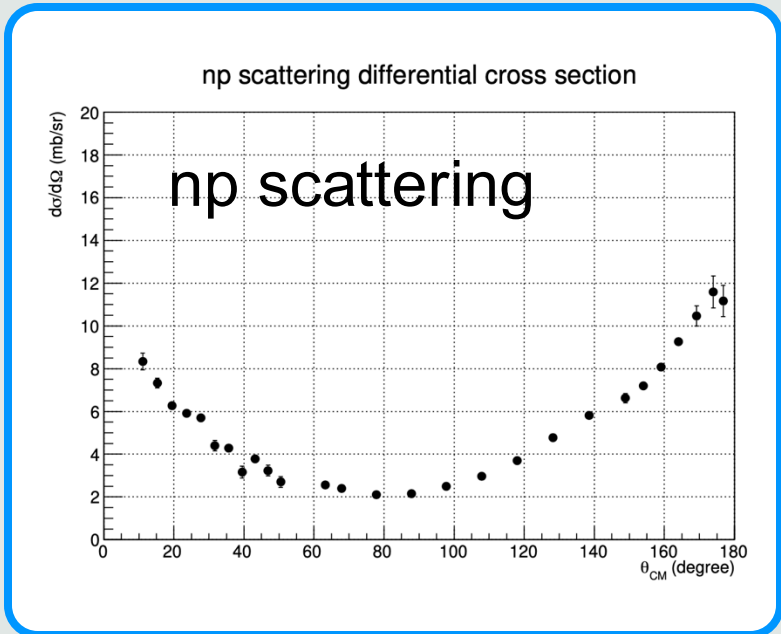


YN scattering experiment was regarded as impossible experiment

1. *Introduction* Spectroscopic studies of hypernuclei have played remarkable roles in our understanding of hyperon-nucleon (YN) and hyperon-hyperon (YY) interactions, since the short lifetimes of hyperons make YN and YY scattering experiments technically difficult, unlike the nucleon-nucleon (NN) case. For investigation of  $\Lambda$  hypernuclei structure, two types of spectroscopic techniques, one reaction based and the other  $\gamma$ -ray based, have made active progress in recent years.

# NN scattering and hyperon-nucleon (YN) scattering

Clearly there is a big difference in data quality between NN and YN scatterings



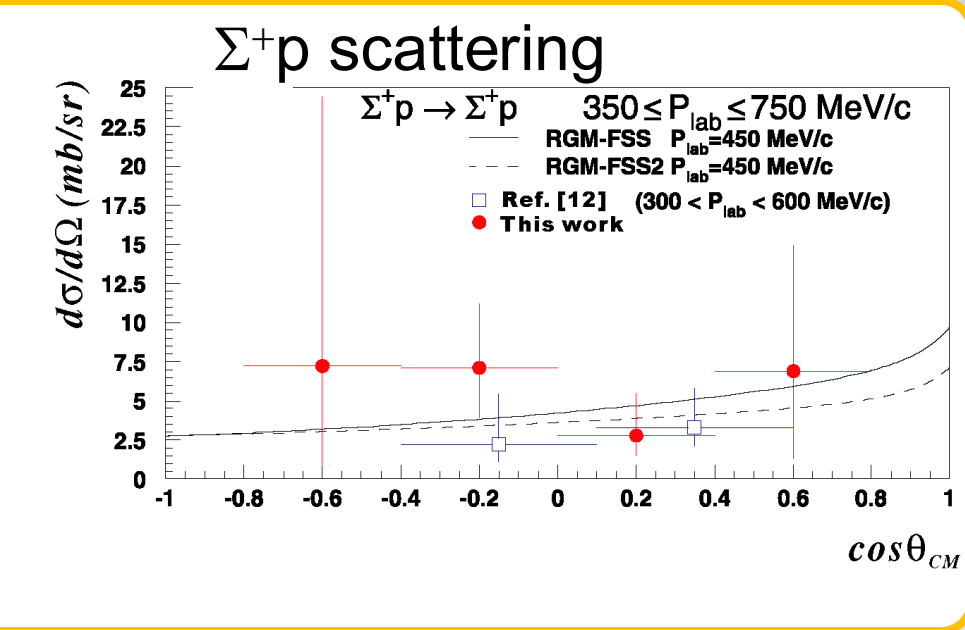
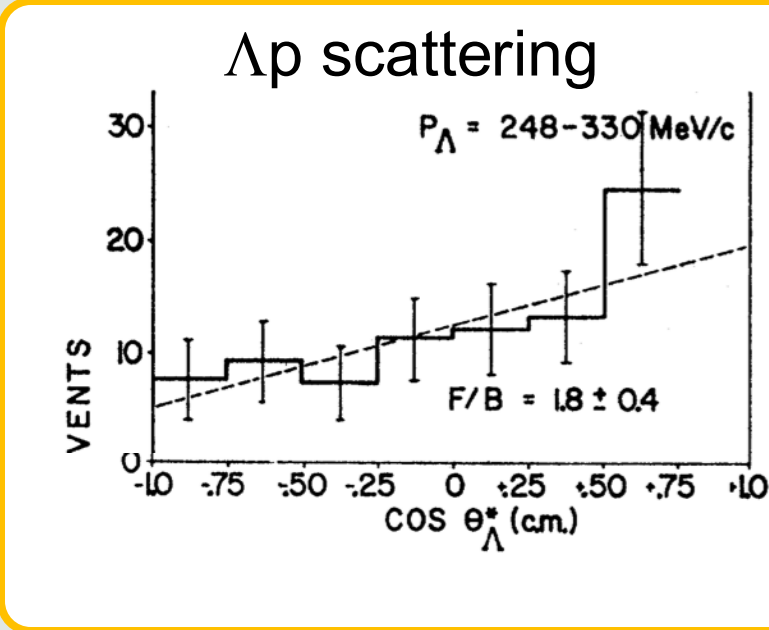
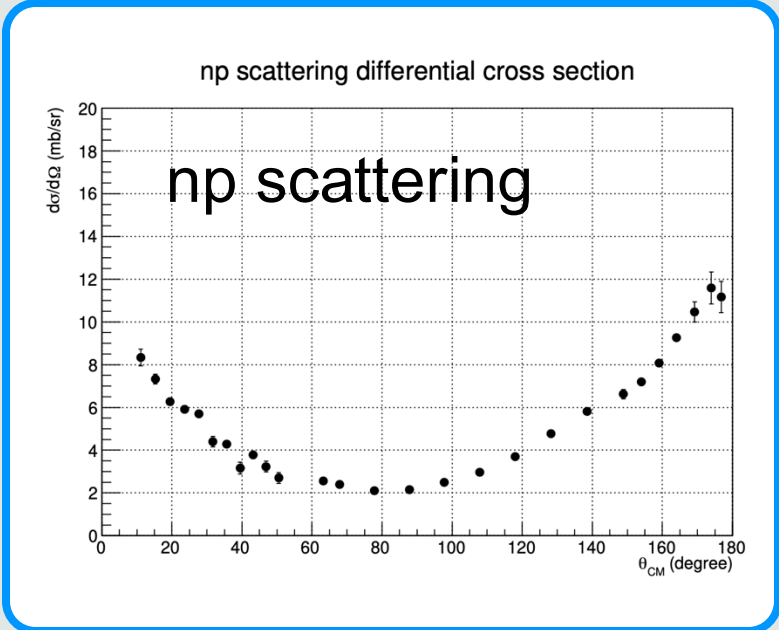
YN scattering experiment was regarded as impossible experiment

In principle, interactions between baryons can be studied by baryon-baryon scattering experiments. However, such scattering experiments are extremely difficult except for the nucleon-nucleon (NN) case due to the short lifetimes of the other baryons. On the other hand,  $\Lambda$ -hypernuclear data can provide information on the  $\Lambda N$  interaction.

1. *Int*... remarkable roles in our...  
 understa... ions, since the short...  
 lifetimes: except for the nucleon-nucleon (NN) case due to the short...  
 nucleon- lifetimes of the other baryons.... difficult, unlike the...  
 techniqu... hypernuclear data can provide information on the  $\Lambda N$ ...  
 interaction. ... types of spectroscopic...  
 ... progress in recent years.

# NN scattering and hyperon-nucleon (YN) scattering

Clearly there is a big difference in data quality between NN and YN scatterings



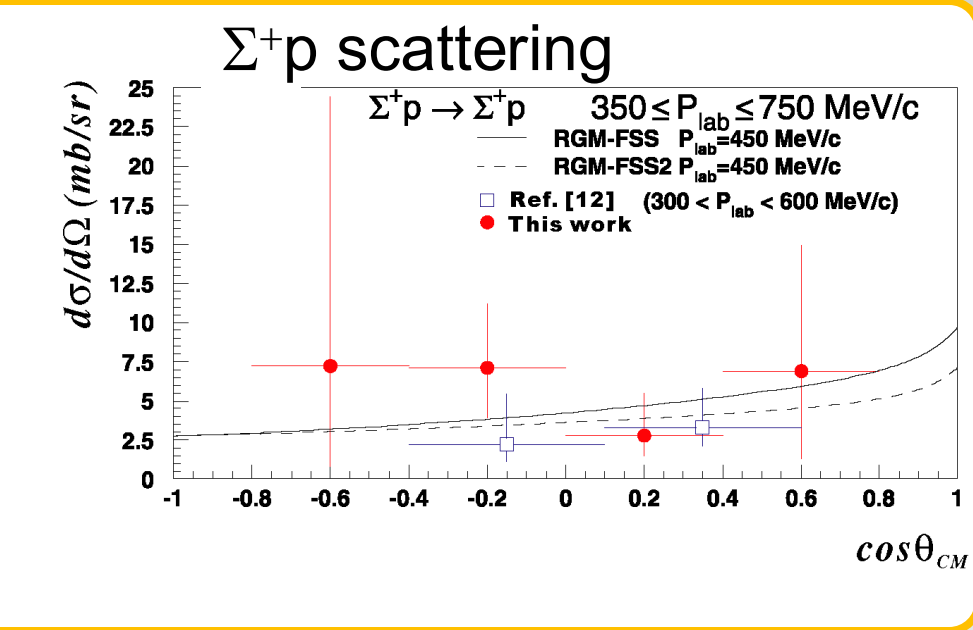
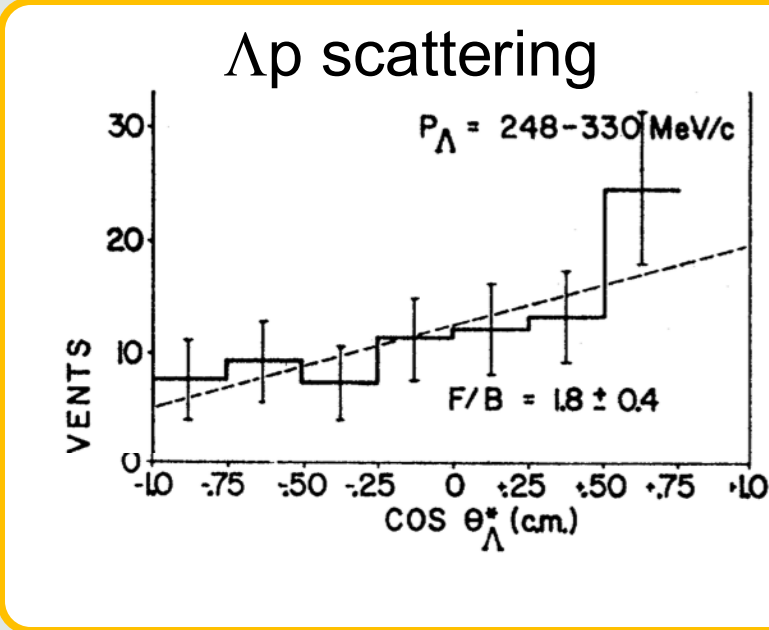
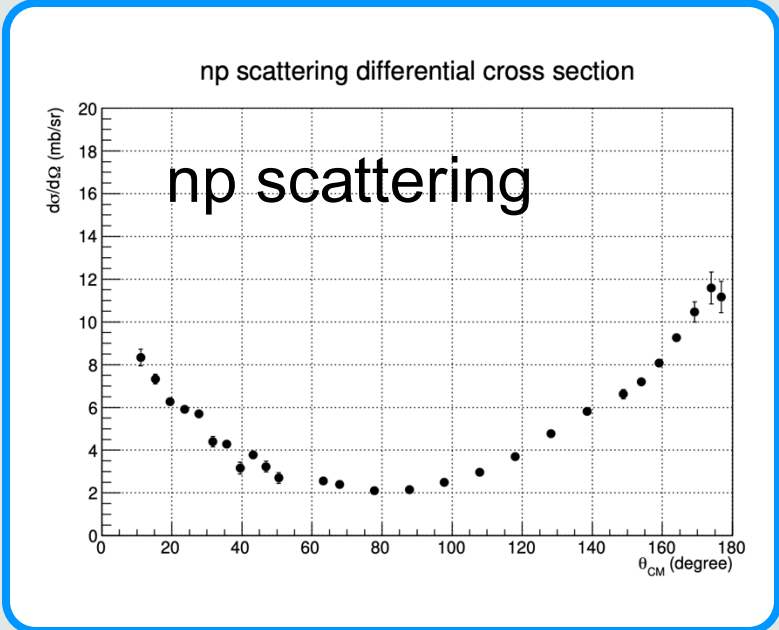
YN scattering experiment was regarded as impossible experiment

In principle, interactions between baryons can be studied

1. *Introduction* by barvon-barvon scattering experiments. However, Experimental investigations of the YN and YY interactions from low-energy YN and YY scattering experiments are, however, extremely difficult due to short lifetimes of hyperons. On the other hand, experimental data on hypernuclei provide rich information on the YN and YY interactions. The interaction models, which are theoretically constructed

# NN scattering and hyperon-nucleon (YN) scattering

Clearly there is a big difference in data quality between NN and YN scatterings



## YN scattering exp

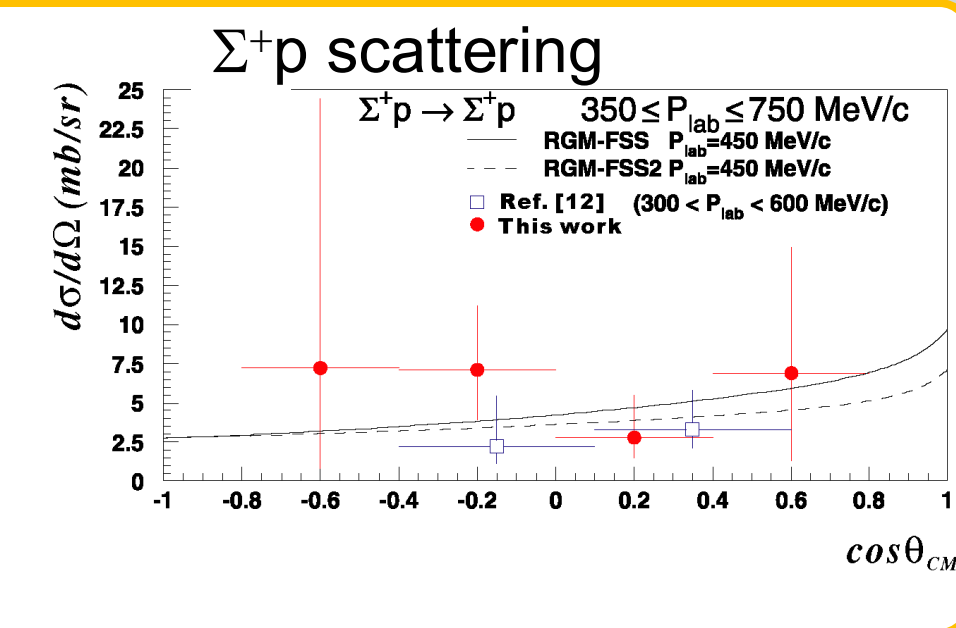
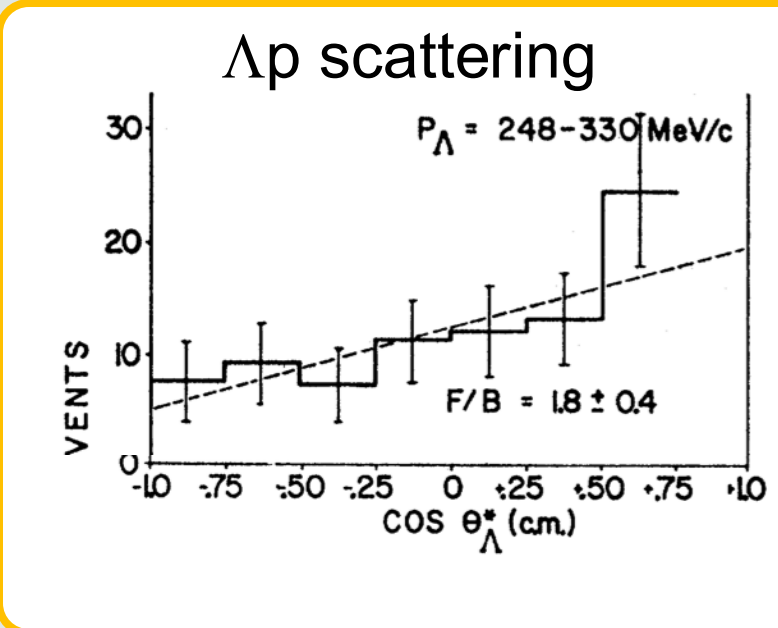
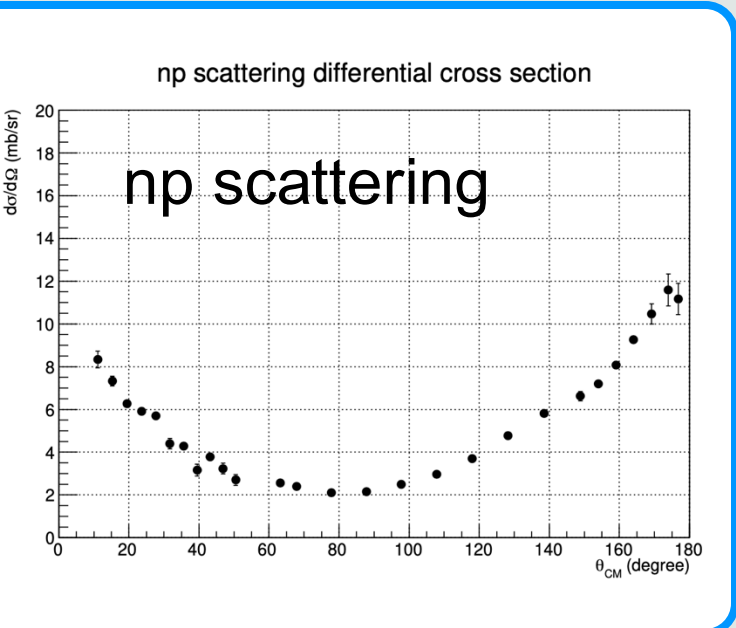
In prin  
 1. *Int* ied by ba  
 understa su Ex  
lifetimes ce YY s  
nucleon- lif yperon  
 techniqu hy the Y  
 in

A precise measurement of  $\Lambda$  hypernuclear level spacing is a powerful and realistic method, instead of difficult  $\Lambda N$  scattering experiments, to investigate the spin-dependent  $\Lambda N$  interactions. Two previous experiments with Hyperball [1–3], a large acceptance germanium (Ge) detector array, have established high-resolution  $\gamma$ -ray spectroscopy of hypernuclei and resolved the spin-doublet splittings in  $p$ -shell hypernuclei for the first time.

from low-energy YN and to short lifetimes of hy-  
 provide rich information on  
 e theoretically constructed

# NN scattering and hyperon-nucleon (YN) scattering

Clearly there is a big difference in data quality between NN and YN scatterings



## YN scattering exp

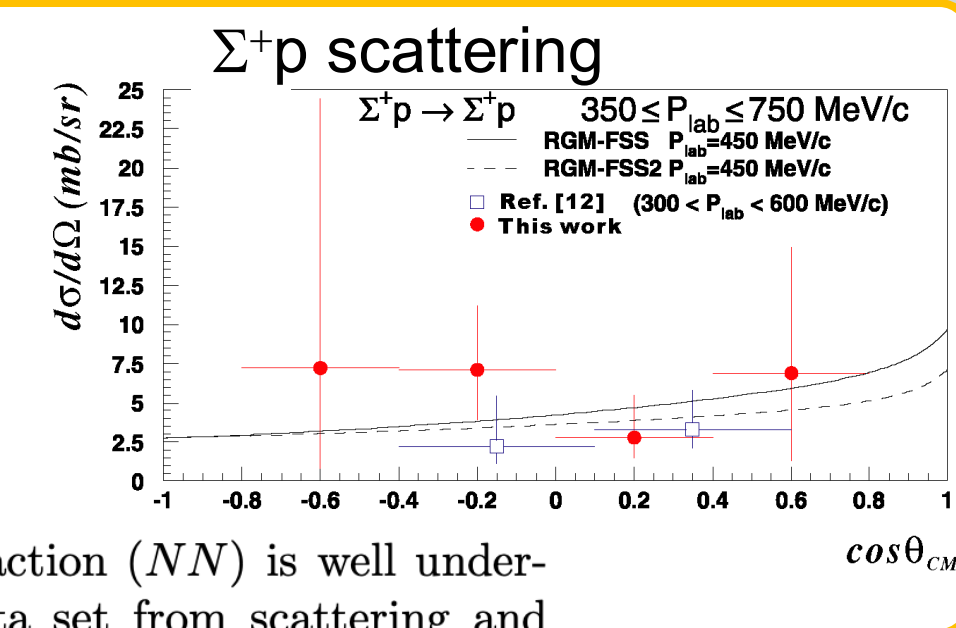
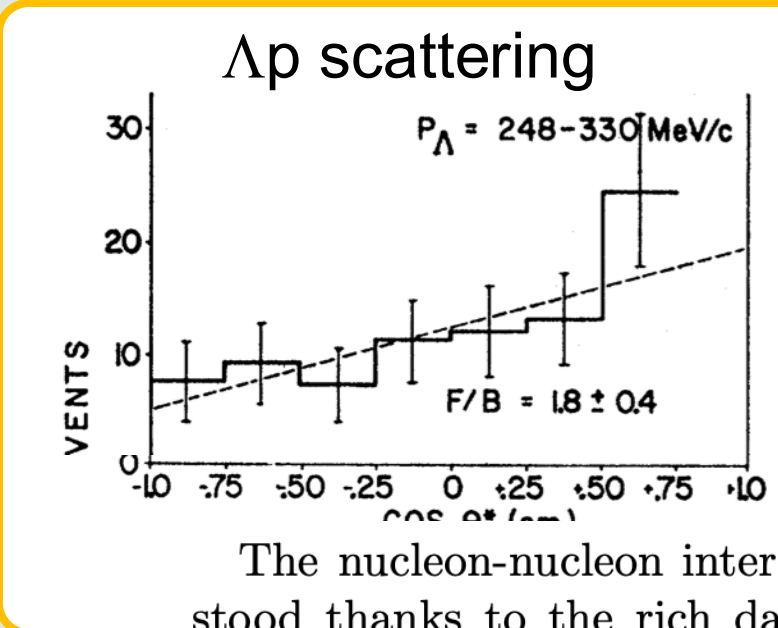
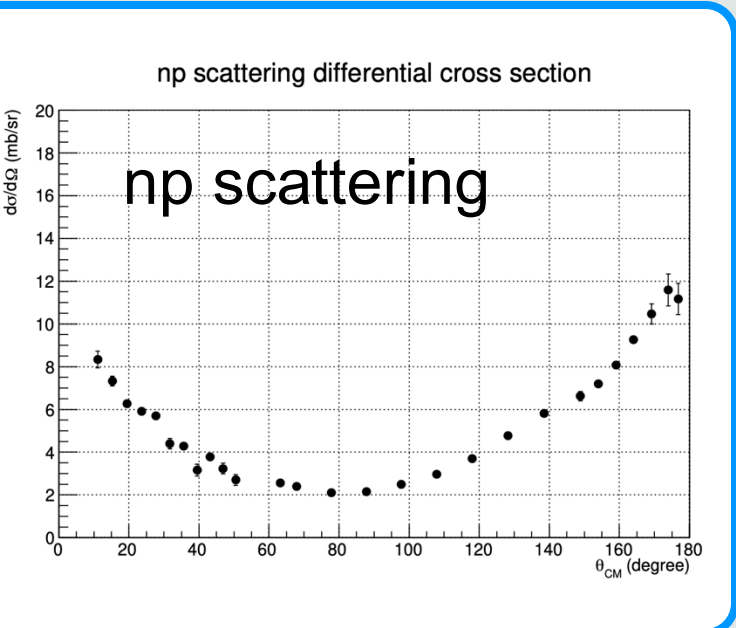
In prin  
 1. *Int* ied by ba  
 understa su Ex  
lifetimes ce YY s  
nucleon- lif yperon  
 techniqu hy the Y  
 in

A precise measurement of  $\Lambda$  hypernuclear level spacing is a powerful and realistic method, instead of difficult  $\Lambda N$  scattering experiments, to investigate the spin-dependence of the core nucleus for  $p$ -shell hypernuclei. By measuring such doublet spacings, we can obtain information on the  $\Lambda N$  spin-dependent interactions, which are extremely difficult to study by  $\Lambda N$  scattering experiments. In the case

$\Lambda N$  and  
s of hy-  
 ation on  
 structured

# NN scattering and hyperon-nucleon (YN) scattering

Clearly there is a big difference in data quality between NN and YN scatterings



## YN scattering exper

1. *Int* understood by lifetimes nucleon-technique

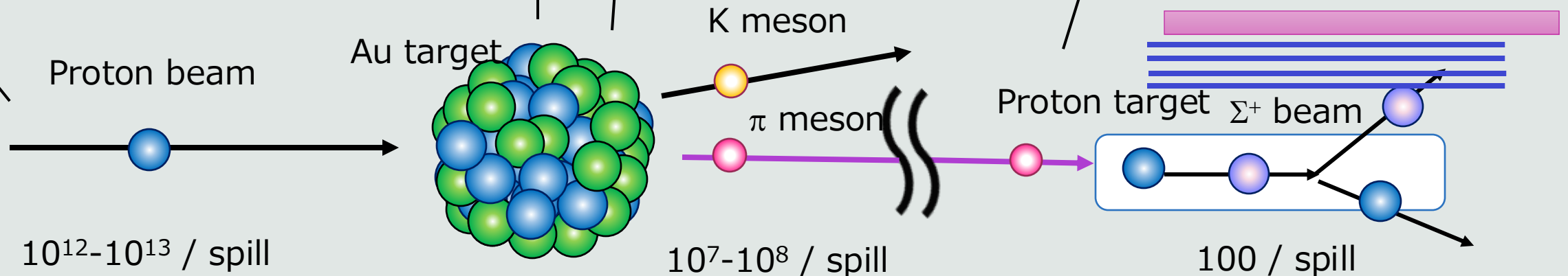
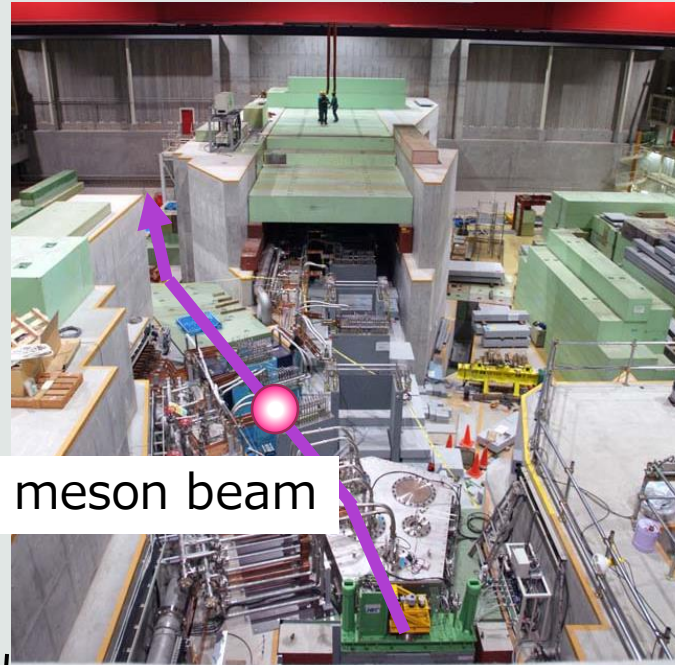
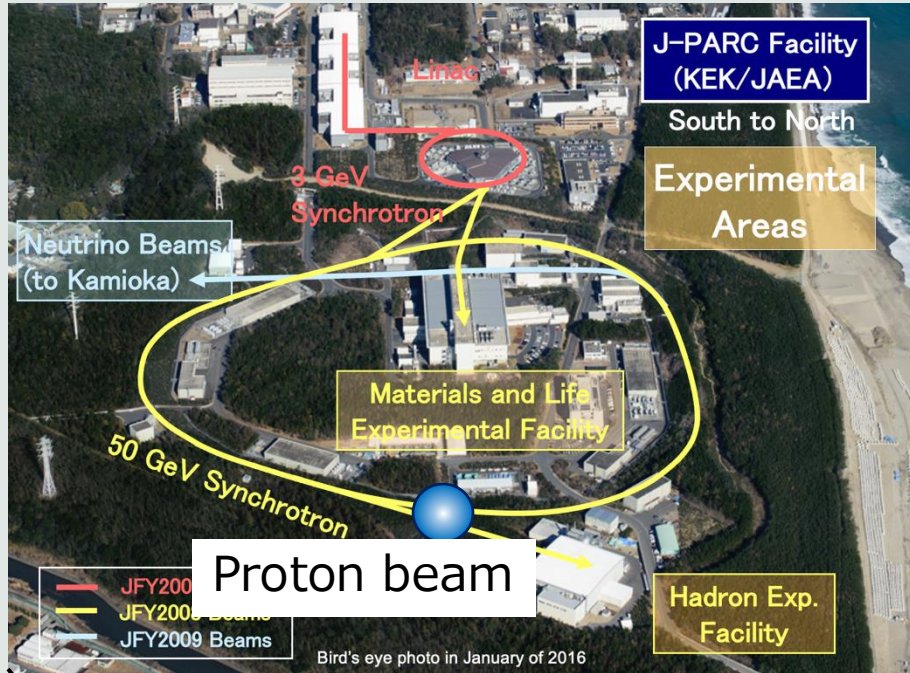
A precise measurement of  $\Lambda N$  scattering experiments is a powerful and realistic tool for the study of the core nucleus such doublet spacing.  $\Lambda N$  spin-dependent interactions are likely to be different from the strange quark content. Data for  $\Lambda N$  spin-dependent interactions are difficult to study by

The nucleon-nucleon interaction ( $NN$ ) is well understood thanks to the rich data set from scattering and nuclear spectroscopy experiments. On the other hand, hyperon-nucleon ( $YN$ ) interactions are less understood. On the other hand, the two-body potentials for the hyperon-nucleon interaction,  $YN$ , are not determined as well as those for  $NN$ , due to the experimental difficulties of producing and detecting hyperons in free scattering experiments. However, embedding a hyperon within the nuclear medium (hypernucleus) does allow extraction of

On the other hand, the two-body potentials for the hyperon-nucleon interaction,  $YN$ , are not determined as well as those for  $NN$ , due to the experimental difficulties of producing and detecting hyperons in free scattering experiments. However, embedding a hyperon within the nuclear medium (hypernucleus) does allow extraction of

# Produce a lot of hyperons at J-PARC

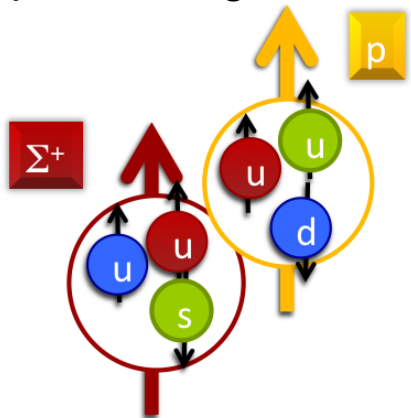
We recently realized hyperon proton scattering experiment by producing 100 times more hyperons than that in previous experiment.



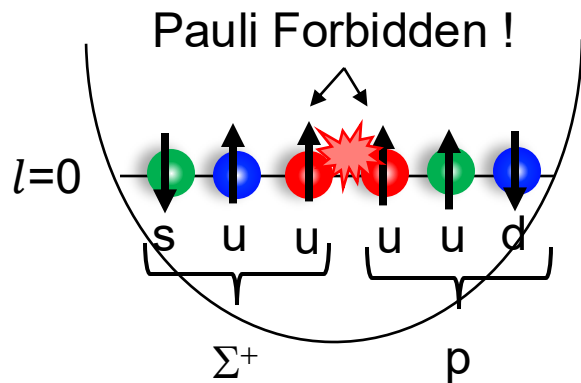
# J-PARC E40 : Measurement of $d\sigma/d\Omega$ of $\Sigma^+p$ scatterings<sup>12</sup>

## Verification of quark Pauli repulsion

$\Sigma^+p$  scattering



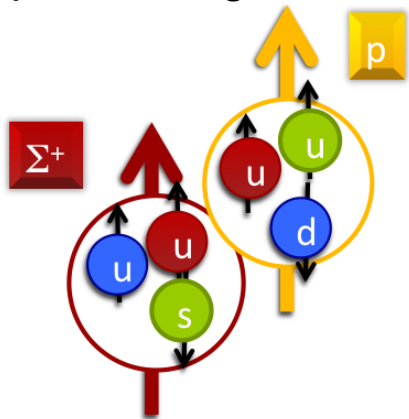
6 quarks can stay in s state in normal case



# J-PARC E40 : Measurement of $d\sigma/d\Omega$ of $\Sigma p$ scatterings

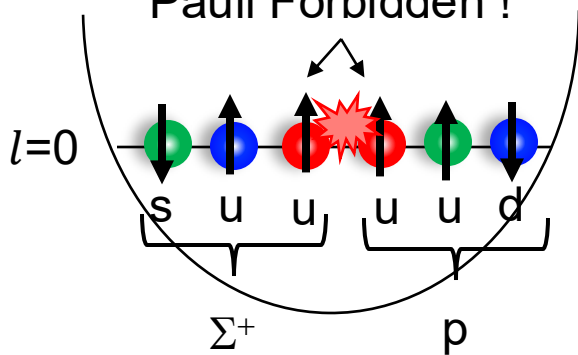
## Verification of quark Pauli repulsion

$\Sigma^+ p$  scattering



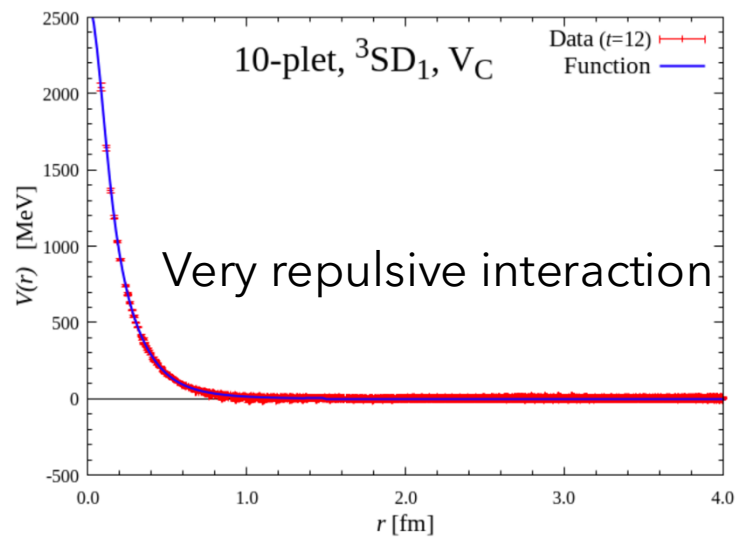
6 quarks can stay in s state in normal case

Pauli Forbidden !



Lattice QCD calculation

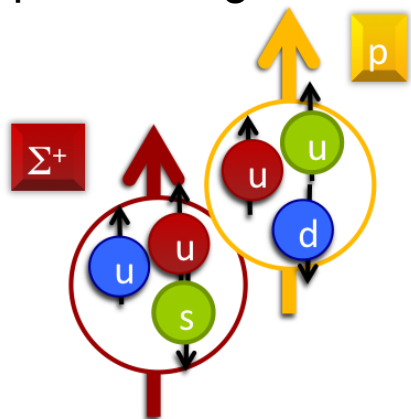
T. Inoue, AIP Conf. Proc. 2130, 020002 (2019)



# J-PARC E40 : Measurement of $d\sigma/d\Omega$ of $\Sigma p$ scatterings

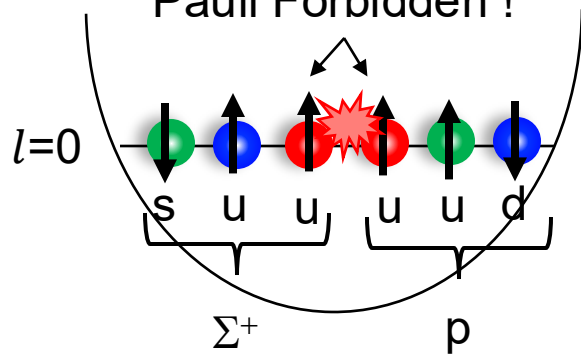
## Verification of quark Pauli repulsion

$\Sigma^+ p$  scattering



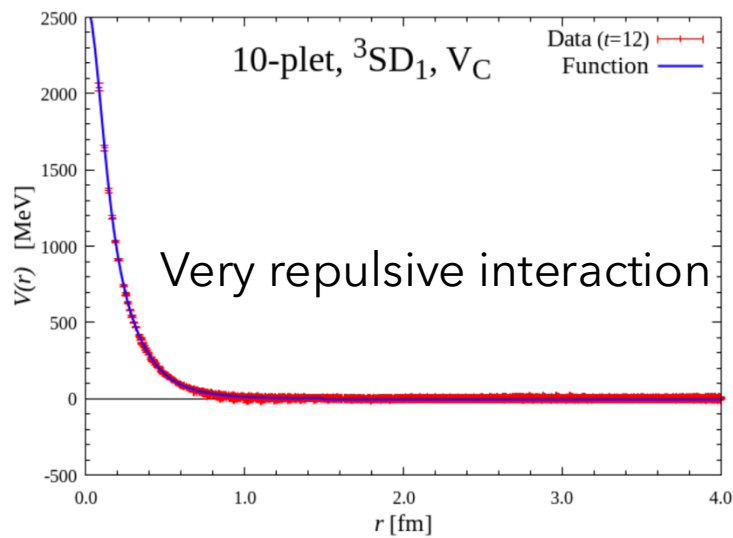
6 quarks can stay in s state in normal case

Pauli Forbidden !



Lattice QCD calculation

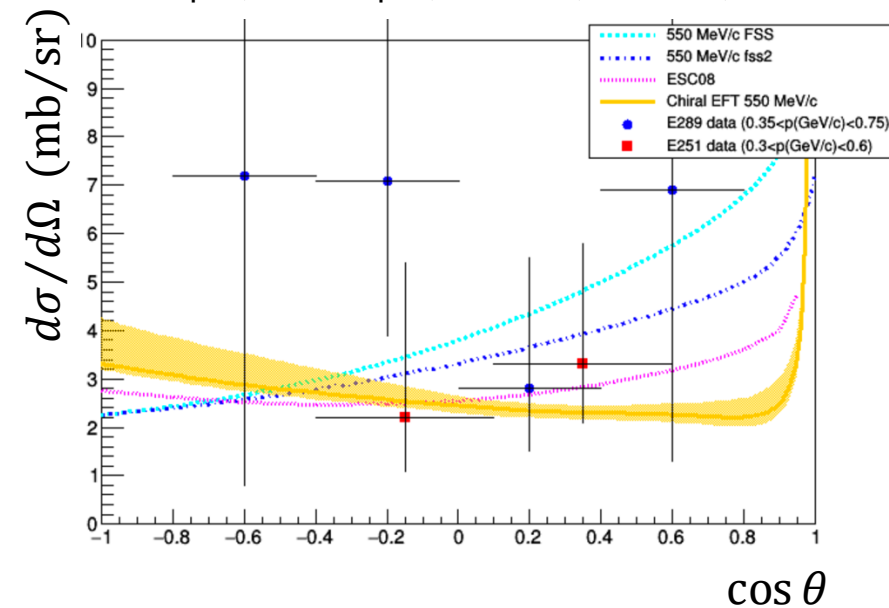
T. Inoue, AIP Conf. Proc. 2130, 020002 (2019)



## Constraint for BB int. theories

- - - Quark Cluster model (FSS, fss2)
- - - Nijmegen model
- Chiral EFT (NLO)

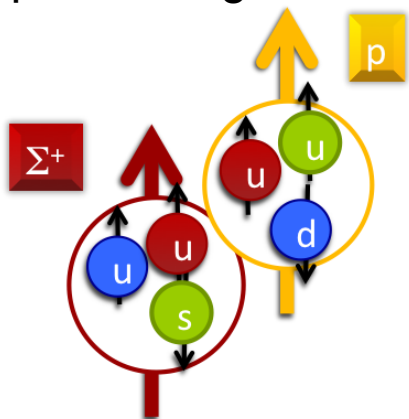
$\Sigma^+ p$  ( $0.5 < p$  (GeV/c)  $< 0.6$ )



# J-PARC E40 : Measurement of $d\sigma/d\Omega$ of $\Sigma p$ scatterings

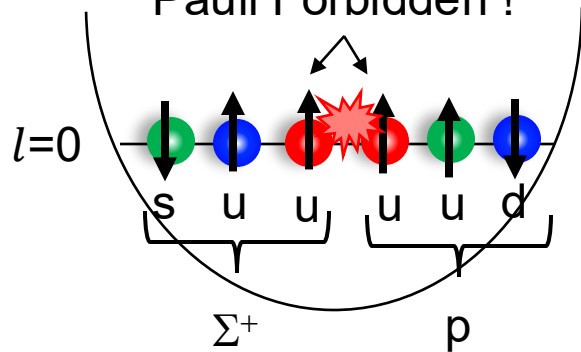
## Verification of quark Pauli repulsion

$\Sigma^+ p$  scattering



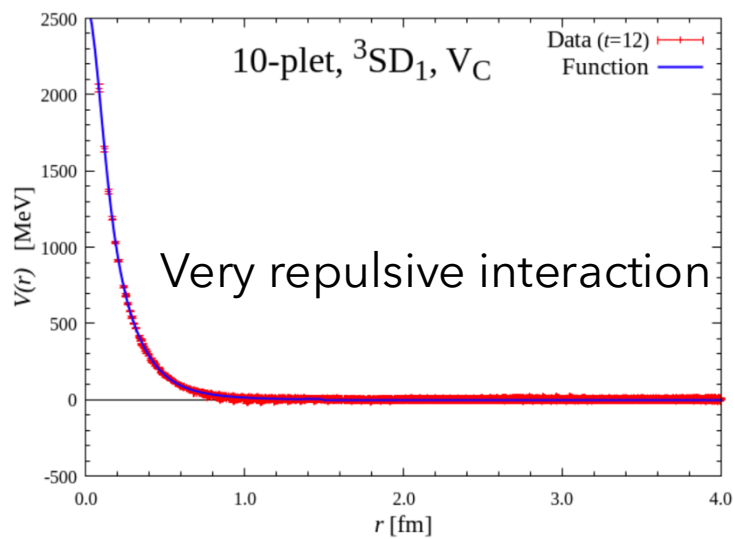
6 quarks can stay in s state in normal case

Pauli Forbidden !



Lattice QCD calculation

T. Inoue, AIP Conf. Proc. 2130, 020002 (2019)

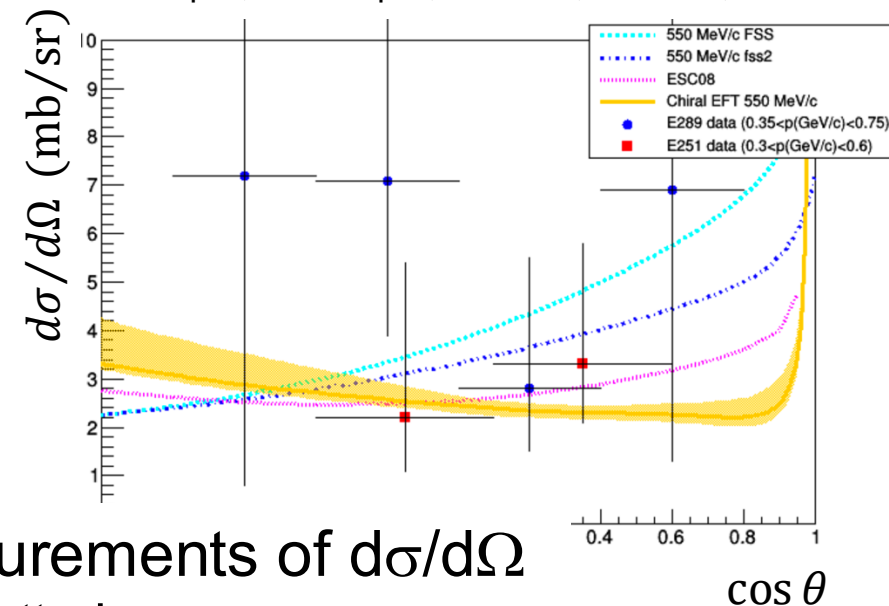


Very repulsive interaction

## Constraint for BB int. theories

- Quark Cluster model (FSS, fss2)
- Nijmegen model
- Chiral EFT (NLO)

$\Sigma^+ p$  ( $0.5 < p$  (GeV/c)  $< 0.6$ )



### Systematic measurements of $d\sigma/d\Omega$

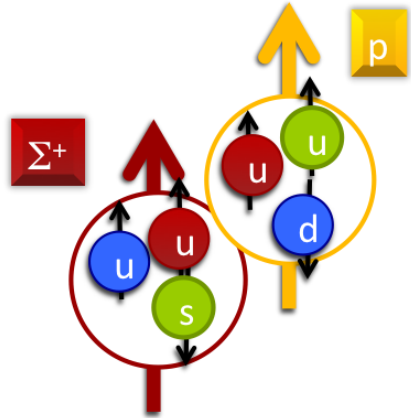
- $\Sigma^+ p$  elastic scattering
- $\Sigma^- p$  elastic scattering
- $\Sigma^- p \rightarrow \Lambda n$  inelastic scattering

# J-PARC E40 : Measurement of $d\sigma/d\Omega$ of $\Sigma p$ scatterings

## Verification of quark Pauli repulsion

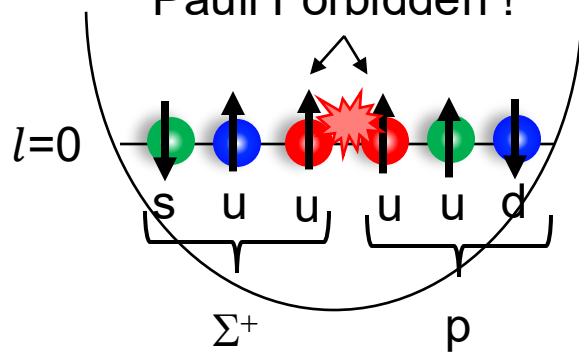
## Constraint for BB int. theories

$\Sigma^+ p$  scattering



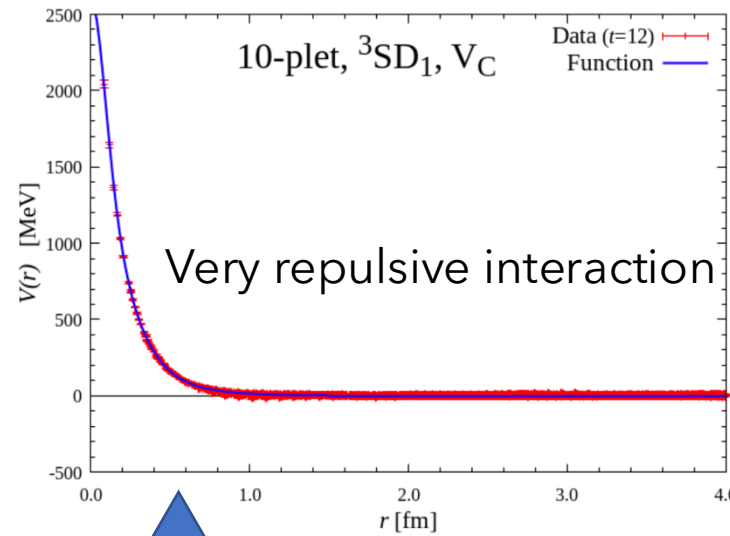
6 quarks can stay in s state in normal case

Pauli Forbidden !



Lattice QCD calculation

T. Inoue, AIP Conf. Proc. 2130, 020002 (2019)



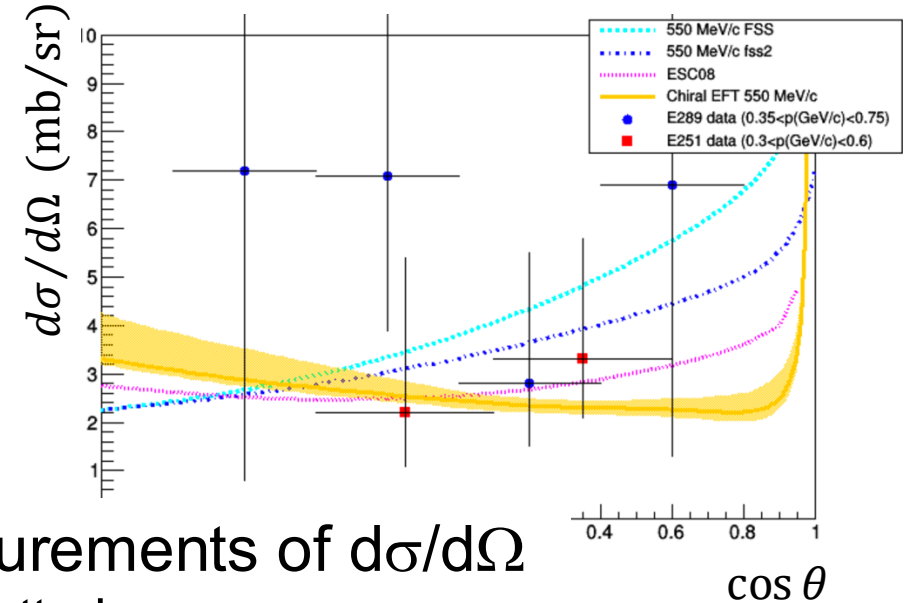
Phase-shift measurement

Systematic measurements of  $d\sigma/d\Omega$

- $\Sigma^+ p$  elastic scattering
- $\Sigma^- p$  elastic scattering
- $\Sigma^- p \rightarrow \Lambda n$  inelastic scattering

- Quark Cluster model (FSS, fss2)
- Nijmegen model
- Chiral EFT (NLO)

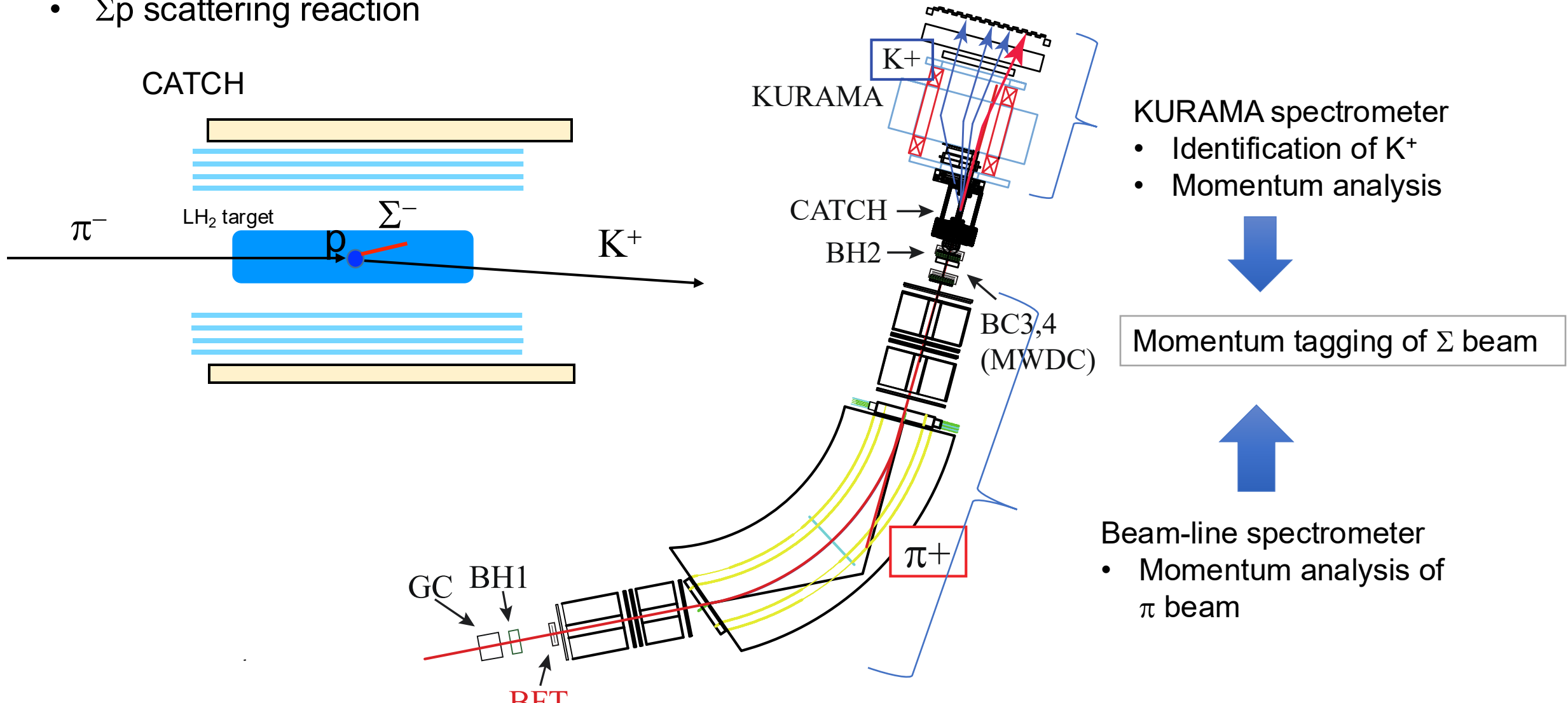
$\Sigma^+ p$  ( $0.5 < p$  (GeV/c)  $< 0.6$ )



# J-PARC E40 experimental setup

Two successive two-body reactions

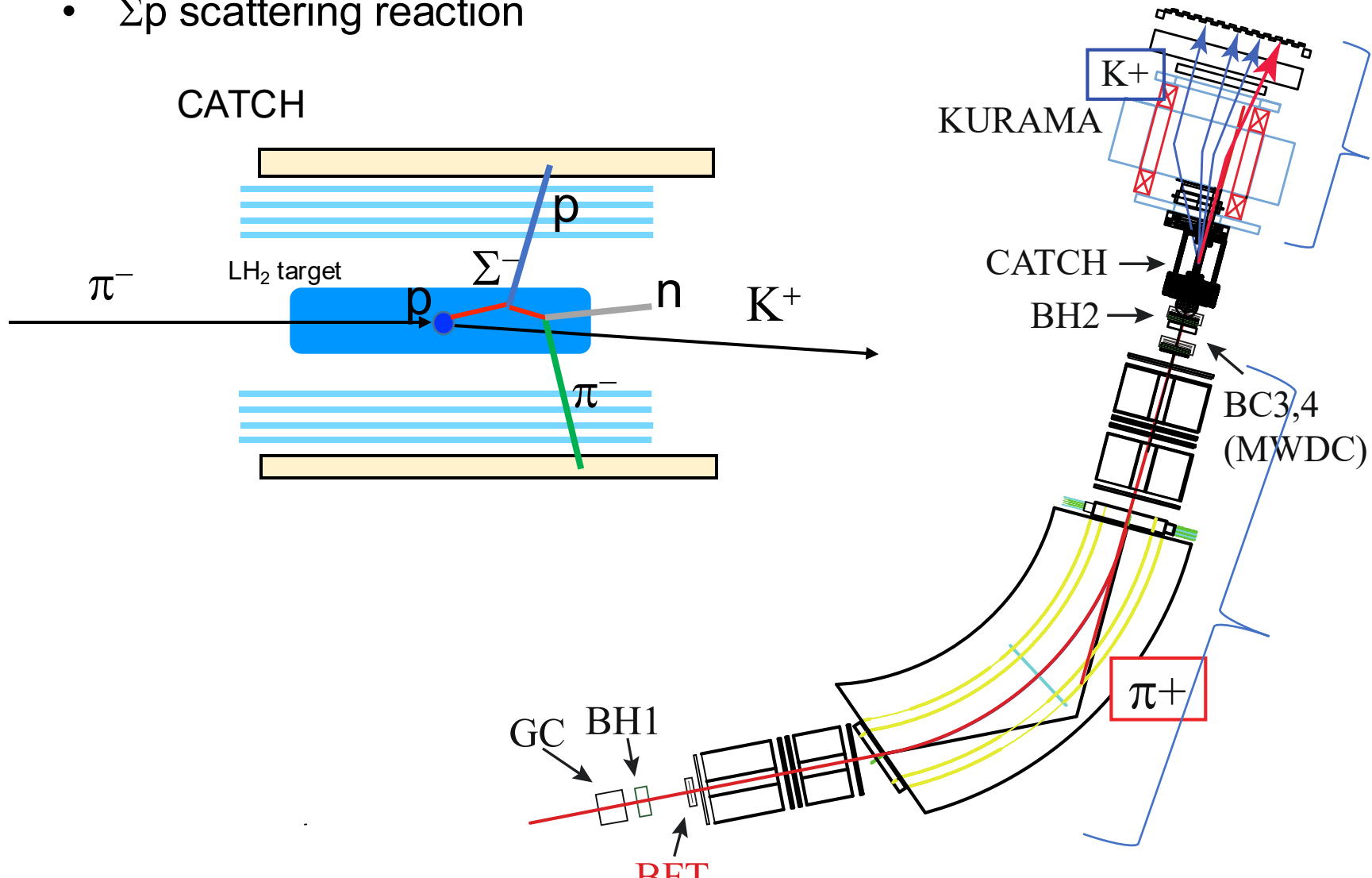
- $\Sigma$  production by  $\pi p \rightarrow K^+ \Sigma$  reaction
- $\Sigma p$  scattering reaction



# J-PARC E40 experimental setup

Two successive two-body reactions

- $\Sigma$  production by  $\pi p \rightarrow K^+ \Sigma$  reaction
- $\Sigma p$  scattering reaction



@ J-PARC K1.8 beam line

KURAMA spectrometer

- Identification of  $K^+$
- Momentum analysis



Momentum tagging of  $\Sigma$  beam



Beam-line spectrometer

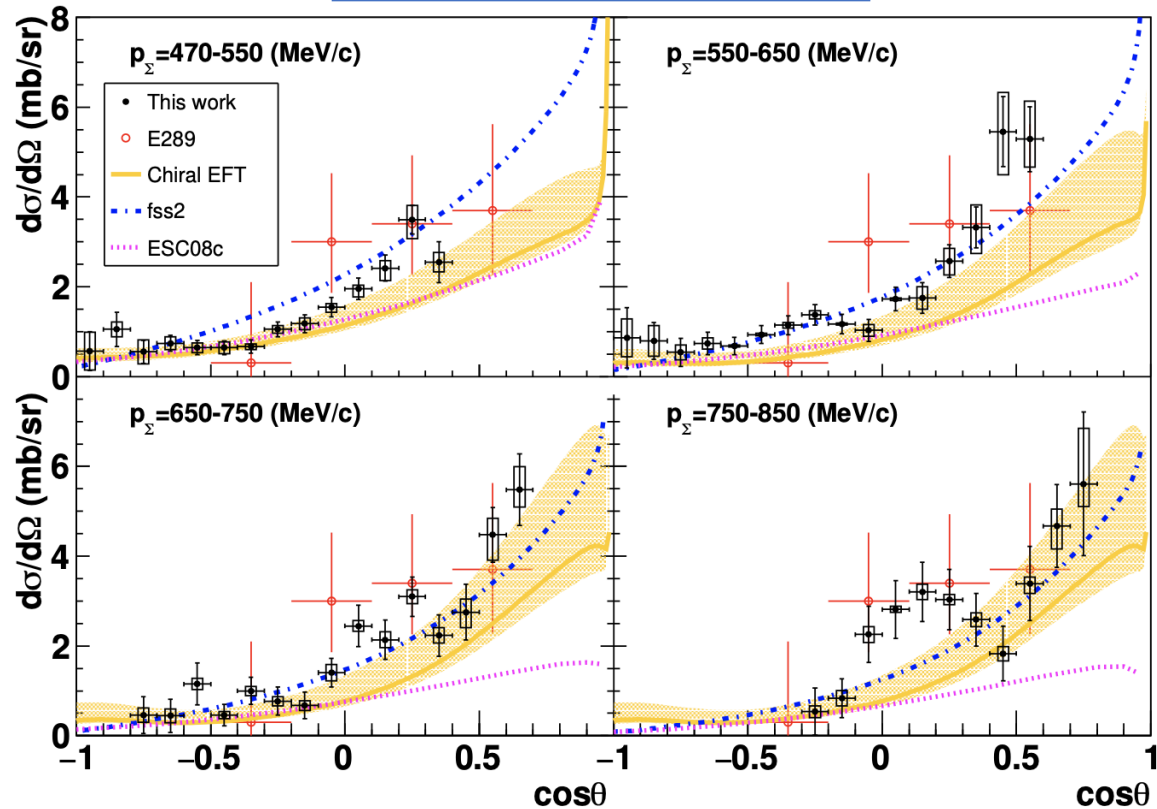
- Momentum analysis of  $\pi$  beam

# $d\sigma/d\Omega$ of the $\Sigma^-p$ channels

$\Sigma^-p$  elastic scattering

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

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

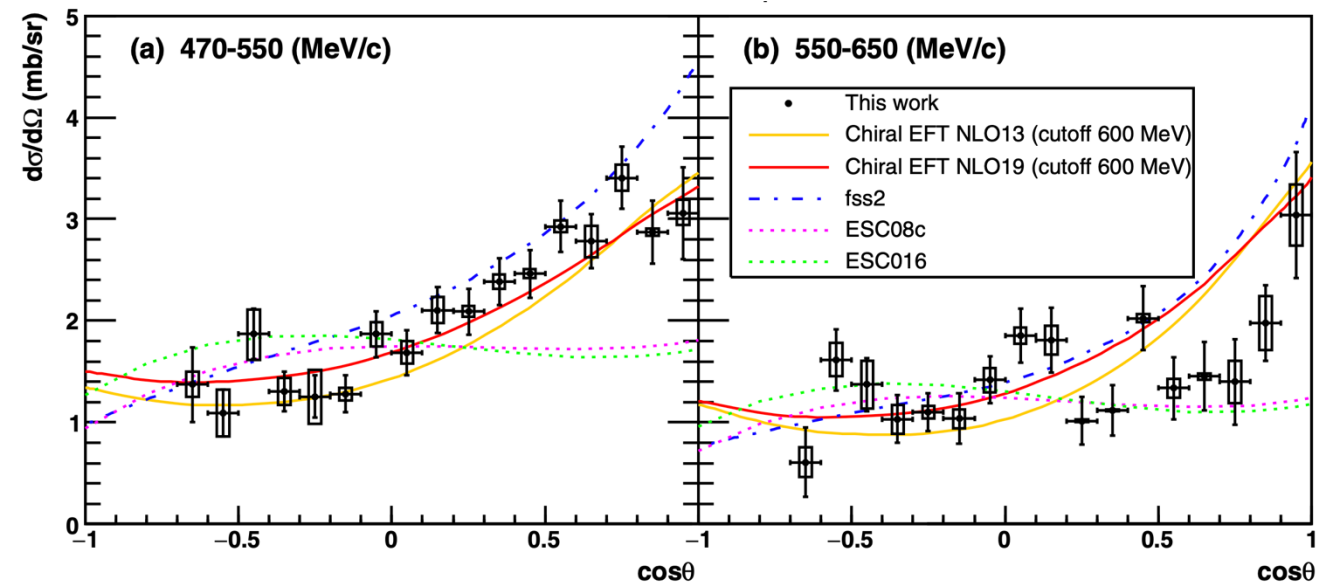


Clear forward peaking angular dependence

Comparison with theories

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

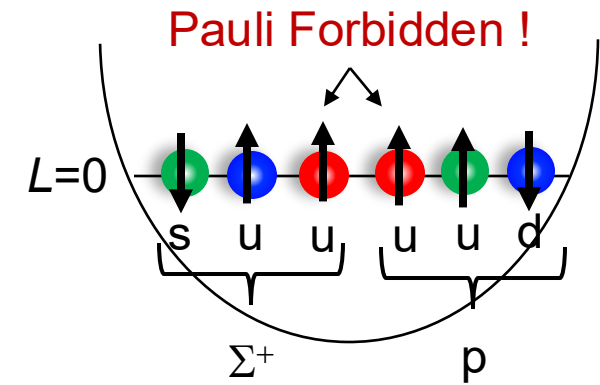
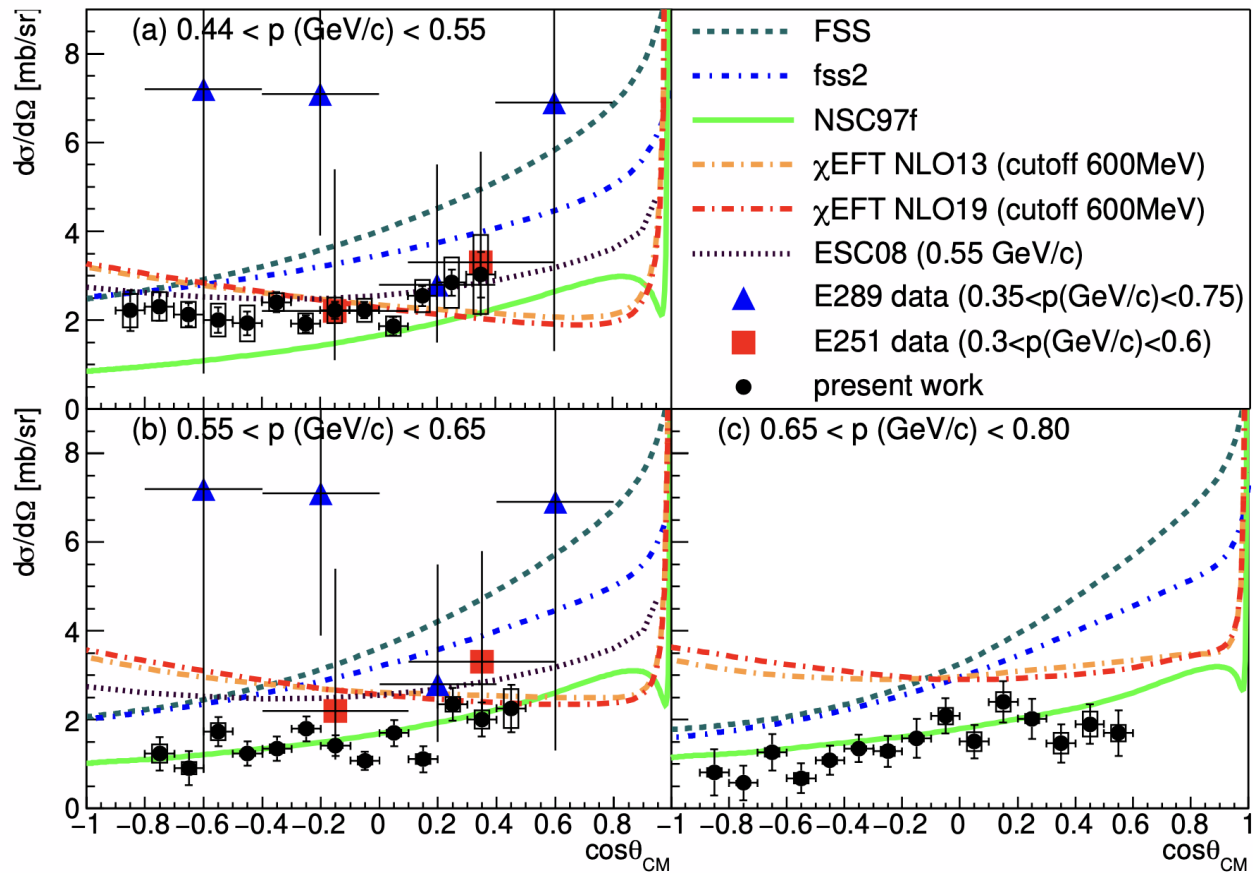
$\Sigma^-p \rightarrow \Lambda n$  inelastic scattering



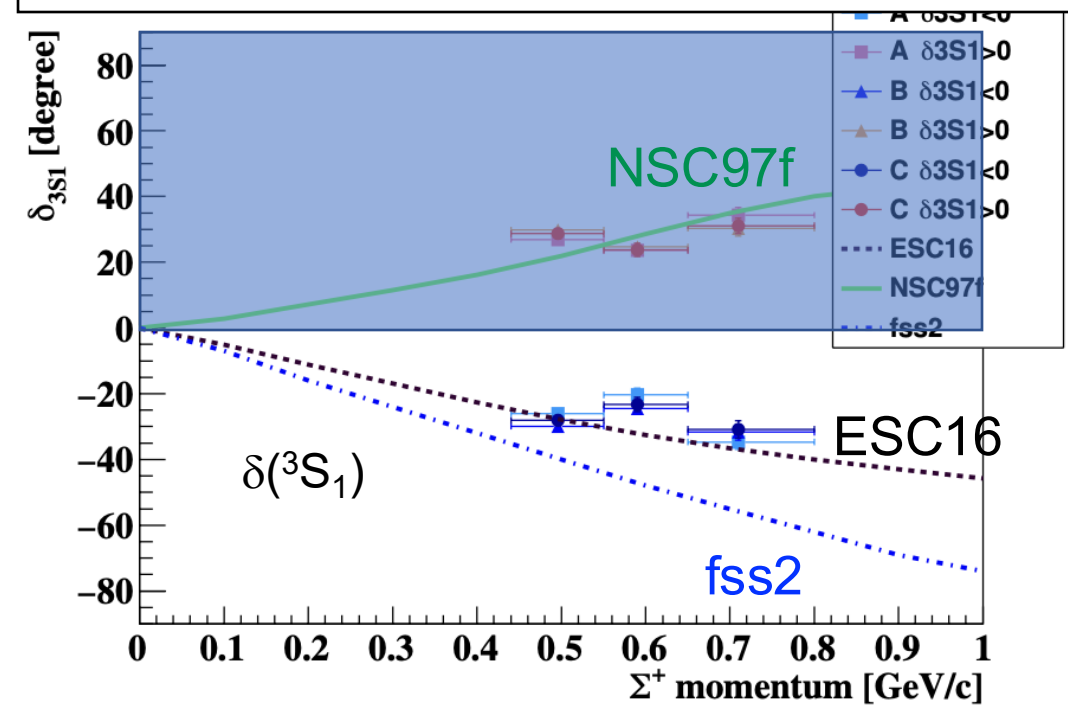
Moderate forward peaking dependence

# $d\sigma/d\Omega$ of $\Sigma^+p$ elastic scattering

T. Nanamura et al., Prog. Theor. Exp. Phys. **2022** 093D01



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

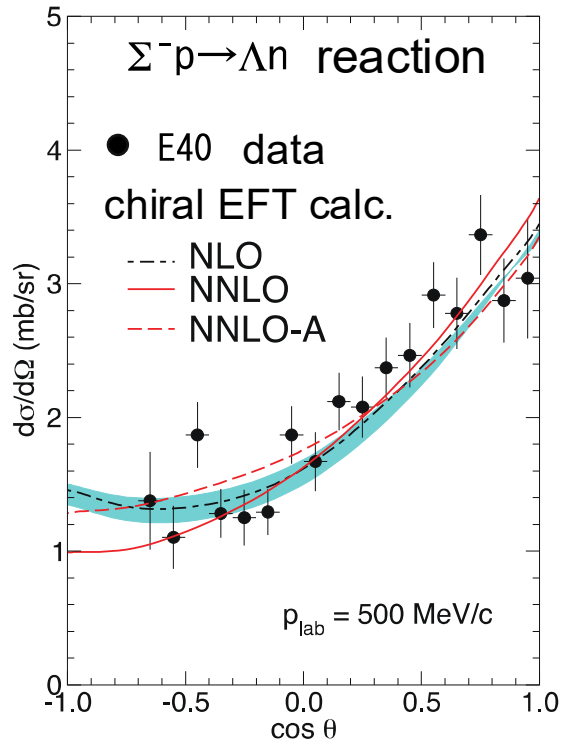


**E40 data : much smaller than fss2 prediction and E289 results**

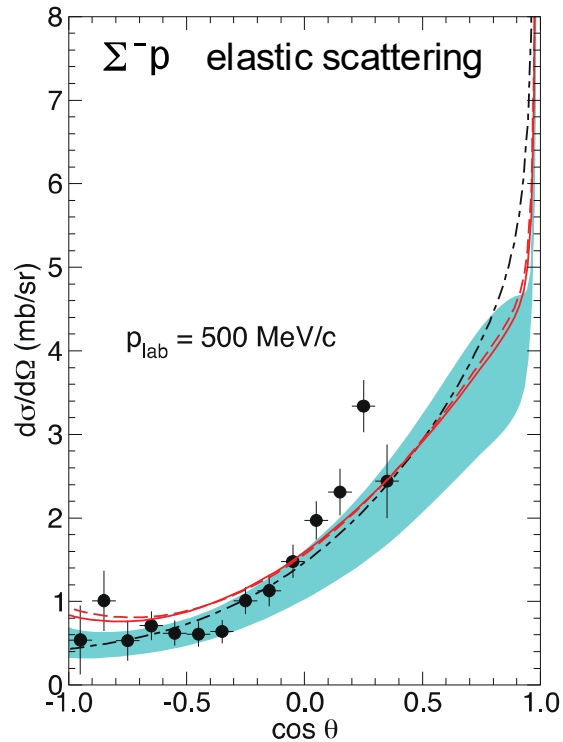
**Derived phase shift suggests that the  $^3S_1$  interaction is moderately repulsive.**

# New $\Sigma p$ scattering data and progress of Chiral EFT

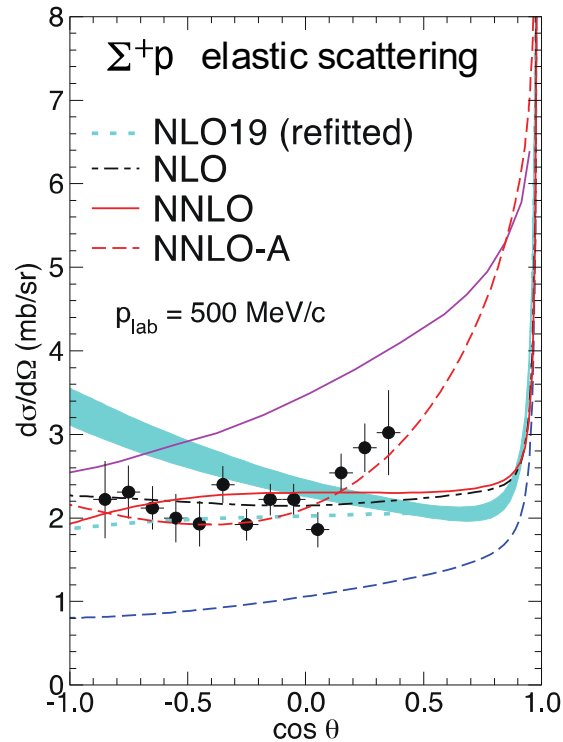
Development of Chiral EFT at NNLO have got started with E40 data



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



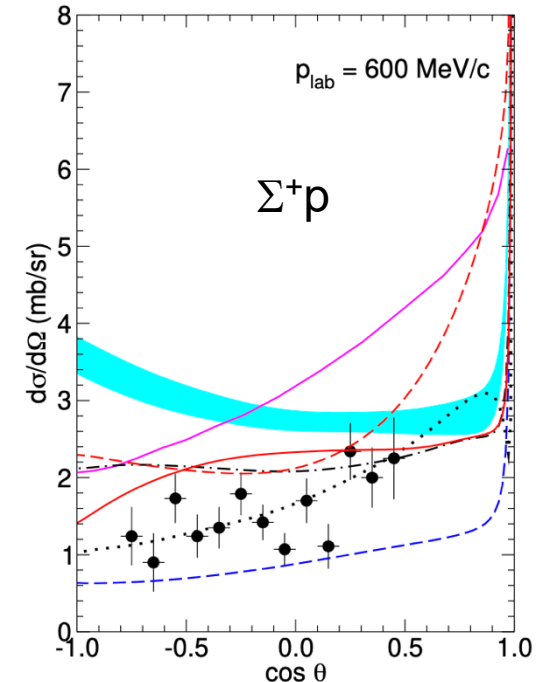
K. Miwa et al.,  
PRC 104, 045204 (2021)



T. Nanamura et al., PTEP 2022 093D01

Difficulty at higher momentum

$\Sigma^+ p \rightarrow \Sigma^+ p$



J. Haidenbauer et al.,  
arXiv:2301.00722

But, the interactions are not uniquely determined yet.

We need more data from additional channels ( $\Lambda p$ , ...) and additional differential observables (polarizations, ...)



**New  $\Lambda p$  scattering experiment.**

# Updated $\Lambda N$ , $\Sigma N$ chiral interaction

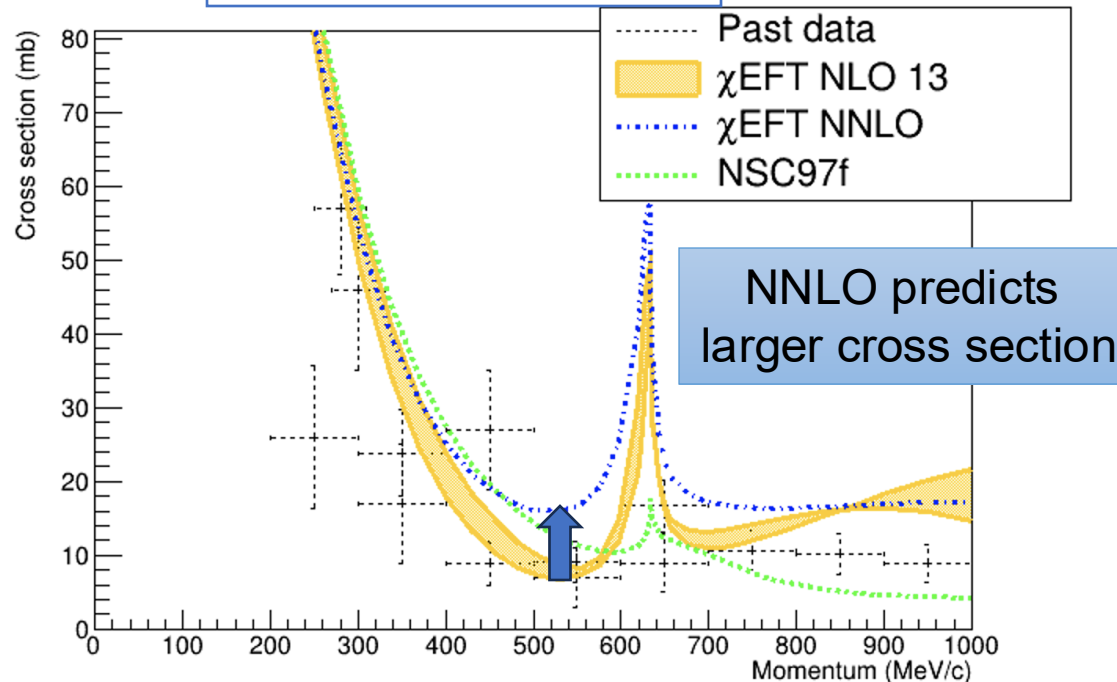
$YN$ potential	$B_\Lambda$ [MeV]	$E$ [MeV]	$P_\Sigma$ [%]	$U_\Lambda(0)$	$U_\Sigma(0)$
SMS N <sup>2</sup> LO(500)	0.147	-2.371	0.25	-33.1	6.4
SMS N <sup>2</sup> LO(550) <sup>a</sup>	0.139	-2.362	0.25	-38.5	2.5
SMS N <sup>2</sup> LO(550) <sup>b</sup>	0.125	-2.348	0.24	-35.9	2.5
SMS N <sup>2</sup> LO(600)	0.172	-2.395	0.22	-37.8	0.1
NLO13(600)	0.090	-2.335	0.25	-21.6	17.1
NLO19(600)	0.091	-2.336	0.21	-32.6	16.9

J. Haidenbauer et al., Eur. Phys. J. A 59 (2023) 63

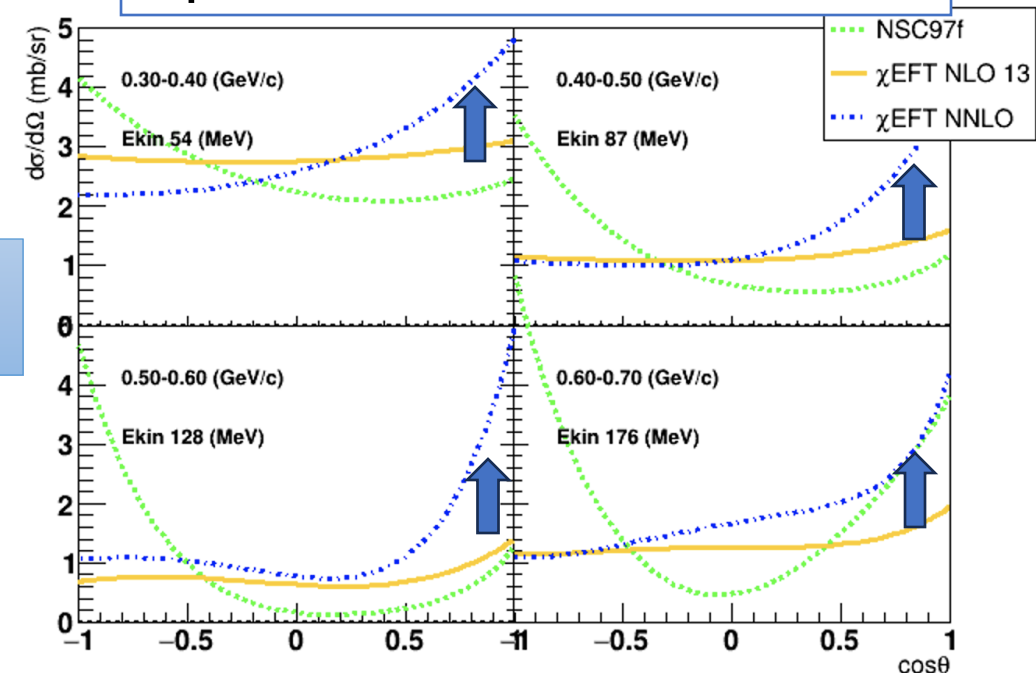
Based on the E40  $\Sigma p$  scattering data,  $U_\Sigma$  becomes less repulsive and  $U_\Lambda$  becomes more attractive.

Calculation by J. Haidenbauer

## $\Lambda p$ cross section

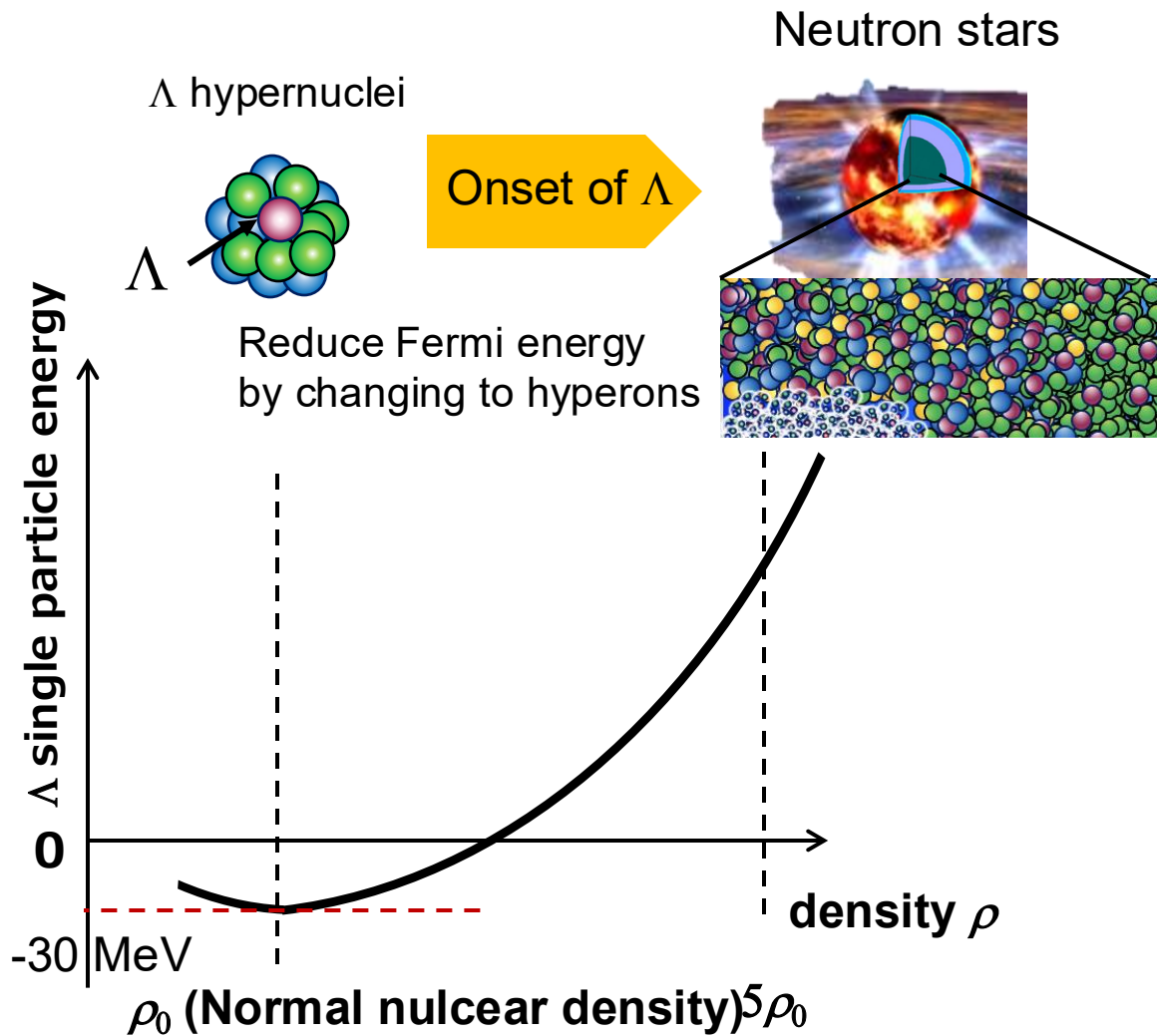


## $\Lambda p$ differential cross section



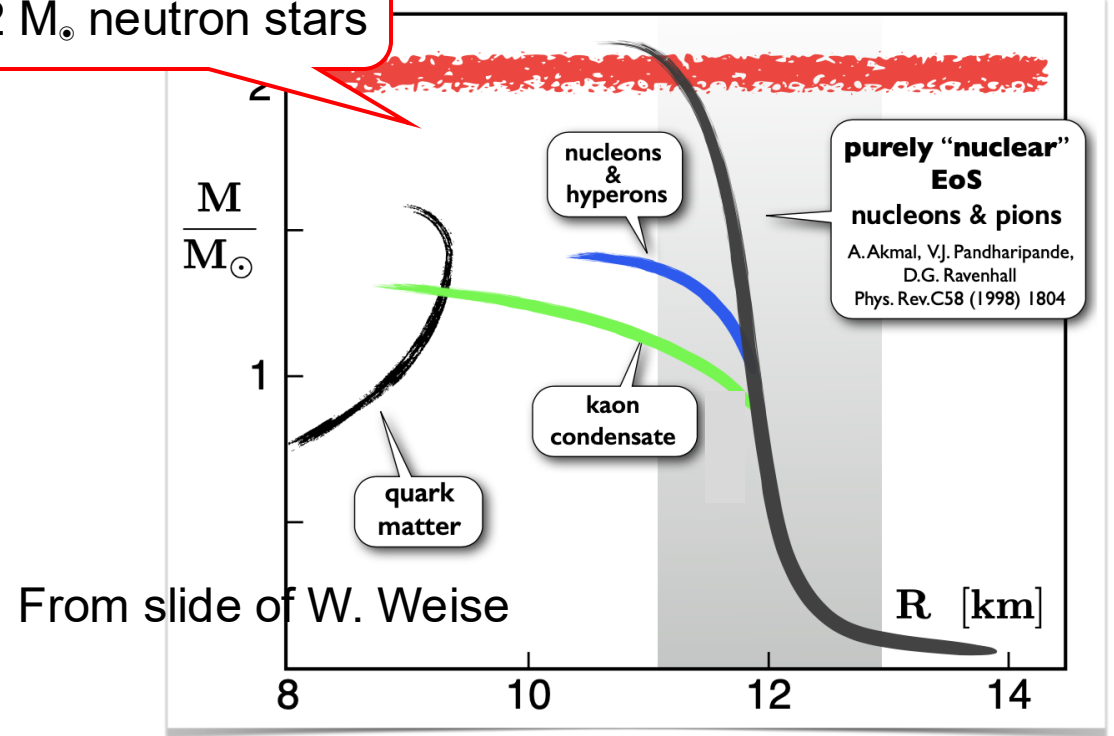
# Hyperon puzzle in neutron stars

Current two-body  $\Lambda N$  interaction alone cannot support massive neutron stars



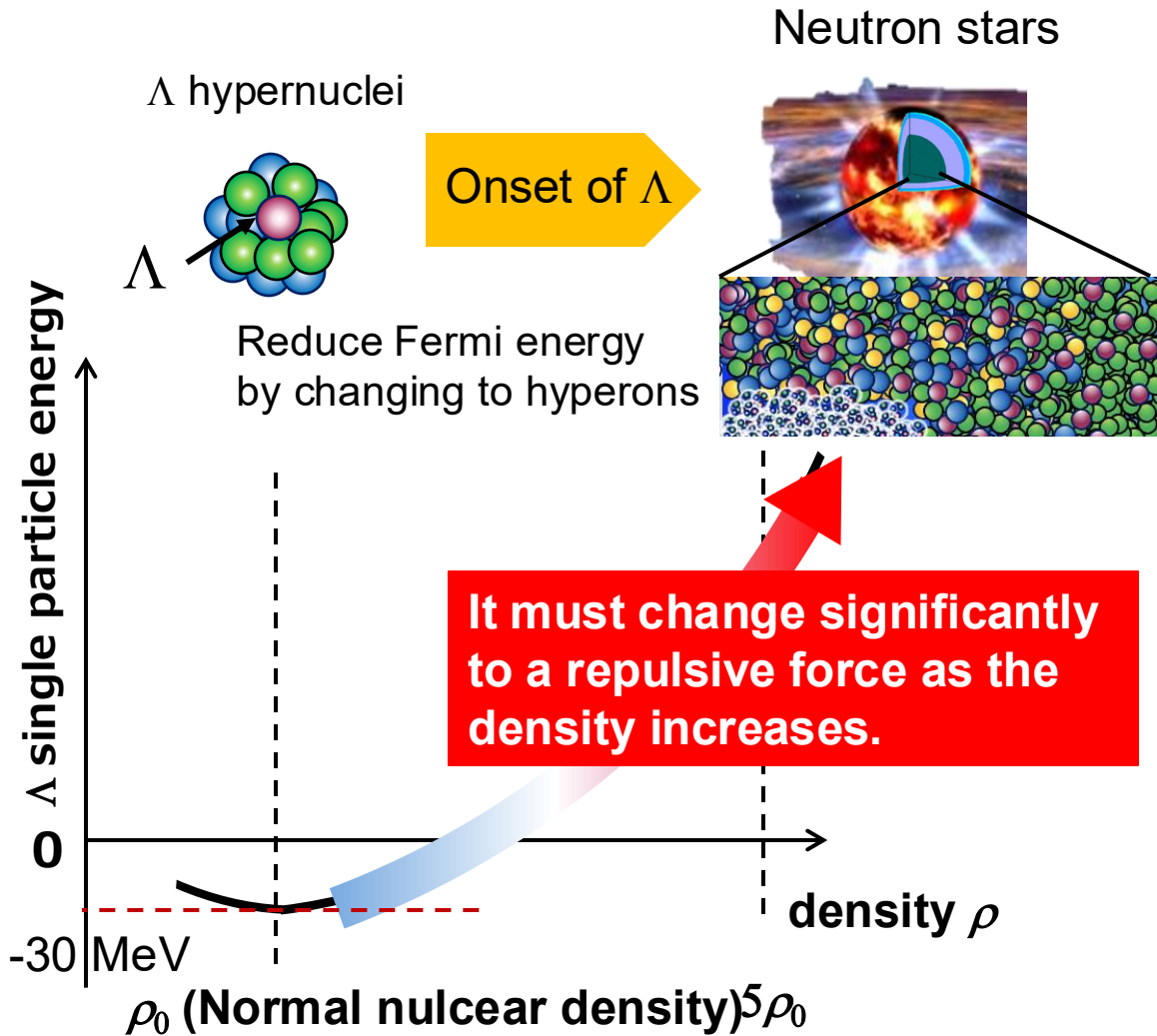
Observation of 2  $M_{\odot}$  neutron stars

## Mass-Radius Relation



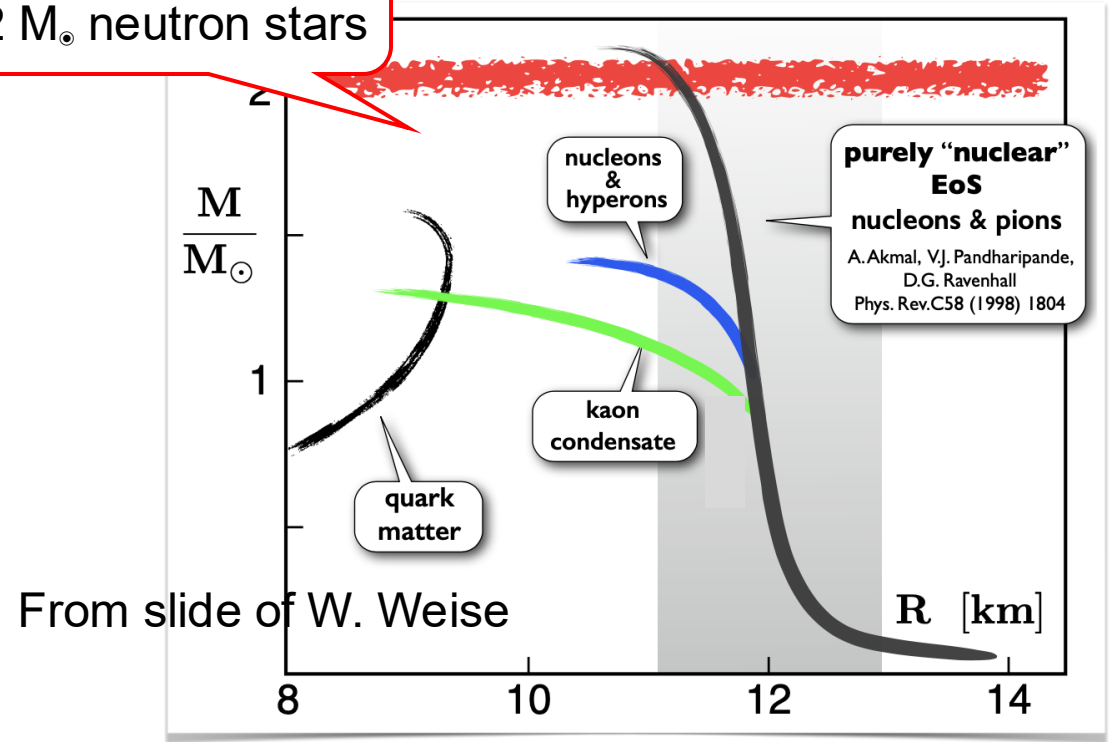
# Hyperon puzzle in neutron stars

Current two-body  $\Lambda N$  interaction alone cannot support massive neutron stars



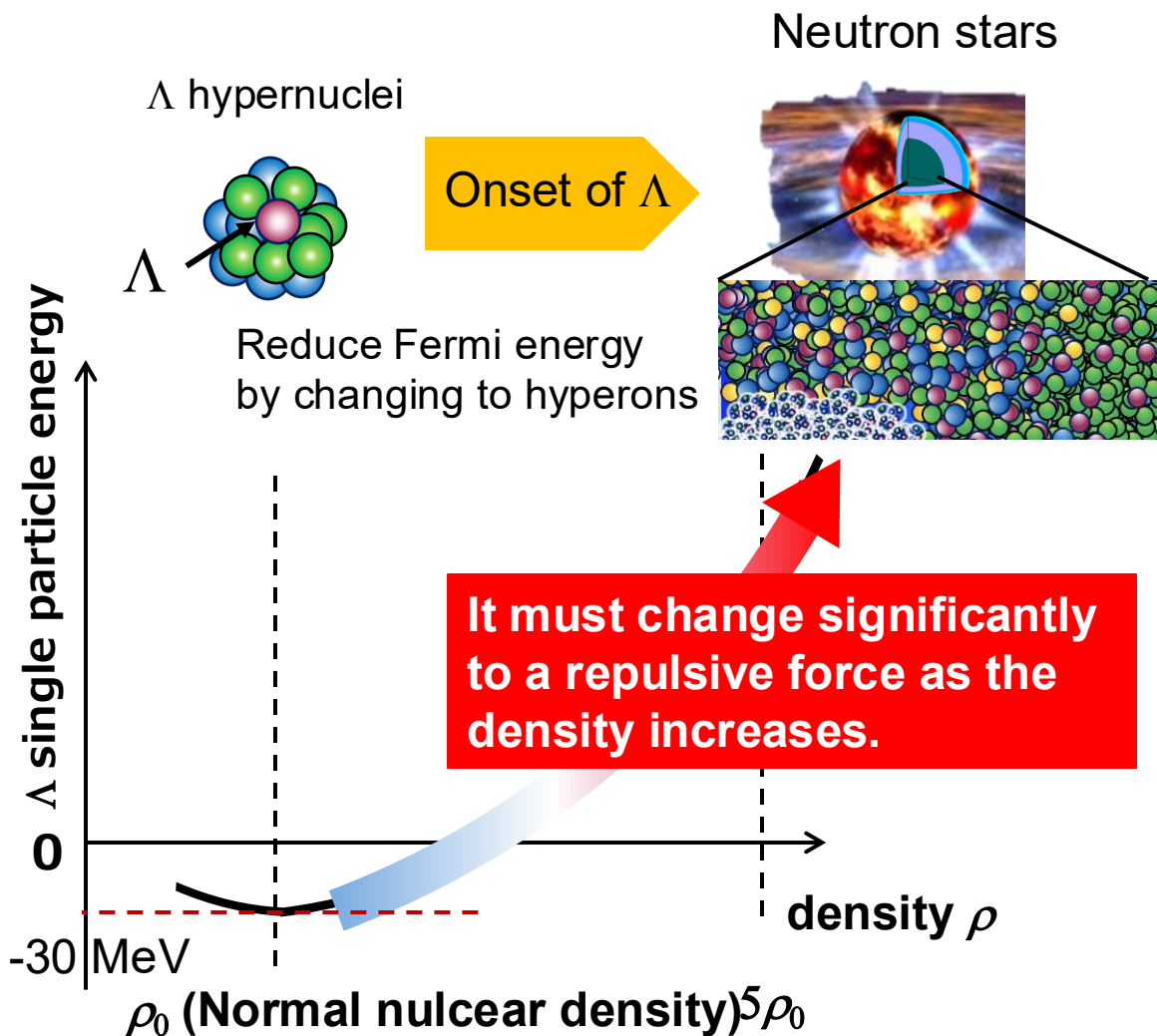
Observation of 2  $M_\odot$  neutron stars

## Mass-Radius Relation



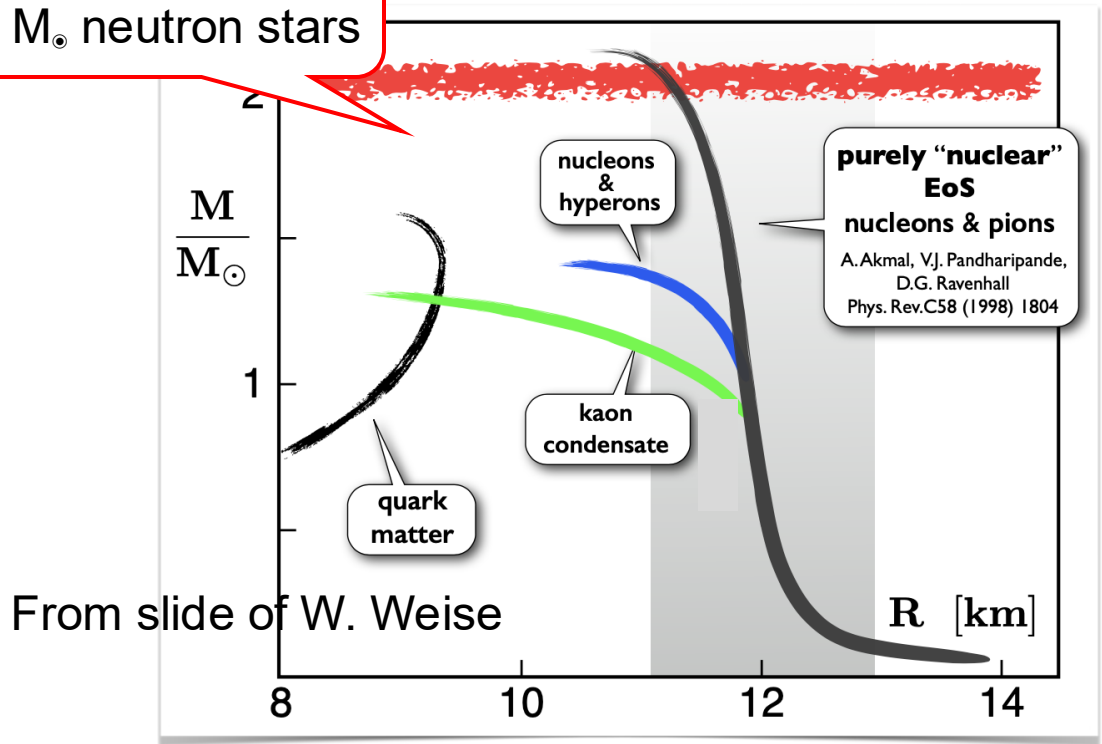
# Hyperon puzzle in neutron stars

Current two-body  $\Lambda N$  interaction alone cannot support massive neutron stars

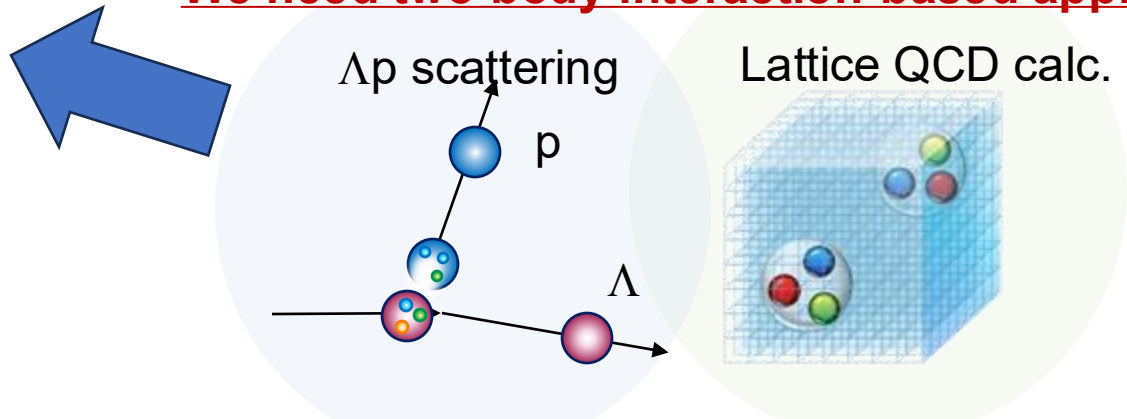


Observation of 2  $M_\odot$  neutron stars

## Mass-Radius Relation



We need two-body interaction-based approach

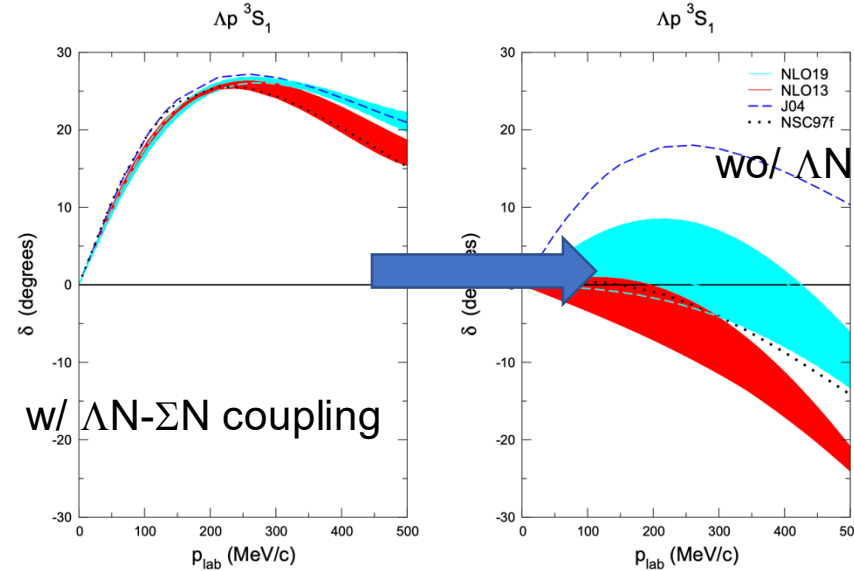
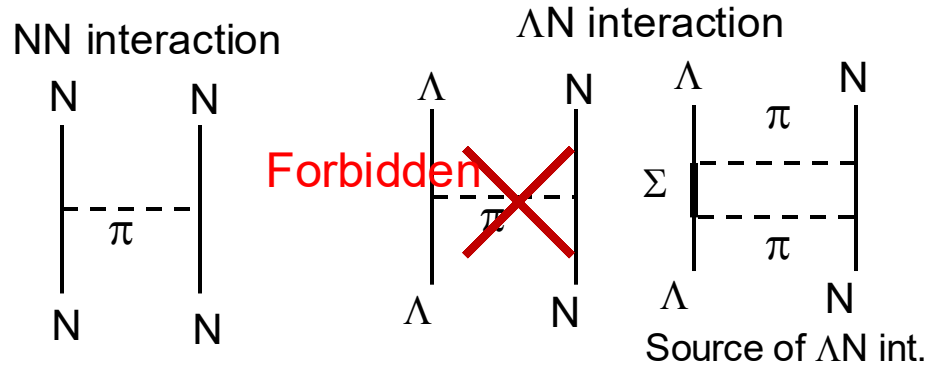


Establish  $\Lambda N$  interaction including  $\Lambda N$ - $\Sigma N$  coupling

# Origin of the density dependence of $\Lambda N$ interaction

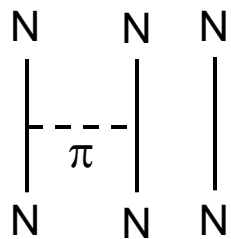
$\Lambda$  is the only isospin 0 baryon that makes up matter  $\rightarrow$  One-pion exchange is forbidden

## Interaction in free space



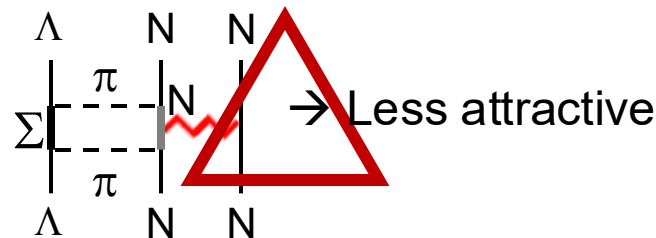
$\Lambda N$  interaction becomes less attractive (repulsive) w/o  $\Lambda N$ - $\Sigma N$  coupling

## Interaction in nuclear medium



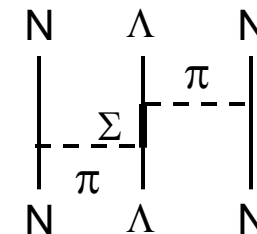
Two-body NN int. might not be affected very much by other nucleons

### Suppression of two-body $\Lambda N$ int.



Due to the Pauli blocking for the intermediate nucleon,  $\Lambda N$ - $\Sigma N$  coupling can be very suppressed

### 3 body int. mediated with $\Sigma$

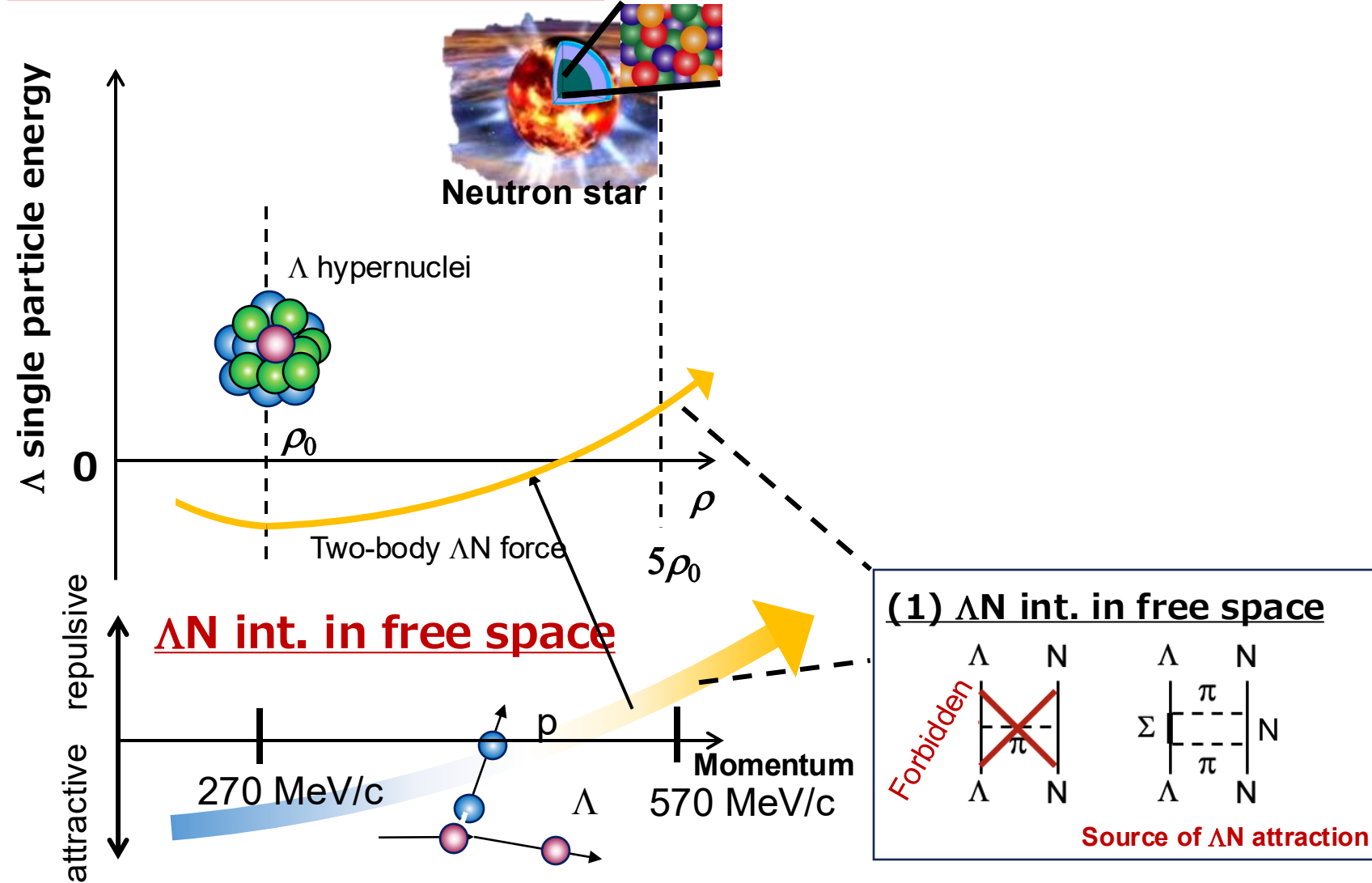


Additional three-body interaction, which does not appear in NN interaction.  
 What is the density dependence of this 3-body int. ?

# Toward the elucidation of the density dependence of the $\Lambda$ N interaction

## $\Lambda$ N int. in nuclear medium

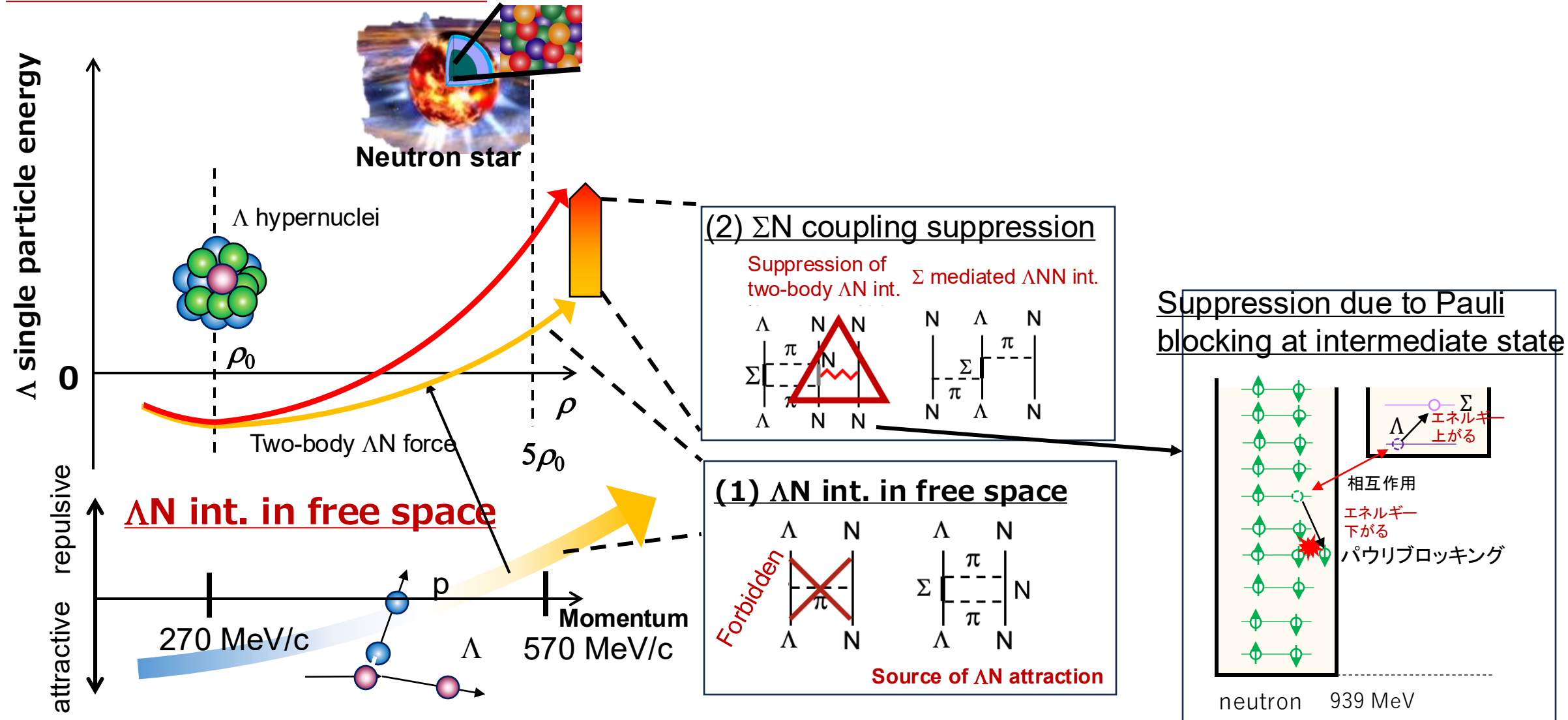
Ingredients of  $\Lambda$ N interaction  
in nuclear medium



# Toward the elucidation of the density dependence of the $\Lambda N$ interaction

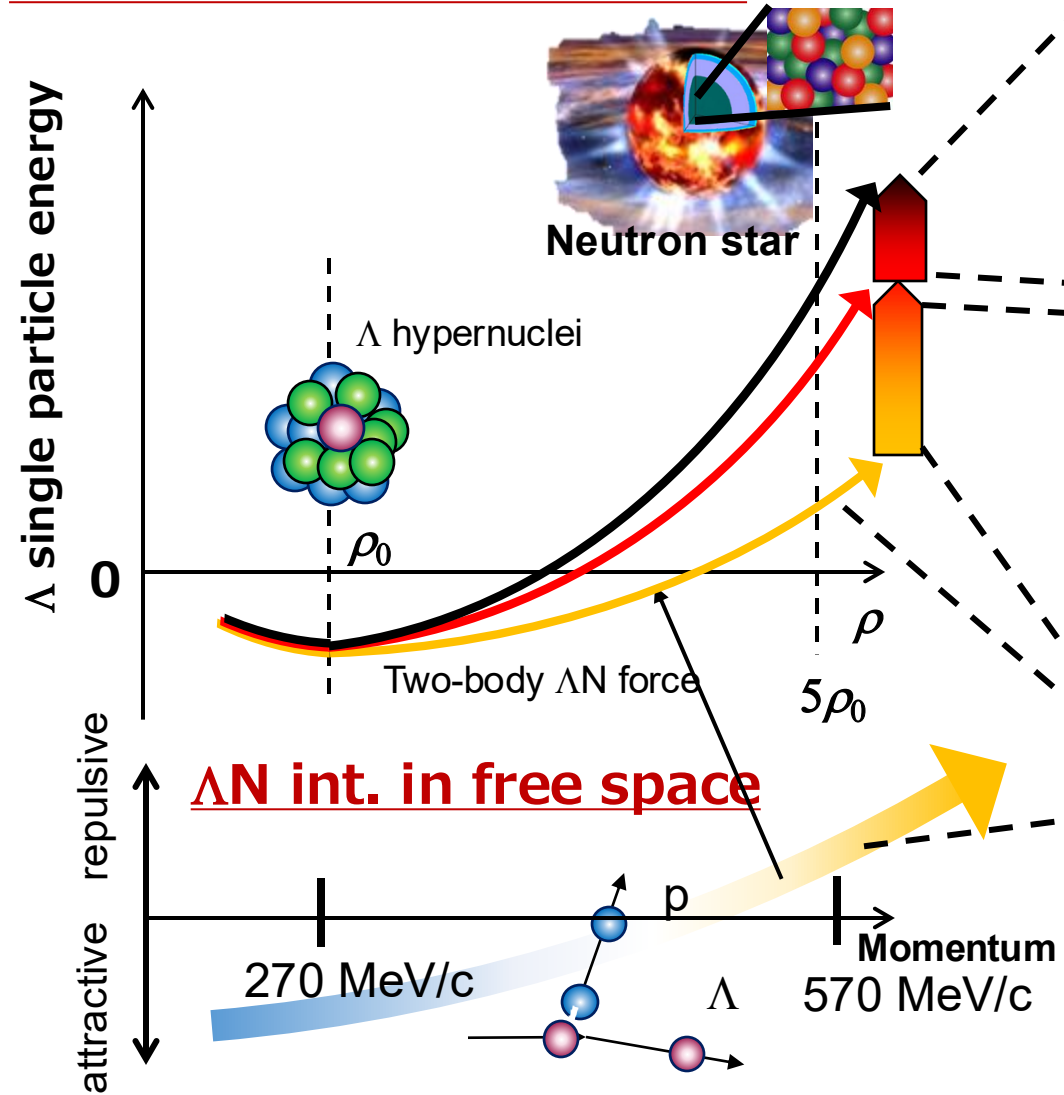
Ingredients of  $\Lambda N$  interaction  
in nuclear medium

## $\Lambda N$ int. in nuclear medium



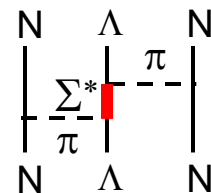
# Toward the elucidation of the density dependence of the $\Lambda N$ interaction

## $\Lambda N$ int. in nuclear medium

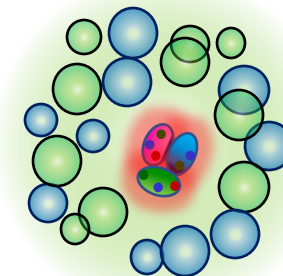


Ingredients of  $\Lambda N$  interaction in nuclear medium

$\Lambda NN$  int. mediated with  $\Sigma^*$

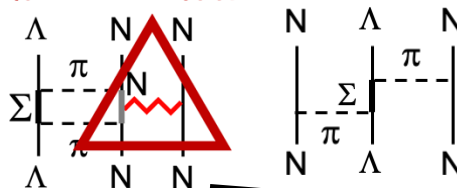


Repulsive force by  $\Lambda NN$  force

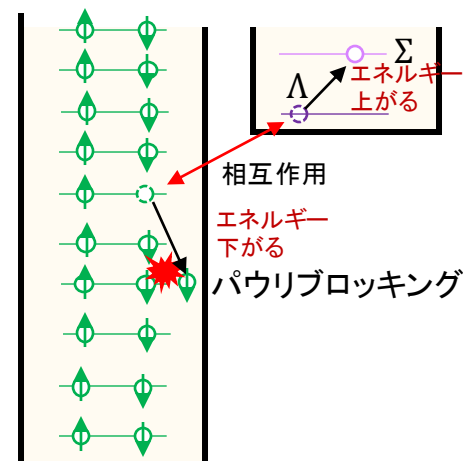


(2)  $\Sigma N$  coupling suppression

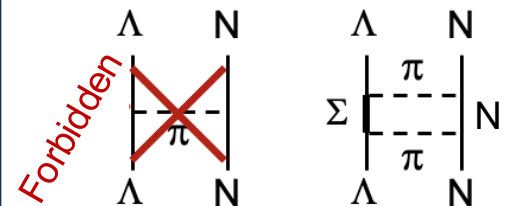
Suppression of two-body  $\Lambda N$  int.  $\Sigma$  mediated  $\Lambda NN$  int.



Suppression due to Pauli blocking at intermediate state



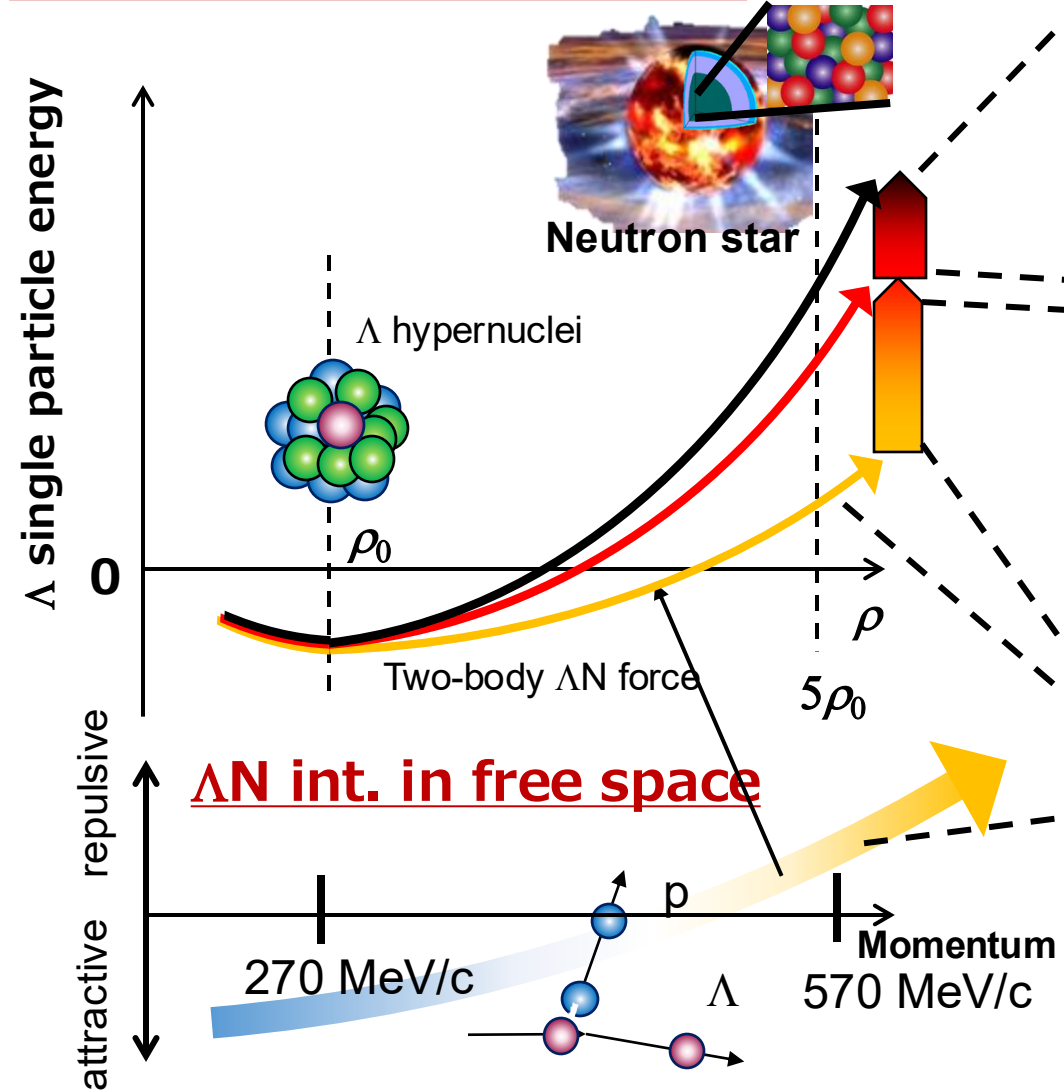
(1)  $\Lambda N$  int. in free space



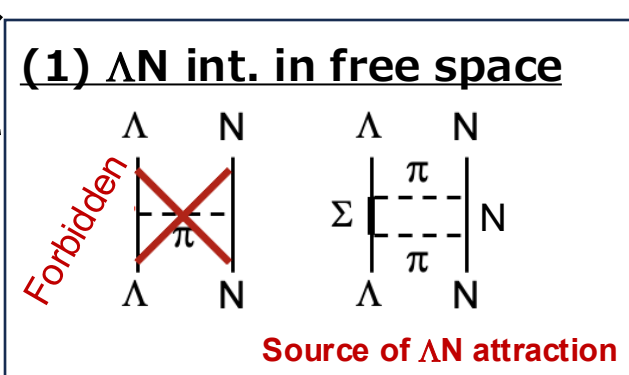
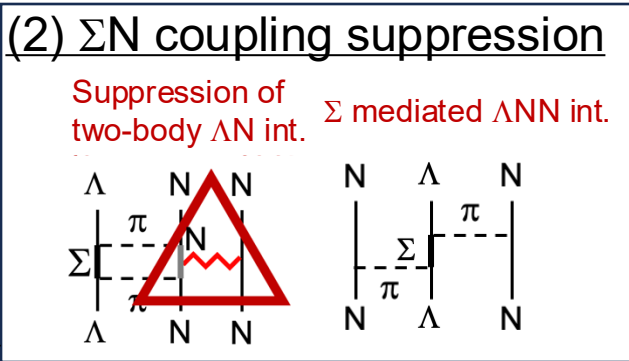
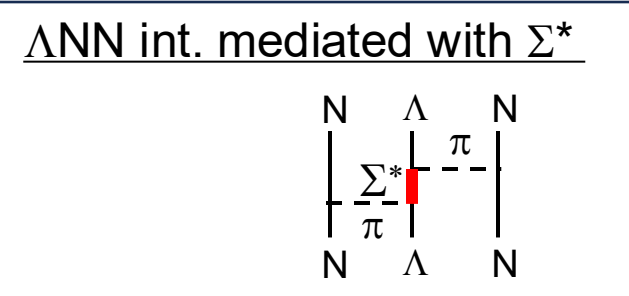
Source of  $\Lambda N$  attraction

# Toward the elucidation of the density dependence of the $\Lambda N$ interaction

## $\Lambda N$ int. in nuclear medium



Ingredients of  $\Lambda N$  interaction in nuclear medium



Determination of  $\Sigma^*$  mediated  $\Lambda NN$  force

Precise  $\Lambda$  hypernuclear spectroscopy

Determination of  $\Lambda N$ - $\Sigma N$  coupling

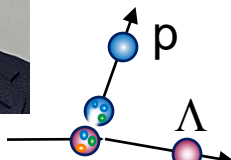
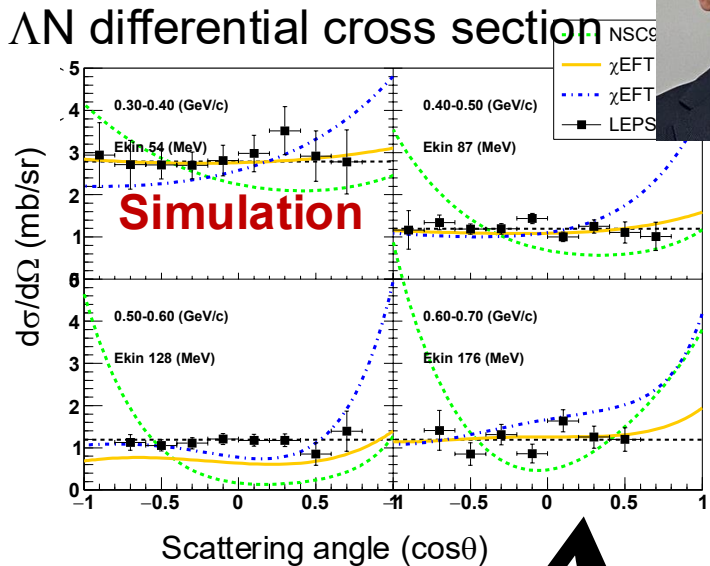
$\Sigma N$  cusp measurement  
Lattice QCD

Realistic  $\Lambda N$  interaction

$\Lambda N$  scattering data  
Lattice QCD

# Collaborative research regarding the two-body $\Lambda N, \Sigma N$ int.

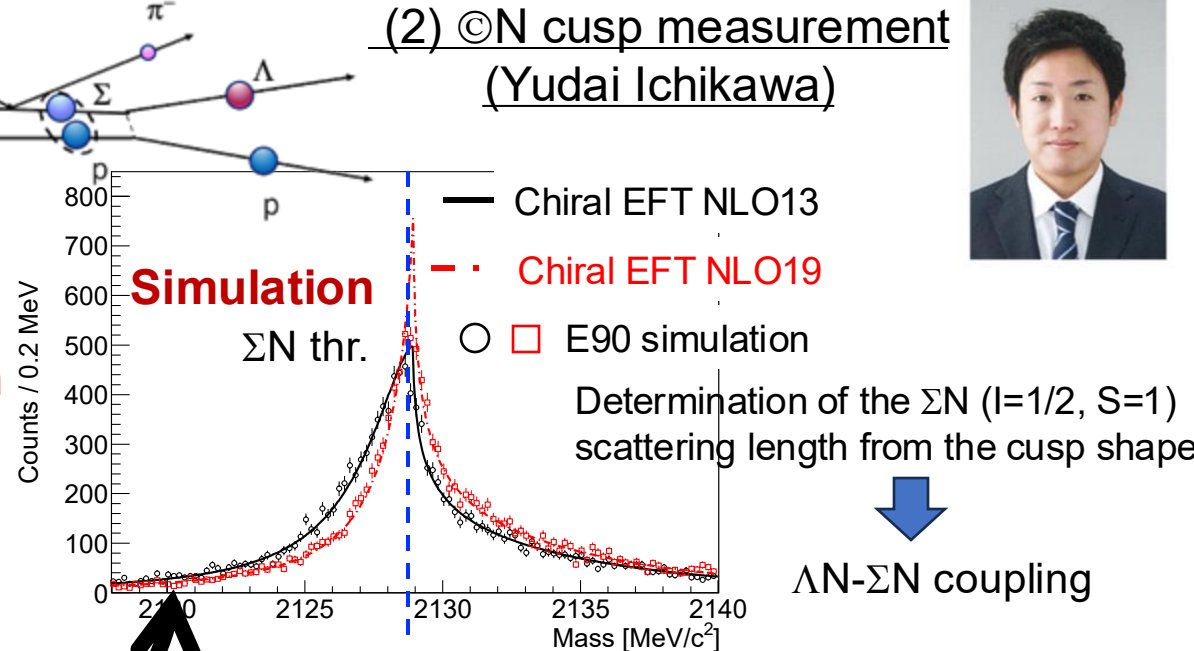
(1)  $\Lambda p$  scattering experiment  
(Koji Miwa)



Consistency check between  $d\sigma/d\Omega$  and  $\Lambda N$ - $\Sigma N$  coupling



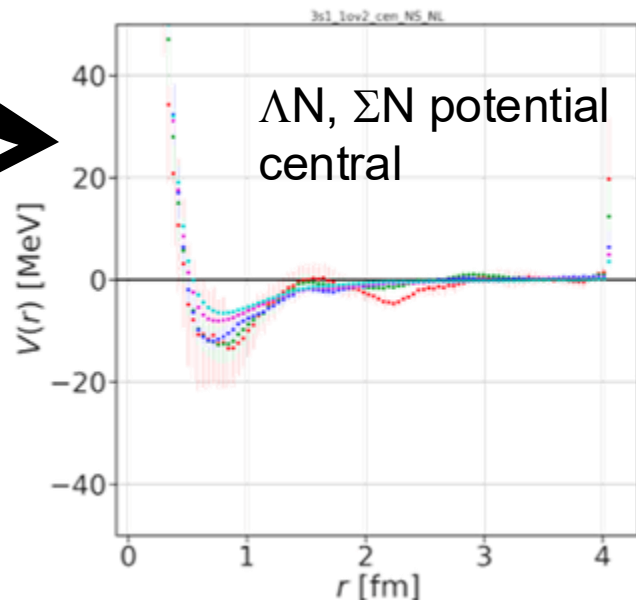
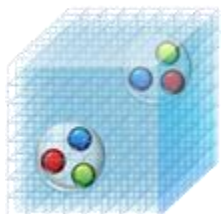
(2)  $\Sigma N$  cusp measurement  
(Yudai Ichikawa)



$\Lambda N$ - $\Sigma N$  coupling



Collaboration to separate  $\Lambda N$   $^3S_1$  and  $^1S_0$  interaction



Independent determination of  $\Lambda N$ - $\Sigma N$  coupling

(3)  $\Lambda N, \Sigma N$  Lattice QCD potential  
(Takahiro Doi)

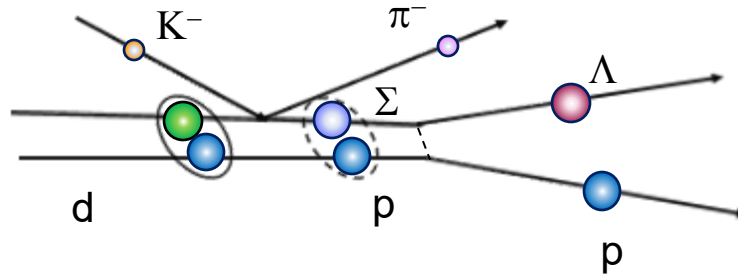


$\Lambda N, \Sigma N$  and  $\Lambda N$ - $\Sigma N$  coupling potentials by HAL QCD

[T. Doi, presentation at 3<sup>rd</sup> J-PARC HEF-ex WS](#)

# Precise $\Sigma N$ cusp measurement with $K^-d \rightarrow \Lambda p \pi^-$ reaction (J-PARC E90)

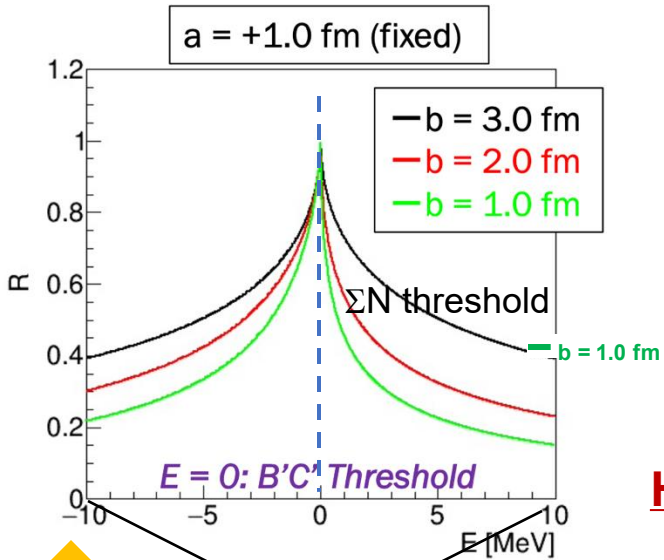
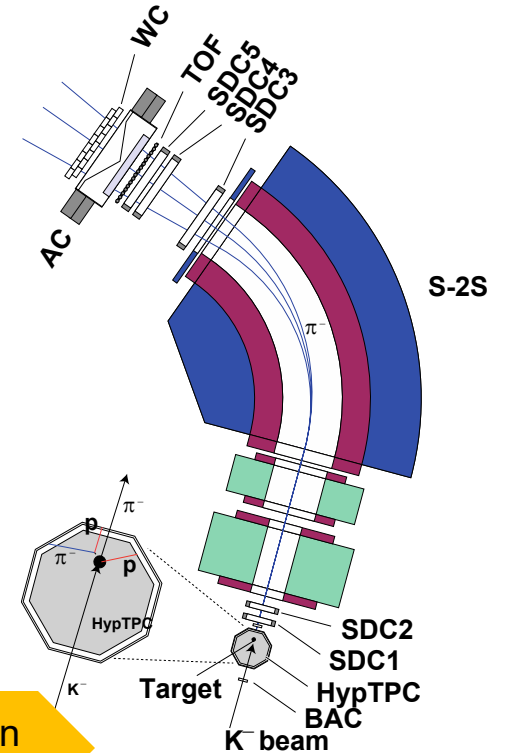
$\Delta N$ - $\Sigma N$  Coupling dependence of cusp shape



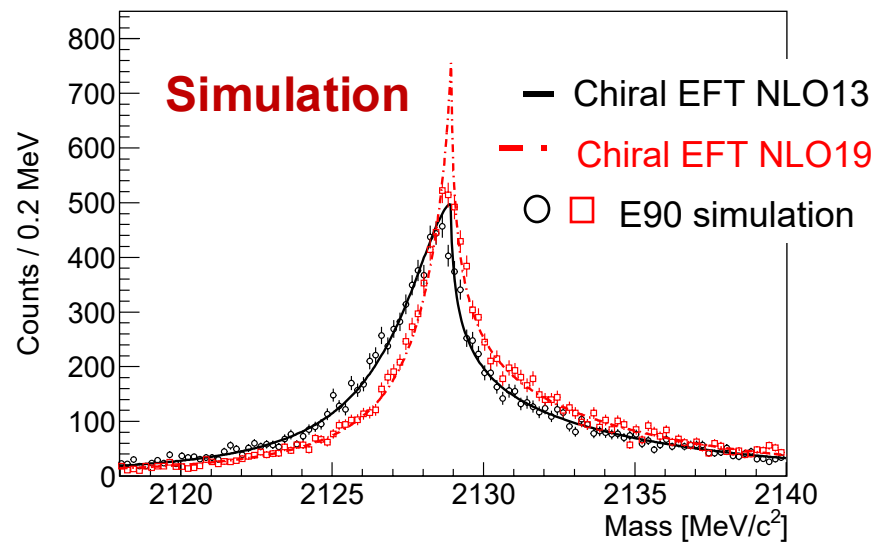
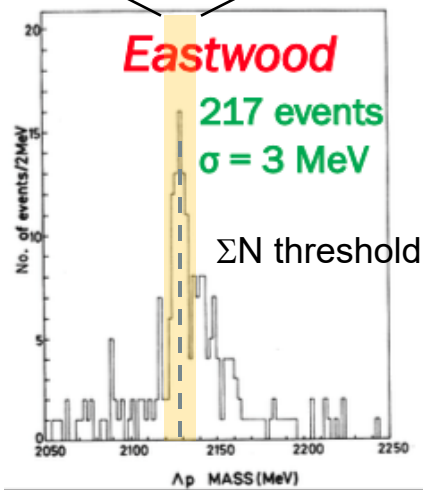
The cusp shape is represented by the scattering length  $A=a + ib$  of  $\Sigma N$  ( $I=1/2, S=1$ ) channel

- Real part  $a$  : Attraction of the  $\Sigma N$  interaction at low energy
- Imaginary part  $b$  :  $\Delta N$ - $\Sigma N$  coupling

**High resolution cusp measurement of  $\sigma=0.4$  MeV w/ S-2S**

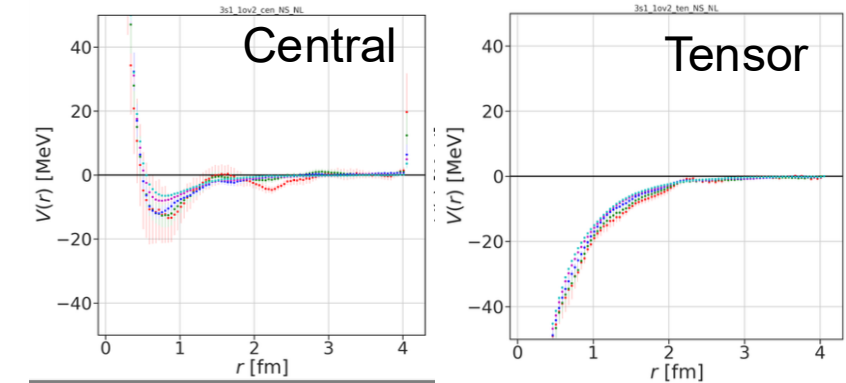


Past measurement



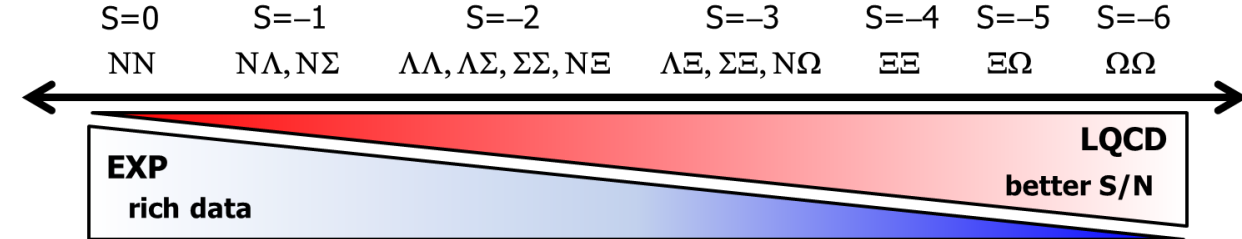
Direct comparison by scattering length

$\Delta N$ - $\Sigma N$  potential from Lattice QCD

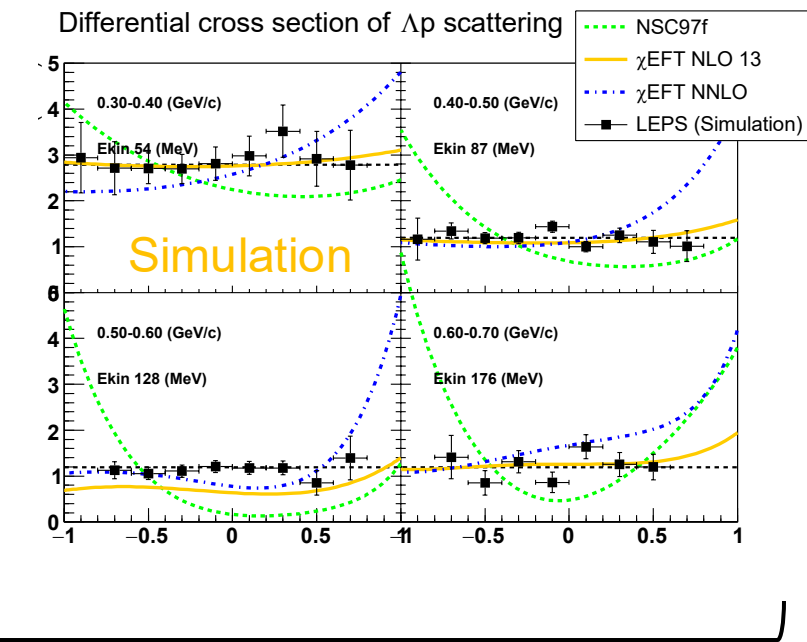
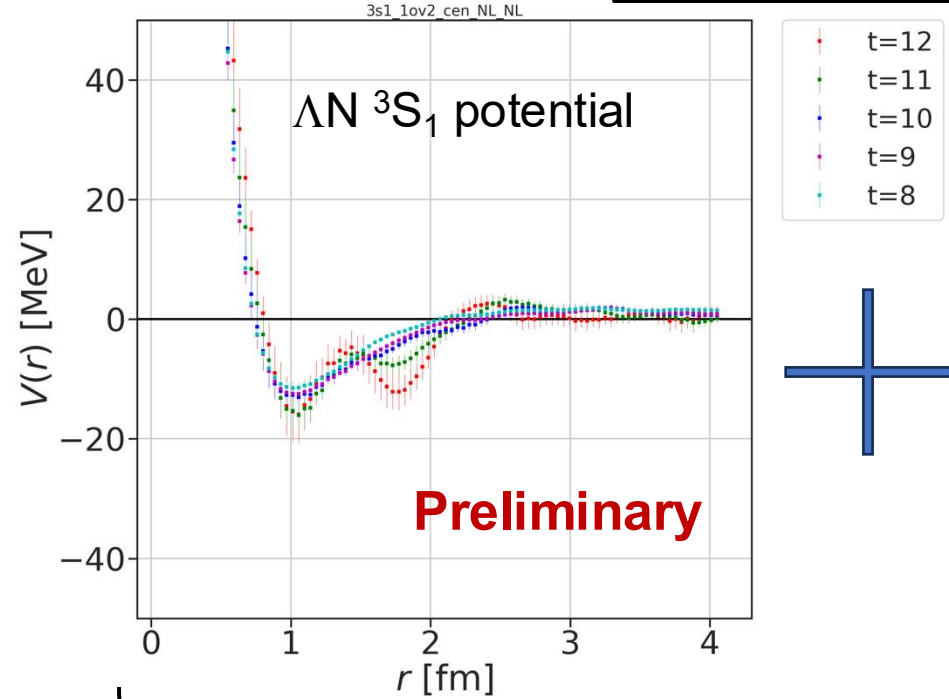
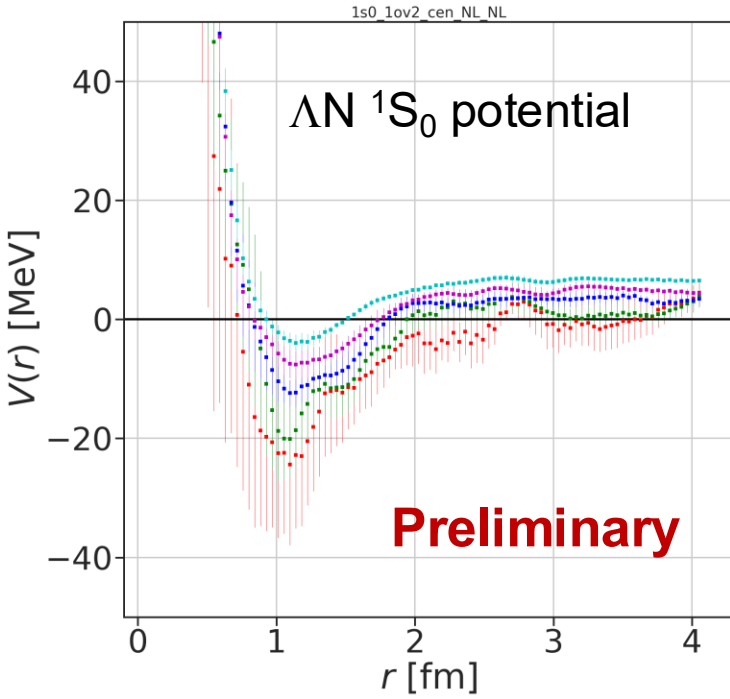


# S=-1 BB interaction potential by Lattice QCD

Takahiro Doi (Kyoto)



Lattice QCD potential for S wave

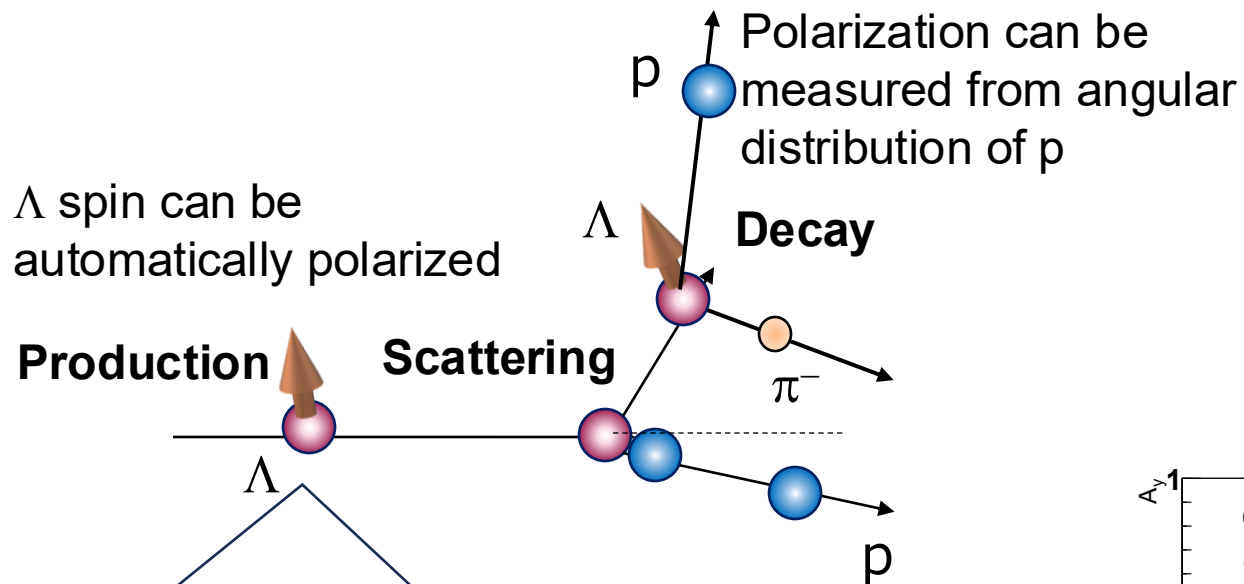


$^3S_1$  : No Pauli forbidden multiplet  $\rightarrow$  Precise calculation  
 $^1S_0$  : Due to Pauli forbidden multiplet, calculation is difficult

Building interaction models by combining lattice QCD data and experimental scattering data

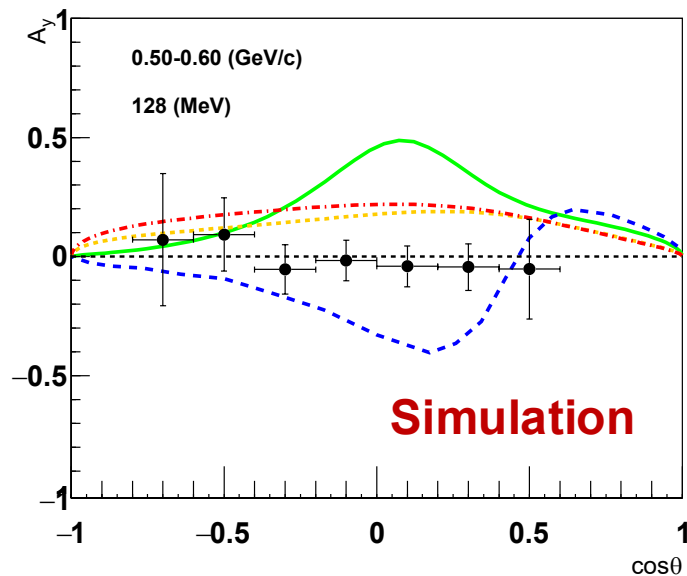
# $\Lambda p$ scattering experiment with polarized $\Lambda$ beam (J-PARC E86)

**Advantage of scattering experiment: Spin observables can be measured thanks to self polarimeter of hyperon**

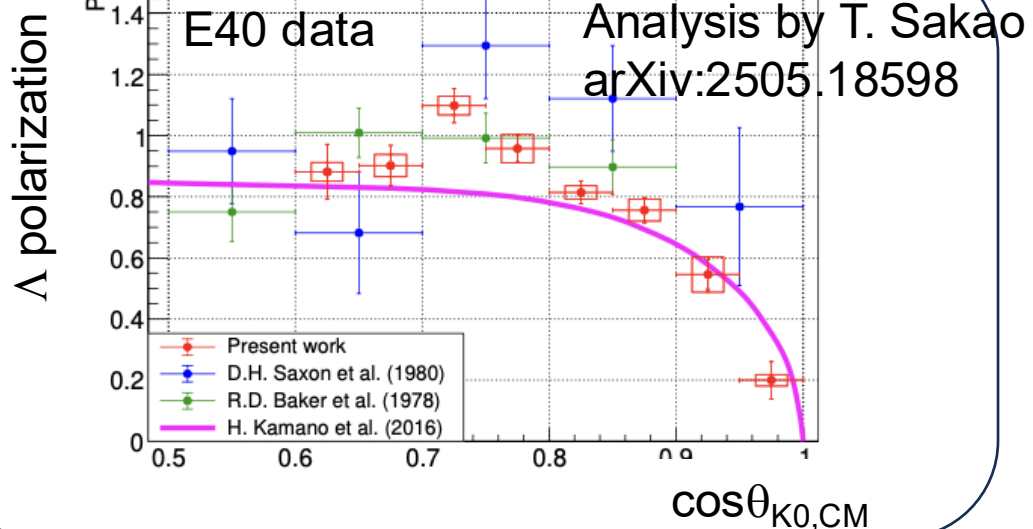
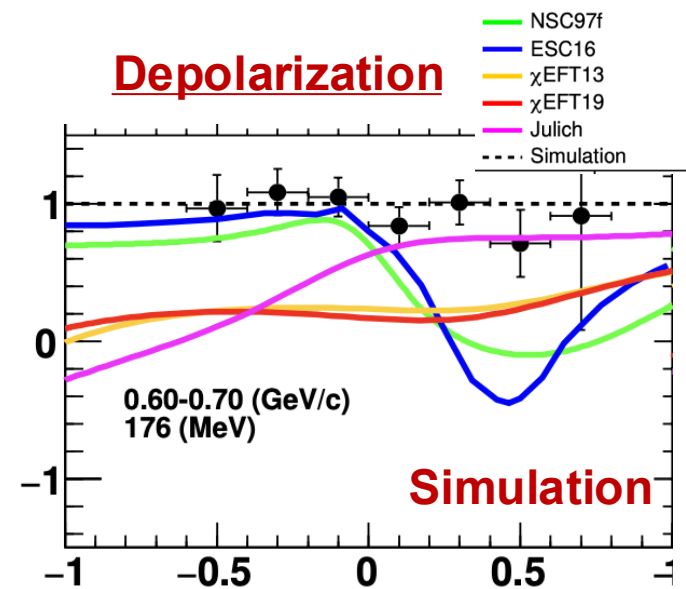


- Left-Right asymmetry of  $\Lambda p$  scattering (Analyzing power)
  - spin-orbit interaction
- Polarization change before and after the scattering (Depolarization)
  - spin-spin interaction, tensor interaction

## Analyzing power



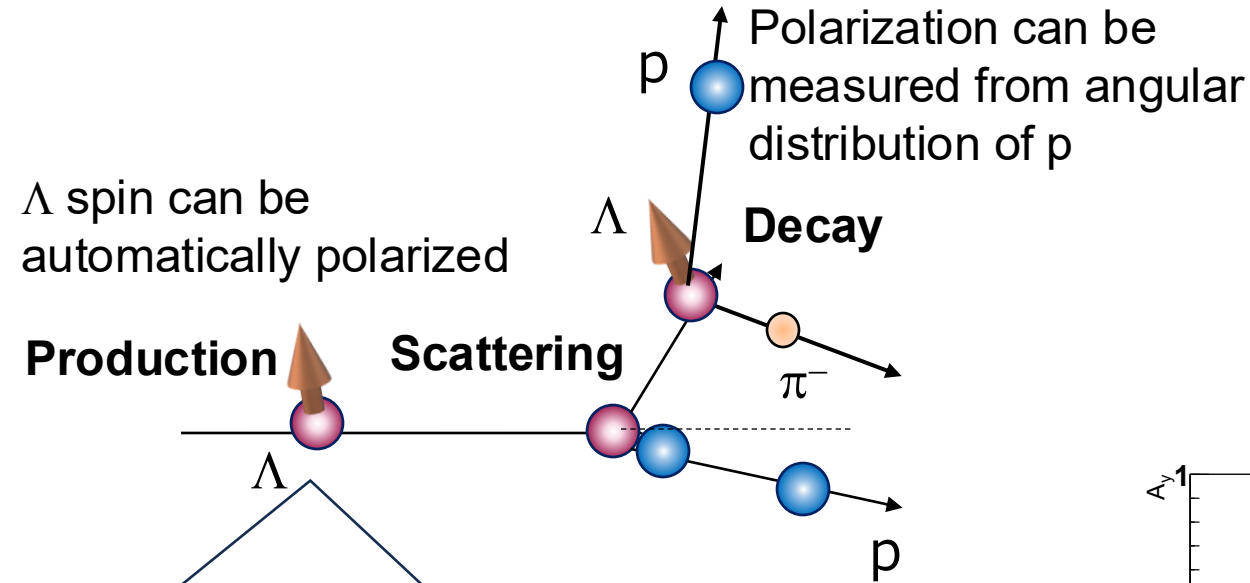
## Depolarization



Essential constraint to determine spin-dependent  $\Lambda N$  interaction

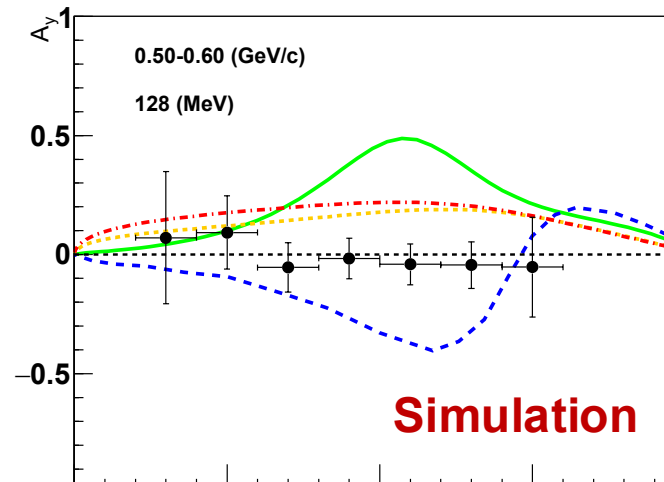
# $\Lambda p$ scattering experiment with polarized $\Lambda$ beam (J-PARC E86)

**Advantage of scattering experiment: Spin observables can be measured thanks to self polarimeter of hyperon**

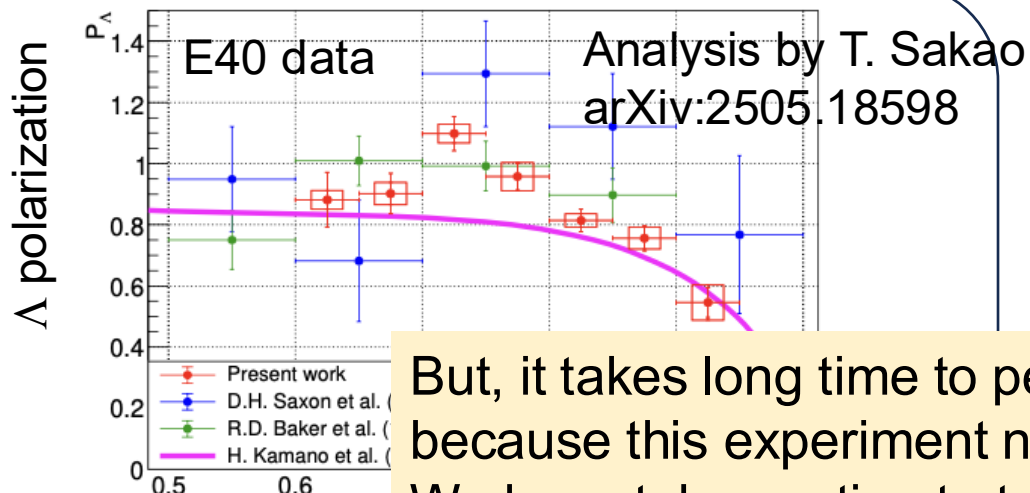
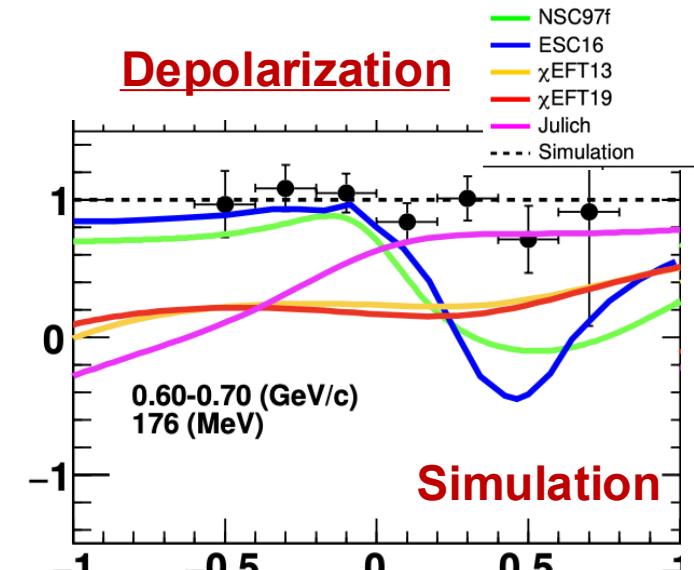


- Left-Right asymmetry of  $\Lambda p$  scattering (Analyzing power)
  - spin-orbit interaction
- Polarization change before and after the scattering (Depolarization)
  - spin-spin interaction, tensor interaction

## Analyzing power



## Depolarization



But, it takes long time to perform this experiment, because this experiment needs a construction of new K1.1 beam line. We have taken action to take data using photon beam at SPring-8 to measure  $d\sigma/d\Omega$ .

# $\Lambda$ p scattering experiment using photo-produced $\Lambda$ at SPring-8 (HYPS project)

This project is performed as RIKEN-TOHOKU project

# Building $\Lambda N$ interaction from $\Lambda N$ scattering experiment using photo-produced $\Lambda$

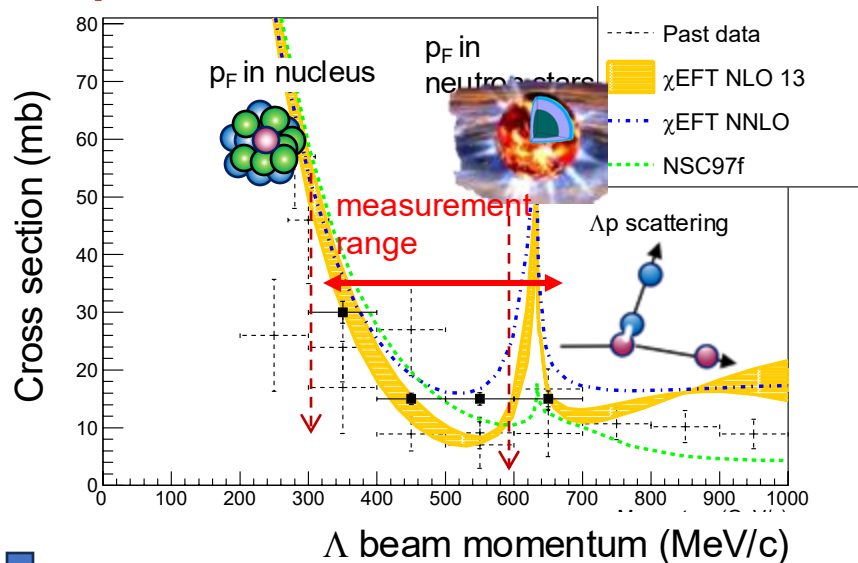
## Purpose of research

Building the realistic  $\Lambda N$  interaction by providing  $\Lambda N$  scattering data to chiral EFT theory

$\Lambda N$  interaction is still uncertain due to lack of scattering data, although the interaction is essential to describe many-body system with  $\Lambda$  such as hypernuclei and neutron stars.

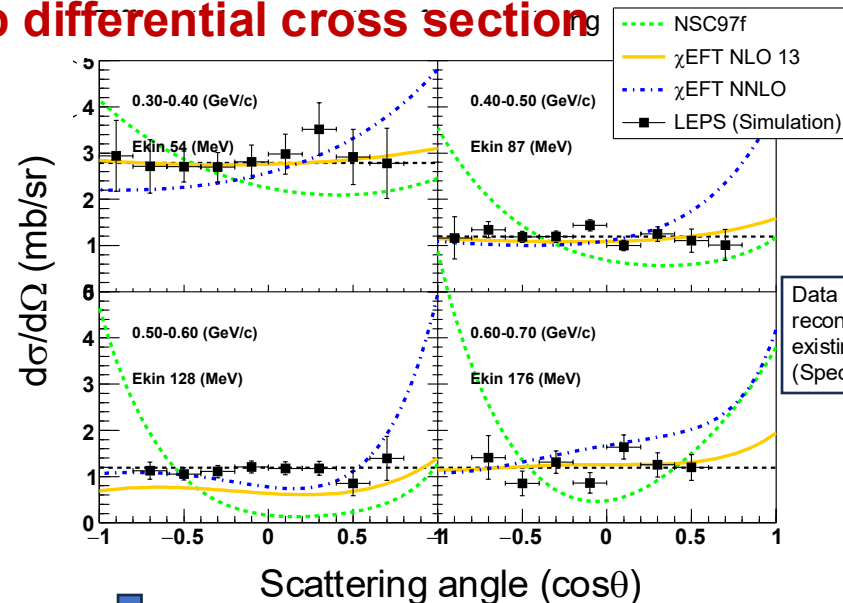
We plan to perform  $\Lambda p$  scattering experiment at BL33LEP

## $\Lambda p$ total cross section



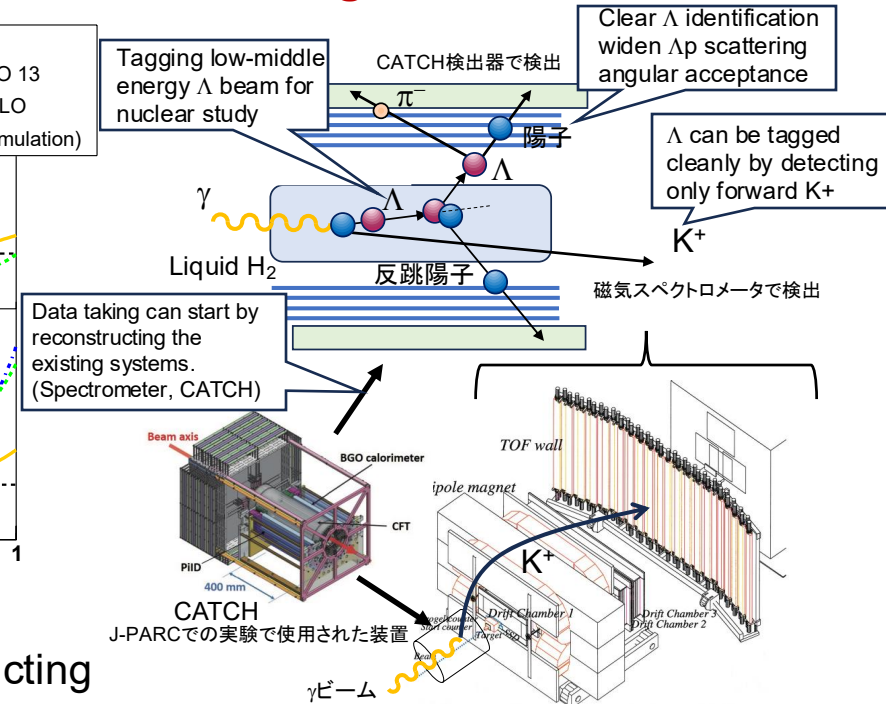
Density (radial) dependence of  $\Lambda N$  interaction

## $\Lambda p$ differential cross section



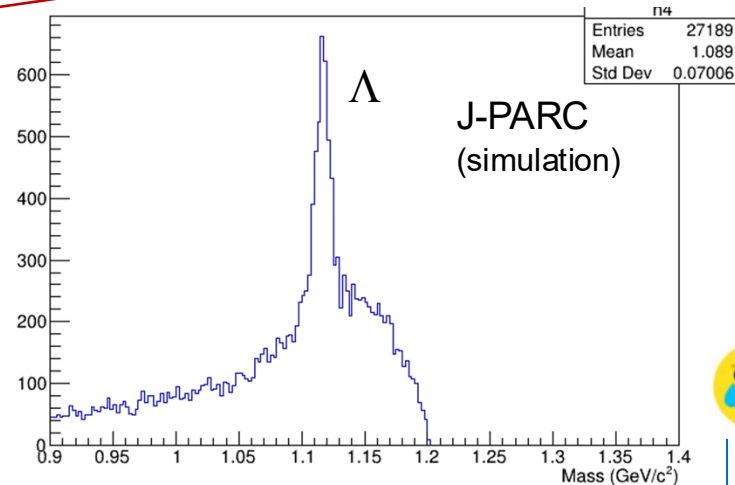
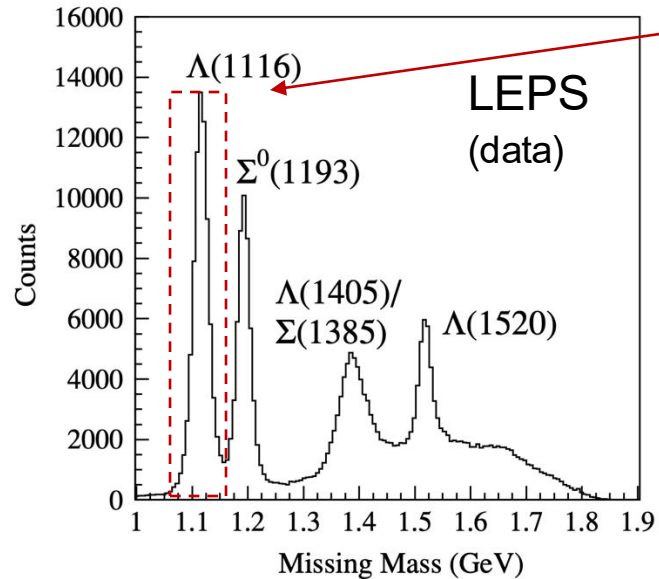
Essential input for constructing realistic  $\Lambda N$  interaction

## Advantage at BL33LEP



# Why BL33LEP?

**Advantage of  $\gamma$  beam:**  $\Lambda$  production can be identified most clearly by detecting  $K^+$



$K^0$  identification

→ Some background remains due to identification method



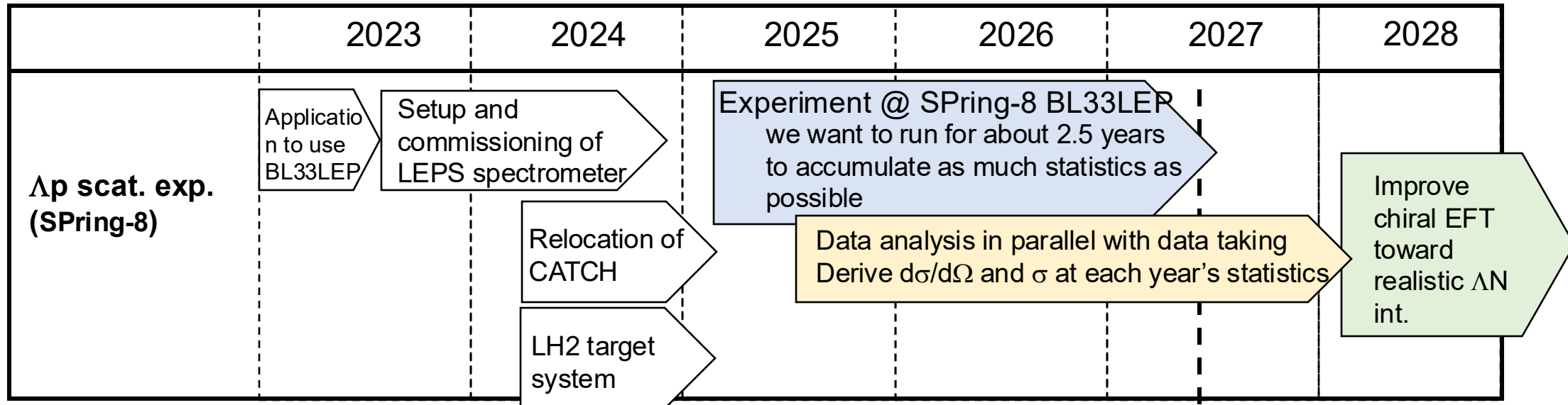
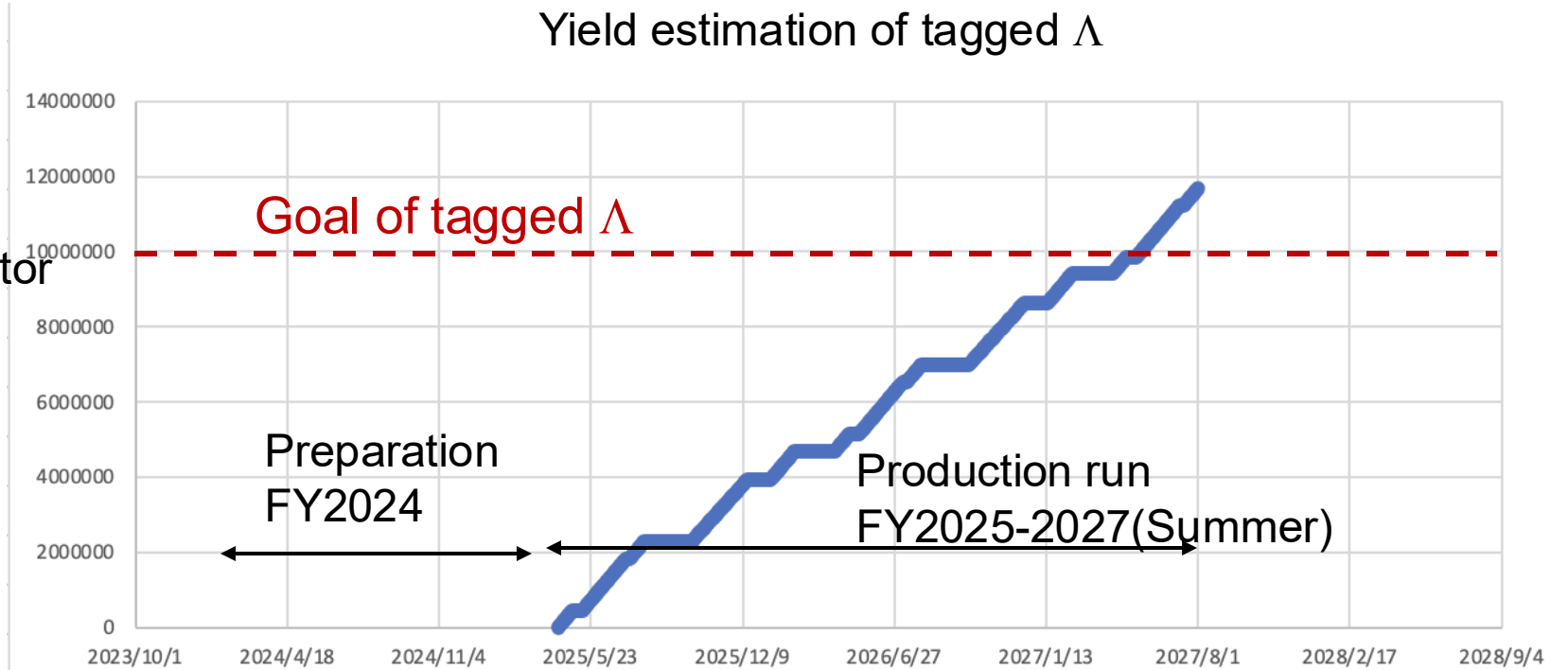
In the scattering analysis, we need to require two protons. This limits angular acceptance of  $\Lambda p$  scattering

**Advantage of backward Compton  $\gamma$  beam:** A forward spectrometer can be placed, making it possible to tag low-energy  $\Lambda$  with small momentum transfer for the first time .

We can get  $\Lambda$  beam from 0.3  $\text{GeV}/c$  (for nuclear study) to 0.6  $\text{GeV}/c$  (for neutron star)

# Timeline

FY2024: Commissioning of detector  
 FY2025: Start data taking  
 until Aug. 2027



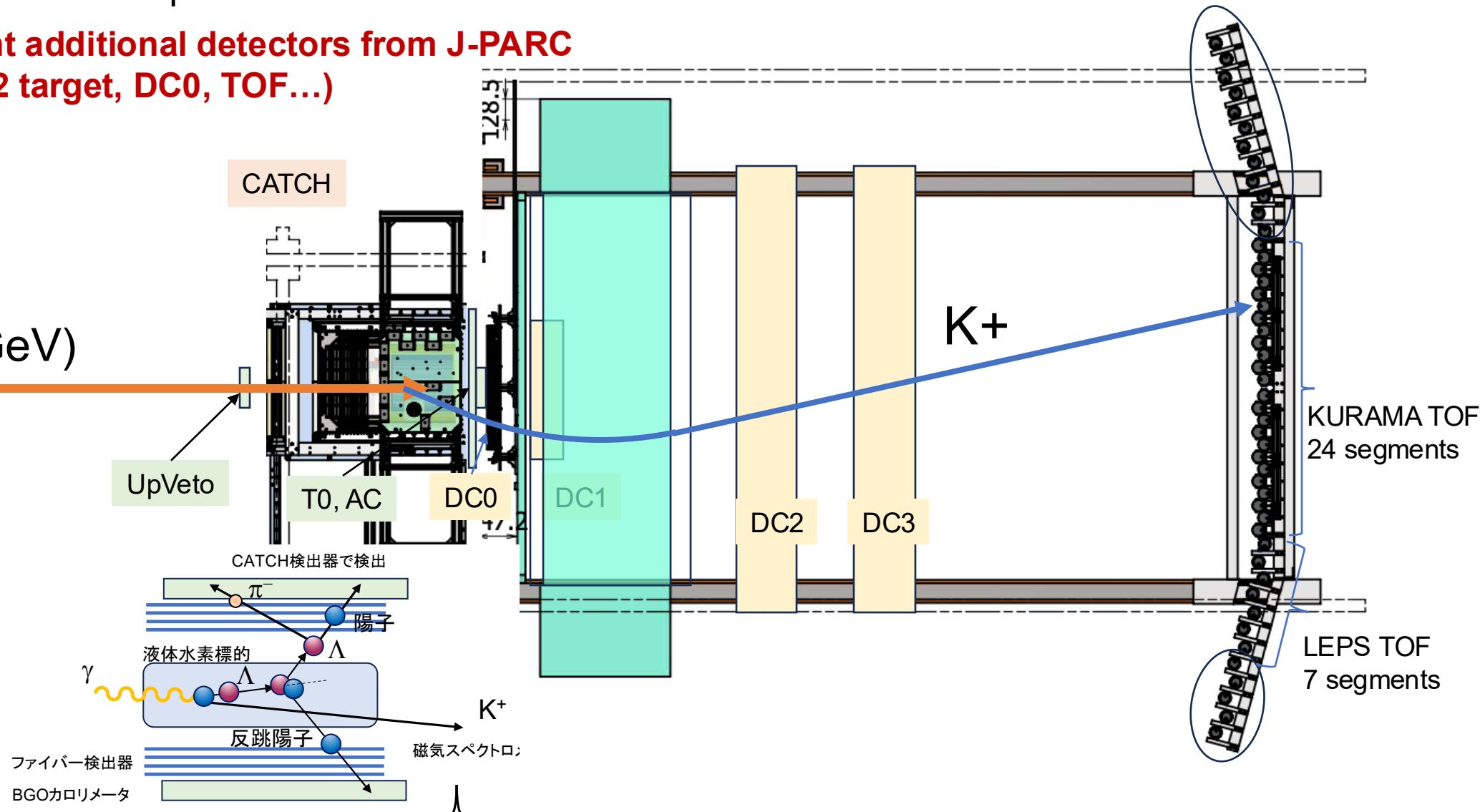
Beam stop at 2027 August ?

# Detector setup

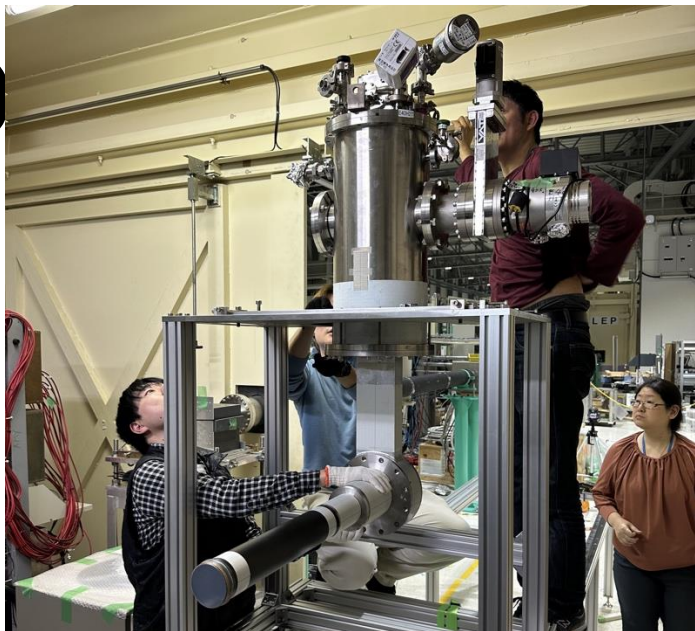
Base system : LEPS spectrometer

+ We brought additional detectors from J-PARC  
(CATCH, LH2 target, DC0, TOF...)

$\gamma$  beam  
(1.5-2.4 GeV)



D



LH2 target

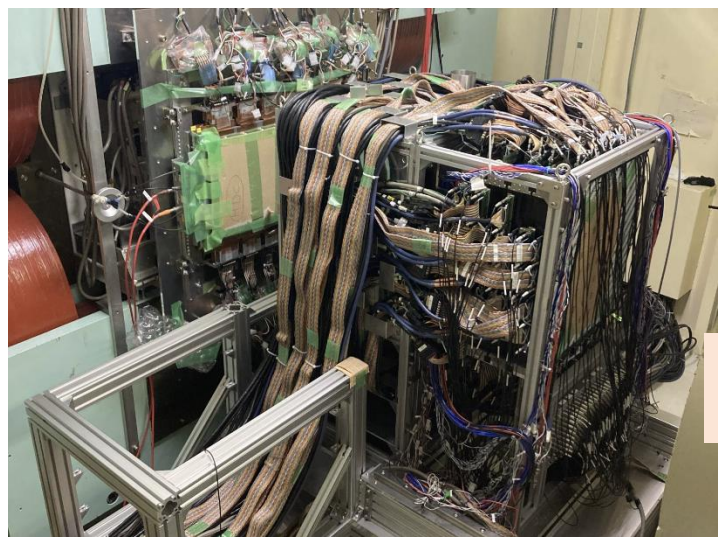
$\gamma$  beam  
(1.5-2.4 GeV)

UpVeto

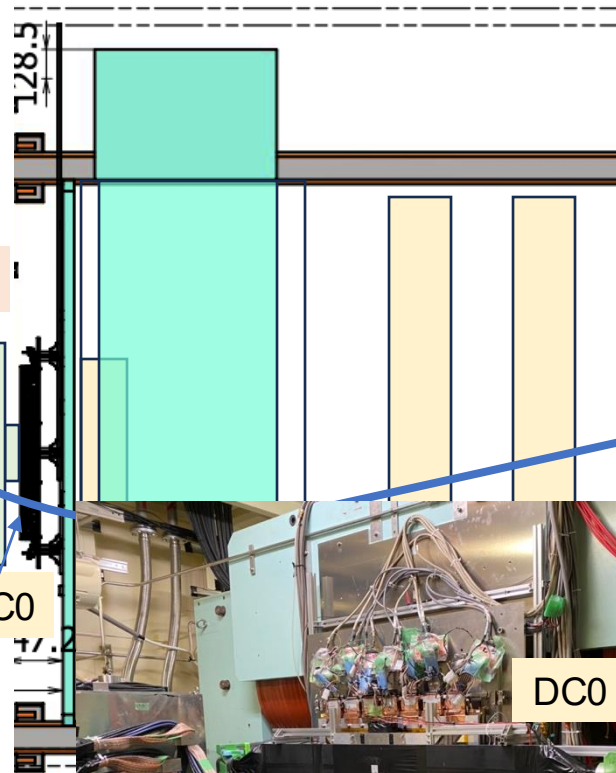
CATCH

T0, AC

DC0

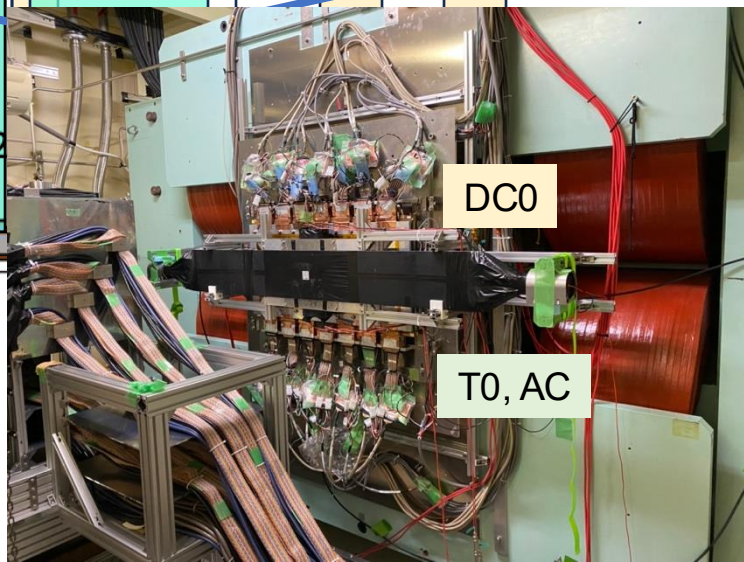


CATCH  
(after cabling)



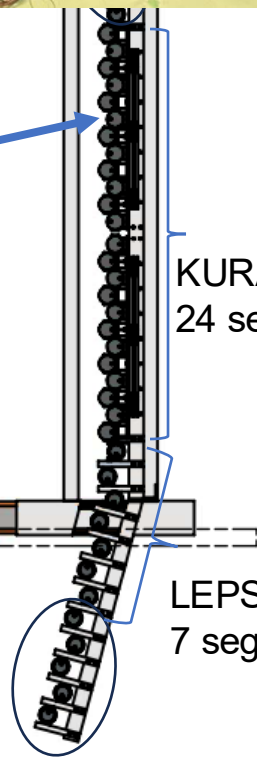
TOF

K<sup>+</sup>



DC0

T0, AC



KURAMA TOF  
24 segments

LEPS TOF  
7 segments

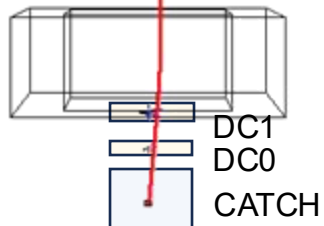
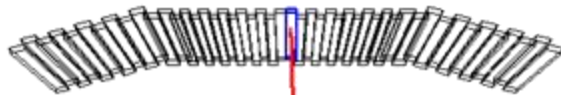
# Just started physics data taking

- We have just started physics data taking from 2025 April
- Detectors are working very well

Run# 240 Event# 86441

Spectrometer

TOFSeg 23  
TOFSeg 23

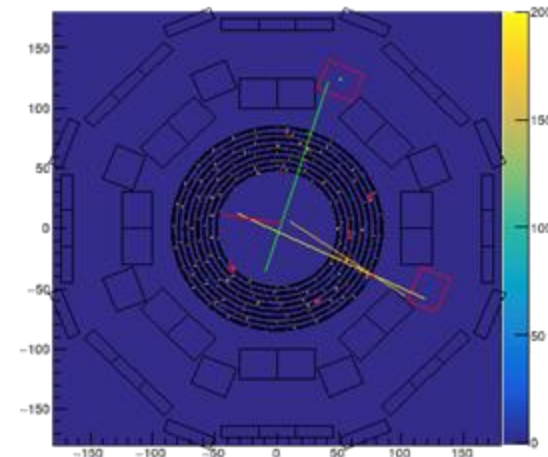


SdcIn  $\chi^2 = 2.482$   
SdcOut  $\chi^2 = 0.308$   
Hyps  $\chi^2 = 0.980$

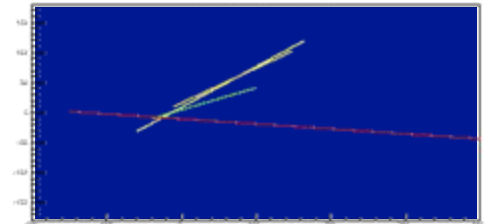
$\gamma$  beam

CATCH

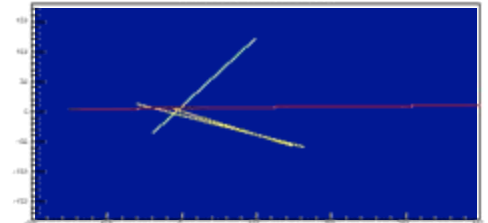
Event Display XY plane



Event Display ZX plane

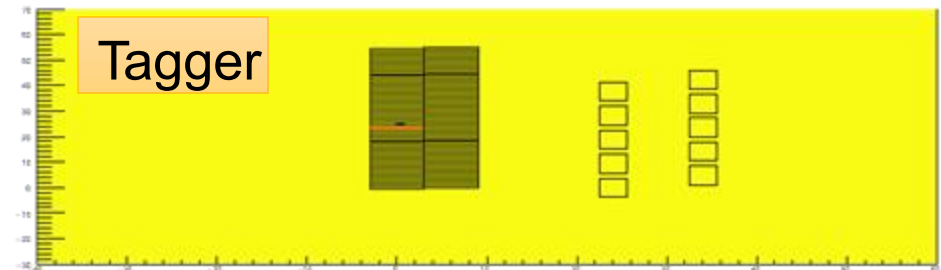


Event Display ZY plane



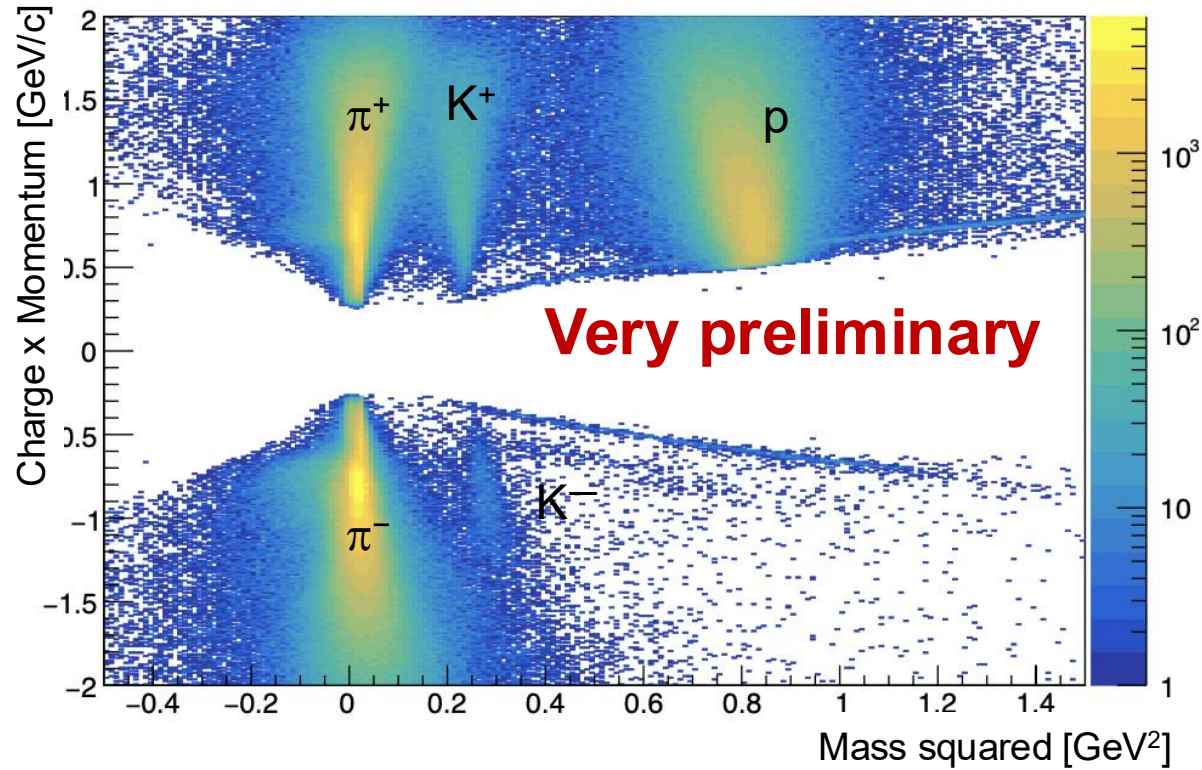
Tagger

Tagger

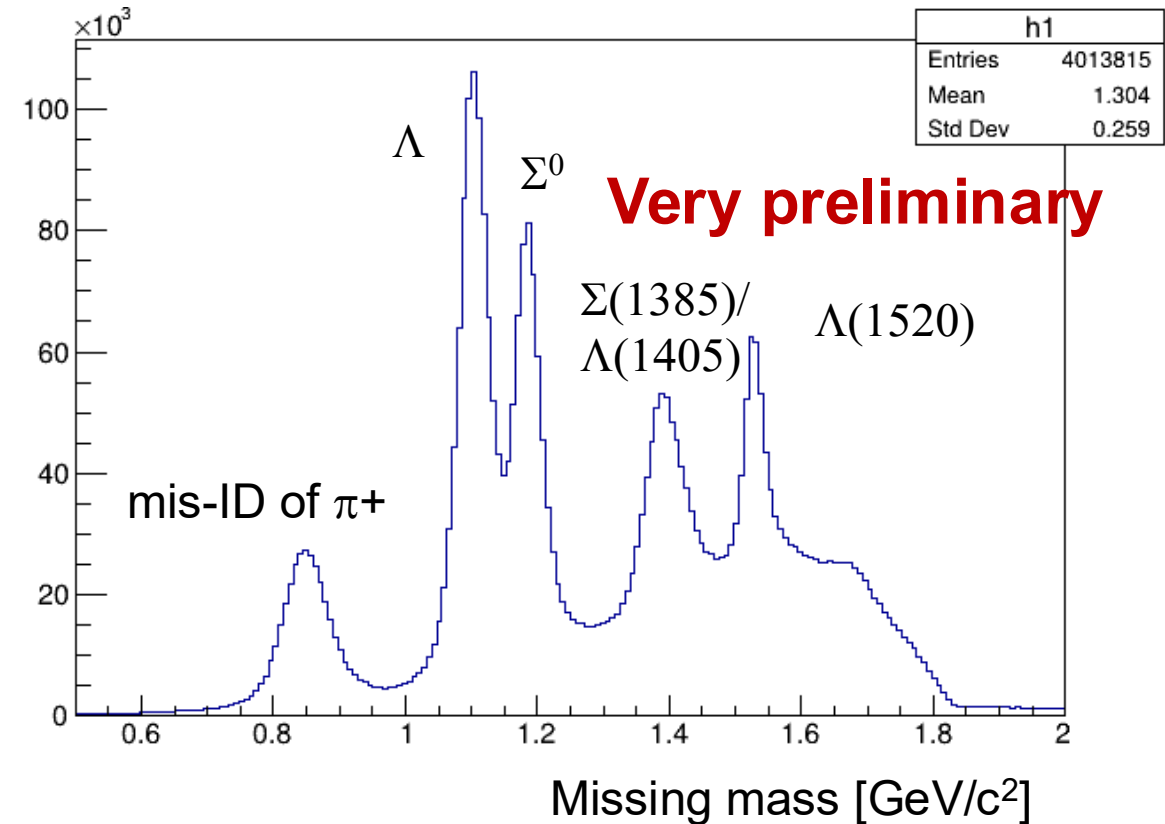


# Spectrometer analysis status

Scattered particle's identification

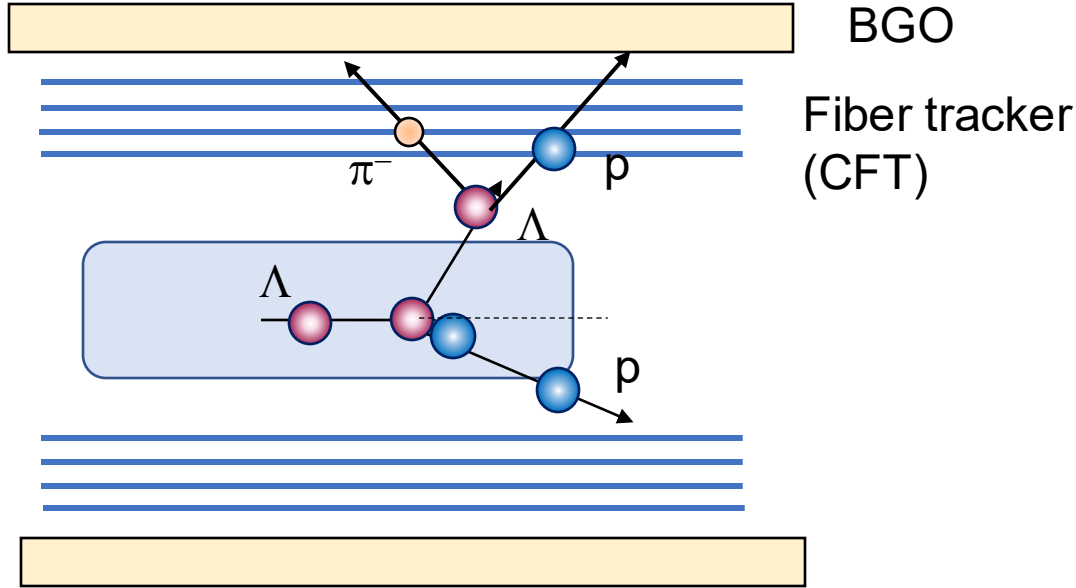


Missing mass spectrum of  $\gamma p \rightarrow K^+ X$  reaction



Detailed analysis status : T. Nanamura

# CATCH analysis



Proton can be stopped in BGO

→ Proton's direction and energy information

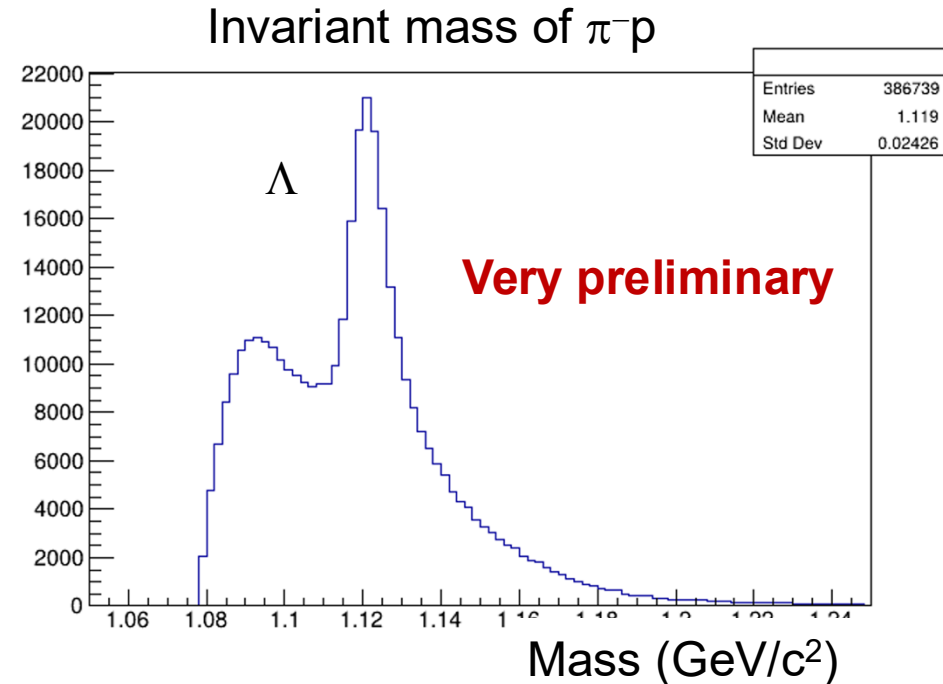
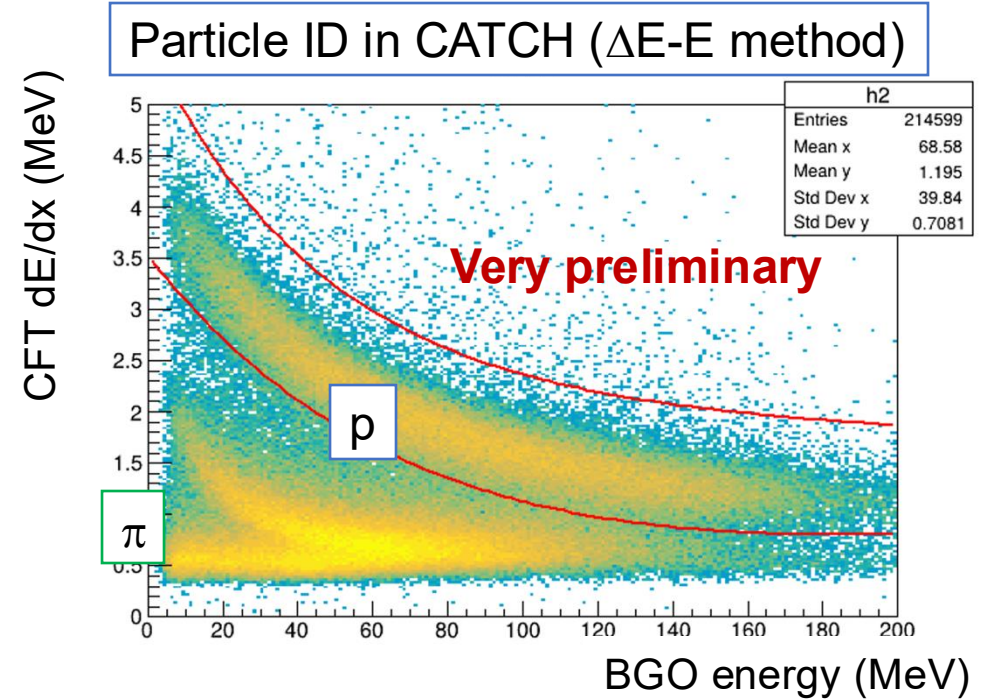
Pion cannot be stopped in BGO for many cases

→ Only direction information

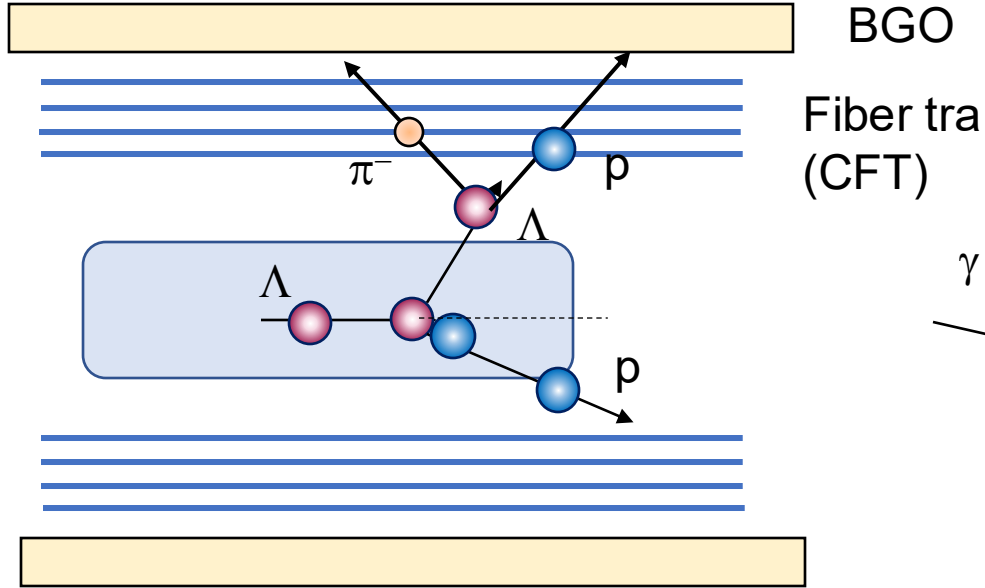
But,  $\pi^-$  from  $\Lambda$  decay has low momentum ( $\sim 150$  MeV/c)

→ many of  $\pi^-$  can be stopped (resolution is not so good)

$\pi^-$  energy is calculated from  $\Lambda$ 's decay kinematics.



# CATCH analysis

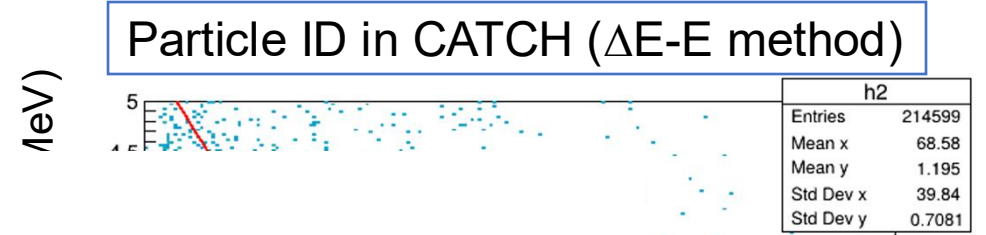


Proton can be stopped in BGO  
 → Proton's direction and energy information

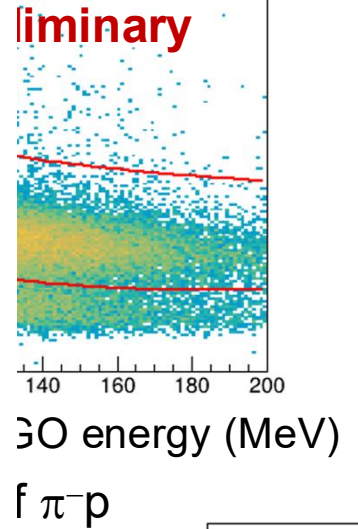
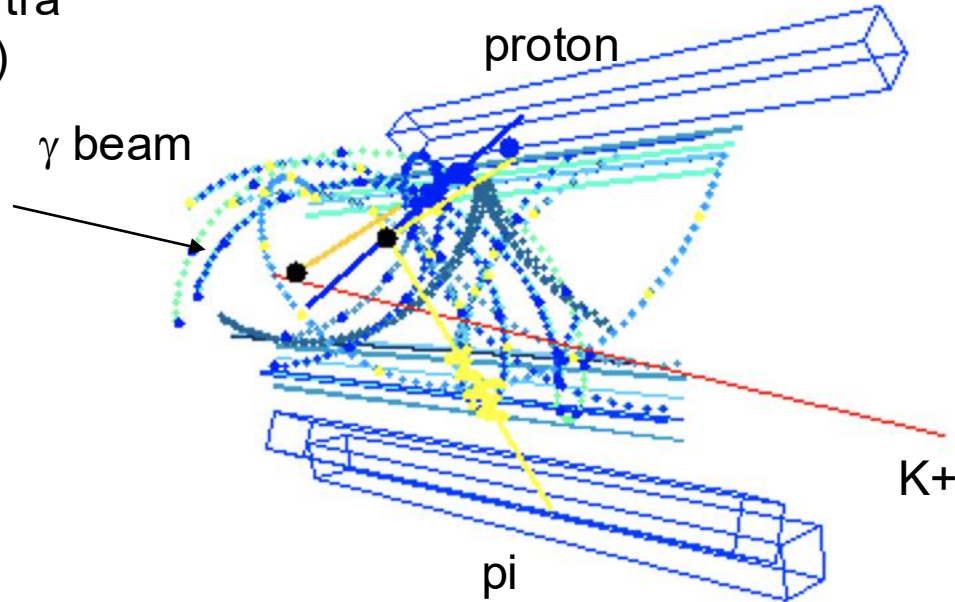
Pion cannot be stopped in BGO for many cases  
 → Only direction information

But,  $\pi^-$  from  $\Lambda$  decay has low momentum ( $\sim 150$  MeV/c)  
 → many of  $\pi^-$  can be stopped (resolution is not so good)

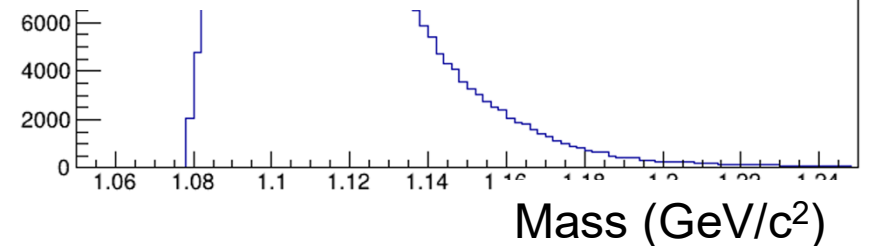
$\pi^-$  energy is calculated from  $\Lambda$ 's decay kinematics.



Typical event display

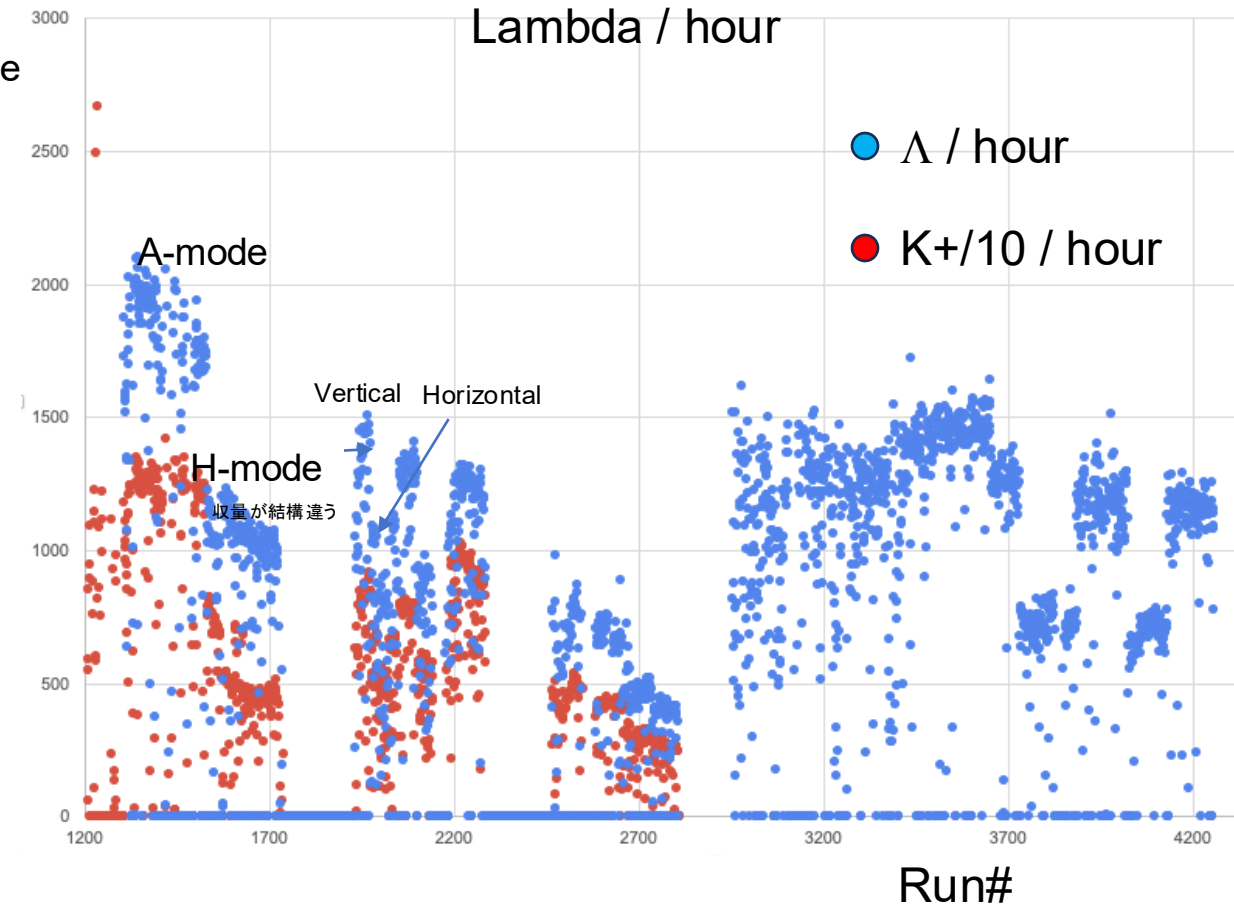
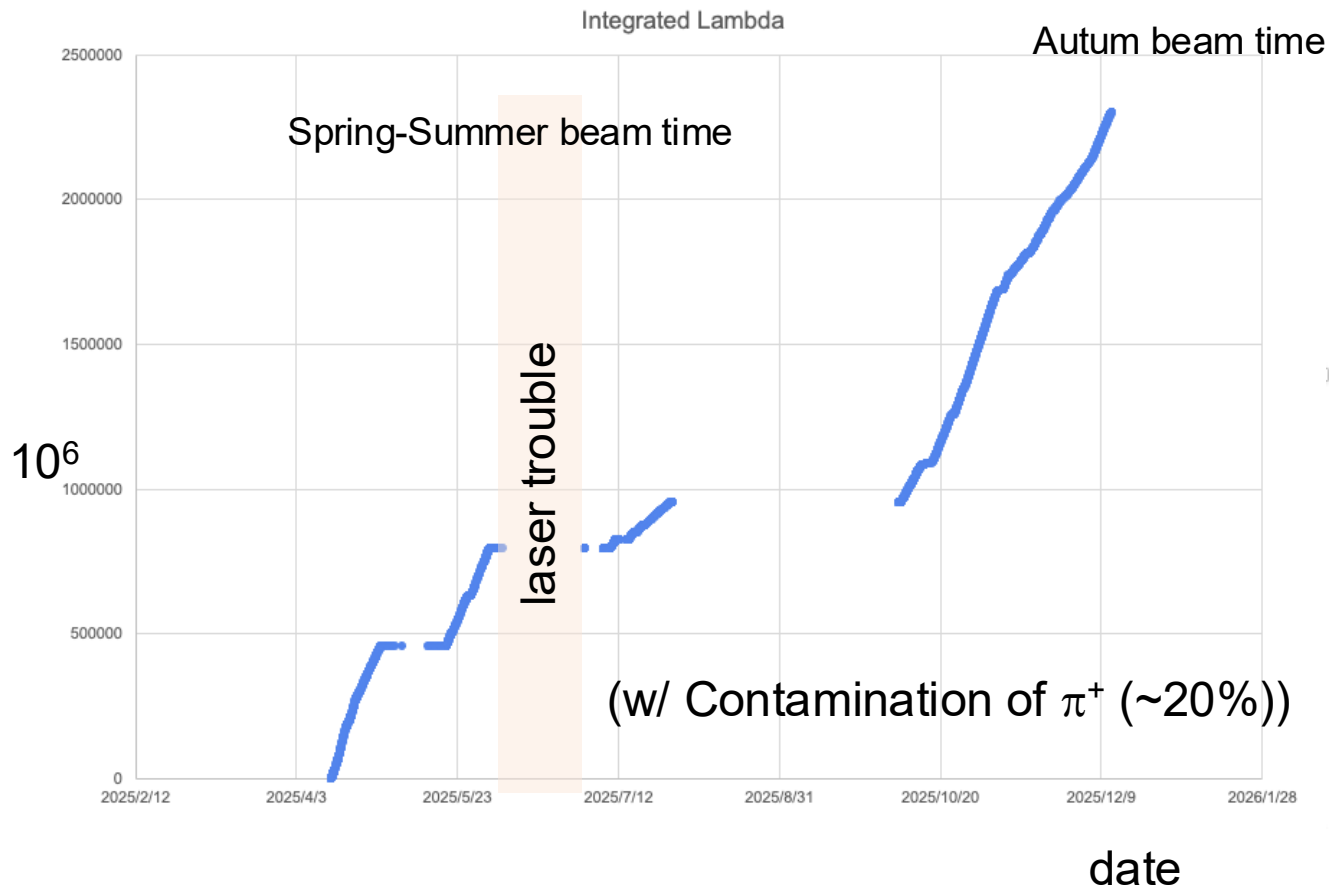


preliminary



# Integrated $\Lambda$ beam

- ✓ we have accumulated  $\sim 2 \times 10^6 \Lambda$
- ✓ We will continue data taking until 2027 July to accumulate  $10^7 \Lambda$



New  $\Lambda p$  scattering data will be provided within a few years !

# Summary

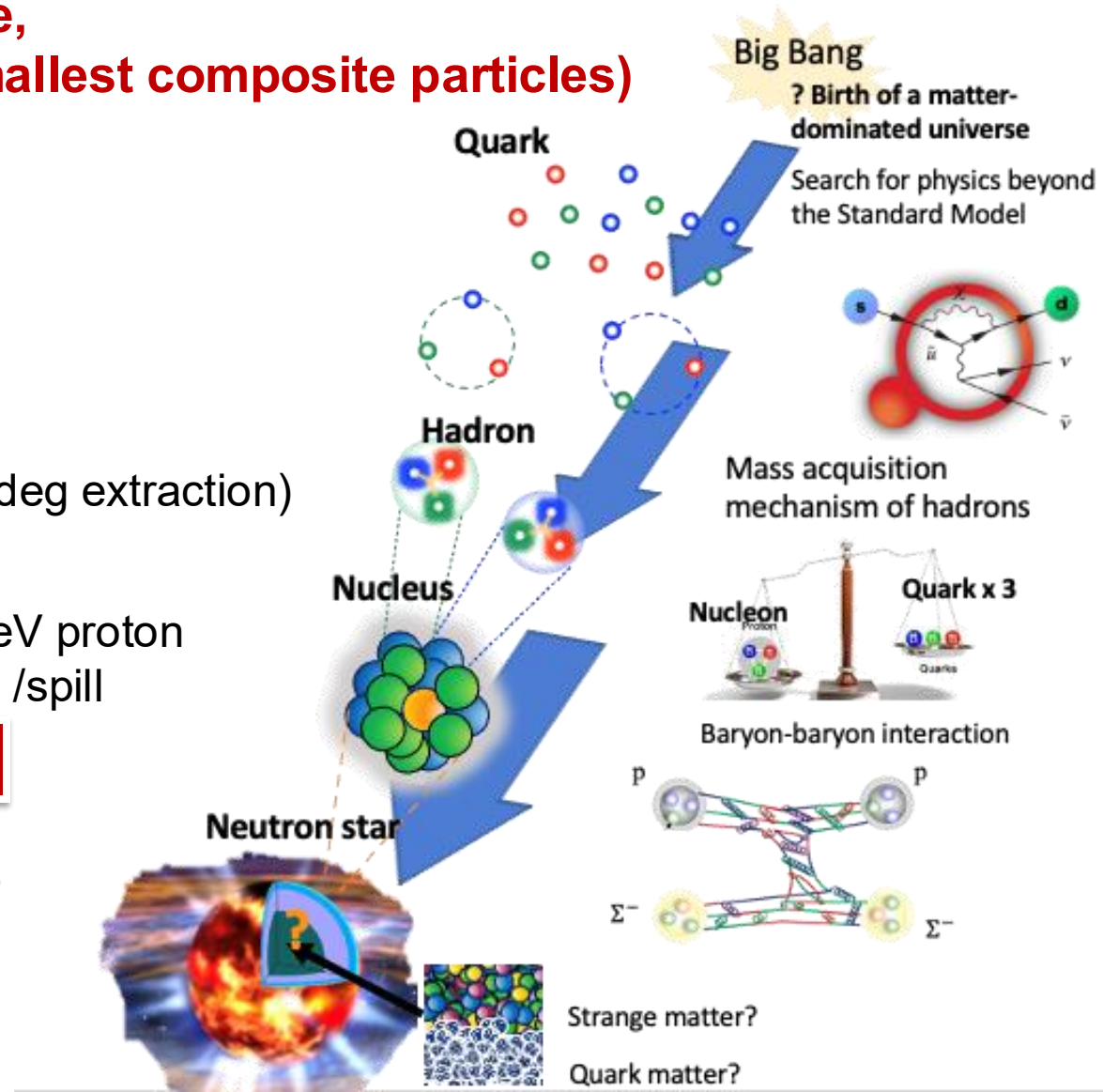
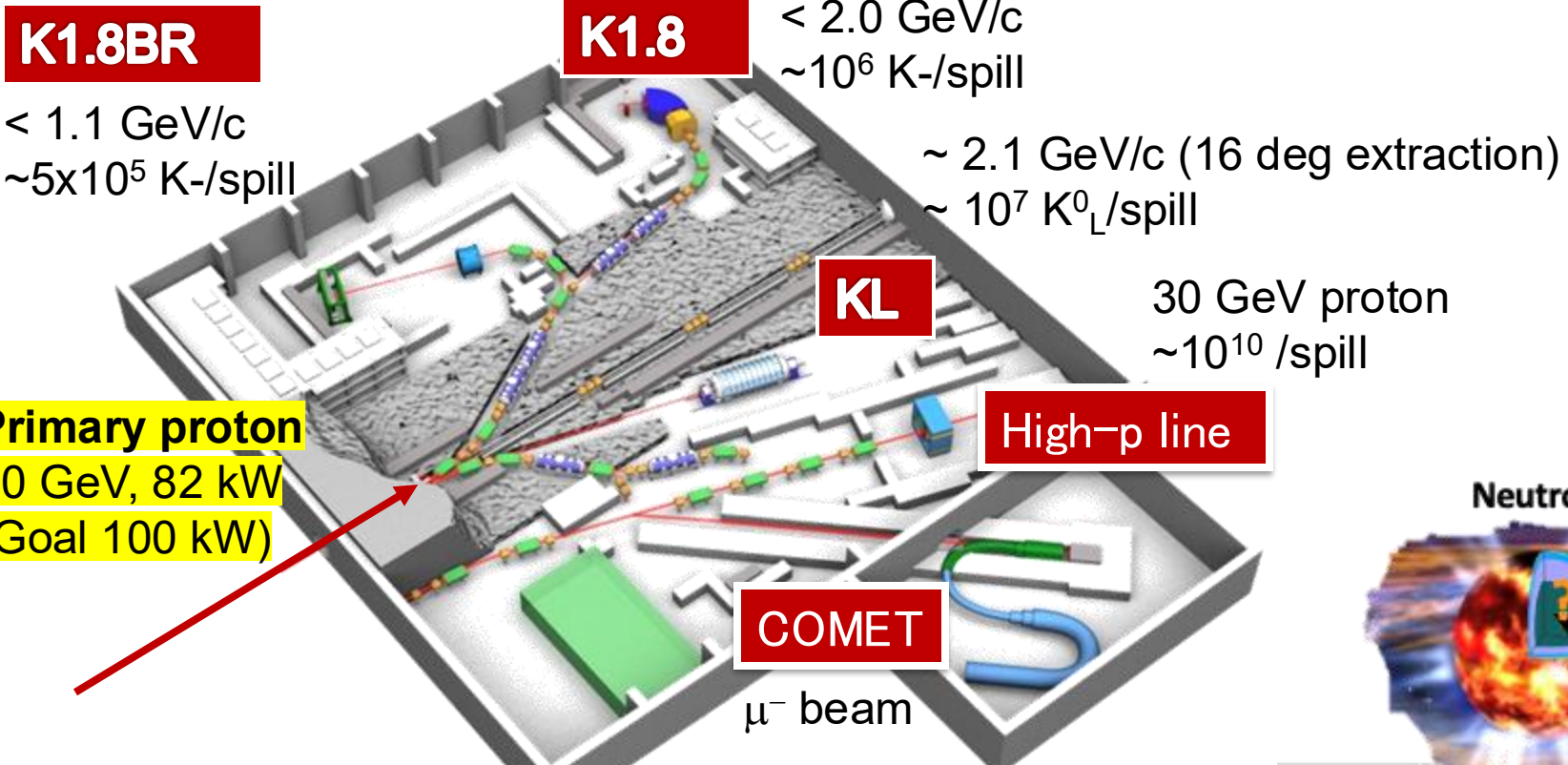
- Many progresses have been obtained in the BB interactions study.
  - Lattice QCD, Chiral EFT, ...
  - Femtoscopy is successfully used for the hadron-hadron interaction study.
  - YN scattering experiment gets possible!
- New collaborative project regarding the two-body  $\Lambda N$ ,  $\Sigma N$  interactions
  - $\Lambda p$  scattering experiment with photo-produced  $\Lambda$
  - Precise measurement of  $\Sigma N$  cusp shape with S-2S
  - Lattice QCD potential of  $\Lambda N$ ,  $\Sigma N$ ,  $\Lambda N$ - $\Sigma N$  potentials
- New experimental project just started at SPring-8 to measure  $\Lambda p$  scattering cross section
  - $\Lambda$  particle ( $300 < p_\Lambda < 600$  MeV/c) can be identified cleanly by  $\gamma p \rightarrow K^+ \Lambda$  reaction.
  - Experimental technology developed at J-PARC is introduced.
  - Our goal
    - Total cross section measurement better than 10%
    - First derivation of the differential cross section for  $\Lambda p$  elastic scattering

# Particle and Nuclear Physics at J-PARC HEF

Comprehensive research on the origin and evolution of matter and the universe

- the mystery of the matter-dominated universe,
- the evolution from quarks to hadrons (the smallest composite particles)
- neutron star as a giant atomic nucleus.

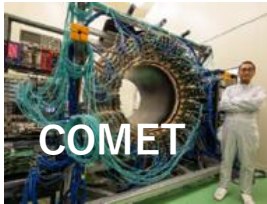
Intensity frontier accelerator providing intense and variety of secondary beams



# Particle and Nuclear Physics at J-PARC HEF

**Comprehensive research on the origin and evolution of matter and the universe**

- the mystery of the matter-dominated universe,
- the evolution from quarks to hadrons (the smallest composite particles)
- the neutron star as a giant atomic nucleus.



## $\mu \rightarrow e$ conversion measurement

Search for charged lepton flavor violation

100 times improvement over present upper limits



## Rare decay of neutral kaon

Search for CP violation beyond the standard model

The world's highest sensitivity exceeding the standard model



## Mass modification of vector mesons in nuclei

Elucidation of the mass acquisition mechanism of hadrons

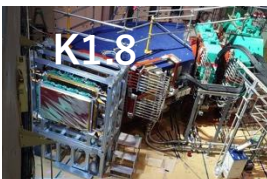
Vector meson in nuclei : 10 times more precision



## Systematic study of Kaonic nuclei

Study of exotic hadron bound system including K-

Mass number dependence of kaonic nuclei



## Spectroscopy of S=-1, -2 hypernuclei

Elucidation of the appearance mechanism of  $\Xi$ ,  $\Lambda$  hyperons in dense matter

Excellent mass resolution of 2 MeV for  $\Xi$  hypernuclei

