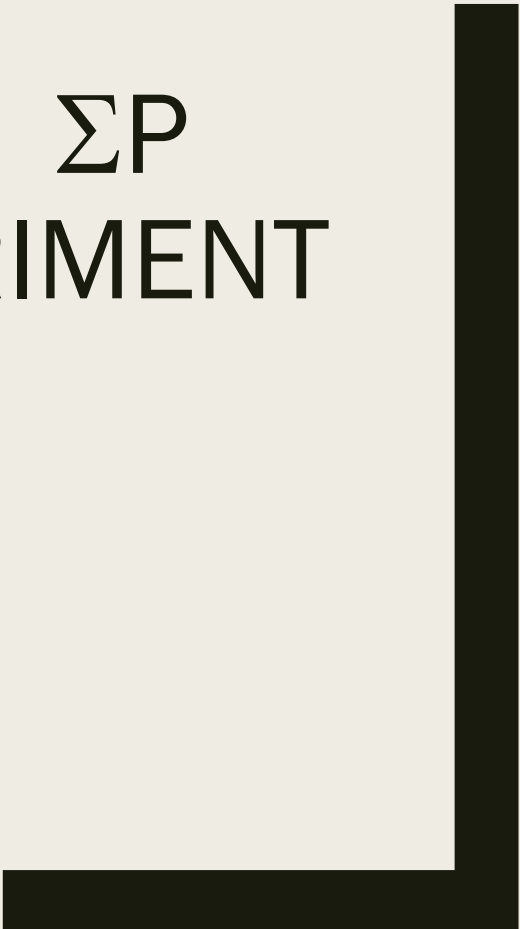




HIGH STATISTICS ΣP SCATTERING EXPERIMENT AT J-PARC

Koji Miwa (Tohoku univ.)
for the E40 collaboration



Collaborators

Tohoku Univ. : T. Aramaki, N. Chiga, N. Fujioka, M. Fujita, R. Honda, M. Ikeda, Y. Ishikawa, H. Kanauchi, S. Kajikawa,
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Osaka Univ. : K. Kobayashi, S. Hoshino, Y. Nakada, R. Nagatomi,
M. Nakagawa, A. Sakaguchi

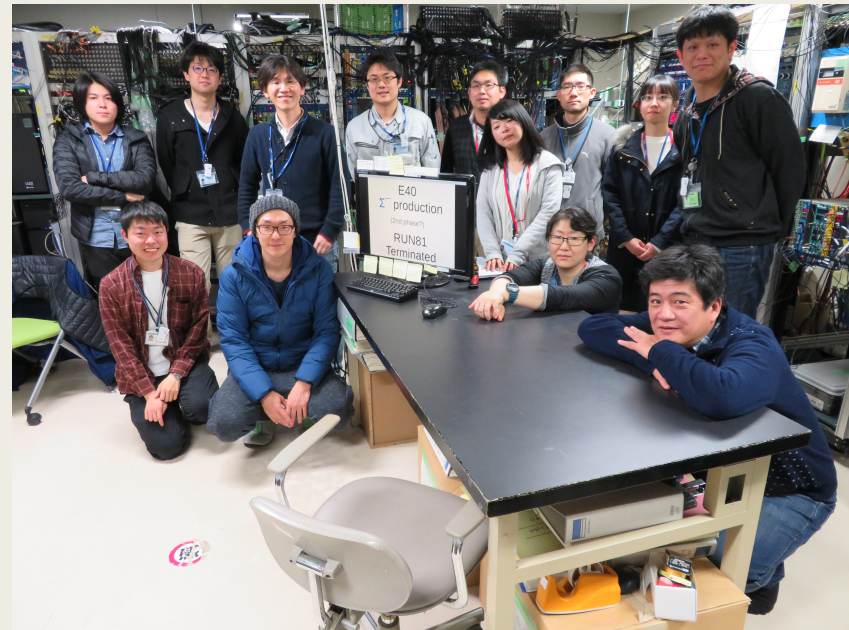
RCNP : H. Kanda, K. Shiotori, T.N. Takahashi

Okayama Univ. : K. Yoshimura

Korea Univ. : J.K. Ahn, S.H. Kim, W.S. Jung, S.W. Choi, B.M. Kang

OMEGA Ecole Polytechnique-CNRS/IN2P3 : S. Callier, C.d.L. Taille,
L. Raux

Joint Institute for Nuclear Research : P. Evtoukhovitch,
Z. Tsamalaidze



Contents

- YN interaction and Σp scattering
- Analysis status
 - $\Sigma^- p, \Sigma^- p \rightarrow \Lambda n$ scatterings
 - $\Sigma^+ p$ scattering
- Summary

Strategy of hypernuclear physics

Nuclear physics

Known nuclear force



Unknown nuclear structure

Hypernuclear physics

Unknown YN interaction



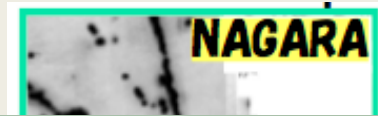
Expect from hypernuclear structure



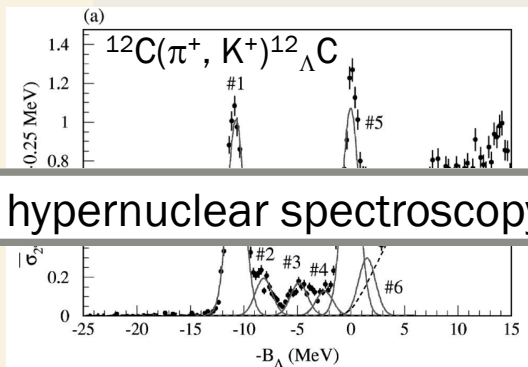
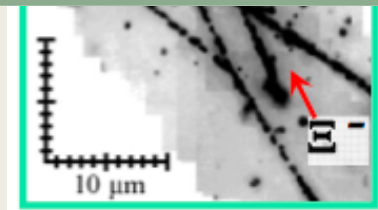
Hyperon proton scattering

Lattice QCD

Theoretical framework extended to $SU_F(3)$ symmetry

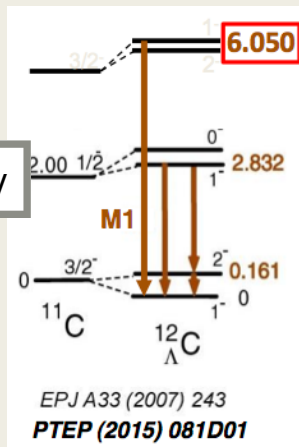


10 times more $\Lambda\Lambda$ hypernuclei



hypernuclear spectroscopy

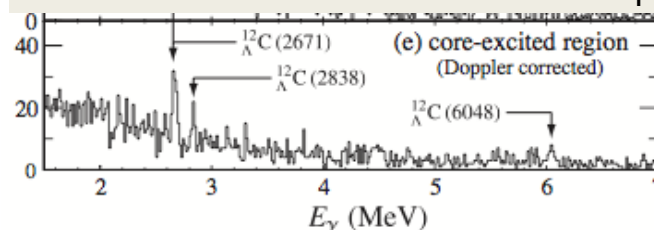
PRC 64 044302 (2001)



EPJ A33 (2007) 243
PTEP (2015) 081D01

sd-shell Λ hypernuclei

γ -ray spectroscopy

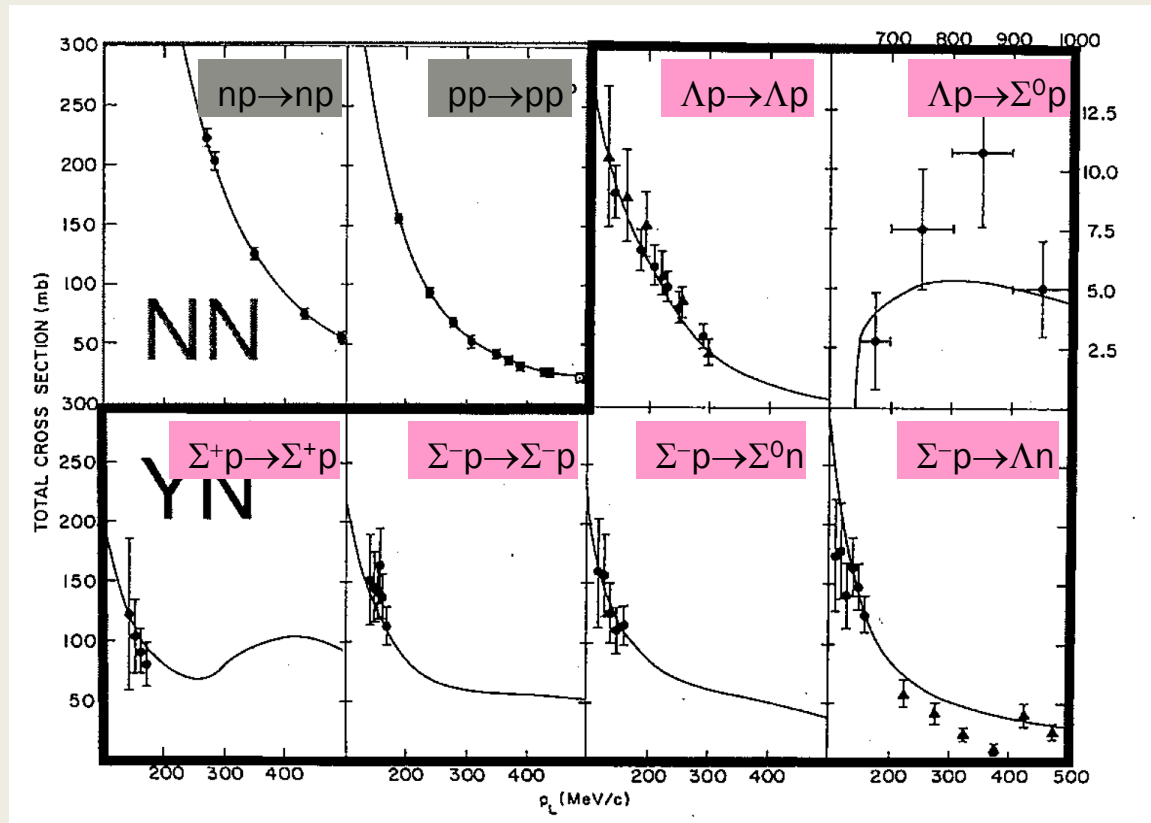


PRL 87 212502 (2001)

Current status of YN scattering experiment

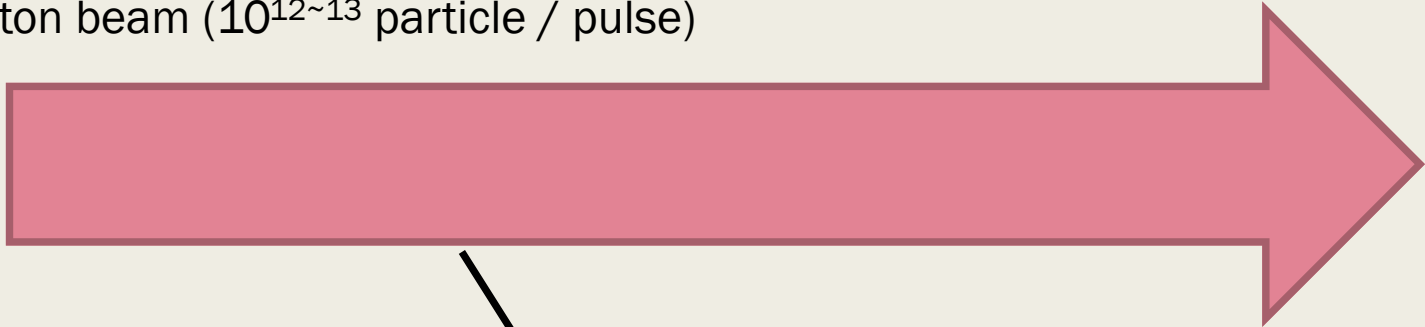
- NN scattering data : quite accurate
- YN scattering data : very poor statistics

Y. Kondo Doctor thesis



Comparison of Beam

Proton beam ($10^{12\sim 13}$ particle / pulse)



Secondary beam (π , K)
(10^7 particle / pulse)



flight length : ~ 80 m

Third beam (Σ , Λ)
(~ 100 particle / pulse)
even in E40 experiment



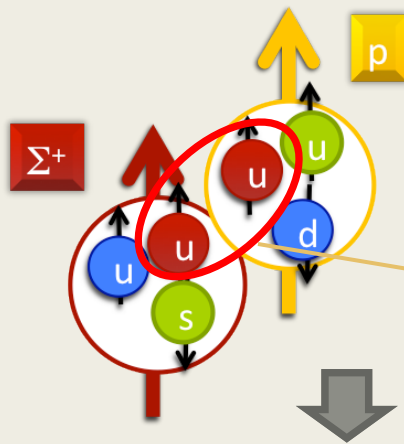
flight length : ~ 1.2 cm

J-PARC E40 :

Measurement of $d\sigma/d\Omega$ of Σp scatterings

■ Physics motivations

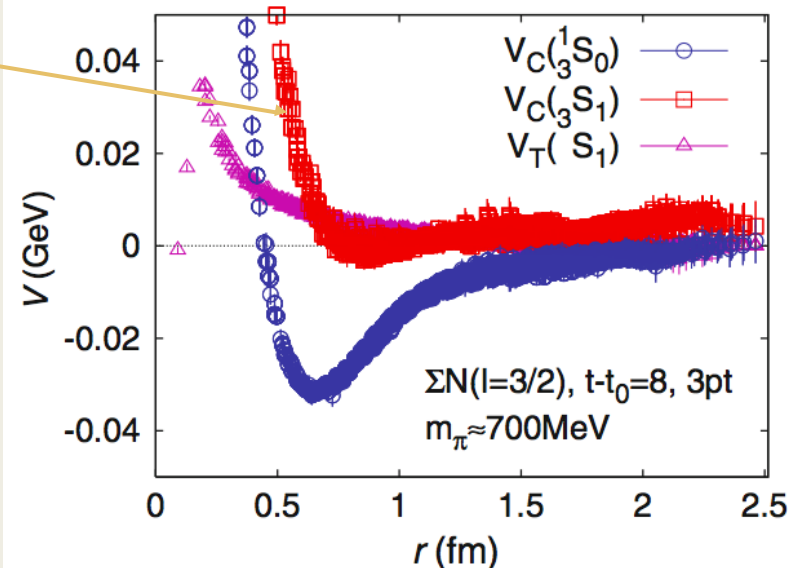
- Verification of repulsive force due to quark Pauli effect in the $\Sigma^+ p$ channel
- Systematic study of the ΣN interaction by separating isospin channel



Pauli effect in quark level

Large repulsive core is expected in Lattice QCD

$\Sigma^+ p$ potential by Lattice QCD



Large $d\sigma/d\Omega$ is predicted in $\Sigma^+ p$ channel

Measurement of $d\sigma/d\Omega$

Aim to detect 10,000 events

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

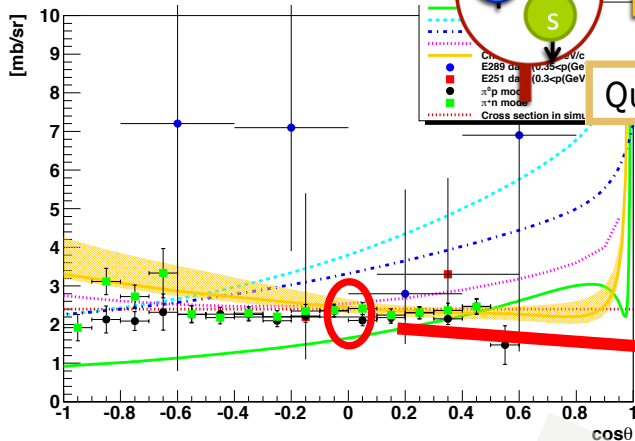
Our goal

Theories

- *Quark Cluster model (FSS, fss2)*
 - Y. Fujiwara et al., Prog. in Part. and Nucl. Phys. 58 (2007) 429, and private communication
- *Nijmegen model (ESC08c)*
 - T. A. Rijken, Prog. of Theor. Phys. Suppl. 185 (2010) 14, and private communication
- Chiral EFT (NLO)*
 - J. Haidenbauer et al., Nucl. Phys. A 915 (2013) 24, and private communication

$I=3/2$

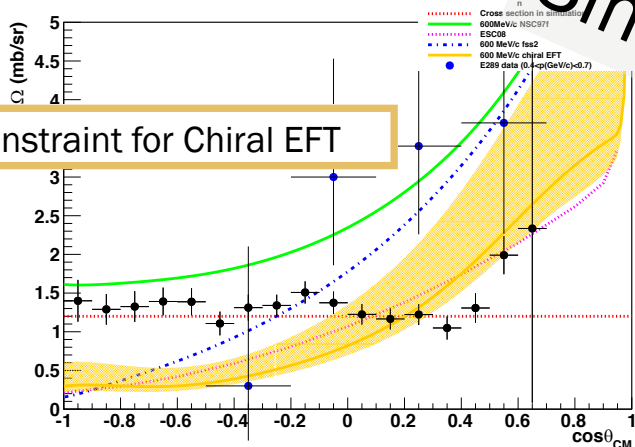
Σ^+p ($0.5 < p$ (GeV/c) < 0.6)



Phase shift of quark Pauli channel

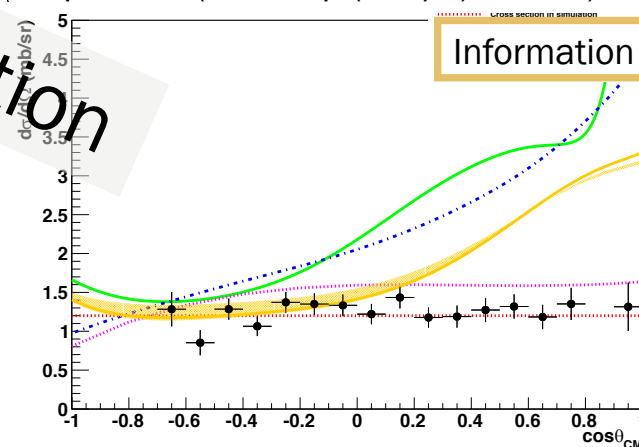
$$\frac{3}{4} \frac{1}{k^2} \sin^2 \delta_{3S1} = \frac{d\sigma}{d\Omega}(90^\circ) - (\text{higher waves})$$

Σ^-p ($0.55 < p$ (GeV/c) < 0.65)



Simulation

$\Sigma^-p \rightarrow \Lambda n$ ($0.55 < p$ (GeV/c) < 0.65)



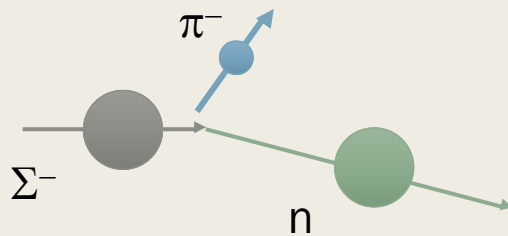
$I=1/2$

Experiments at J-PARC

2018

1st production run

Σ^- -p scattering in June 2018 (~2 days)



Σ^- : Longer life time
No decay channel to proton



Easier to check experimental feasibility

2019

2nd production run

Σ^- -p scattering production run in 2019 Feb. – March (~20 days)

17 M Σ^-

Σ^+ -p scattering production run in 2019 April (~13 days)

40 M Σ^+

Due to accelerator trouble, half of beam time was postponed.

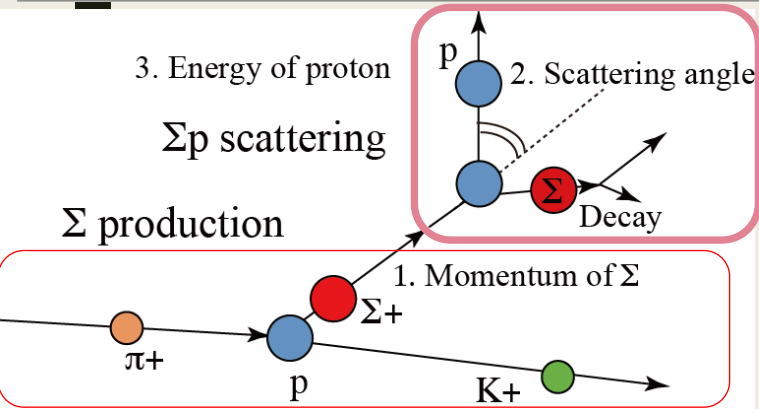
2020

3rd production run

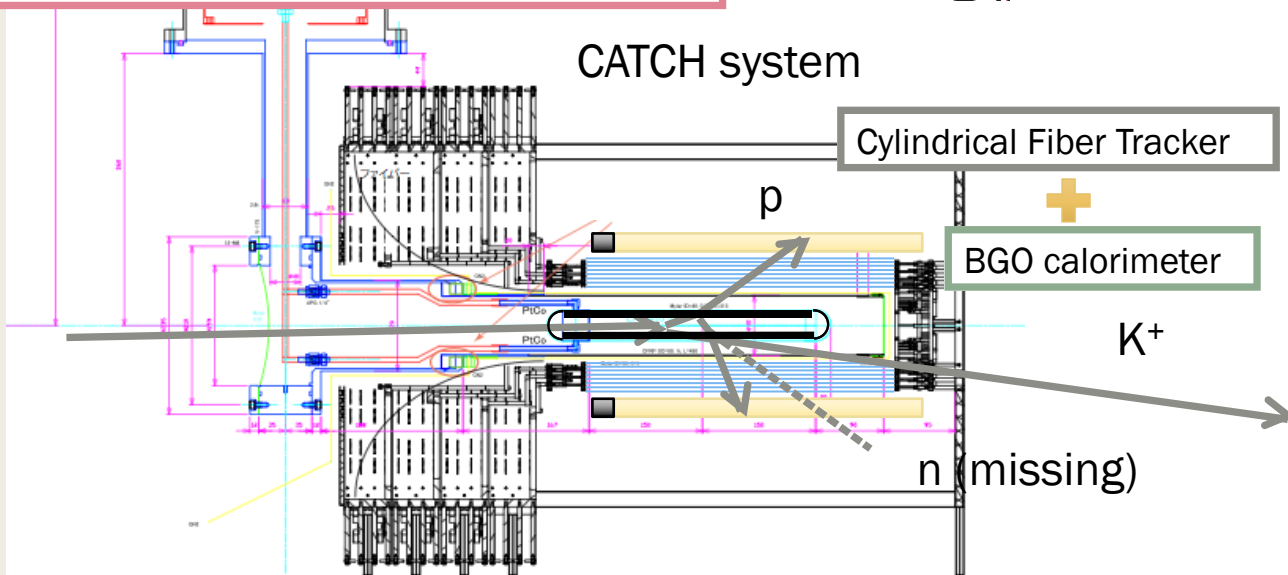
Σ^+ -p scattering production run in 2020 Feb. - March

E40 detector setup concept

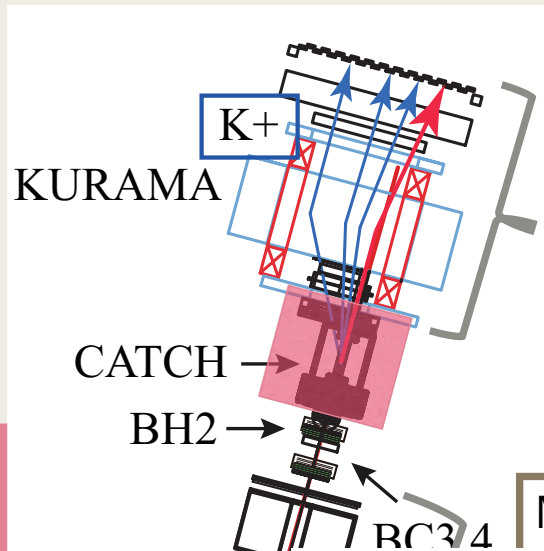
Two successive two-body reactions



Detection of Σp scattering event by CATCH detector



J-PARC K1.8 beamline



KURAMA spectrometer

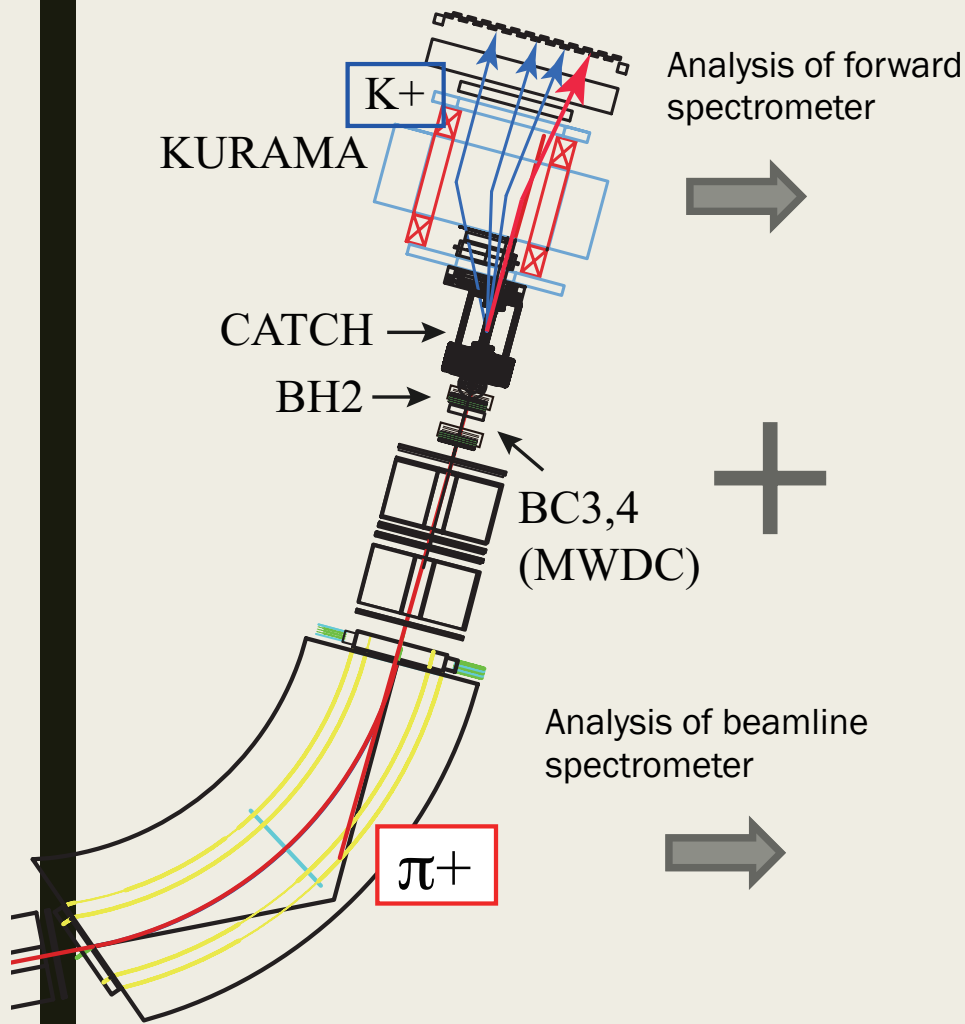
- Identification of K^+
- Momentum analysis

Momentum reconstruction
 Σ beam

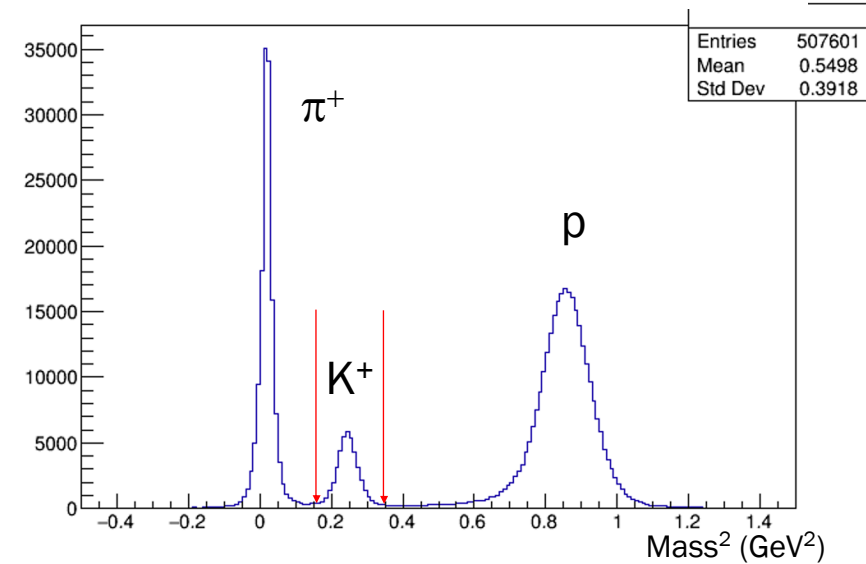
Beamline spectrometer

- Momentum analysis of π beam

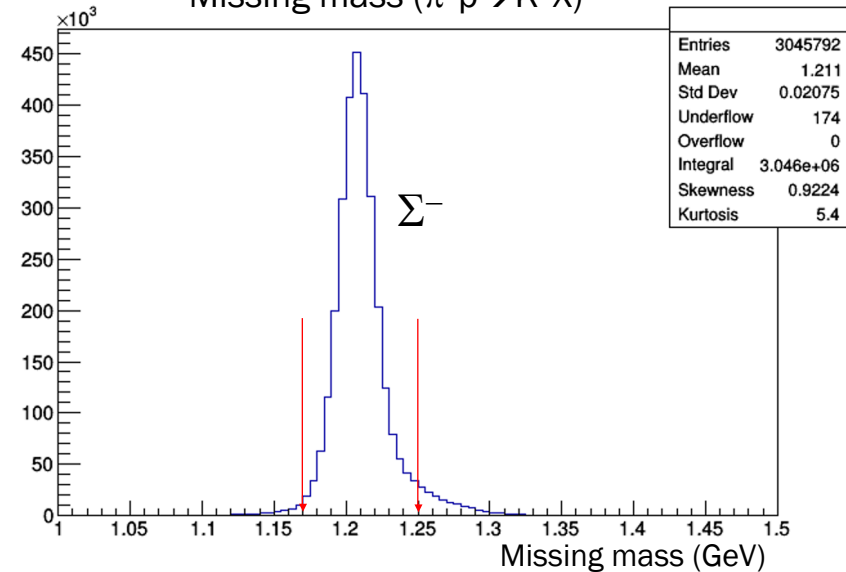
Σ Identification



Mass square distribution of outgoing particle



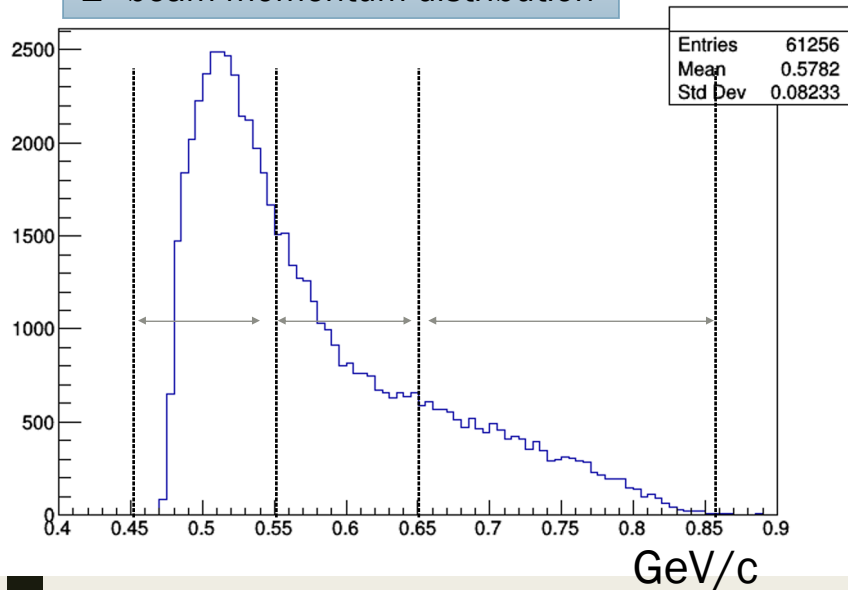
Missing mass ($\pi p \rightarrow K^+ X$)



Σ beam momentum distribution

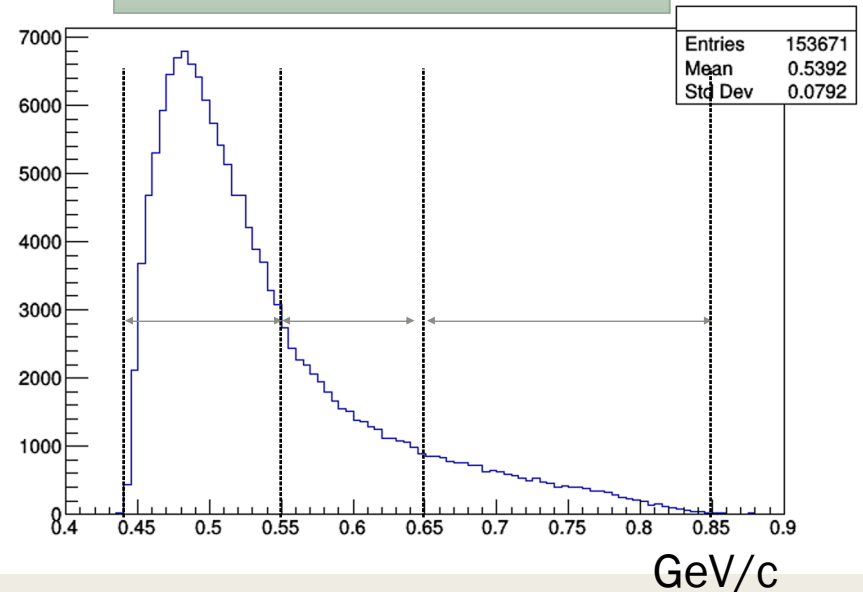
Σ^- yield : ~17 M (Our goal 18M)
 $c\tau = 4.4$ cm

Σ^- beam momentum distribution



Σ^+ yield : ~40 M (Our goal 80M)
 $c\tau = 2.4$ cm

Σ^+ beam momentum distribution

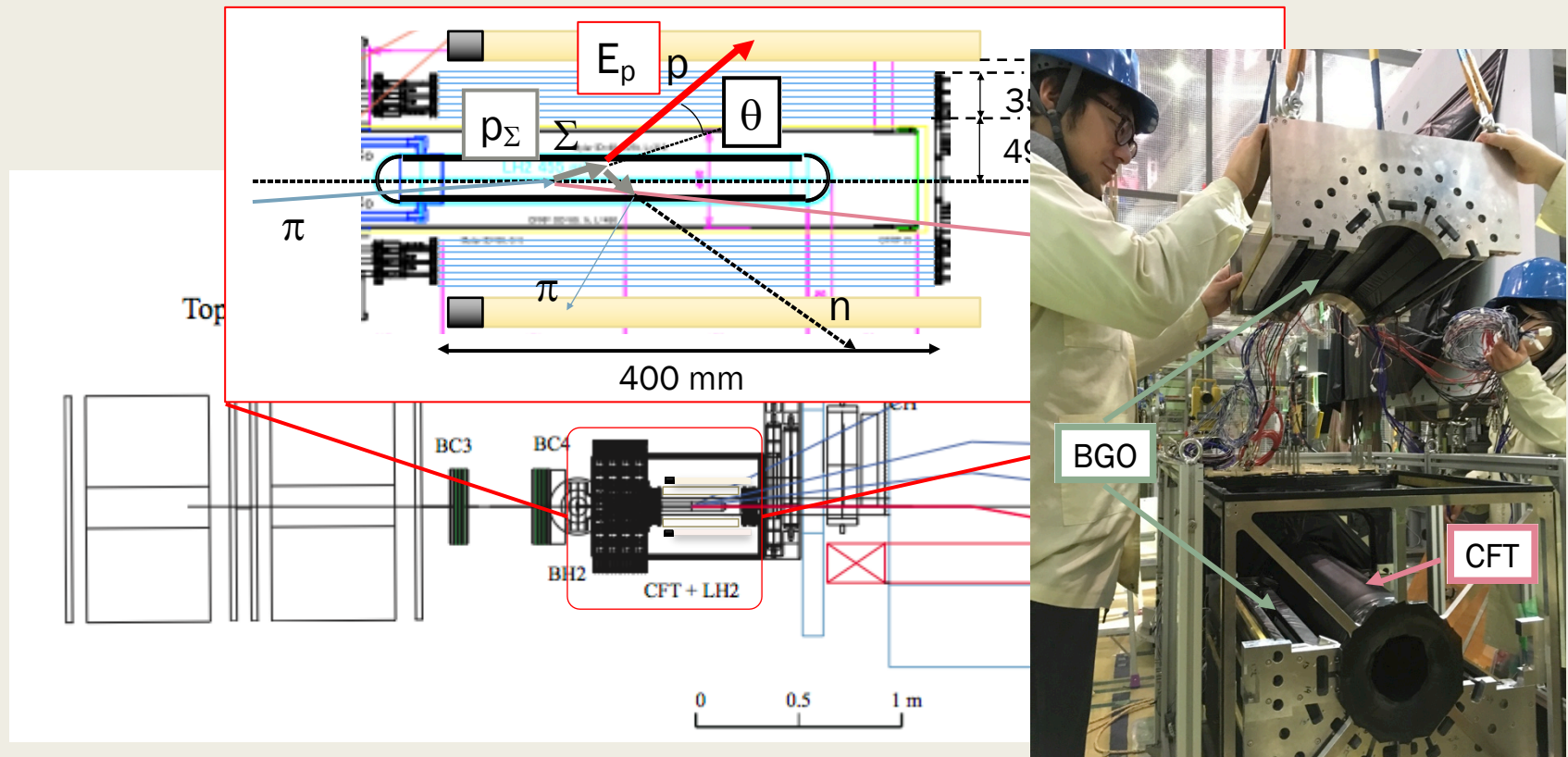


Derive differential cross section for three momentum ranges to understand beam momentum dependence

Σp scattering detector (CATCH)

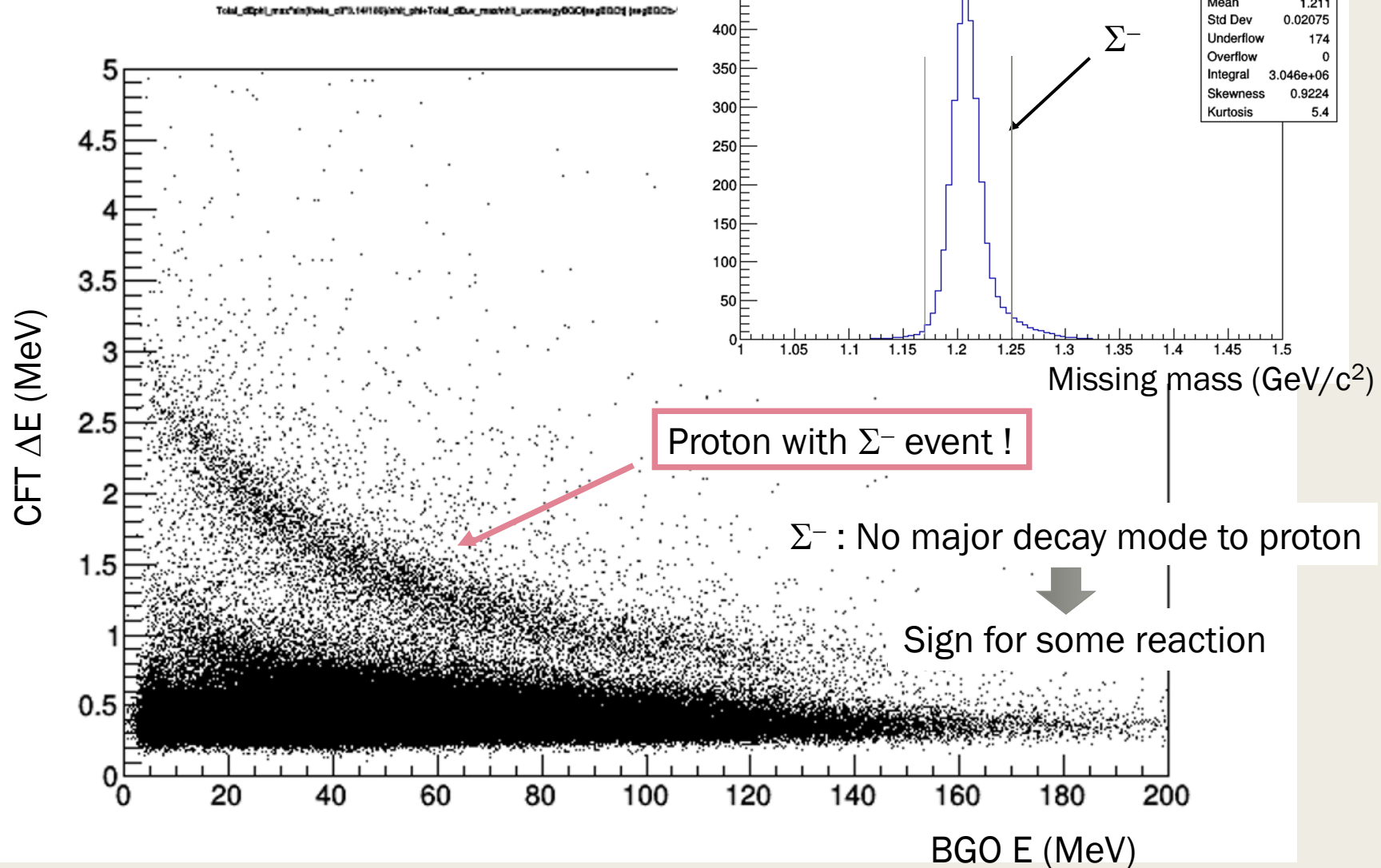
- Compact setup to satisfy both K^+ acceptance and Σp scattering acceptance
- Fast response detector to reject accidental coincidence events

Cylindrical Fiber Tracker + BGO calorimeter configuration



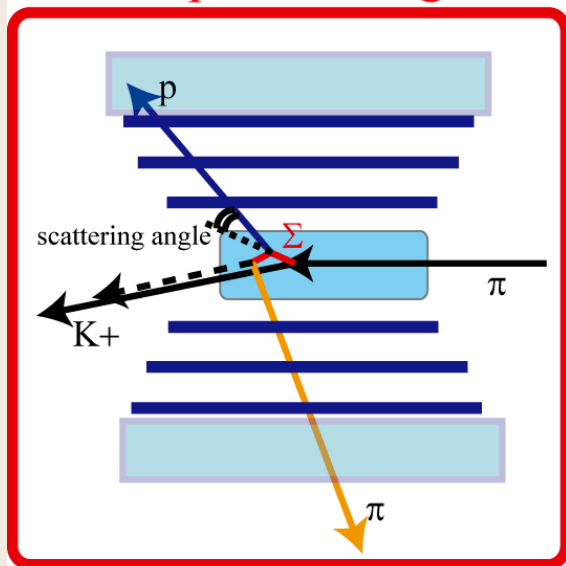
CATCH Particle ID w/ Σ^- event

Missing mass

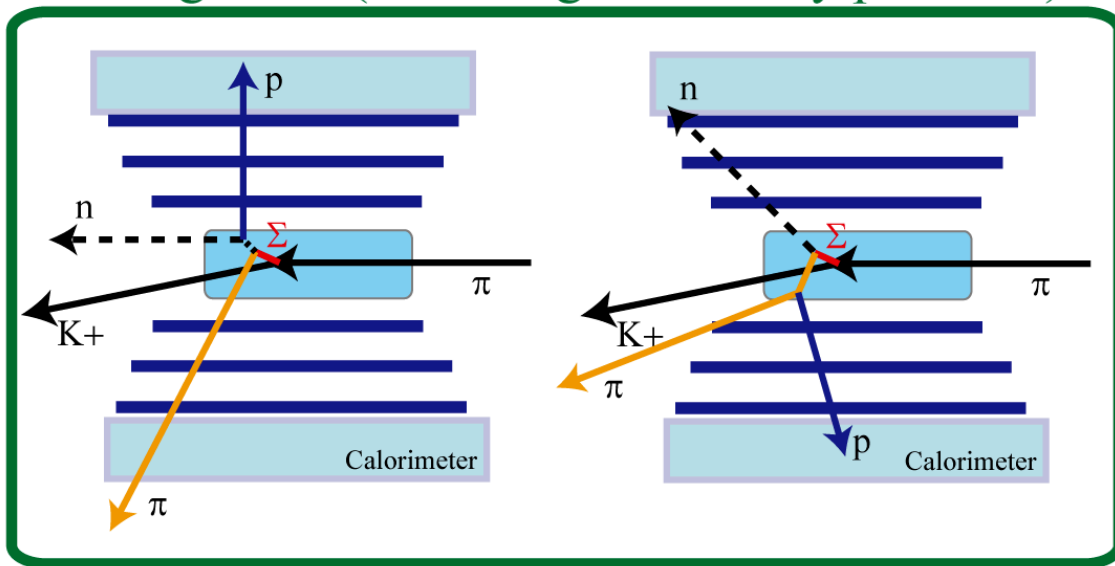


Proton event in Σ^- production

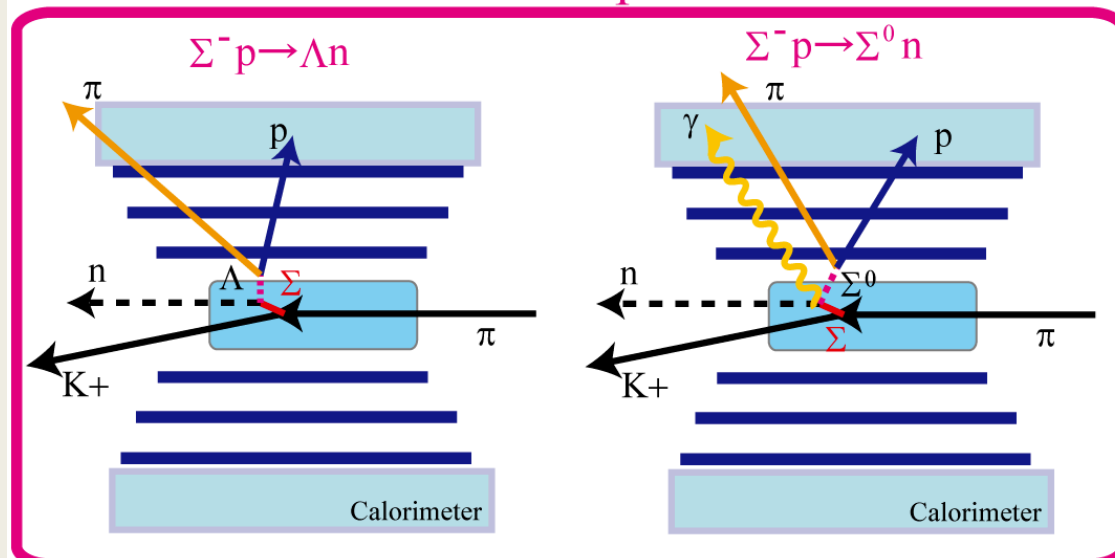
Σp scattering



Background (scattering with decay products)

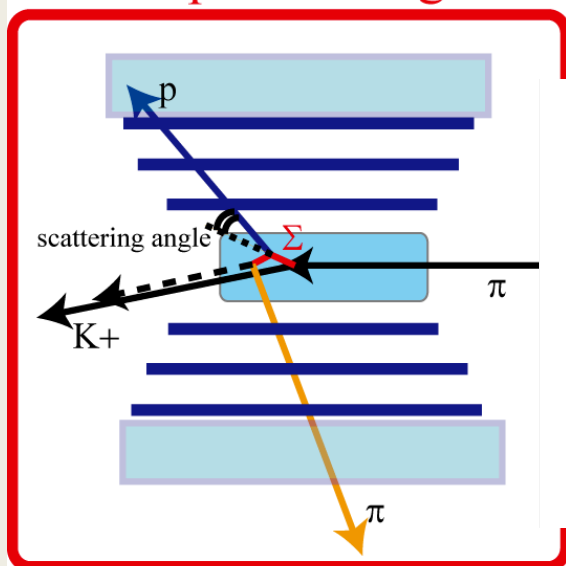


Conversion process

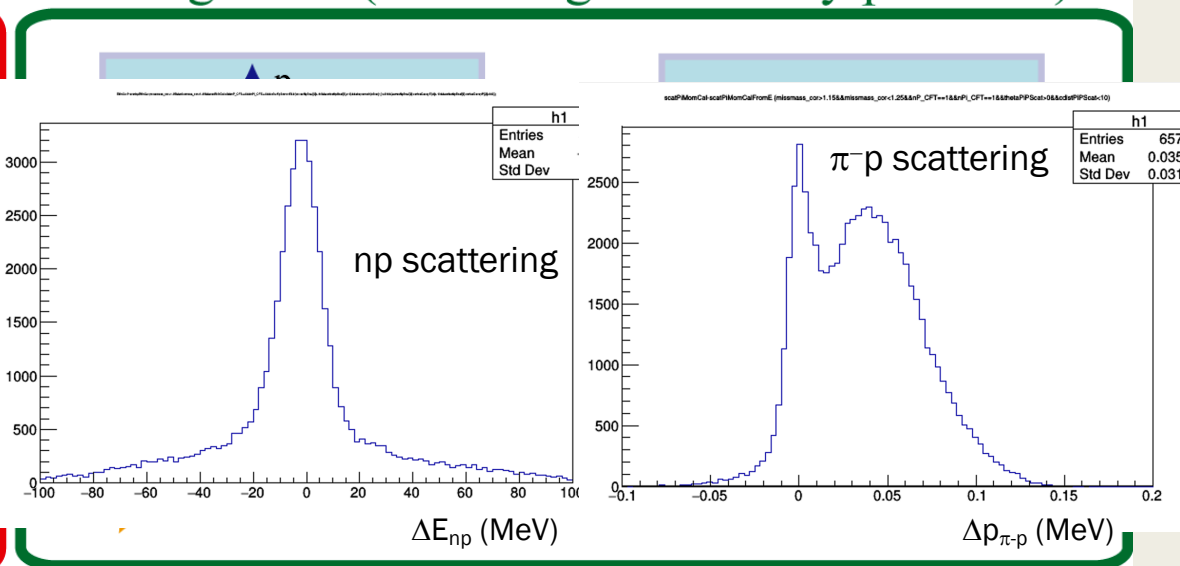


Proton event in Σ^- production

Σp scattering

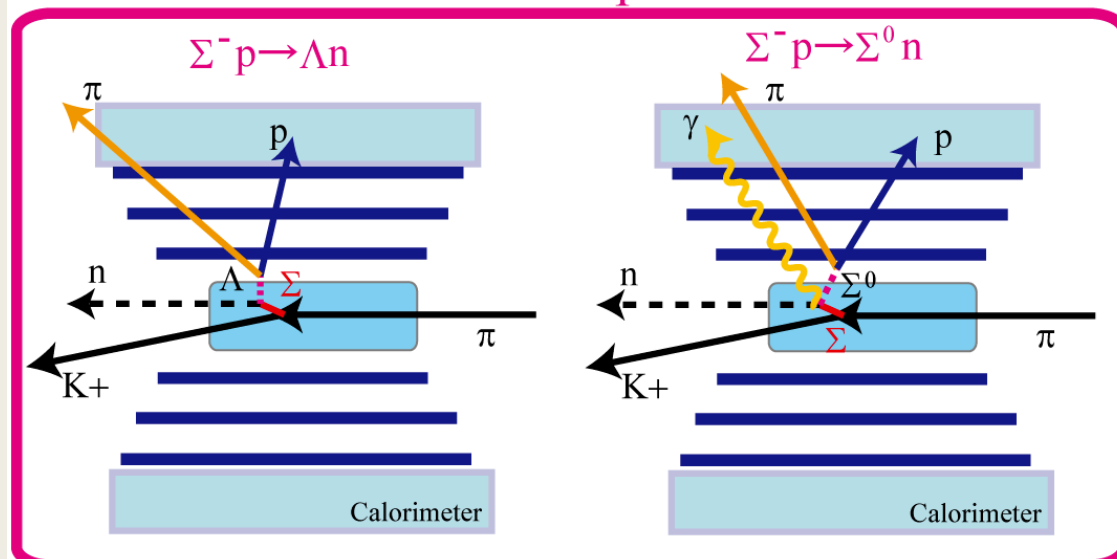


Background (scattering with decay products)



Conversion process

$$\Delta E = E_{\text{measured}} - E_{\text{calculated}}(\theta)$$

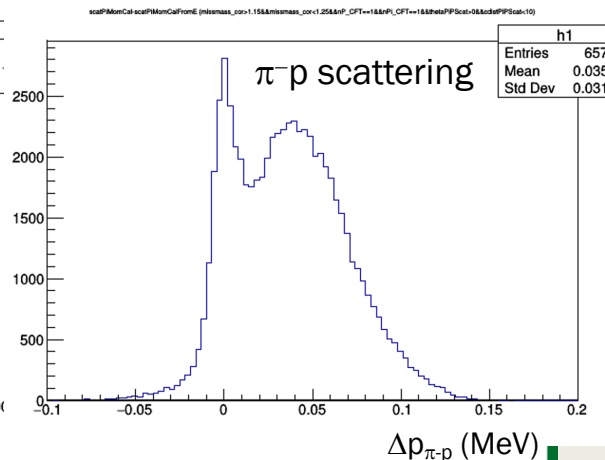
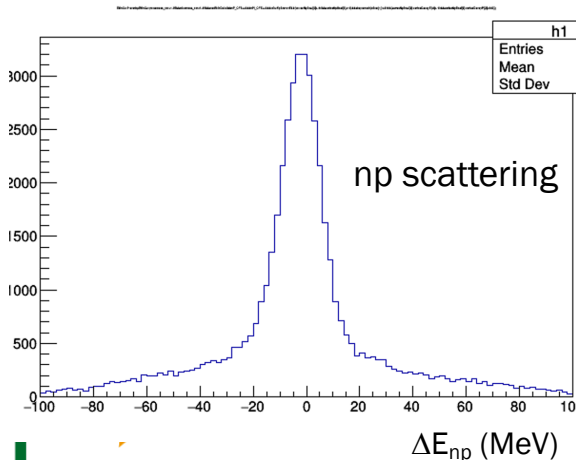
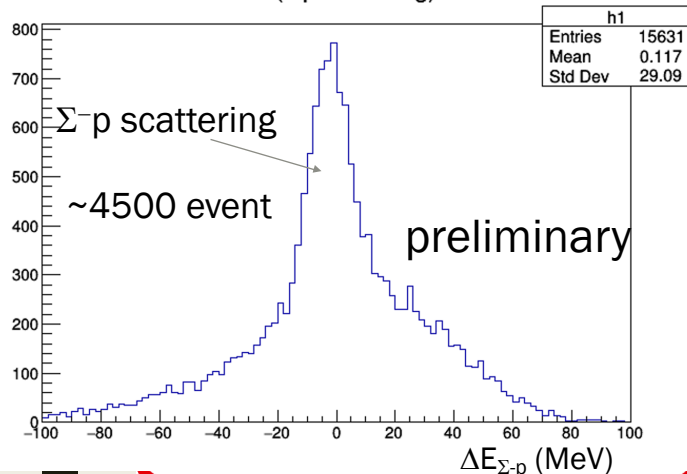


Proton event in Σ^- production

Σp scattering

Background (scattering with decay products)

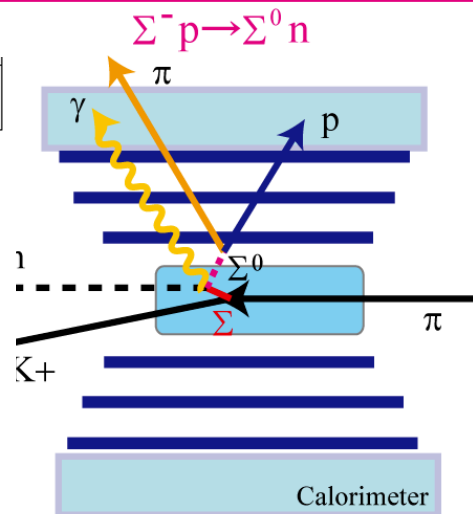
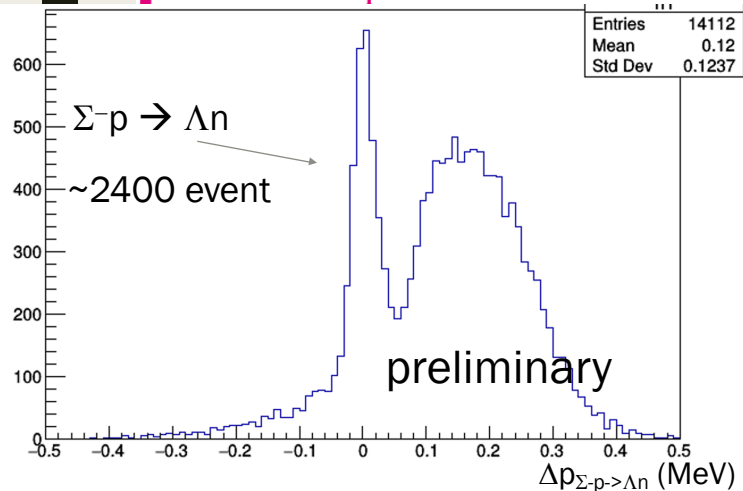
$\Delta E(\Sigma^- p \text{ scattering})$



Conversion process

$$\Delta E = E_{\text{measured}} - E_{\text{calculated}}(\theta)$$

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

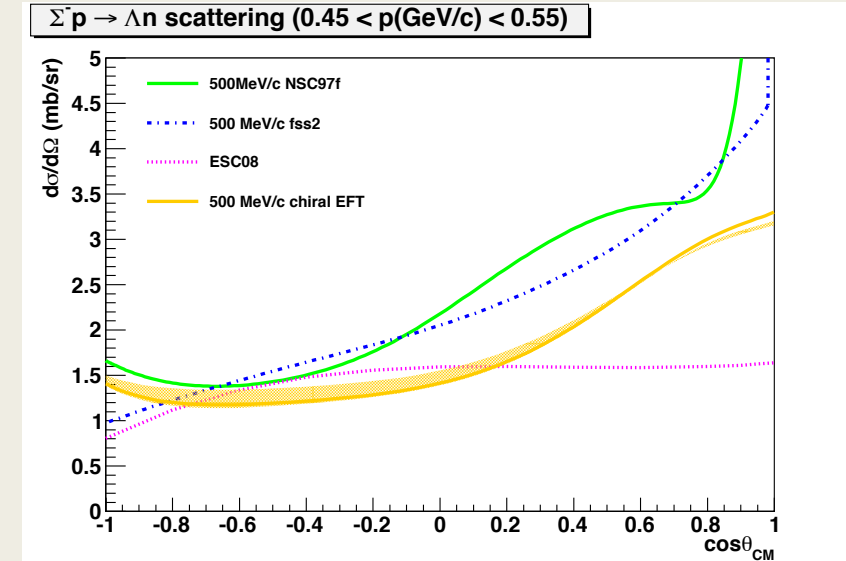
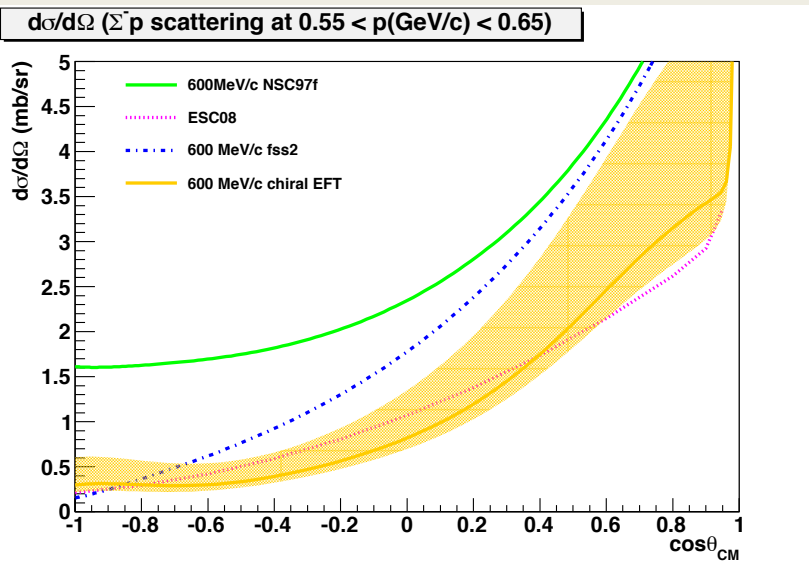
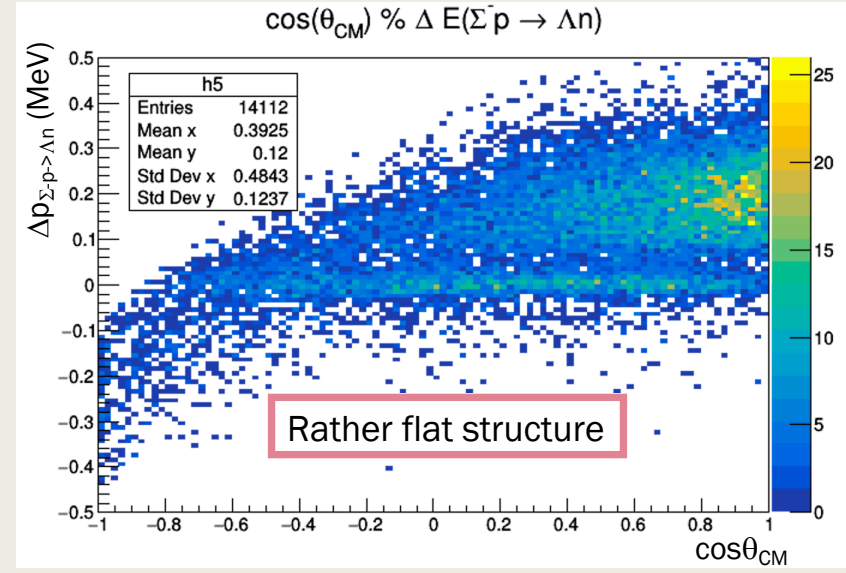
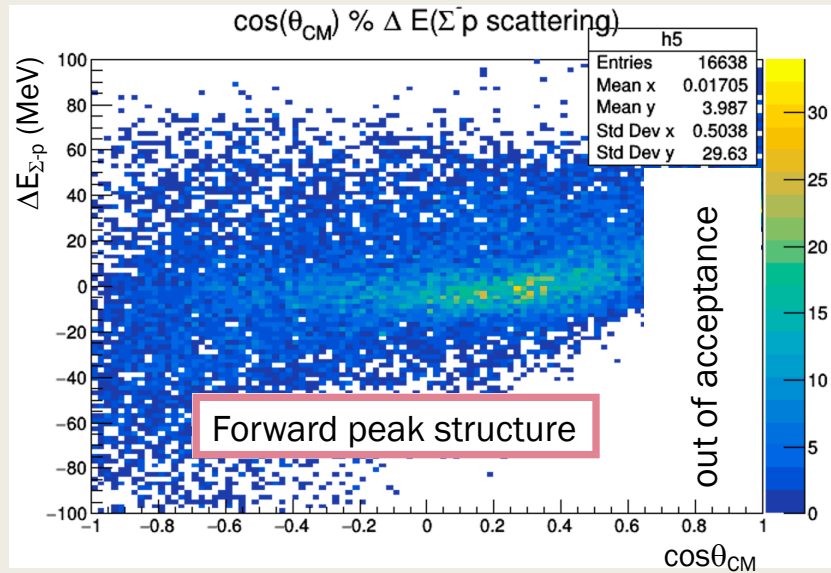


Angular dependence

Before acceptance and efficiency correction

preliminary

preliminary



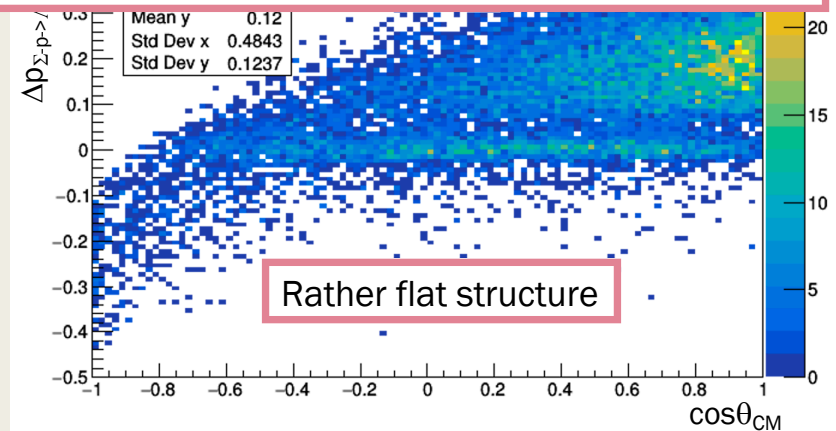
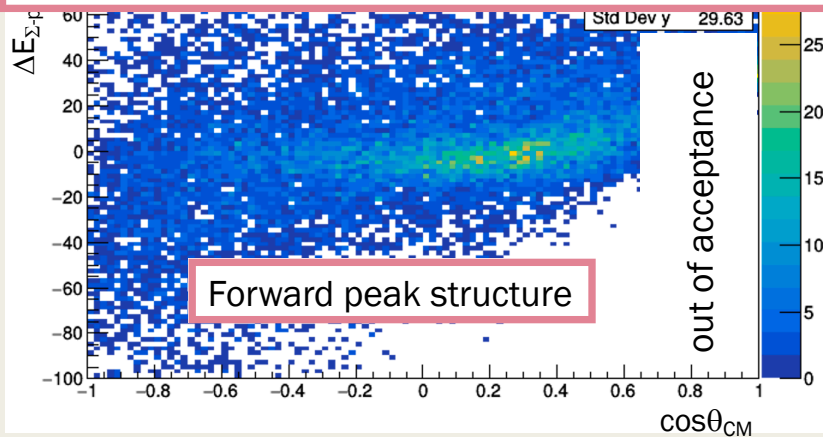
Angular dependence

Before acceptance and efficiency correction

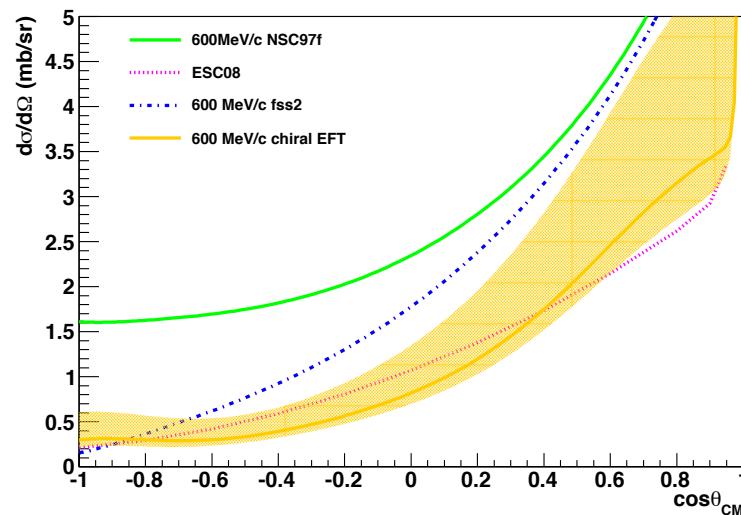
preliminary

preliminary

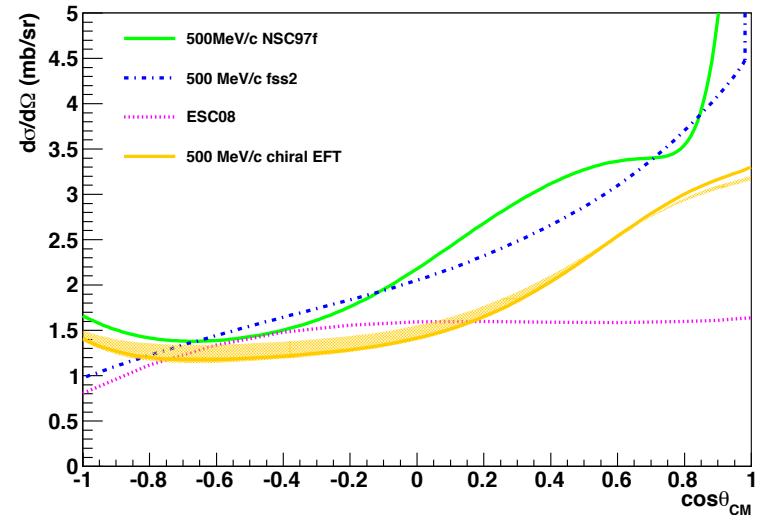
We could collect enough data to study the angular dependence with good accuracy. We will also check the Σ^- beam momentum dependence.



$d\sigma/d\Omega$ (Σ^-p scattering at $0.55 < p(\text{GeV}/c) < 0.65$)

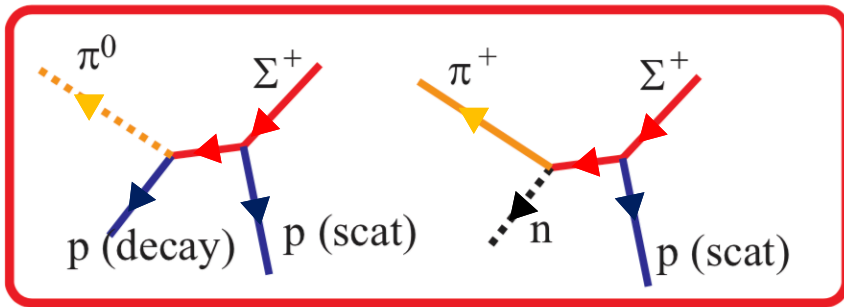


$\Sigma^-p \rightarrow \Lambda n$ scattering ($0.45 < p(\text{GeV}/c) < 0.55$)

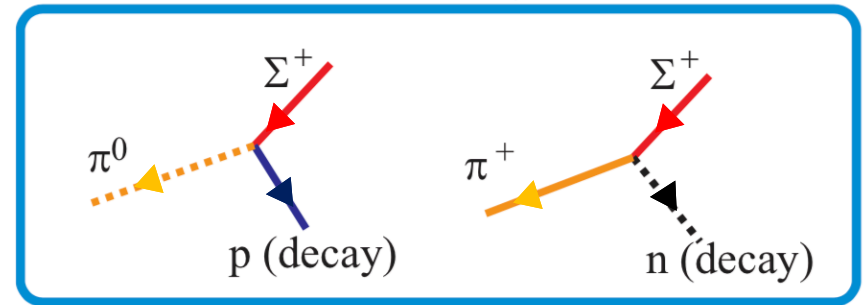


Σ^+p analysis

Σ^+p scattering



Σ^+ decay



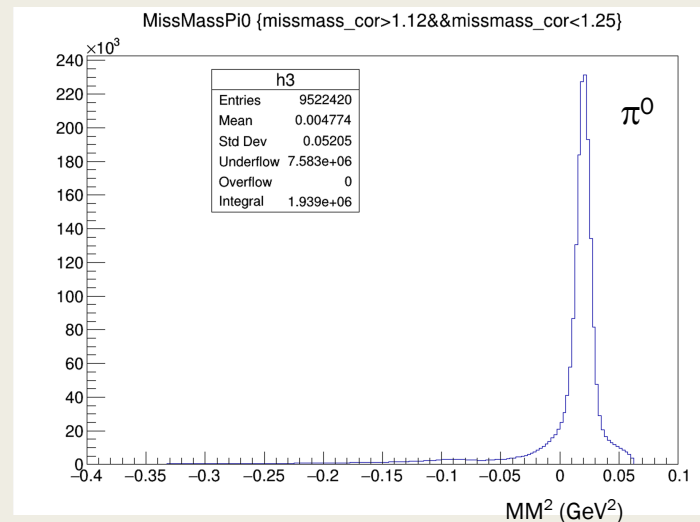
- Experimental difficulty
 - Many protons from $\Sigma^+ \rightarrow p\pi^0$ decay
 - Much shorter flight length (~ 1.2 cm)

Σ^+ decay make a large background in Σ^+p scattering for $\Sigma^+ \rightarrow \pi^+n$ decay mode



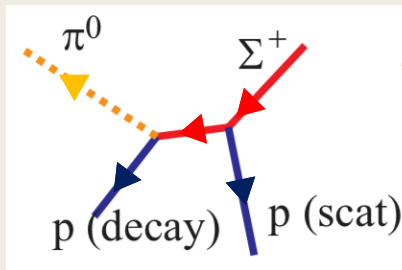
Start from 2 proton final event

$\Sigma^+ \rightarrow p + \pi^0$ decay event

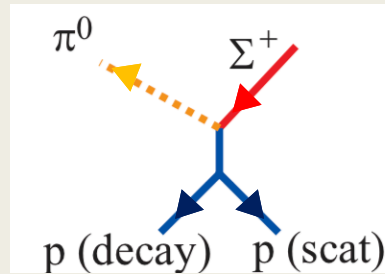


Two proton event in Σ^+ production

Σ^+p scattering

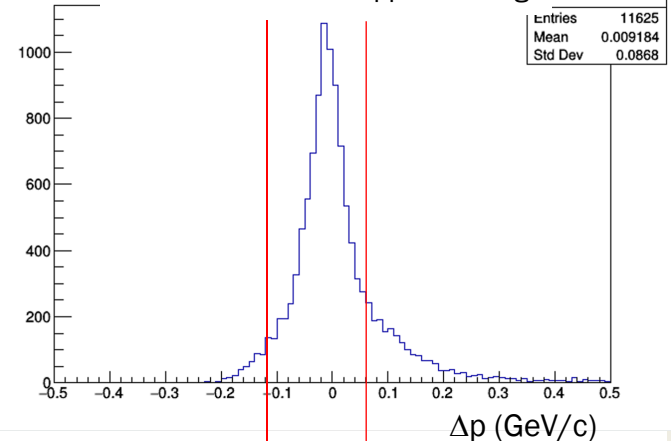


pp scattering from Σ^+ decay



pp opening angle

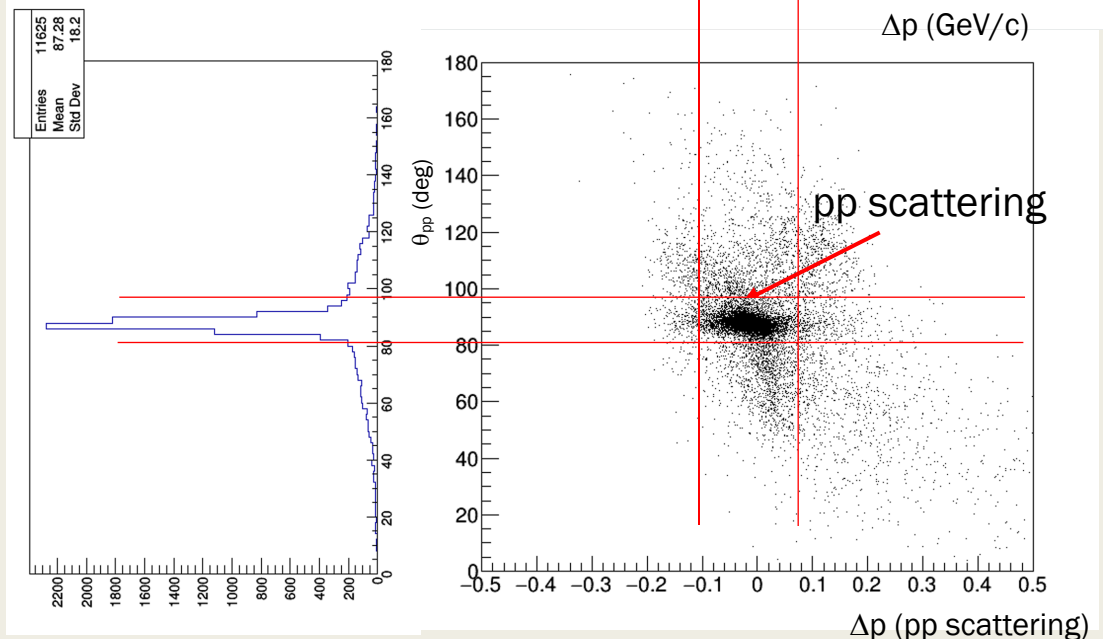
Kinematical check of pp scattering



Clear identification of pp scattering



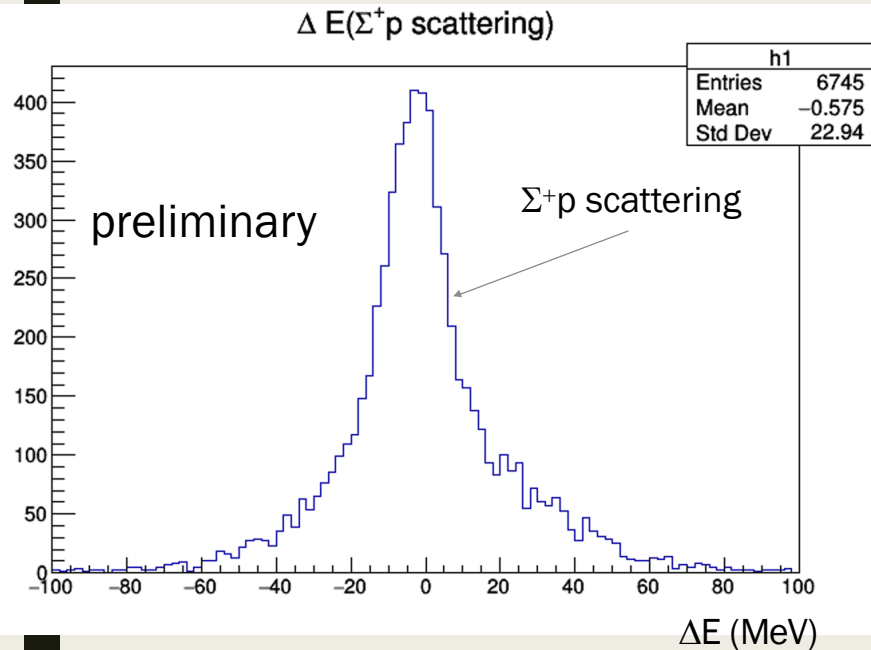
Detectors work well



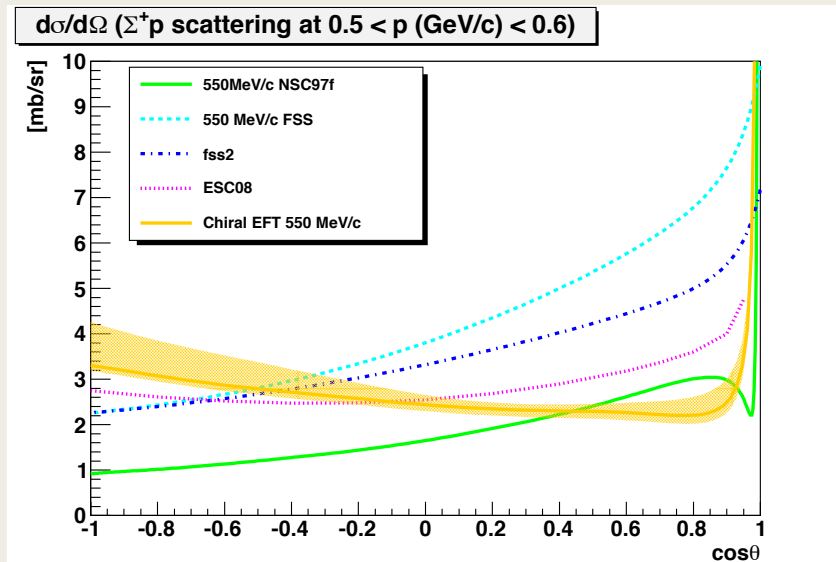
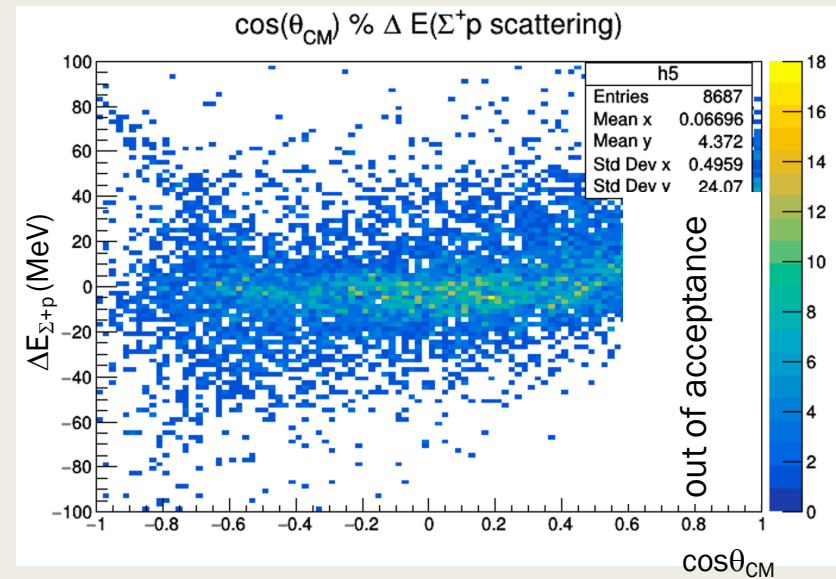
Σ^+p scattering

~40 M Σ^+ beam

Σ^+p scattering event ~2500



Before acceptance and efficiency correction



Summary

- YN interaction from Yp scattering
 - *We have to establish this new direction*
- Σ yield summary
 - Σ^-p : 17M (94%)
 - Σ^+p : 40M (50%)
- Analysis is on going
 - *Every scattering reaction is confirmed well*
 - Background reactions
 - Σp scattering reactions
 - *We can provide sufficient data to discuss the angular distribution of C.S.*
 - *We could establish the modern Yp scattering experimental technique.*
- Future prospects
 - *Derivation of $d\sigma/d\Omega$*
 - *U/D asymmetry of proton from hyperon decay for spin observable measurement*