

Hyperon-nucleon interactions at BESIII

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on behalf of the BESIII collaboration

Fudan University

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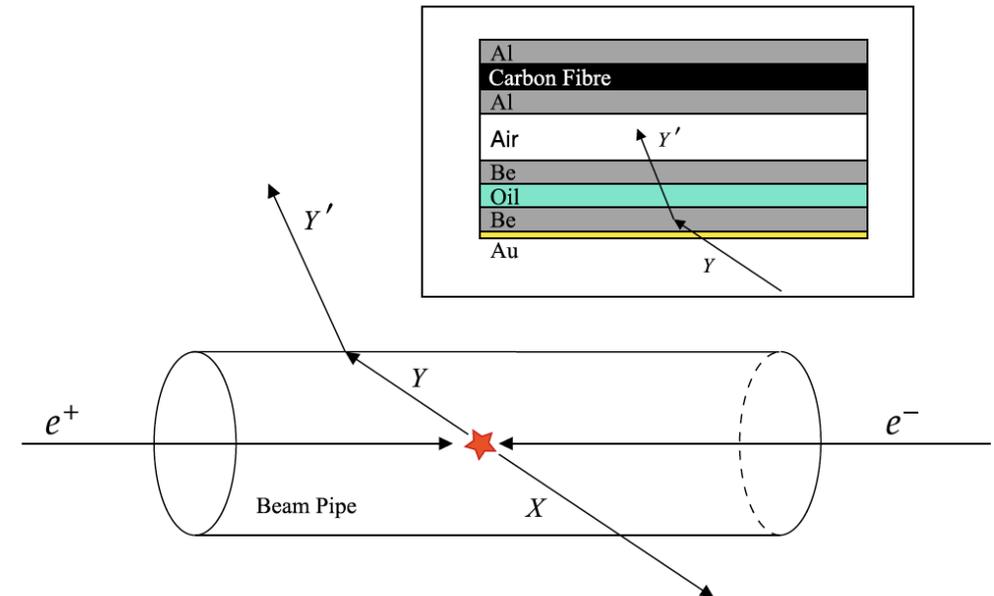
Outline

01 Introduction

02 Study of hyperon-nucleon interactions at BESIII

- PRL 130, 251902 (2023)
- arXiv: 2505.19907
- PRC 109, L052201 (2024)
- PRL 132, 231902 (2024)

03 Summary



/// The hyperons

- Hyperons are the strange siblings of the proton and neutron

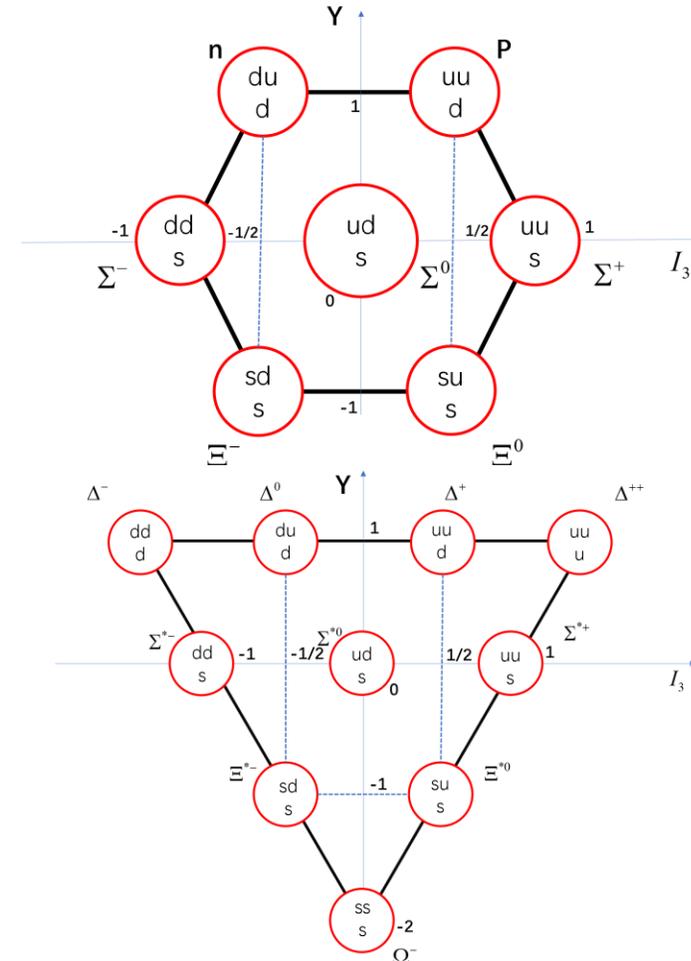
- **Half lives:** $\tau_Y \sim 10^{-10} \text{ s}$;
✓ 10^{-2} of τ for K^+, K_L

- **Rich phenomenology:**

- ✓ **Spin** → sensitivity to various NP

- structures

- ✓ **SU(3)-relations to nucleon-structure**



Hyperon source

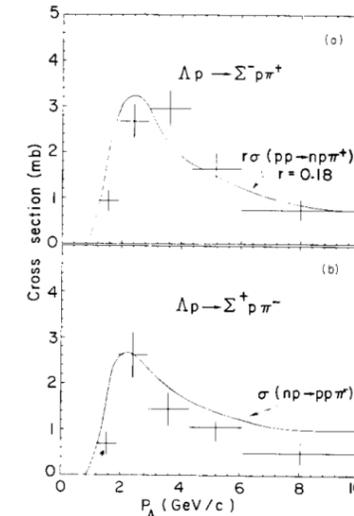
- Hyperons are produced by bombarding a hydrogen bubble chamber or a scintillating fiber target with K^- mesons.
- The intensity of hyperon beams is low, leading to scarce experimental measurements with substantial uncertainties.
- Until now, there is no dedicated anti-hyperon source.

PLB 38, 123 (1972)

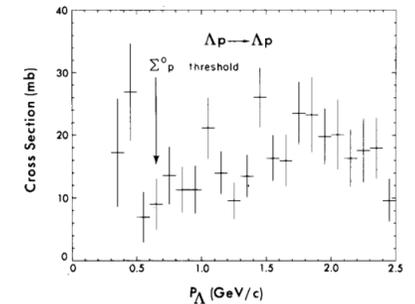
reaction	events *	signature	cross-section events **	cross-section (mb)
$\Xi^0 + p \rightarrow \Xi^0 + p$	2	K, Λ	1	8
$\Xi^0 + p \rightarrow \Lambda + \Sigma^+$	6	Λ	4	24
$\Xi^0 + p \rightarrow \Sigma^0 + \Sigma^+$	1	Λ	1	6
$\Xi^0 + p \rightarrow \pi^+ + \Lambda + \Lambda$	1	K, Λ	1	6
$\Xi^0 + p \rightarrow \pi^0 + \Lambda + \Sigma^+$	1	Λ	1	6
$\Xi^0 + p \rightarrow \pi^+ + \Xi^- + p$	1	K or Λ	1	5
$\Xi^0 + p \rightarrow \pi^+ + \pi^+ + \Xi^- + n$	1	K, Λ	1	6
$\Xi^0 + p \rightarrow \Xi^- + p$	2	Λ	2	8
$\Xi^0 + p \rightarrow \Sigma^- + \Sigma^+$	1	K	1	4
$\Xi^0 + p \rightarrow \Sigma^- + K^0 + p$	1	K	1	4

PLB 32, 720 (1970)

Reaction	Number of events
$\Lambda p \rightarrow \Lambda p$ (elastic)	584 (1)
$\Lambda p \rightarrow \Sigma^- p \pi^+$	132 (2)
$\Lambda p \rightarrow \Sigma^+ p \pi^-$	60 (3)
$\Lambda p \rightarrow \Lambda p \pi^+ \pi^-$	181 (4)
$\Lambda p \rightarrow \Sigma^0 p$	35 (5)
various $\Xi^0 p$ interactions	25



NPB 125, 29 (1977)

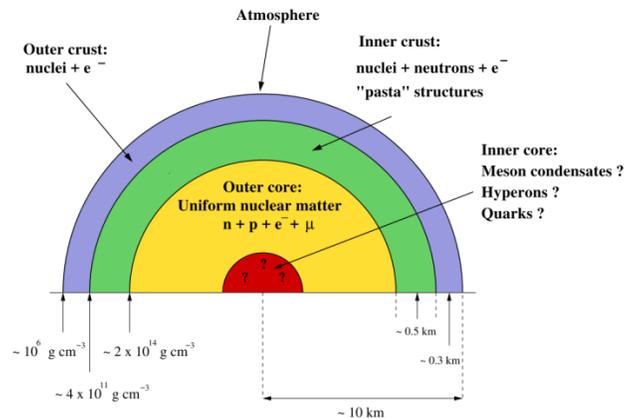


PLB 32, 720 (1970)

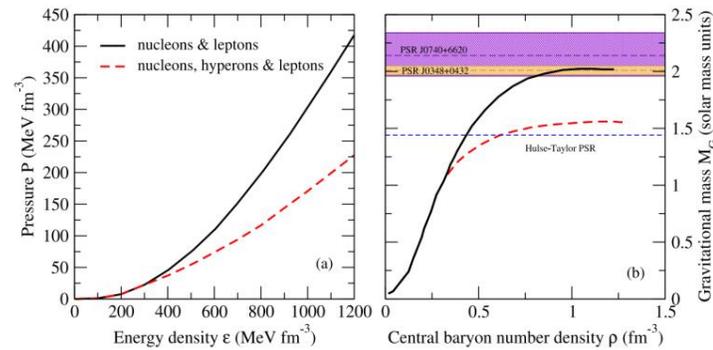
Reaction	Momentum interval (GeV/c)	Number of events	σ (mb)
$\Lambda p \rightarrow \text{all}$	0.5 - 1.0	25	25.8 ± 6.2
	1.0 - 1.5	31	31.3 ± 6.5
	1.5 - 2.0	42	42.8 ± 7.1
	2.0 - 2.5	37	37.5 ± 7.2
	2.5 - 3.0	34	34.1 ± 8.3
$\Lambda p \rightarrow \Lambda p$	0.5 - 1.0	20	22.2 ± 5.0
	1.0 - 1.5	21	12.9 ± 2.8
	1.5 - 2.0	37	22.0 ± 3.6
	2.0 - 2.5	28	16.1 ± 3.1
$\Lambda p \rightarrow \Sigma^0 p$	0.66 - 4.0	11	1.5 ± 0.5
	0.88 - 4.0	29	4.1 ± 0.8
$\Lambda p \rightarrow \Lambda p \pi^+ \pi^-$	1.36 - 4.0	12	1.9 ± 0.6
	0.5 - 1.5	10	31.2 ± 10.1
$\Sigma^+ p \rightarrow \Sigma^+ p$	1.5 - 2.5	8	18.7 ± 6.6
	2.5 - 4.0	4	15.3 ± 7.8
$\Sigma^- p \rightarrow \Sigma^- p$	0.5 - 1.5	6	13.2 ± 4.7
	1.5 - 2.5	11	13.9 ± 4.1
	2.5 - 4.0	4	7.5 ± 3.8
$\Xi^- p \rightarrow \Xi^- p$	1.0 - 4.0	6	13 ± 6
	1.0 - 4.0	4	19 ± 10

“Hyperon puzzle” of neutron stars

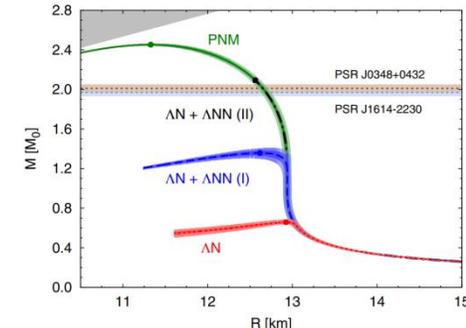
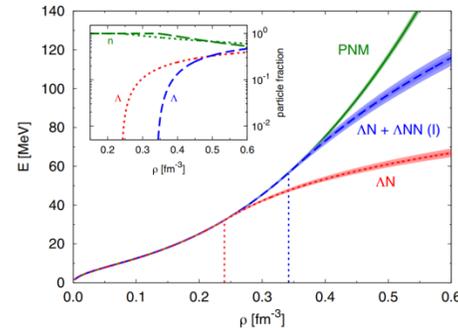
- Hyperons are thought to exist in the inner core of neutron stars.
- Hyperon appearance softens the equation of state, resulting in a maximum mass that neutron stars can sustain being lower than that of already observed neutron stars.
- A repulsive force—such as that arising from a combination of ΛN and ΛNN interactions—is introduced to stiffen the equation of state, making hyperon-nucleon interaction studies critical for solving the “hyperon puzzle” of the neutron stars.



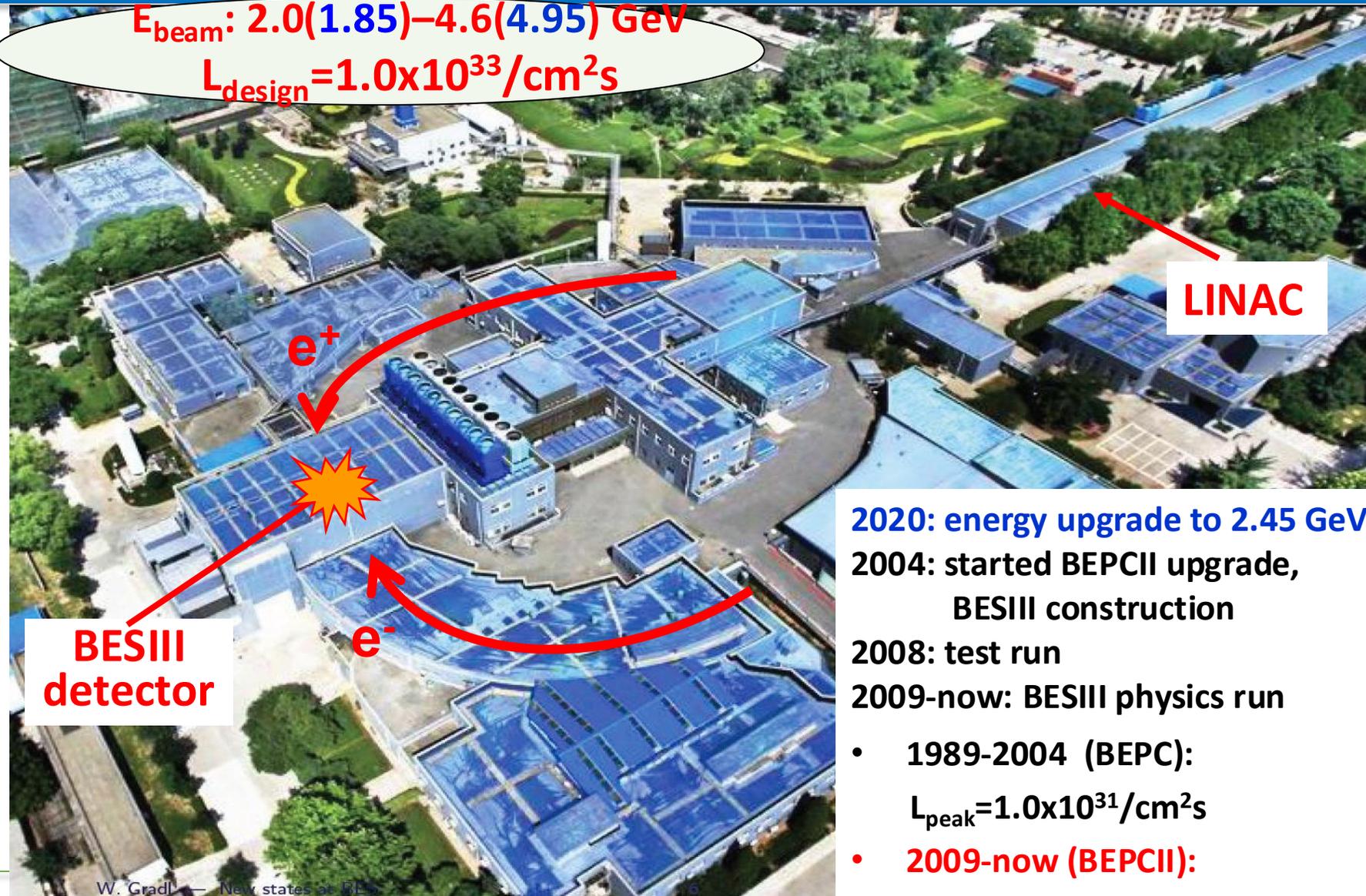
PRL 114, 092301 (2015)



PPNP 112, 103770 (2020)

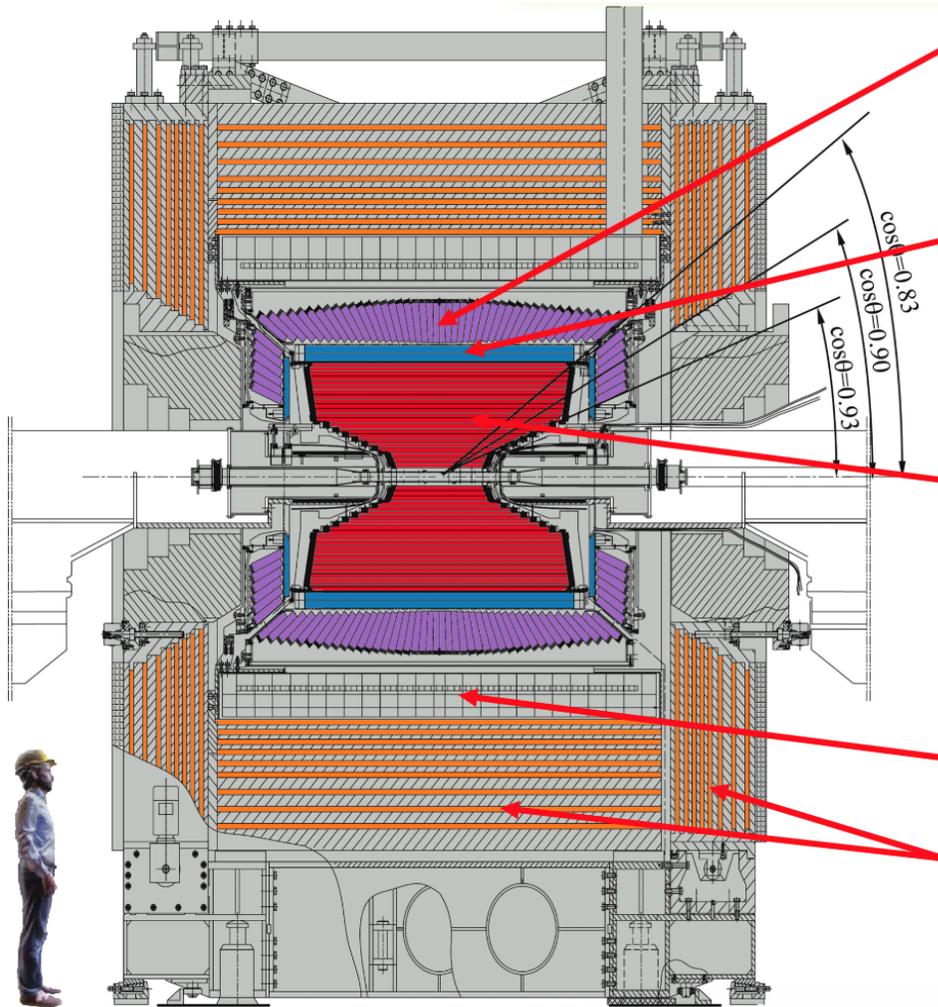


/// The Beijing Electron-Positron Collider II (BEPC II)



/// The BEijing Spectrum III (BESIII)

The detector is designed for neutral and charged particle with excellent resolution, PID, and large coverage.



EMC: CsI crystals

$\Delta E/E = 2.5\%$ @ 1 GeV - Barrel

$\Delta E/E = 5.0\%$ @ 1 GeV - Endcaps

TOF:

$\sigma_T = 80$ ps Barrel

$\sigma_T = 110$ (60) ps Endcap

MDC: small cell & He gas

$\sigma_{xy} = 130$ μm

$\sigma_p/p = 0.5\%$ @1GeV

$dE/dx = 6\%$

Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Has been in full operation since 2008,
all subdetectors are in very good status!

Why hyperon physics at BESIII?

10 billion J/ψ and 3 billion $\psi(2S)$ events collected

Large BF's in J/ψ decays

Large datasets of hyperon pair

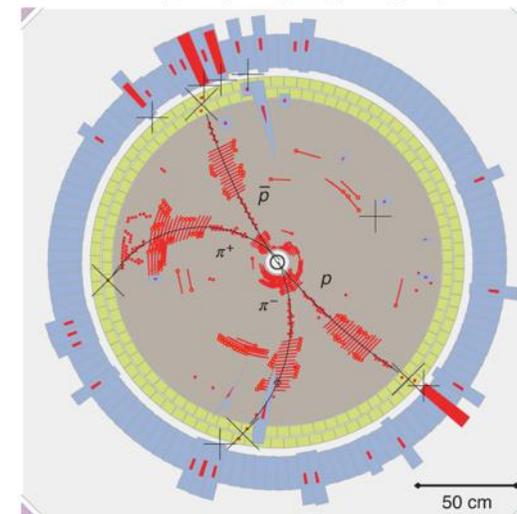
Hyperon pair production

Double tag method

Polarized-hyperon Quantum correlated factories (BESIII&SCTF)

Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_{B\bar{B}}(\times 10^6)$
$J/\psi \rightarrow \Lambda\bar{\Lambda}$	1.89 ± 0.09	19.06 ± 0.91
$J/\psi \rightarrow \Sigma^0\bar{\Sigma}^0$	1.17 ± 0.03	11.82 ± 0.32
$J/\psi \rightarrow \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.13 ± 2.42
$J/\psi \rightarrow \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	0.31 ± 0.05	3.13 ± 0.50
$J/\psi \rightarrow \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.16 ± 0.05	11.70 ± 0.50
$J/\psi \rightarrow \Xi^0\bar{\Xi}^0$	1.17 ± 0.04	11.80 ± 0.40
$J/\psi \rightarrow \Xi^-\bar{\Xi}^+$	0.97 ± 0.08	9.78 ± 0.81
$J/\psi \rightarrow \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.23 ± 1.41
$J/\psi \rightarrow \Xi(1530)^-\bar{\Xi}^+$	0.32 ± 0.01	3.21 ± 0.08
$\psi(2S) \rightarrow \Omega^-\bar{\Omega}^+$	0.05 ± 0.004	0.16 ± 0.01

$J/\psi \rightarrow (\Lambda \rightarrow p\pi^-)(\bar{\Lambda} \rightarrow \bar{p}\pi^+)$



Nature Physics 15, 631-634(2019)

4-momentum conservation

Known initial 4-momentum

Information on the neutrino

Advantage of double tag method:

- ✓ Absolute BF
- ✓ Low background
- ✓ Cancel the systematic uncertainties in tag side

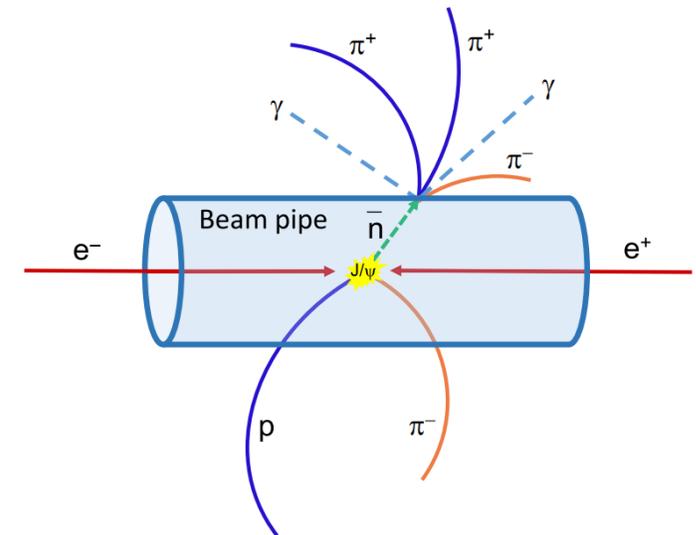
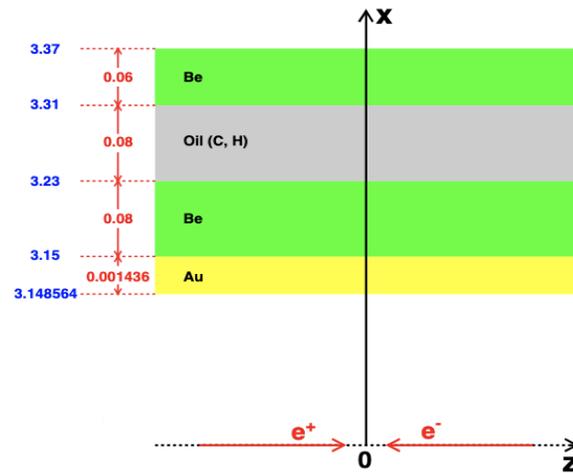
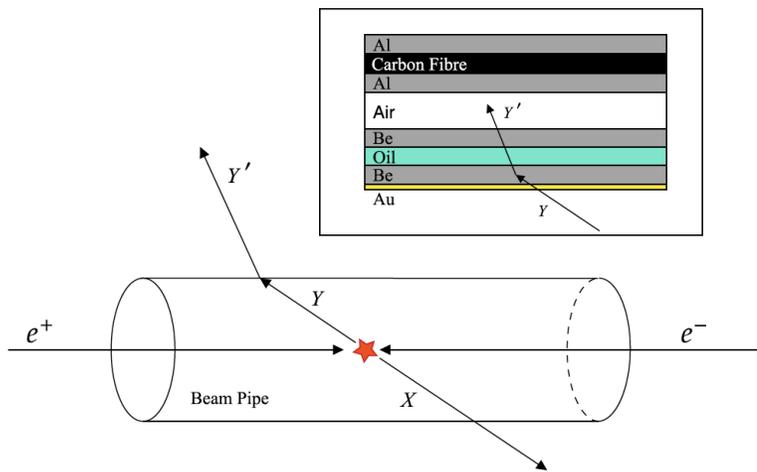
/// Experimental study on particle targeting at BESIII

Particle source: Hyperon from J/ψ decays
Target material: Beam pipe
Detector: BESIII detector

PRL 127, 012003 (2021)

$$\bar{n}p \rightarrow \pi^+ \pi^+ \pi^- \pi^0, \pi^0 \rightarrow \gamma\gamma$$

CPC 48, 073003 (2024)



/// Recent results on hyperon-nucleon interactions at BESIII

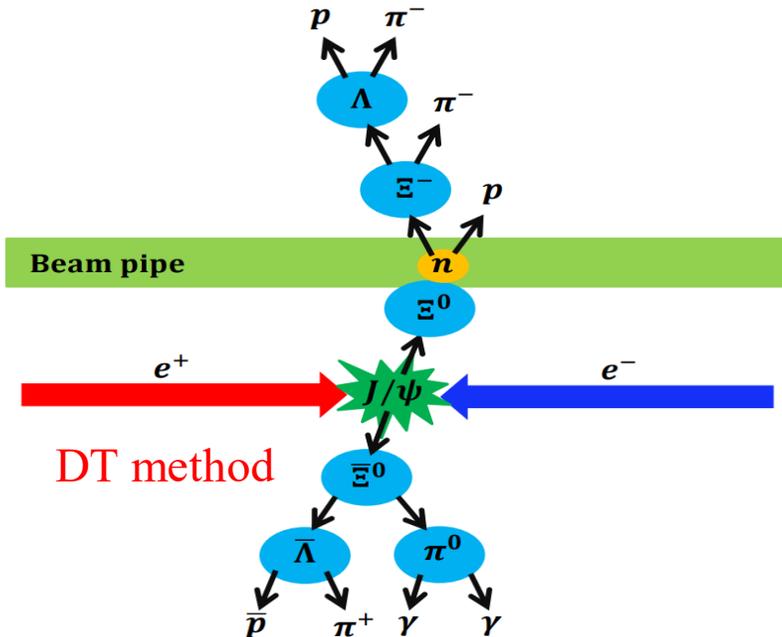
- **First study of reaction $\Xi^0 n \rightarrow \Xi^- p$ using Ξ^0 -nucleus scattering**
PRL 130, 251902 (2023)
- **First measurement of $\Sigma^+ n \rightarrow \Lambda p$ and $\Sigma^+ n \rightarrow \Sigma^0 p$ cross sections**
arXiv: 2505.19907
- **First measurement of $\Lambda N \rightarrow \Sigma^+ X$ with Λ from $e^+ e^- \rightarrow J/\psi \rightarrow \Lambda \bar{\Lambda}$**
PRC 109, L052201 (2024)
- **First study of antihyperon-nucleon scattering $\bar{\Lambda} p \rightarrow \bar{\Lambda} p$ and measurement of $\Lambda p \rightarrow \Lambda p$**
PRL 132, 231902 (2024)

Study of $\Xi^0 n \rightarrow \Xi^- p$

Reaction chain :

$$J/\psi \rightarrow \Xi^0 \bar{\Xi}^0, \bar{\Xi}^0 \rightarrow \bar{\Lambda} \pi^0, \bar{\Lambda} \rightarrow \bar{p} \pi^+, \pi^0 \rightarrow \gamma \gamma,$$

$$\Xi^0 n \rightarrow \Xi^- p, \Xi^- \rightarrow \Lambda \pi^-, \Lambda \rightarrow p \pi^-.$$



intense monoenergetic Ξ^0 baryon

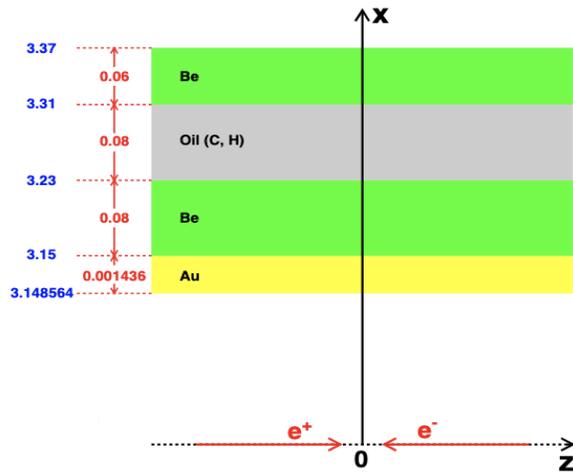
10 billion J/ψ data

Analysis method :

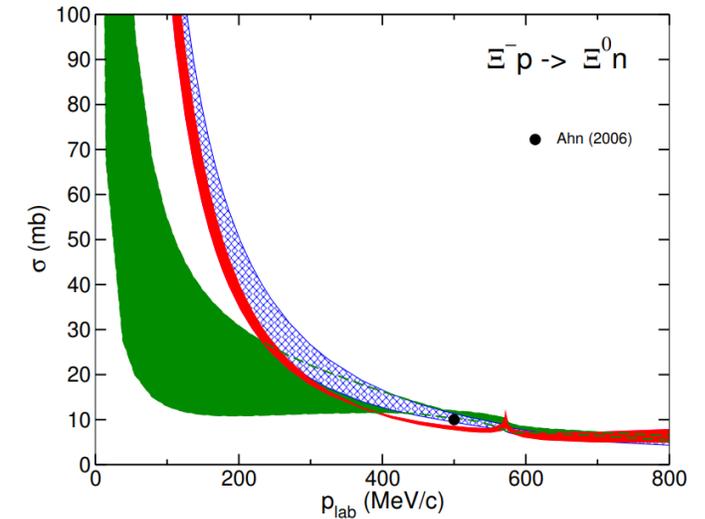
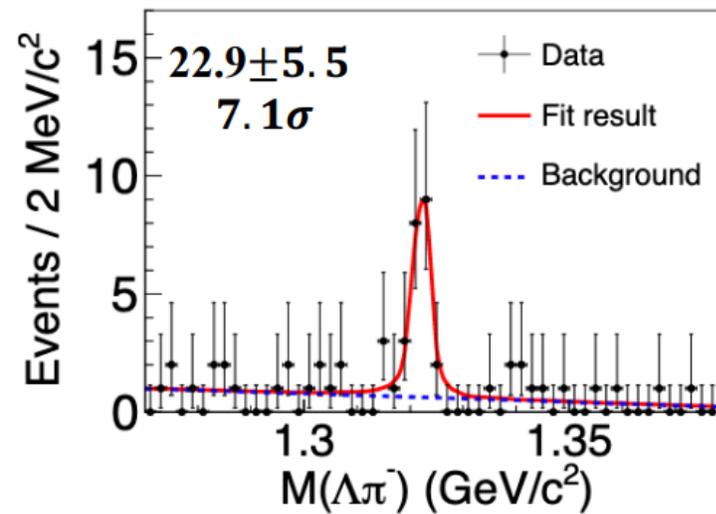
Using $\bar{\Xi}^0$ to tag the event and requiring the recoiling mass in Ξ^0 region. Then reconstructing Ξ^- and p in the signal side.

Two-body decay, $P_{\Xi^0} \approx 0.818 \text{ GeV}/c$, a very small horizontal crossing angle of 11 mrad for e^+ and e^- beams.

Study of $\Xi^0 n \rightarrow \Xi^- p$



Phys. Rev. Lett. 130 251902 (2023)



For Ξ^0 momentum is 0.818 GeV/c

$$\sigma(\Xi^0 n \rightarrow \Xi^- p) = (7.4 \pm 1.8_{\text{stat}} \pm 1.5_{\text{sys}}) \text{ mb} \quad \Xi^0 n \rightarrow \Xi^- p \text{ is observed for the first time}$$

(assuming the effective number of reaction neutrons in ^9Be is 3 [PLB 633, 214 (2006)])

$$\sigma(\Xi^0 + ^9\text{Be} \rightarrow \Xi^- + p + ^8\text{Be}) = (22.1 \pm 5.3_{\text{stat}} \pm 4.5_{\text{sys}}) \text{ mb}$$

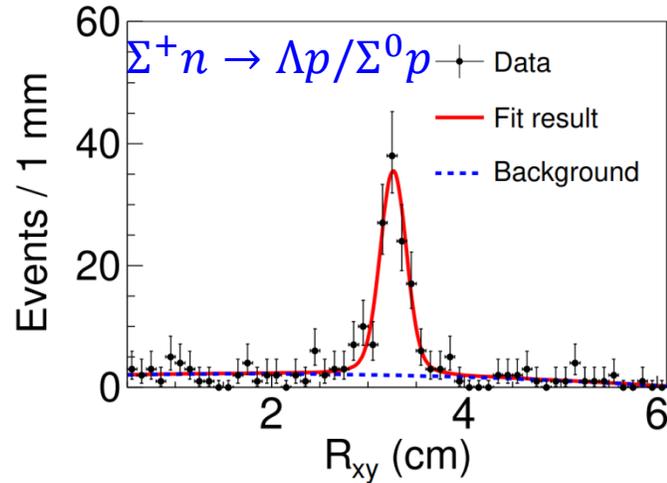
LO : H. Polinder, J.H., U.-G. Meißner, PLB 653 (2007) 29
 NLO16: J.H., U.-G. Meißner, S. Petschauer, NPA 954 (2016) 273
 NLO19: J.H., U.-G. Meißner, EPJA 55 (2019) 23

The first study of hyperon–nucleon interactions in electron-positron collisions , and opens up a new direction for such research!

Study of $\Sigma^+ n \rightarrow \Lambda p$ and $\Sigma^+ n \rightarrow \Sigma^0 p$

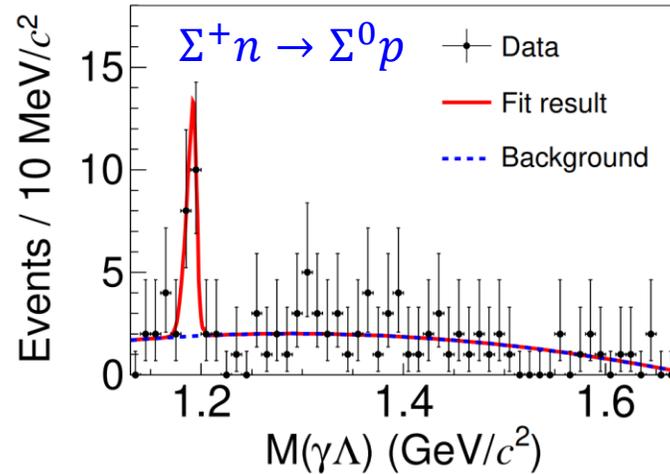
R_{xy} is distance from reconstructed Λp vertex to z axis

arXiv: 2505.19907



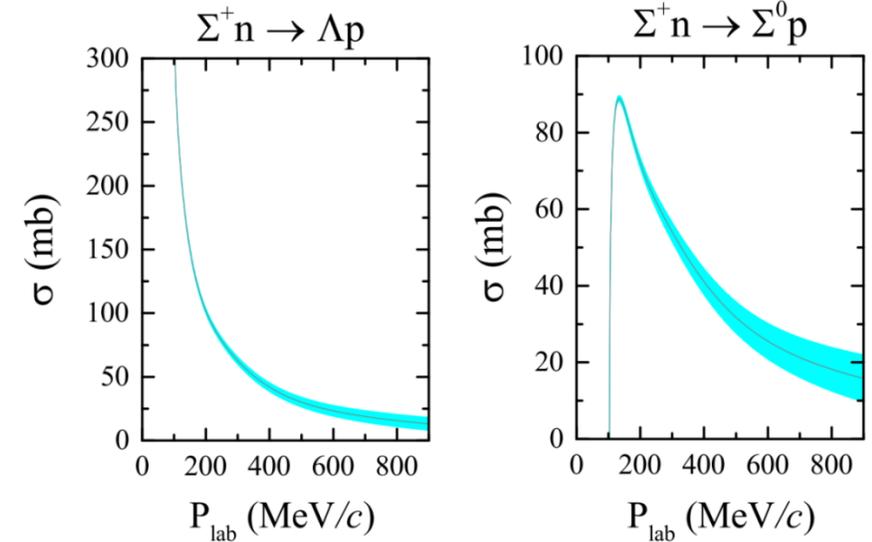
$$N_{\Lambda} = 77.6 \pm 20.8$$

$$\varepsilon_{\Lambda} = 14.44\%$$



$$N_{\Sigma^0} = 14.1 \pm 4.6$$

$$\varepsilon_{\Sigma^0} = 3.98\%$$



PRC 105, 035203 (2022)

For $P_{\Sigma^+} \approx 0.992 \text{ GeV}/c$

Consistent with theoretical predictions

$$\sigma(\Sigma^+ n \rightarrow \Lambda p) = (15.1 \pm 4.0_{\text{stat}} \pm 2.4_{\text{sys}}) \text{ mb}$$

$$\sigma(\Sigma^+ n \rightarrow \Sigma^0 p) = (9.9 \pm 3.2_{\text{stat}} \pm 2.3_{\text{sys}}) \text{ mb}$$

$$\sigma(\Sigma^+ + {}^9\text{Be} \rightarrow \Lambda + p + {}^8\text{Be}) = (45.2 \pm 12.1_{\text{stat}} \pm 7.2_{\text{sys}}) \text{ mb}$$

$$\sigma(\Sigma^+ + {}^9\text{Be} \rightarrow \Sigma^0 + p + {}^8\text{Be}) = (29.8 \pm 9.7_{\text{stat}} \pm 6.9_{\text{sys}}) \text{ mb}$$

The first exploration of Σ -nucleon scattering at an electron-positron collider.

These results provide valuable constraints on ΛN - ΣN coupling, and help understanding the role of Σ -nucleon scattering in the neutron star.

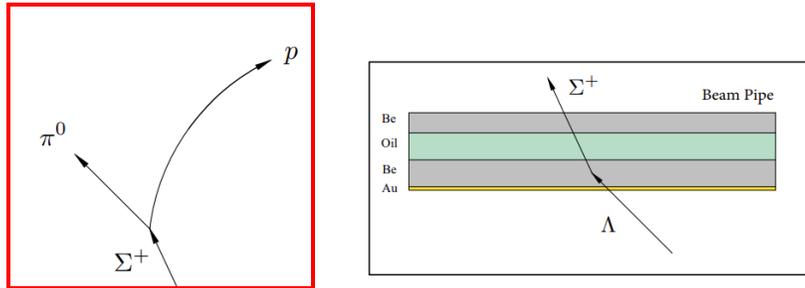
Study of $\Lambda N \rightarrow \Sigma^+ X$

Reaction chain :

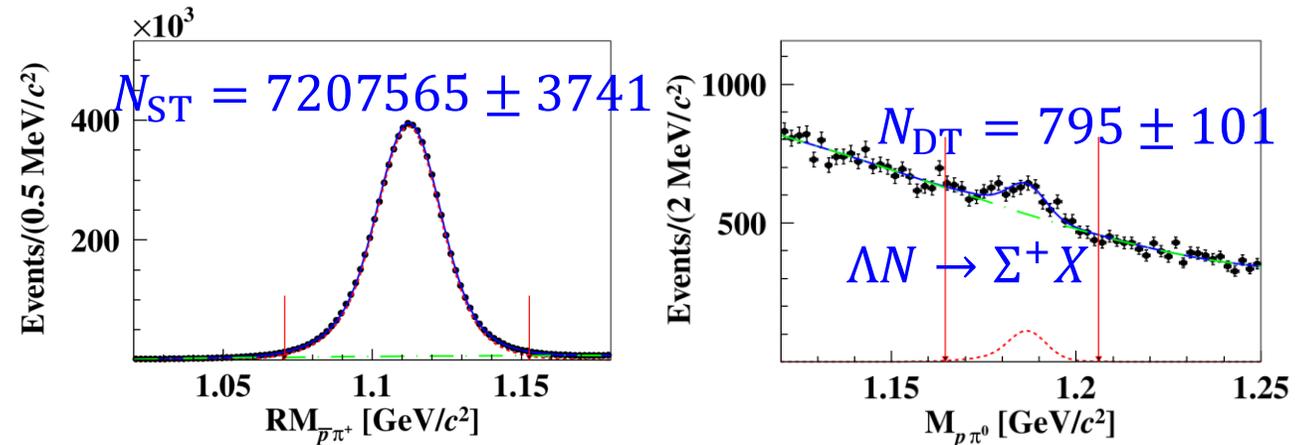
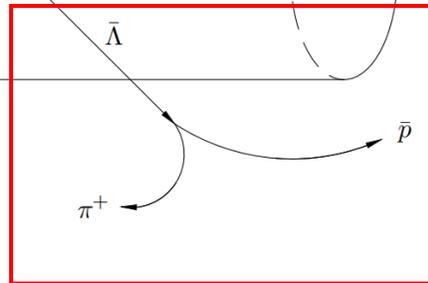
PRC 109, L052201 (2024)

$J/\psi \rightarrow \Lambda \bar{\Lambda}$, $\bar{\Lambda} \rightarrow \bar{p} \pi^+$, $\Lambda + N(\text{nucleus}) \rightarrow \Sigma^+ + X(\text{anything})$, $\Sigma^+ \rightarrow p \pi^0$, $\pi^0 \rightarrow \gamma \gamma$.

Signal side



Single tag side



For $P_\Lambda \approx 1.074 \text{ GeV}/c$

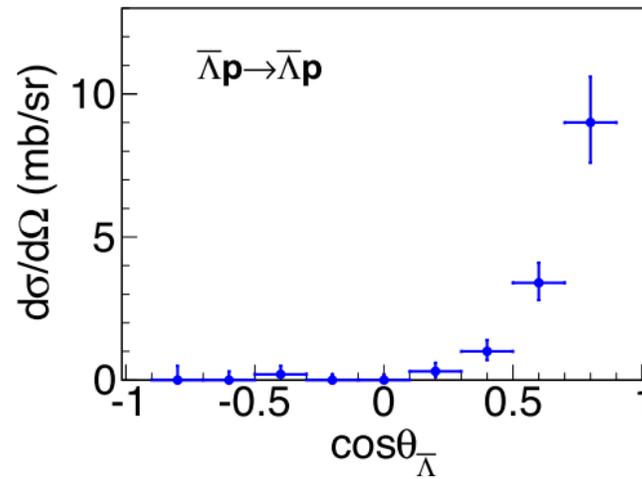
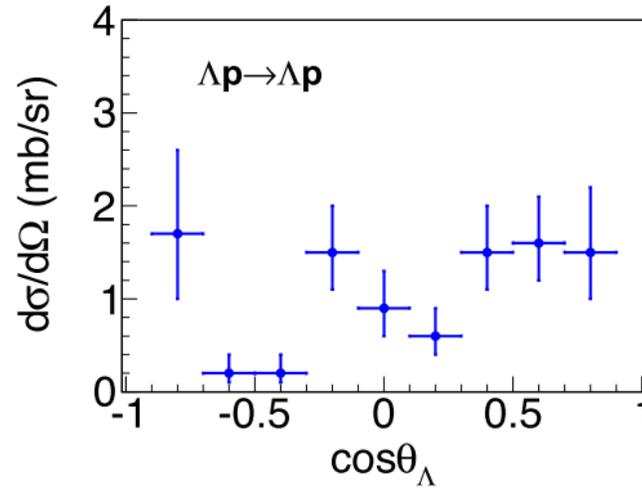
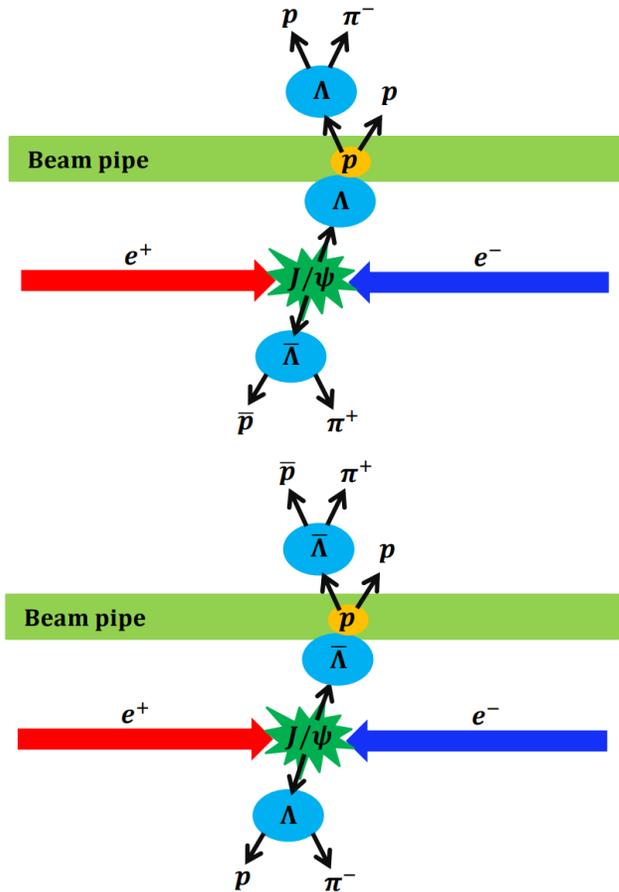
$$\sigma(\Lambda + {}^9\text{Be} \rightarrow \Sigma^+ + X) = (37.3 \pm 4.7_{\text{stat}} \pm 3.5_{\text{sys}}) \text{ mb}$$

$$\sigma(\Lambda p \rightarrow \Sigma^+ X) = (19.3 \pm 2.4_{\text{stat}} \pm 1.8_{\text{sys}}) \text{ mb}$$

The first attempt to investigate Λ -nucleus interaction at an e^+e^- collider.

Study of $\Lambda p \rightarrow \Lambda p$ and $\bar{\Lambda} p \rightarrow \bar{\Lambda} p$

PRL 132, 231902 (2024)



$\cos \theta_{\Lambda/\bar{\Lambda}}$	N_i^{sig}	ϵ_i (%)	$(d\sigma/d\Omega)$ (mb/sr)
$[-0.9, -0.7]$	$(5.0^{+2.6}_{-1.9}, 0.0^{+1.1}_{-0.0})$	(6.94, 4.93)	$(1.7^{+0.9}_{-0.7}, 0.0^{+0.5}_{-0.0})$
$(-0.7, -0.5]$	$(1.0^{+1.4}_{-0.7}, 0.0^{+1.1}_{-0.0})$	(14.13, 10.44)	$(0.2^{+0.2}_{-0.1}, 0.0^{+0.3}_{-0.0})$
$(-0.5, -0.3]$	$(1.0^{+1.4}_{-0.7}, 1.0^{+1.4}_{-0.7})$	(17.32, 13.27)	$(0.2^{+0.2}_{-0.1}, 0.2^{+0.3}_{-0.1})$
$(-0.3, -0.1]$	$(11.0^{+3.7}_{-3.0}, 0.0^{+1.1}_{-0.0})$	(17.74, 14.66)	$(1.5^{+0.5}_{-0.4}, 0.0^{+0.2}_{-0.0})$
$(-0.1, 0.1]$	$(6.9^{+3.0}_{-2.3}, 0.0^{+1.1}_{-0.0})$	(19.11, 15.79)	$(0.9^{+0.4}_{-0.3}, 0.0^{+0.2}_{-0.0})$
$(0.1, 0.3]$	$(5.0^{+2.6}_{-1.9}, 2.0^{+1.8}_{-1.1})$	(19.53, 16.82)	$(0.6^{+0.3}_{-0.2}, 0.3^{+0.3}_{-0.2})$
$(0.3, 0.5]$	$(12.0^{+3.8}_{-3.1}, 7.0^{+3.0}_{-2.3})$	(19.21, 17.68)	$(1.5^{+0.5}_{-0.4}, 1.0^{+0.4}_{-0.3})$
$(0.5, 0.7]$	$(13.0^{+3.9}_{-3.3}, 25.0^{+5.3}_{-4.7})$	(19.71, 17.60)	$(1.6^{+0.5}_{-0.4}, 3.4^{+0.7}_{-0.6})$
$(0.7, 0.9]$	$(6.0^{+2.8}_{-2.1}, 37.0^{+6.4}_{-5.8})$	(9.80, 9.93)	$(1.5^{+0.7}_{-0.5}, 9.0^{+1.6}_{-1.4})$

Cross sections in $-0.9 \leq \cos \theta_{\Lambda/\bar{\Lambda}} \leq 0.9$ are measured to be

$$\sigma(\Lambda p \rightarrow \Lambda p) = (12.2 \pm 1.6_{\text{stat}} \pm 1.1_{\text{sys}}) \text{ mb}$$

$$\sigma(\bar{\Lambda} p \rightarrow \bar{\Lambda} p) = (17.5 \pm 2.1_{\text{stat}} \pm 1.6_{\text{stat}}) \text{ mb}$$

Total cross sections are determined to be

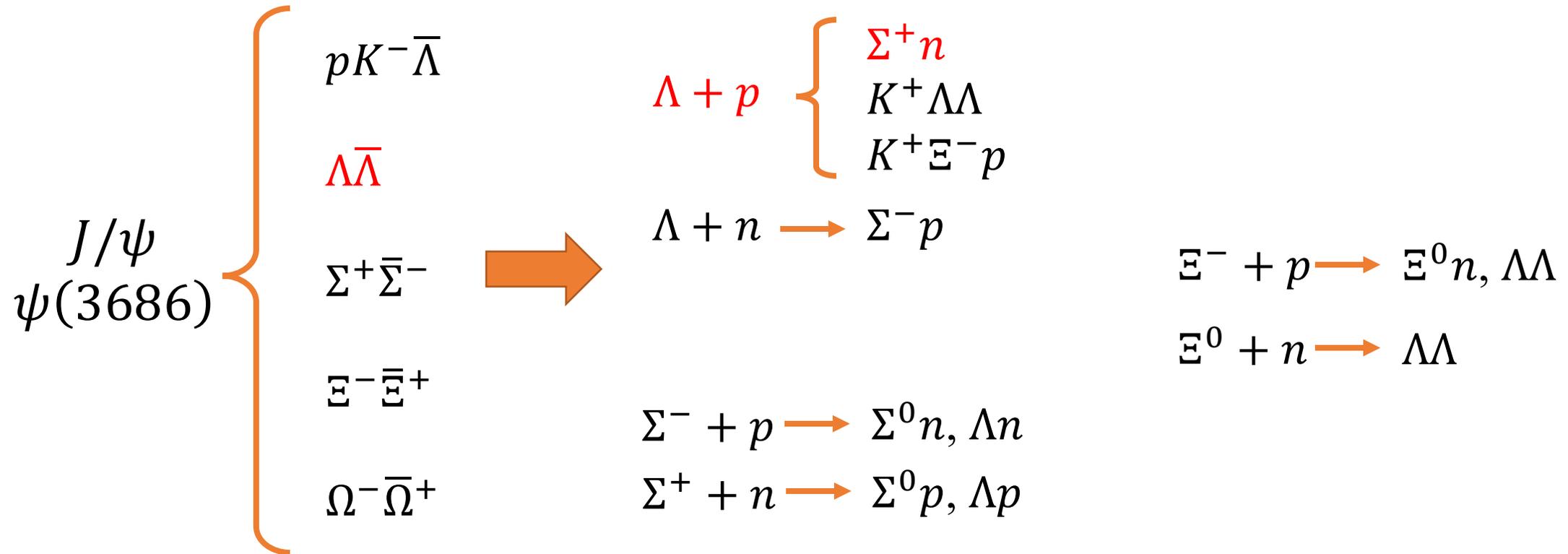
$$\sigma_t(\Lambda p \rightarrow \Lambda p) = (14.2 \pm 1.8_{\text{stat}} \pm 1.3_{\text{sys}}) \text{ mb}$$

$$\sigma_t(\bar{\Lambda} p \rightarrow \bar{\Lambda} p) = (27.4 \pm 3.2_{\text{stat}} \pm 2.5_{\text{sys}}) \text{ mb}$$

First measurement of antihyperon-nucleon scattering

More (anti)hyperon-nucleon scattering can be studied

Chin. Phys. C 48, 073003 (2024)



Hyperon beam

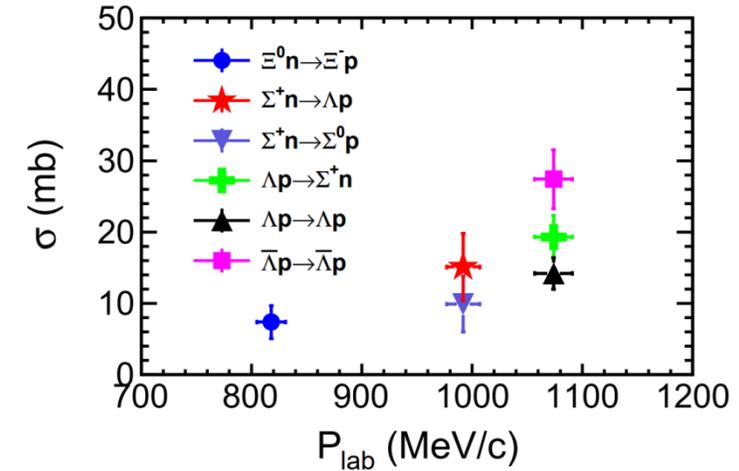
Possible reactions

A wealth of interesting findings will be released soon,
with a special focus on anti-hyperon-nucleon interaction research!

/// Summary

1. Based on a novel method, hyperon-nucleon scattering has been studied at BESIII.

- $\Xi^0 n \rightarrow \Xi^- p$
- $\Sigma^+ n \rightarrow \Lambda p, \Sigma^+ n \rightarrow \Sigma^0 p$
- $\Lambda N \rightarrow \Sigma^+ X$
- $\Lambda p \rightarrow \Lambda p, \bar{\Lambda} p \rightarrow \bar{\Lambda} p$



2. This is the first study of hyperon-nucleon interactions in electron-positron collisions, opening a new direction for such research—especially the first investigation of antihyperon-nucleon scattering.

3. More statistics from future super tau-charm facilities will enable the study of momentum-dependent and differential cross sections.

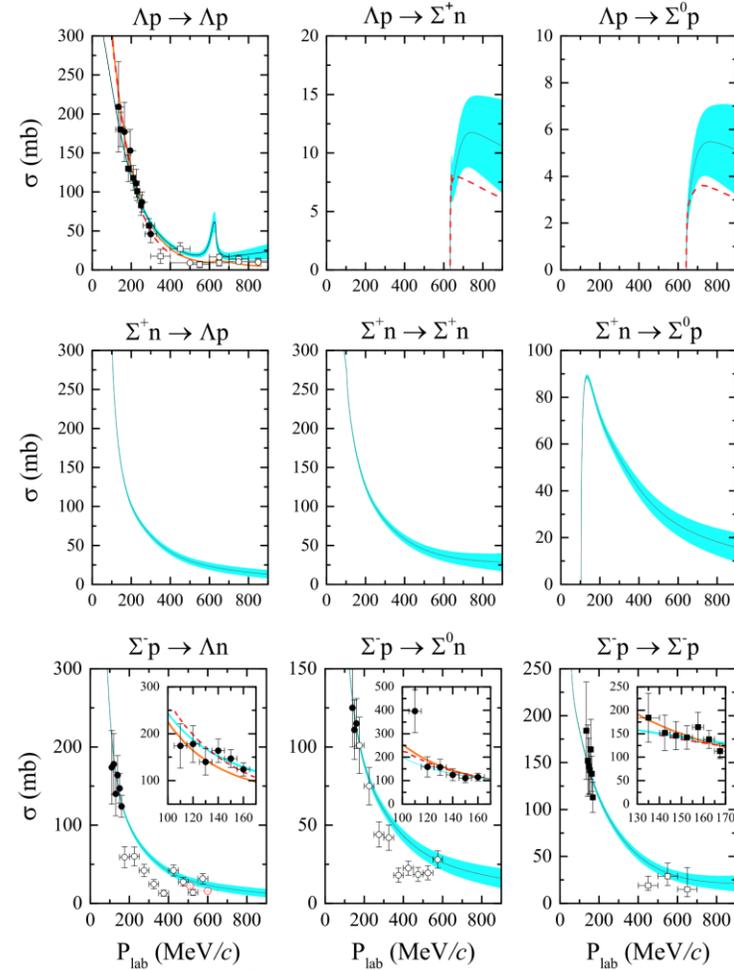
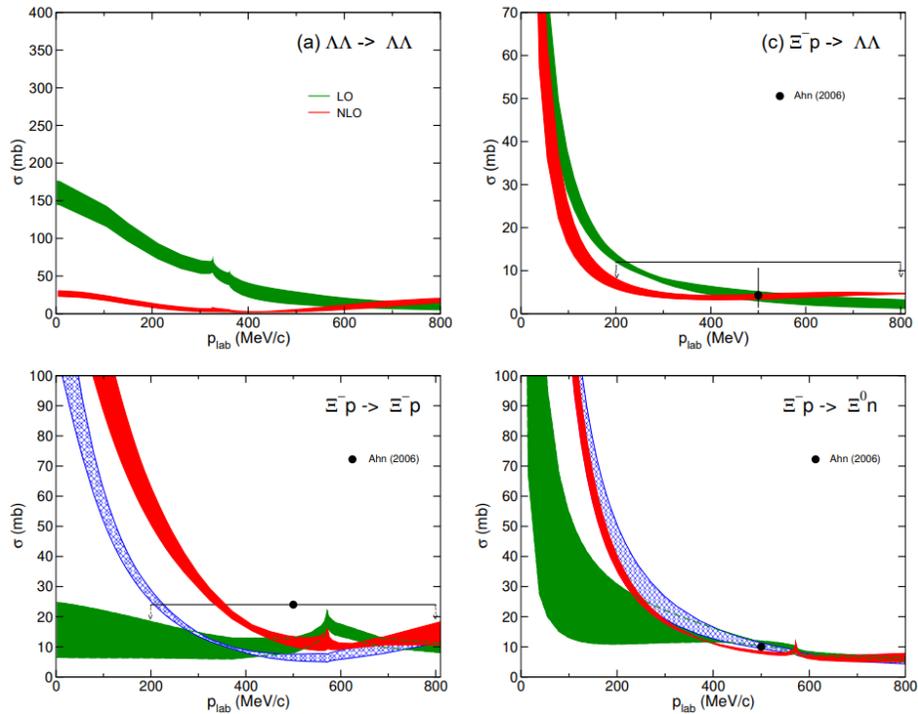
Thank you!

Backup

Theoretical status of hyperon-nucleon interaction

- Hyperon-nucleon interaction theory has significant uncertainties due to insufficient relevant measurements.

LO : H. Polinder, J.H., U.-G. Meißner, PLB 653 (2007) 29
 NLO16: J.H., U.-G. Meißner, S. Petschauer, NPA 954 (2016) 273
 NLO19: J.H., U.-G. Meißner, EPJA 55 (2019) 23



PRC 105, 035203 (2022)