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Combined Analysis of $K_L p \to \pi^+\Sigma^0$ and $\pi^+\Lambda$ Scattering

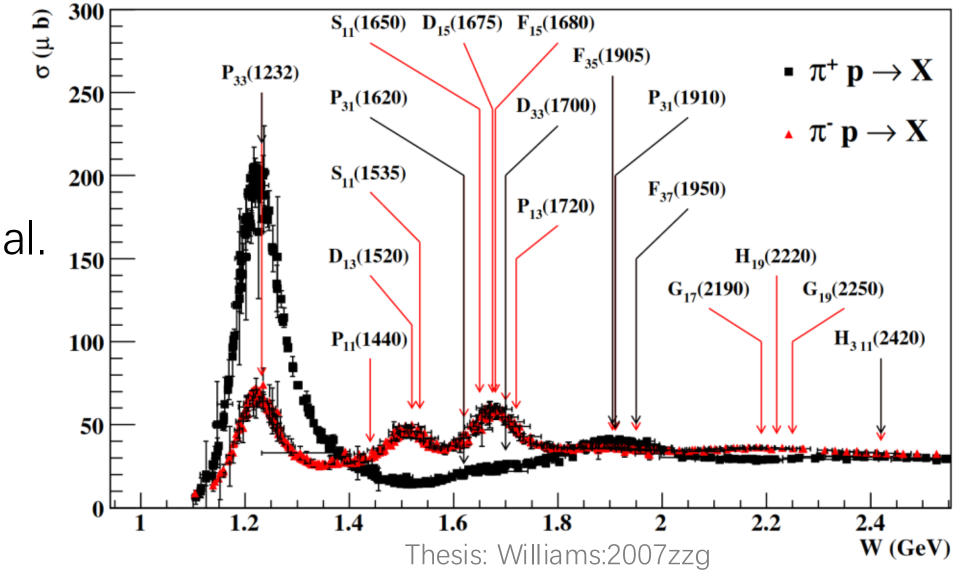
Dan Guo（郭丹） On behalf of KLF

Yanshan University

Dan Guo, Jun Shi (South-China Normal U.), Igor Strakovsky (Goerge-Washington U.) and Bing-Song Zou (Tsinghua U.), Analysis of Σ^* via isospin selective reaction $K_L p \to \pi^+ \Sigma^0$, Phys. Rev. D 112, 034006 (2025). And latest updates

2026轻强子专题研讨会，商丘师范学院，河南·商丘，May 15-17,2026

πN scattering: ~10^5 datasets
most clear in particle & nuclear physics.
All four-star N^*, Δ^*. Basic couplings $g_{\pi NN}$ et al.
PWA: SAID, MAID.

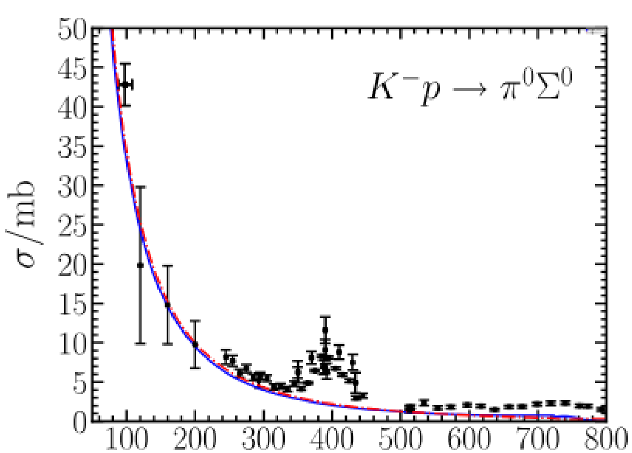


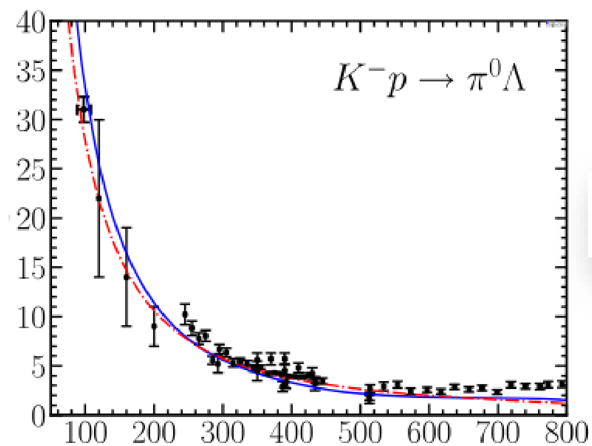
For **hyperon**: Λ^*, Σ^*, Ξ^*, Ω^*. $\bar{K}N$ scattering is most favored.

$Q > 0$ reaction,
kinematically allowed @ $P_{lab} = 0\ MeV$

$$Q = \sum_i m_i - \sum_f m_f$$

Near $\bar{K}N$ threshold with large phase space, strong coupling





~10 mb

$$\frac{d\sigma_{\pi^0\Lambda}}{d\Omega} = \frac{d\sigma_{\pi^0\Lambda}}{2\pi\, d\cos\theta} = \frac{1}{64\pi^2 s}\frac{|\mathbf{q}|}{|\mathbf{k}|}\overline{|\mathcal{M}|^2}$$

However, **hyperon** spectrum is very **ambiguous**

Mainly due to: old scattering data (1980s), scarcity of polarizations, **isospin-mixing**

$$
\begin{aligned}
T(K^- p \to \pi^- \Sigma^+) &= -\frac{1}{2} T^1(\overline{K}N \to \pi\Sigma) - \frac{1}{\sqrt{6}} T^0(\overline{K}N \to \pi\Sigma), \\
T(K^- p \to \pi^+ \Sigma^-) &= \frac{1}{2} T^1(\overline{K}N \to \pi\Sigma) - \frac{1}{\sqrt{6}} T^0(\overline{K}N \to \pi\Sigma), \\
T(K^- p \to \pi^0 \Sigma^0) &= \frac{1}{\sqrt{6}} T^0(\overline{K}N \to \pi\Sigma),
\end{aligned}
$$

$K^- p$ include $I = 0, 1$ amplitudes

E. Wang, L. S. Geng, J. J. Wu, J. J. Xie, and B. S. Zou, Review of the low-lying excited baryons $\Sigma^*(1/2^-)$, Chin. Phys. Lett. 41, 101401 (2024).

Difficulties of amplitude reversion: **phase ambiguity**, parameter degeneracy, incomplete exp. obser. set→ Multi-solution problem (nonlinear)

$$Observables \propto |\mathcal{M}|^2 = \mathcal{M} * \mathcal{M}^\dagger$$

allow an arbitrary phase $e^{i\phi}$

$$Observables \propto |\mathcal{M}|^2 = (e^{i\phi} * \mathcal{M}) * \left(e^{i\phi} * \mathcal{M}\right)^\dagger$$

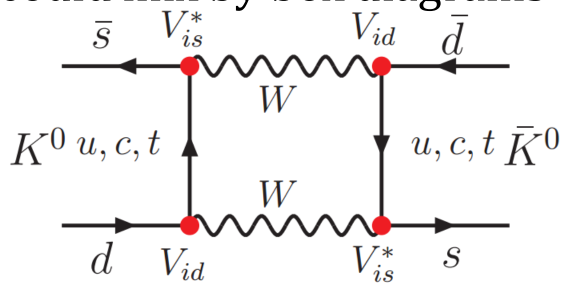
For multi-resonance reaction, relative phase must introduced.

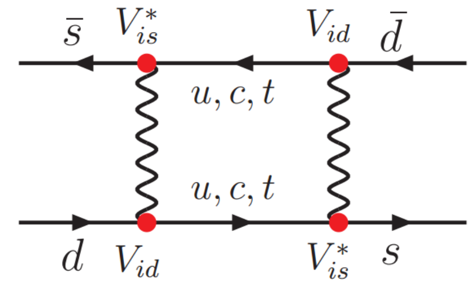
At least, ± 1, $\pm i$ phase.

isospin selective $K_L p \to \pi^+\Sigma^0$ process

K^0 $\bar{K}^0$ as flavor eigenstates, could mix by box diagrams

$K^0 - \bar{K}^0$ mixing





Ignore CP-violation term ($< 10^{-3}$), define CP eigenstates:

$$K_S^0 = \frac{1}{\sqrt{2}}(K^0 + \bar{K}^0),\ K_L^0 = \frac{1}{\sqrt{2}}(K^0 - \bar{K}^0)$$

mean life K_L: $5.116 \times 10^{-8}\ s$ ($c\tau = 15.3$ m)
K_S: $0.895 \times 10^{-10}\ s$ ($c\tau = 2.68$ cm)

K_L suitable as a beam to collide on the proton target.

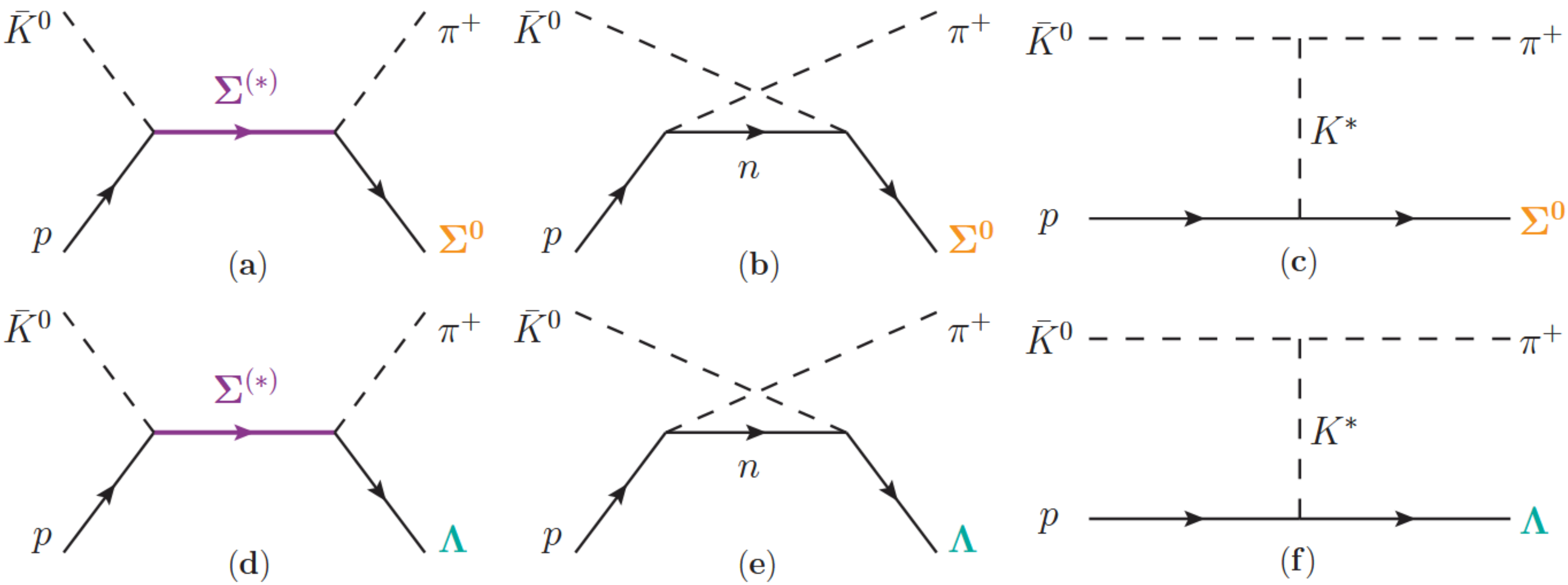
Most of $\bar{K}N$ scattering data from $K^- p$ reaction, contain both isoscalar and isovector

$$T(K_L p \to \pi^+\Sigma^0) = -\frac{1}{2} T^1(\bar{K}N \to \pi\Sigma),$$
$$T(K_L p \to \pi^0\Sigma^+) = \frac{1}{2} T^1(\bar{K}N \to \pi\Sigma),$$

$$T(K_L p \to \pi^+\Lambda) = -\frac{1}{\sqrt{2}} T^1(\bar{K}N \to \pi\Lambda),$$
$$T(K^- p \to \pi^0\Lambda) = \frac{1}{\sqrt{2}} T^1(\bar{K}N \to \pi\Lambda).$$

$\boldsymbol{K_L p}$ only $I = 1$ amplitudes

For $\boldsymbol{K_L p \to \pi^+ \Sigma^0 / \pi^+ \Lambda}$, only $\bar{K}^0$ contributes, tree-level Feynman diagrams:



In the energy range up to 1.7 GeV, Σ^* resonances(up to D-wave): $J^P = 1/2^{\pm}, 3/2^{\pm}, 5/2^{-}$

effective Lagrangian:

$$\mathcal{L}_{KN\Sigma} = \frac{g_{KN\Sigma}}{M_N + M_\Sigma}\partial_\mu \bar{K}\,\bar{\Sigma}\cdot\tau\gamma^\mu\gamma_5 N + \text{H.c.},$$
$$\mathcal{L}_{\pi\Sigma\Sigma} = i\frac{f_{\pi\Sigma\Sigma}}{m_\pi}\bar{\Sigma}\gamma^\mu\gamma_5 \times \Sigma\cdot\partial_\mu\pi + \text{H.c.},$$
$$\mathcal{L}_{\pi\Lambda\Sigma} = \frac{g_{\pi\Lambda\Sigma}}{M_\Lambda + M_\Sigma}\bar{\Lambda}\gamma^\mu\gamma_5\partial_\mu\pi\cdot\Sigma + \text{H.c.},$$

$1/2^+$

$$\mathcal{L}_{KN\Sigma(1/2^-)} = -ig_{KN\Sigma(1/2^-)}\bar{K}\,\bar{\Sigma}(1/2^-)\cdot\tau N + \text{H.c.},$$
$$\mathcal{L}_{\pi\Sigma\Sigma(1/2^-)} = g_{\pi\Sigma\Sigma(1/2^-)}\bar{\Sigma}(1/2^-)\times\Sigma\cdot\pi + \text{H.c.},$$
$$\mathcal{L}_{\pi\Lambda\Sigma(1/2^-)} = -ig_{\pi\Lambda\Sigma(1/2^-)}\bar{\Sigma}(1/2^-)\Lambda\pi + \text{H.c.}$$

$1/2^-$

$$\mathcal{L}_{KN\Sigma^*} = \frac{f_{KN\Sigma^*}}{m_K}\partial_\mu\bar{K}\,\bar{\Sigma}^{*\mu}\cdot\tau N + \text{H.c.},$$
$$\mathcal{L}_{\pi\Sigma\Sigma^*} = i\frac{f_{\pi\Sigma\Sigma^*}}{m_\pi}\partial_\mu\pi\cdot\bar{\Sigma}^{*\mu}\times\Sigma + \text{H.c.},$$
$$\mathcal{L}_{\pi\Lambda\Sigma^*} = \frac{f_{\pi\Lambda\Sigma^*}}{m_\pi}\partial_\mu\pi\cdot\bar{\Sigma}^{*\mu}\Lambda + \text{H.c.}$$

$3/2^+$

$$\mathcal{L}_{KN\Sigma(3/2^-)} = \frac{f_{KN\Sigma(3/2^-)}}{m_K}\partial_\mu\bar{K}\,\bar{\Sigma}^\mu(3/2^-)\cdot\tau\gamma_5 N + \text{H.c.},$$
$$\mathcal{L}_{\pi\Sigma\Sigma(3/2^-)} = i\frac{f_{\pi\Sigma\Sigma(3/2^-)}}{m_\pi}\partial_\mu\pi\cdot\bar{\Sigma}^\mu(3/2^-)\times\gamma_5\Sigma + \text{H.c.},$$
$$\mathcal{L}_{\pi\Lambda\Sigma(3/2^-)} = \frac{f_{\pi\Lambda\Sigma(3/2^-)}}{m_\pi}\partial_\mu\pi\bar{\Sigma}^\mu(3/2^-)\gamma_5\Lambda + \text{H.c.}$$

$3/2^-$

$$\mathcal{L}_{KN\Sigma(5/2^-)} = g_{KN\Sigma(5/2^-)}\partial_\mu\partial_\nu\bar{K}\,\bar{\Sigma}^{\mu\nu}(5/2^-)\cdot\tau N + \text{H.c.},$$
$$\mathcal{L}_{\pi\Sigma\Sigma(5/2^-)} = ig_{\pi\Sigma\Sigma(5/2^-)}\partial_\mu\partial_\nu\pi\cdot\bar{\Sigma}^{\mu\nu}(5/2^-)\times\Sigma + \text{H.c.},$$
$$\mathcal{L}_{\pi\Lambda\Sigma(5/2^-)} = g_{\pi\Lambda\Sigma(5/2^-)}\partial_\mu\partial_\nu\pi\cdot\bar{\Sigma}^{\mu\nu}(5/2^-)\Lambda + \text{H.c.}$$

$5/2^-$

$$\mathcal{L}_{\pi NN} = \frac{g_{\pi NN}}{2M_N}\bar{N}\gamma^\mu\gamma_5\partial_\mu\pi\cdot\tau N,$$
$$\mathcal{L}_{KN\Lambda} = \frac{g_{KN\Lambda}}{M_N + M_\Lambda}\bar{N}\gamma^\mu\gamma_5\Lambda\partial_\mu K + \text{H.c.},$$

u-channel

$$\mathcal{L}_{K^*K\pi} = ig_{K^*K\pi}\bar{K}^*_\mu(\pi\cdot\tau\partial^\mu K - \partial^\mu\pi\cdot\tau K),$$
$$\mathcal{L}_{K^*N\Sigma} = -g_{K^*N\Sigma}\bar{\Sigma}\cdot\tau\left(\gamma_\mu\bar{K}^{*\mu} - \frac{\kappa_{K^*N\Sigma}}{2M_N}\sigma_{\mu\nu}\partial^\nu\bar{K}^{*\mu}\right)N + \text{H.c.}$$
$$\mathcal{L}_{K^*N\Lambda} = -g_{K^*N\Lambda}\bar{\Lambda}\left(\gamma_\mu K^{*\mu} - \frac{\kappa_{K^*N\Lambda}}{2M_N}\sigma_{\mu\nu}\partial^\nu K^{*\mu}\right)N + \text{H.c.}$$

t-channel

$$F_B(q_{ex}^2, M_{ex}) = \frac{\Lambda^4}{\Lambda^4 + (q_{ex}^2 - M_{ex}^2)^2}$$

Form factors account for off-shell effects

$$\mathcal{M}^{r_2,r_1}_{\bar{K}^0 p\to\pi^+\Sigma^0} = \bar{u}_{r_2}(p_2)\mathcal{A}u_{r_1}(p_1) = \bar{u}_{r_2}(p_2)\left(\sum_i\mathcal{A}_i\right)u_{r_1}(p_1)$$

Total amp.

$$\frac{d\sigma_{K_Lp\to\pi^+\Sigma^0}}{d\Omega} = \frac{d\sigma_{K_Lp\to\pi^+\Sigma^0}}{2\pi d\cos(\theta)} = \frac{1}{2}\frac{1}{64\pi^2 s}\frac{|\vec{k}_2|}{|\vec{k}_1|}\overline{|\mathcal{M}_{\bar{K}^0p\to\pi^+\Sigma^0}|}^2$$

Differential cross section

Initial couplings estimated from SU(3) relations or partial decay widths.
A tunable scaling factor ∈ [1/2, 2] is introduced account for SU(3) breaking.

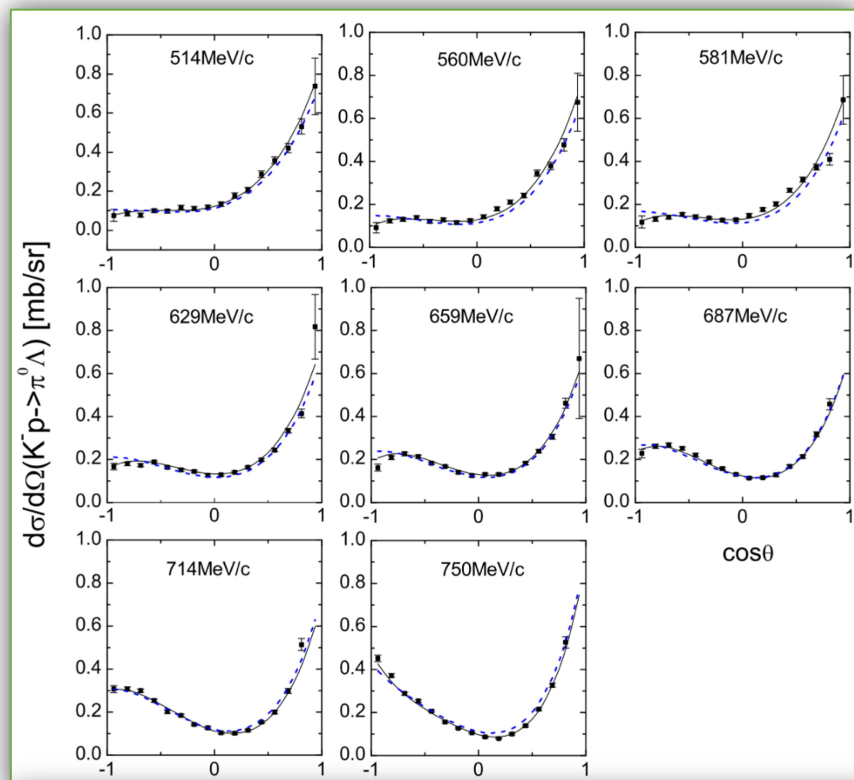
	Mass (MeV) (PDG estimate)	Γ_{tot} (MeV) (PDG estimate)	$(\Gamma_{\pi\Lambda}\Gamma_{KN})^{\frac{1}{2}}/\Gamma_{tot}$ (PDG range)
$\Sigma(1670)\frac{3}{2}^-$	$1673.1^{+1.4}_{-1.6}$ (1665, 1685)	$53^{+7}_{-5.5}$ (40, 80)	$+0.08^{+0.022}_{-0.018}$ (0.02, 0.17)
$\Sigma(1635)$ or $\Sigma(1660)\frac{1}{2}^+$	$1634.8^{+2.7}_{-4.5}$ (1630, 1690)	120 ± 12 (40, 200)	$-0.065^{+0.015}_{-0.017}$ (0,0.24)

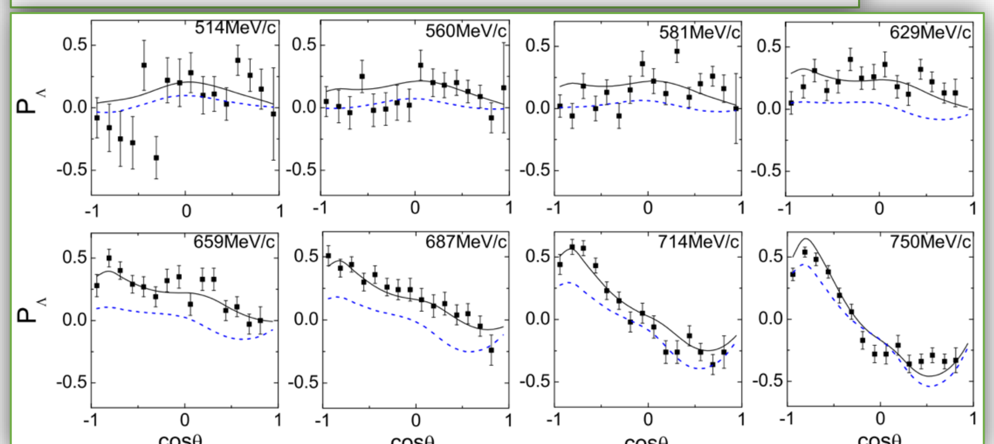
Our previous work:

P. Gao, B.S. Zou, A. Sibirtsev/ Nuclear Physics A 867 41 (2011)

$K^- p \to \pi^0 \Lambda$: dcs and recoil polarization

Cited by PDG





Σ(1660) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1640 to 1680 (≈ 1660) OUR ESTIMATE				
1665 ±20	SARANTSEV	19	DPWA	$\overline{K}N$ multichannel
1633 ± 3	GAO	12	DPWA	$\overline{K}N \to \Lambda\pi$
1665.1±11.2	[1] KOISO	85	DPWA	$K^- p \to \Sigma\pi$
1670 ±10	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
1679 ±10	ALSTON-...	78	DPWA	$\overline{K}N \to \overline{K}N$
1668 ±25	VANHORN	75	DPWA	$K^- p \to \Lambda\pi^0$
1670 ±20	KANE	74	DPWA	$K^- p \to \Sigma\pi$

Σ(1660) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
100 to 300 (≈ 200) OUR ESTIMATE				
300^{+140}_{-40}	SARANTSEV	19	DPWA	$\overline{K}N$ multichannel
121^{+4}_{-7}	GAO	12	DPWA	$\overline{K}N \to \Lambda\pi$
81.5± 22.2	[1] KOISO	85	DPWA	$K^- p \to \Sigma\pi$
152 ± 20	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1660) \to \Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
$-0.064^{+0.005}_{-0.003}$	GAO	12	DPWA	$\overline{K}N \to \Lambda\pi$
< 0.04	GOPAL	77	DPWA	$\overline{K}N$ multichannel
$0.12^{+0.12}_{-0.04}$	VANHORN	75	DPWA	$K^- p \to \Lambda\pi^0$

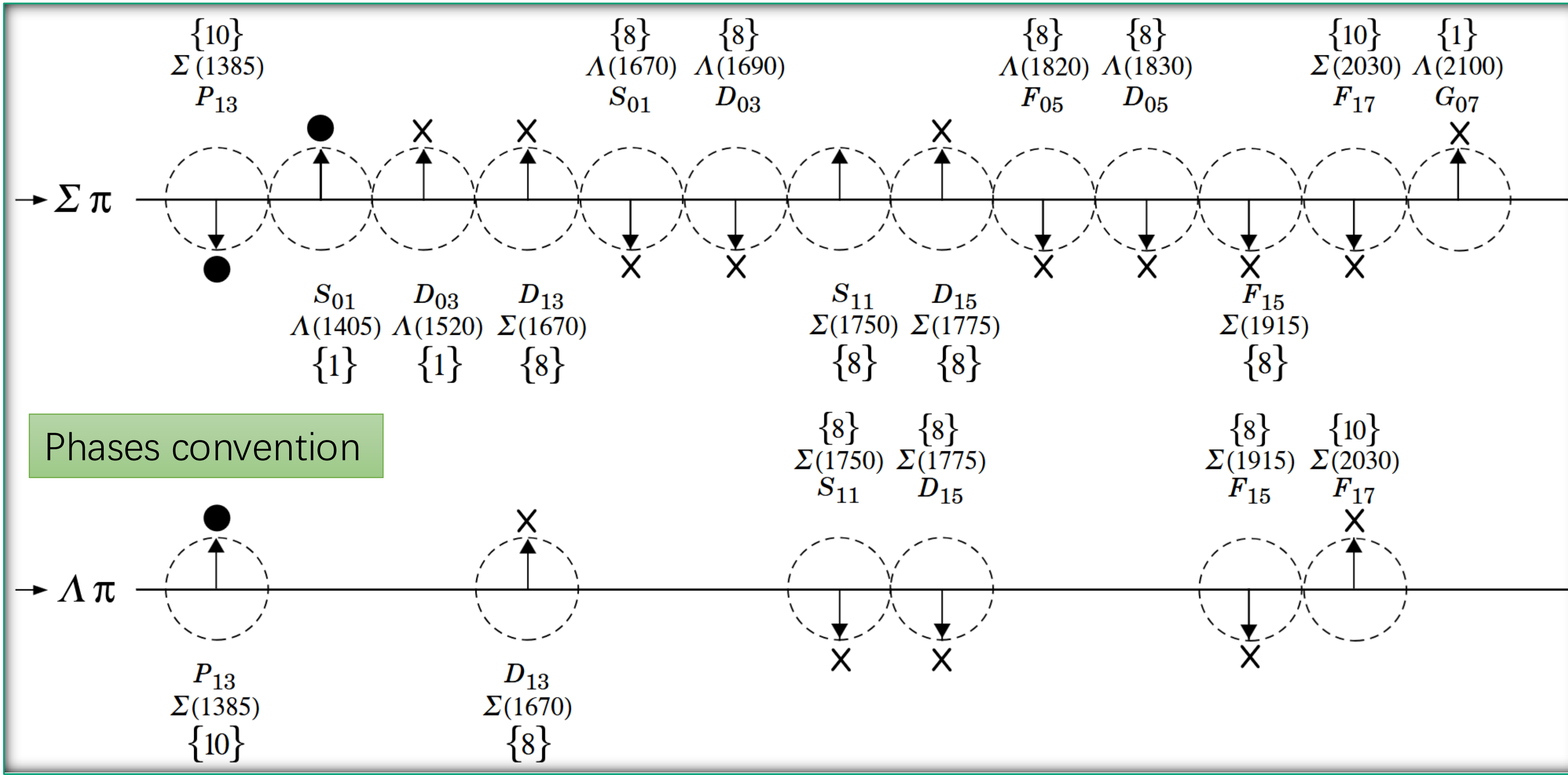
The sign denotes amp. phase

PDG review:

82. Λ and Σ Resonances

Revised August 2021 by V.D. Burkert (Jefferson Lab), V. Crede (Florida State U.), E. Klempt (Bonn U.), U. Thoma (Bonn U.), L. Tiator (KPH, JGU Mainz) and R.L. Workman (George Washington U.).

$\Sigma\pi$ final state: Σ^* Λ^* signs, $\Lambda\pi$: Σ^* signs.



● set by convention, ⇂↿ by SU(3) assignments, × experiment determined

Include four-star $\Sigma^{(*)}$: $\Sigma(1189)1/2^+$, $\Sigma(1385)3/2^+$, $\Sigma(1670)3/2^-$, $\Sigma(1775)5/2^-$
unestablished states: $\Sigma(1580)3/2^-$, $\Sigma(1620)1/2^-$, $\Sigma(1660)1/2^+$, $\Sigma(1750)1/2^-$

Fitted results

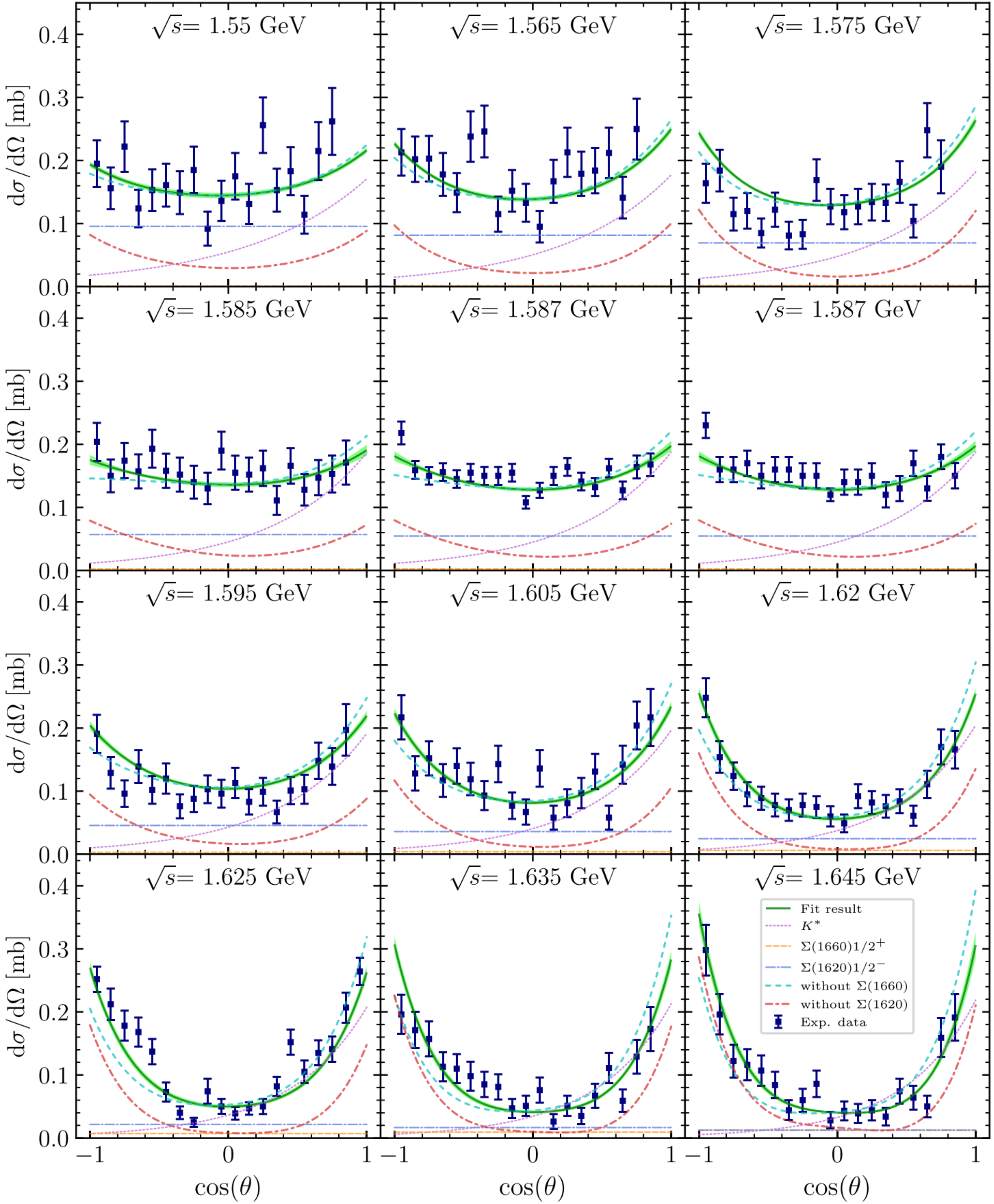
Origin: only **** states: $\chi^2/dof = 2.8$

keeping strict phase conventions

	m (MeV)	Γ (MeV)	Signs
$\Sigma(1189)1/2^+$	1192	0	…
$\Sigma(1385)3/2^+$	1384	36	↓
$\Sigma(1670)3/2^-$	1675	70	↑
$\Sigma(1775)5/2^-$	1775	120	↑

Resonances	Parameters	Optimal fit	Fit I	Fit II	Fit III	Estimates
K^*	$g_{K^*N\Sigma}$	-7.0 ± 0.5	-7.0	-2.7	-7.0 ± 1.2	$[-7.0, -1.2]$
	$\kappa_{K^*N\Sigma}$	-1.6 ± 0.2	-2.3	-2.3	-1.6 ± 0.8	$[-2.3, -0.2]$
	Λ	0.97 ± 0.01	1.01	2.0	0.97 ± 0.09	$[0.5, 2.0]$
N	Λ	1.42 ± 0.04	1.93	1.47	1.4 ± 0.4	$[0.5, 2.0]$
$\Sigma(1189)1/2^+$	$g_{KN\Sigma} f_{\pi\Sigma\Sigma}$	-1.50 ± 3.0	-3.39	-1.35	-1.50 ± 3.0	$[-5.4, -1.3]$
	Λ	0.5 ± 1.1	0.6	0.5	0.5 ± 1.3	$[0.5, 2.0]$
$\Sigma(1385)3/2^+$	$f_{KN\Sigma^*} f_{\pi\Sigma\Sigma^*}$	-1.34 ± 4.0	-4.49	-5.7	-1.34 ± 4.0	$[-5.7, -1.1]$
	Λ	0.50 ± 0.18	0.5	0.6	0.5 ± 1.3	$[0.5, 2.0]$
$\Sigma(1670)3/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	$+0.26 \pm 0.04$	$+0.27$	$+0.29$	$+0.24 \pm 0.06$	$[0.09, 0.38]$
	Λ	0.72 ± 0.07	0.61	0.62	0.76 ± 0.17	$[0.5, 2.0]$
$\Sigma(1775)5/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	$+0.24 \pm 0.04$	$+0.24$	$+0.24$	$+0.24 \pm 0.12$	$[0.06, 0.24]$
	Λ	2.0 ± 1.4	2.0	1.1	2.0 ± 1.5	$[0.5, 2.0]$
$\Sigma(1580)3/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	$+0.032 \pm 0.005$	$+0.034$	…	$+0.031 \pm 0.005$	$[-0.4, 0.4]$
	Λ	0.50 ± 0.09	0.5	…	0.50 ± 0.11	$[0.5, 2.0]$
$\Sigma(1660)1/2^+$	M (GeV)	1.696 ± 0.010	1.75	…	1.673 ± 0.027	$[1.40, 1.75]$
	Γ (GeV)	0.108 ± 0.021	0.073	…	0.10 ± 0.04	$[0.01, 0.40]$
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	-0.112 ± 0.006	-0.121	…	-0.086 ± 0.048	$[-0.48, 0.48]$
	Λ	2.0 ± 0.8	2.0	…	2.0 ± 1.2	$[0.5, 2.0]$
$\Sigma(1620)1/2^-$	M (GeV)	1.541 ± 0.003	1.4(Fixed)	1.545	1.542 ± 0.007	$[1.35, 1.65]$
	Γ (GeV)	0.129 ± 0.002	0.4	0.10	0.16 ± 0.05	$[0.01, 0.40]$
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	-0.633 ± 0.009	-2.32	-0.45	-0.779 ± 0.259	$[-3.2, 3.2]$
	Λ	0.89 ± 0.04	1.07	0.59	0.72 ± 0.19	$[0.5, 2.0]$
$\Sigma(1750)1/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	…	…	…	$+0.093 \pm 0.187$	$[-1.2, 1.2]$
	Λ	…	…	…	1.9 ± 0.8	$[0.5, 2.0]$
	d.o.f.	223	224	229	221	
	χ^2/d.o.f.	1.606	1.707	1.774	1.619	

Phys. Rev. D 112, 034006 (2025).



Narrow 1-σ errorband, robust para constraint

χ^2/DoF=1.606

t-channel dominates the forward-angle.
s-channel no angle dependence.

$\Sigma(1660)1/2^+$	M (GeV)	1.696 ± 0.010
	Γ (GeV)	0.108 ± 0.021
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	-0.112 ± 0.006
	Λ	2.0 ± 0.8
$\Sigma(1620)1/2^-$	M (GeV)	1.541 ± 0.003
	Γ (GeV)	0.129 ± 0.002
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{\rm tot}$	-0.633 ± 0.009
	Λ	0.89 ± 0.04

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow \Sigma(1660) \rightarrow \Sigma\pi$

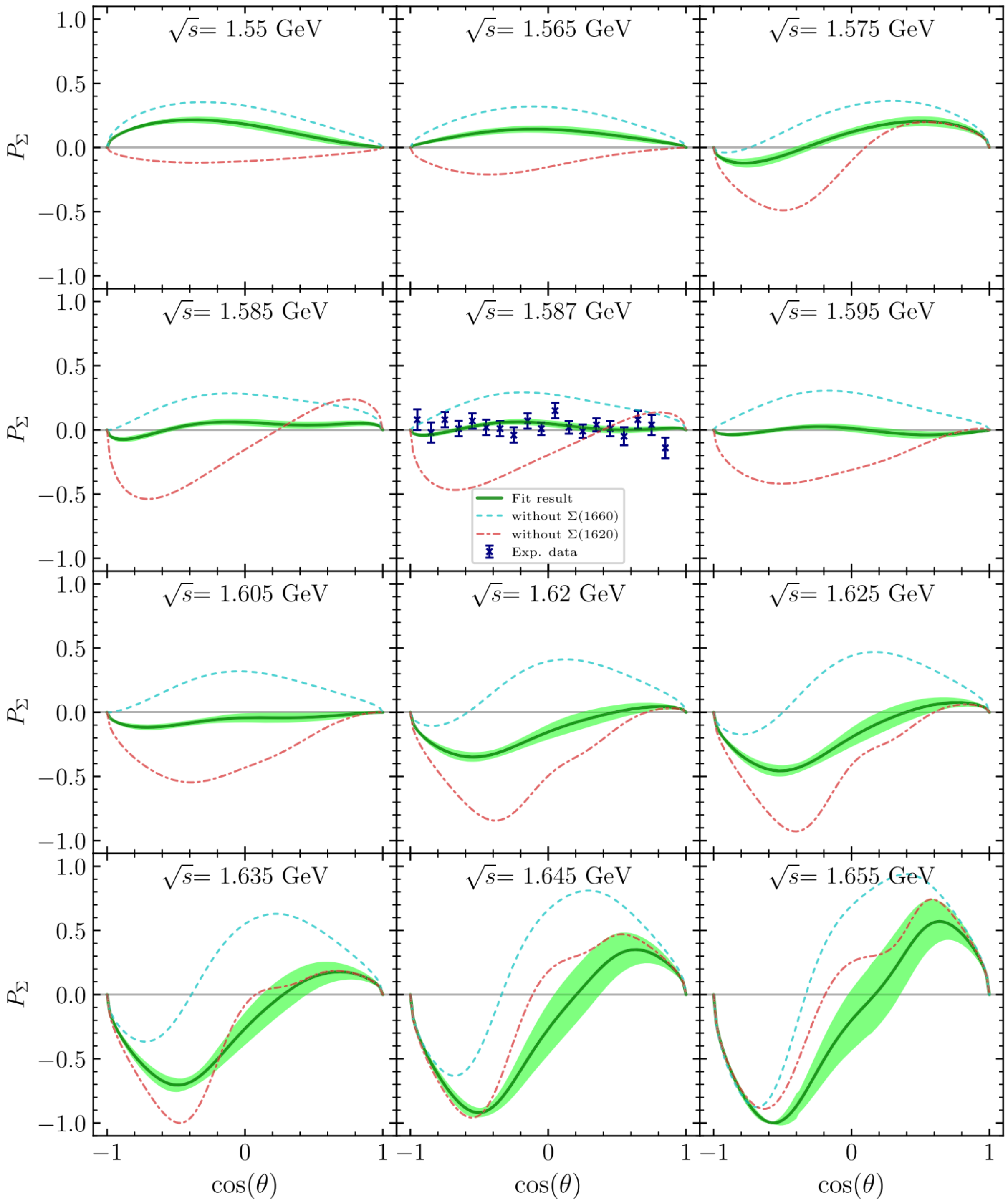
VALUE	*DOCUMENT ID*	
-0.13 ± 0.04	[1] KOISO	85
-0.16 ± 0.03	GOPAL	77
-0.11 ± 0.01	KANE	74

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow \Sigma(1620) \rightarrow \Sigma\pi$

VALUE	*DOCUMENT ID*	
$+0.32\pm0.03$	ZHANG	13A
not seen	HEPP	76B
$+0.40\pm0.06$	LANGBEIN	72
$+0.08$	KIM	71

Fitted M Γ of $\Sigma(1/2^-)$ compatible with
Phys. Rev. C 88, 035205 (2013).
Phys. Rev. C 92, 025205 (2015) .

Phys. Rev. D 112, 034006 (2025).



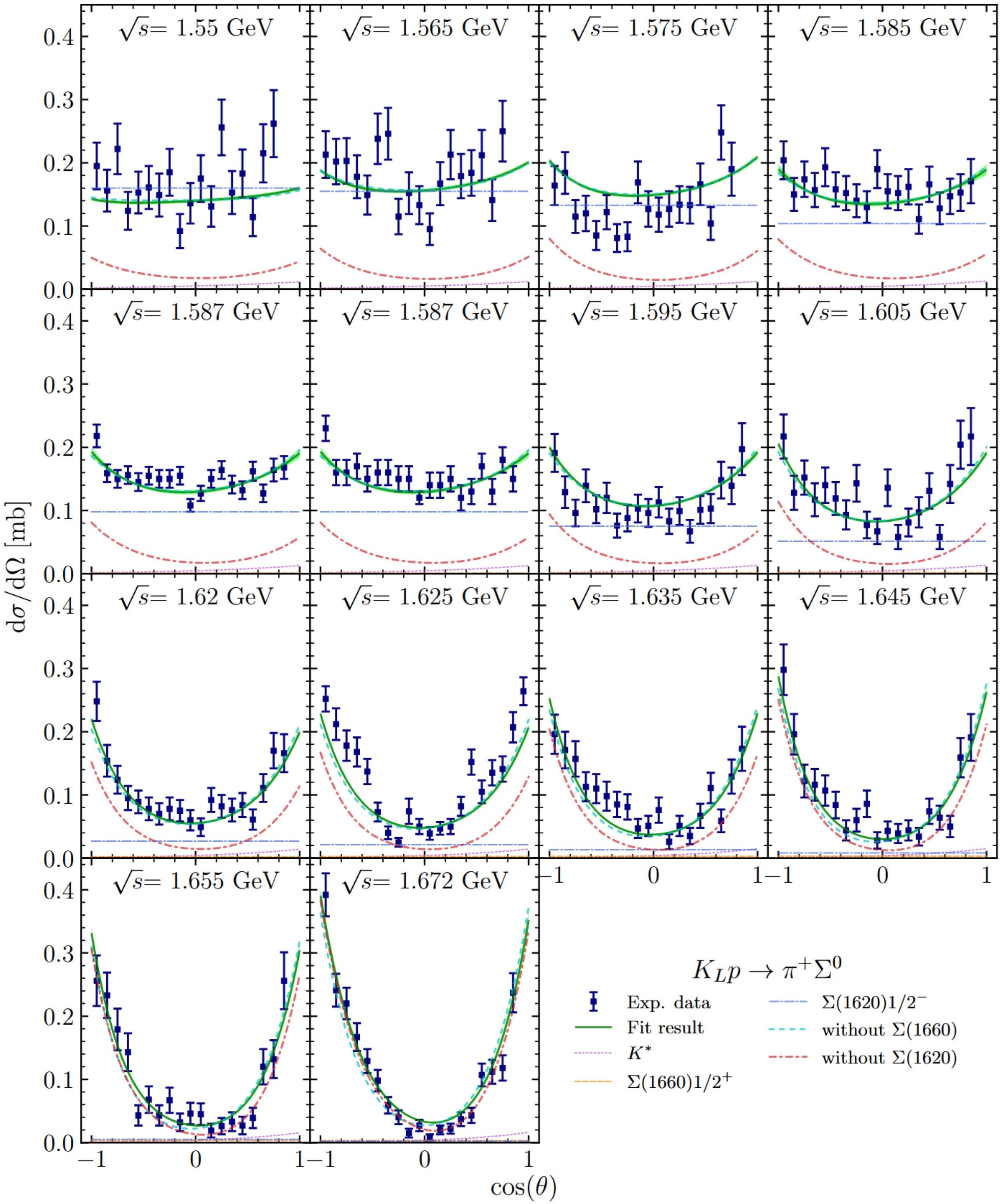
Recoil polarization

$$P_\Sigma = -\frac{2\,\mathrm{Im}\left(\mathcal{M}^{1/2,1/2}_{\bar{K}^0 p\to\pi^+\Sigma^0}\mathcal{M}^{*-1/2,1/2}_{\bar{K}^0 p\to\pi^+\Sigma^0}\right)}{\overline{\left|\mathcal{M}_{\bar{K}^0 p\to\pi^+\Sigma^0}\right|^2}}$$

Polarization arises from interference. Single diagram produce zero polarization.

Measuring the asymmetry in the spin distribution of the recoiling Σ^0 along the direction normal to the reaction plane.

Phys. Rev. D 112, 034006 (2025).



Further, $\pi^+\Sigma^0$ and $\pi^+\Lambda$, joint fitting

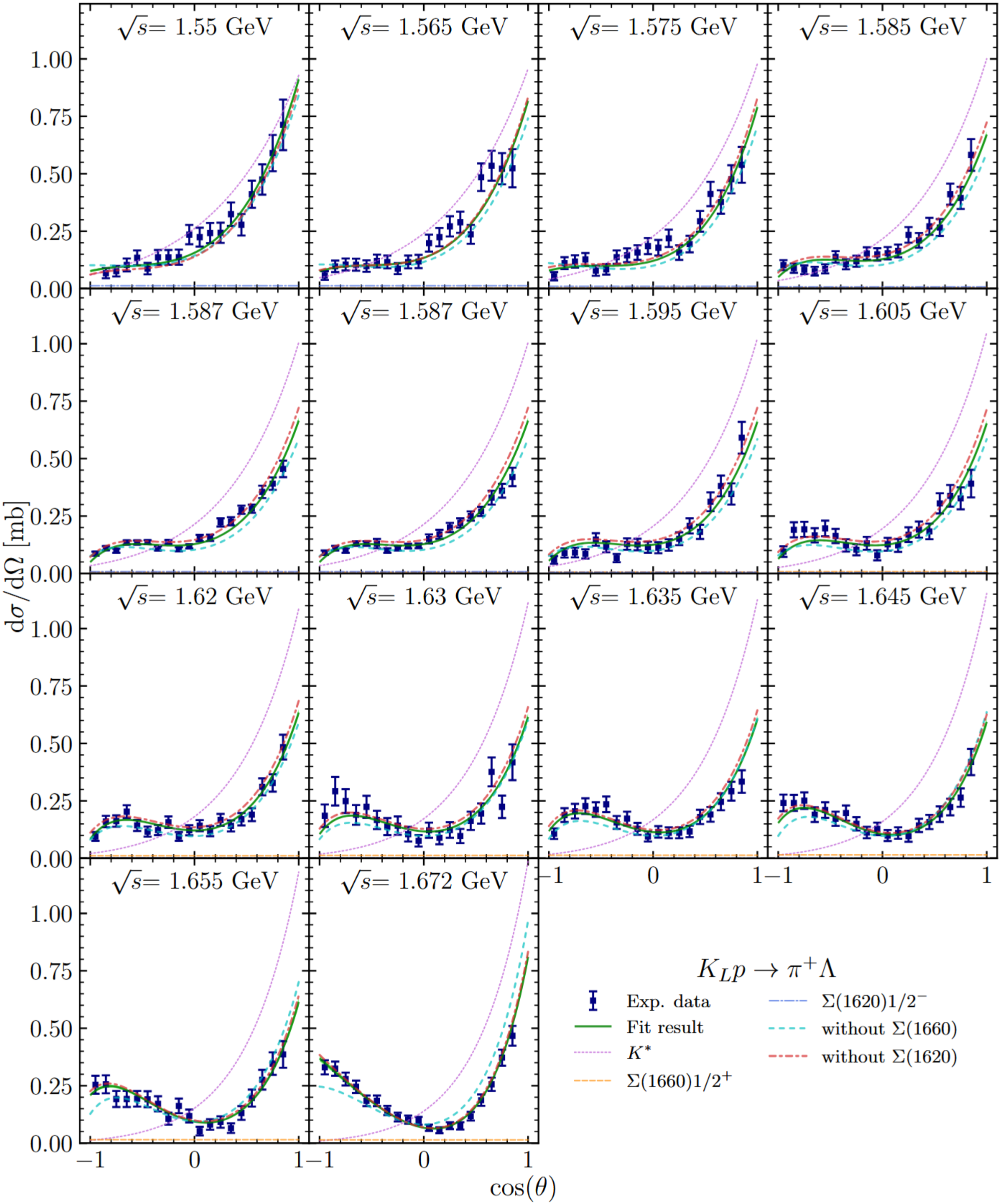
Common cutoffs and Consistent phase for two channels.
Almost invisible errorbands

$\chi^2 = 855.029$,
$\chi^2/\text{dof} = 1.6041$
$\text{dof} = 283 + 284 - 34 = 533$

$\Sigma(1660)1/2^+$:
$m = 1.637$ GeV,
$\Gamma = 0.129$ GeV

$\Sigma(1620)1/2^-$:
$m = 1.557$ GeV,
$\Gamma = 0.117$ GeV
Indispensable!

Latest updates!
Coming soon!



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χ^2= 855.029,
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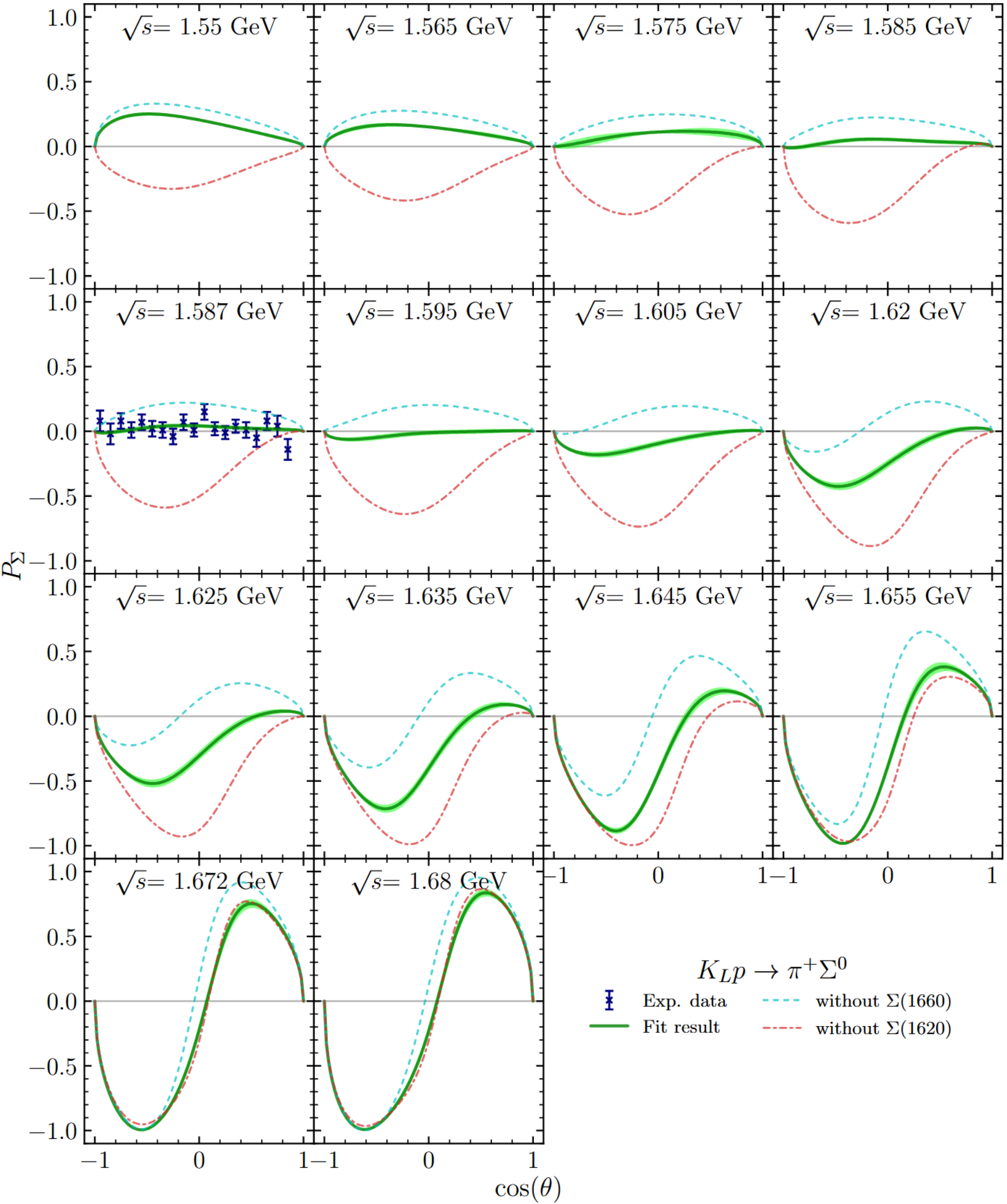
dof=283+284−34=533

$\Sigma(1660)1/2^+$:
$m = 1.637$ GeV,
$\Gamma = 0.129$ GeV

$\Sigma(1620)1/2^-$:
$m = 1.557$ GeV,
$\Gamma = 0.117$ GeV
Negligible!

Latest updates!
Coming soon!

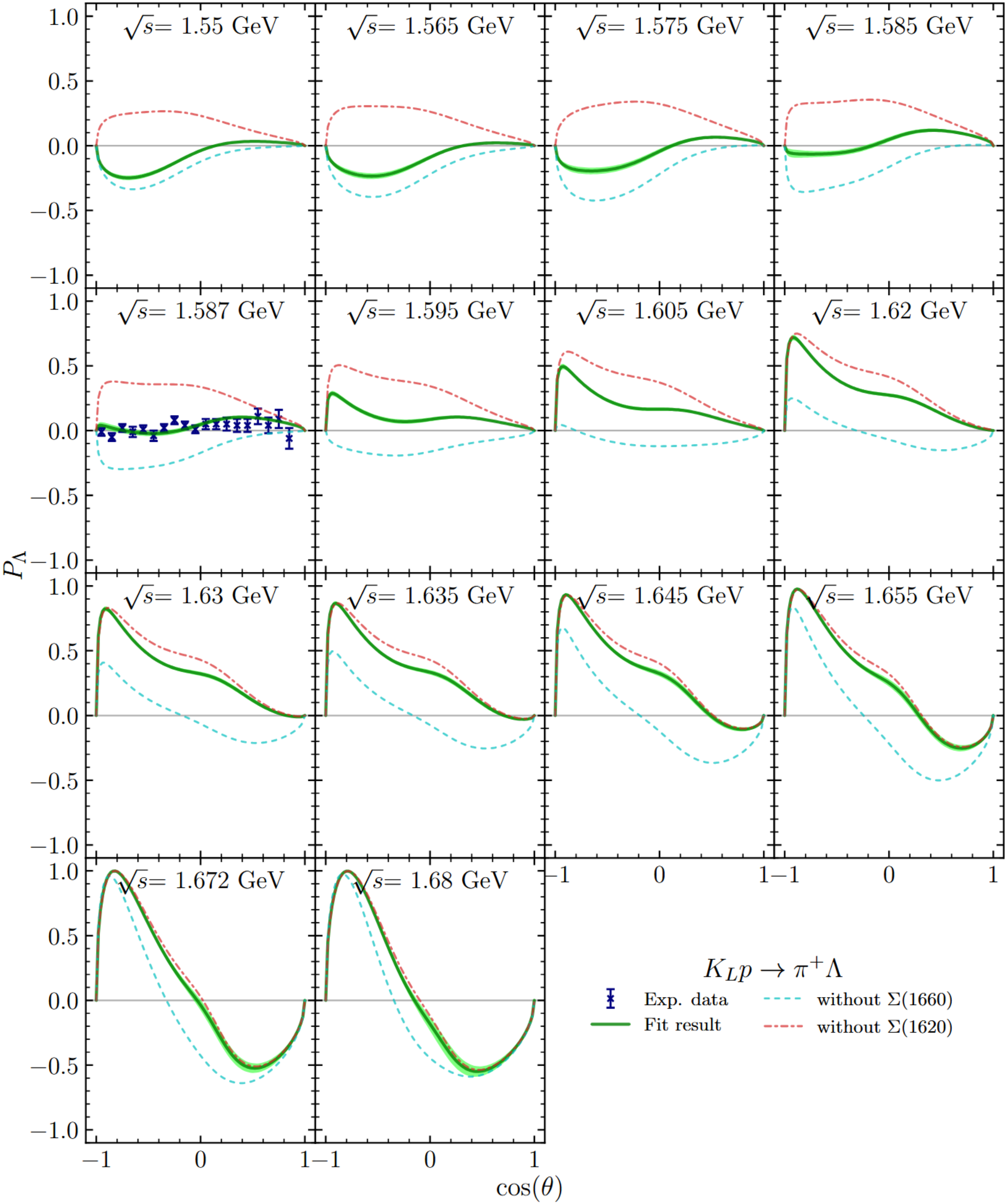


Further, $\pi^+\Sigma^0$ and $\pi^+\Lambda$, joint fitting

Common cutoffs and Consistent phase for two channels. Almost invisible errorbands.

Polarizations @ other E_{cm} also constrained strictly

Latest updates! Coming soon!



Further, $\pi^+\Sigma^0$ and $\pi^+\Lambda$, joint fitting

Common cutoffs and
Consistent phase for
two channels.
Almost invisible errorbands.

Polarizations @ other E_{cm} also constrained strictly

Latest updates!
Coming soon!

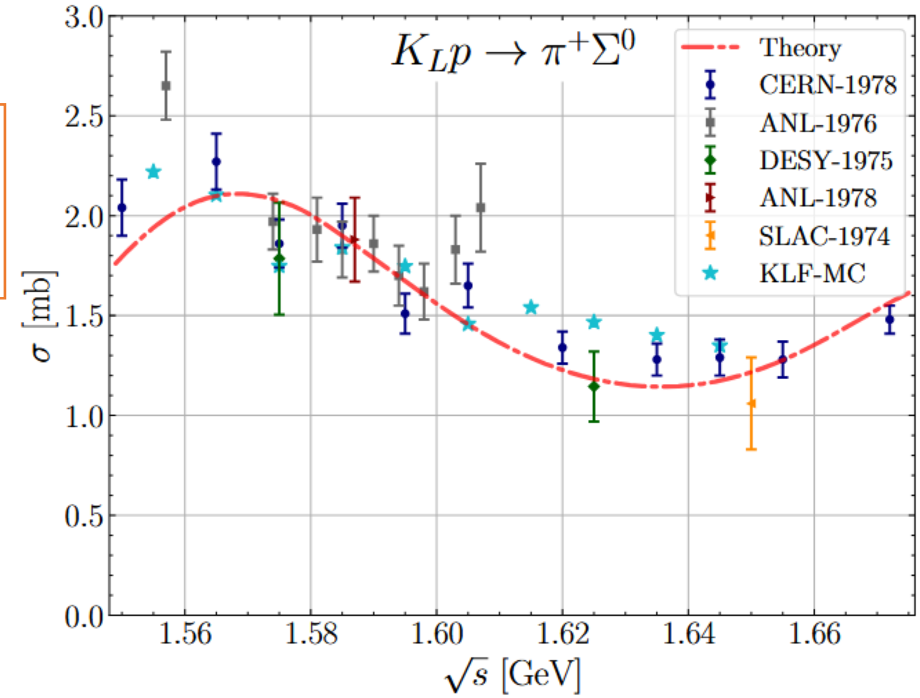
Resonances	Parameters	Optimal Fit	Fit I	Fit II	Fit III	Estimates
K^*	$g_{K^*N\Sigma}$	-1.2±0.1	-1.4	-2.4	-1.8	[-7.0, -1.2]
	$\kappa_{K^*N\Sigma}$	-2.3±0.2	-2.3	-0.2	-2.3	[-2.3, -0.2]
	$g_{K^*N\Lambda}$	-9.8±0.1	-4.1	-7.9	-5.2	[-12.2, -2.1]
	$\kappa_{K^*N\Lambda}$	1.2±0.1	1.2	1.76	1.2	[1.2, 5.3]
	Λ	1.14±0.01	2.0	1.1	1.4	[0.5, 2.0]
N	Λ	0.97±0.01	0.94	1.1	1.0	[0.5, 2.0]
$\Sigma(1189)1/2^+$	$g_{KN\Sigma}f_{\pi\Sigma\Sigma}$	-1.35±0.04	-1.50	-1.35	-1.50	[-5.4, -1.3]
	$g_{KN\Sigma}f_{\pi\Lambda\Sigma}$	69.6±2.8	66.0	47.9	17.4	[17.4, 69.6]
	Λ	1.01±0.02	0.50	0.51	0.5	[0.5, 2.0]
$\Sigma(1385)3/2^+$	$f_{KN\Sigma^*}f_{\pi\Sigma\Sigma^*}$	-1.12±0.10	-1.12	-1.12	-1.12	[-5.7, -1.1]
	$f_{KN\Sigma^*}f_{\pi\Lambda\Sigma^*}$	-8.63±0.54	-8.63	-5.35	-8.63	[-8.6, -2.1]
	Λ	0.61±0.01	0.66	0.79	0.66	[0.5, 2.0]
$\Sigma(1670)3/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{tot}$	+0.20±0.01	+0.18	+0.12	+0.18	[0.09, 0.38]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Lambda}}/\Gamma_{tot}$	+0.14±0.01	+0.05	+0.16	+0.06	[0.04, 0.18]
	Λ	0.97±0.12	2.0	0.95	2.0	[0.5, 2.0]
$\Sigma(1775)5/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{tot}$	+0.24±0.02	+0.24	+0.24	+0.24	[0.06, 0.24]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Lambda}}/\Gamma_{tot}$	-0.15±0.02	-0.43	-0.13	-0.40	[-0.52, -0.13]
	Λ	2.00±0.23	2.0	2.0	1.37	[0.5, 2.0]
$\Sigma(1580)3/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{tot}$	+0.010±0.004	+0.004	+0.012	—	[-0.35, 0.35]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Lambda}}/\Gamma_{tot}$	-0.012±0.002	-0.002	-0.005	—	[-0.39, 0.39]
	Λ	0.50±0.11	0.50	0.50	—	[0.5, 2.0]
$\Sigma(1660)1/2^+$	M [GeV]	1.637±0.003	1.613	1.75	—	[1.40, 1.75]
	Γ [GeV]	0.130±0.006	0.105	0.01	—	[0.01, 0.40]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{tot}$	-0.052±0.005	+0.001	+0.112	—	[-0.48, 0.48]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Lambda}}/\Gamma_{tot}$	-0.077±0.002	-0.055	+0.086	—	[-0.41, 0.41]
	Λ	2.0±1.4	2.0	1.8	—	[0.5, 2.0]
$\Sigma(1620)1/2^-$	M [GeV]	1.557±0.002	1.556	1.4(Fixed)	1.554	[1.35, 1.65]
	Γ [GeV]	0.117±0.001	0.086	0.10	0.086	[0.01, 0.40]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{tot}$	-0.741±0.006	-0.50	-1.68	-0.51	[-3.2, 3.2]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Lambda}}/\Gamma_{tot}$	-0.142±0.006	-0.96	+0.49	+0.003	[-2.4, 2.4]
	Λ	0.62±0.01	0.83	2.0	0.9	[0.5, 2.0]
$\Sigma(1750)1/2^-$	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Sigma}}/\Gamma_{tot}$	+0.45±0.01	—	—	—	[-1.2, 1.2]
	$\sqrt{\Gamma_{\bar{K}N}\Gamma_{\pi\Lambda}}/\Gamma_{tot}$	+0.19±0.01	—	—	—	[-1.2, 1.2]
	Λ	2.0±1.2	—	—	—	[0.5, 2.0]
	D.o.F	533	536	537	544	
	χ^2/D.o.F	1.604	2.210	1.880	2.546	

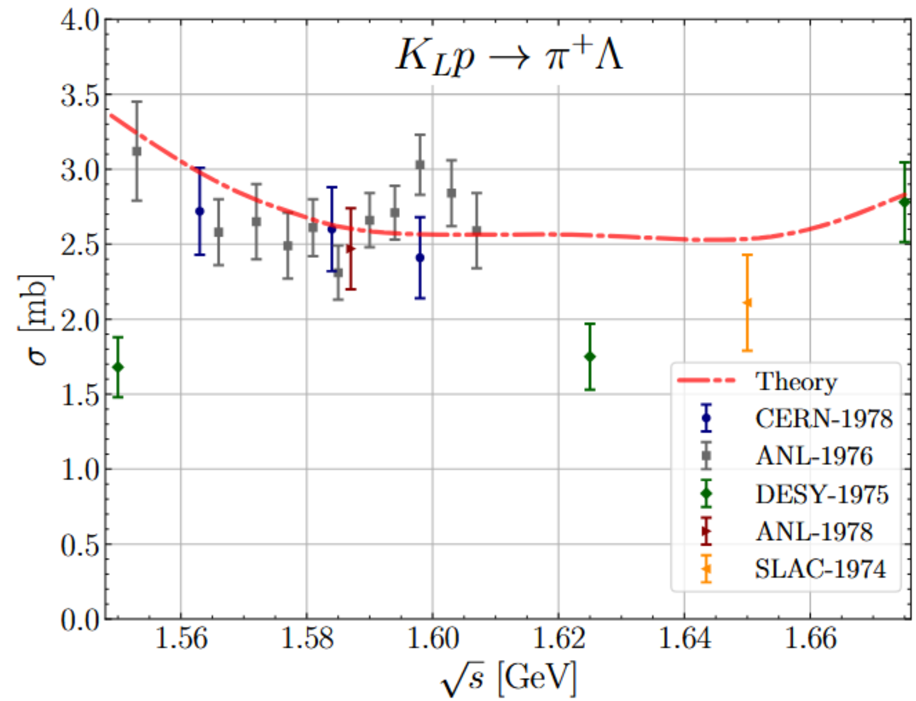
Further, $\pi^+\Sigma^0$ and $\pi^+\Lambda$, joint fitting

Origin: only **** states:
$\chi^2/dof = 5.16$ with 18 paras

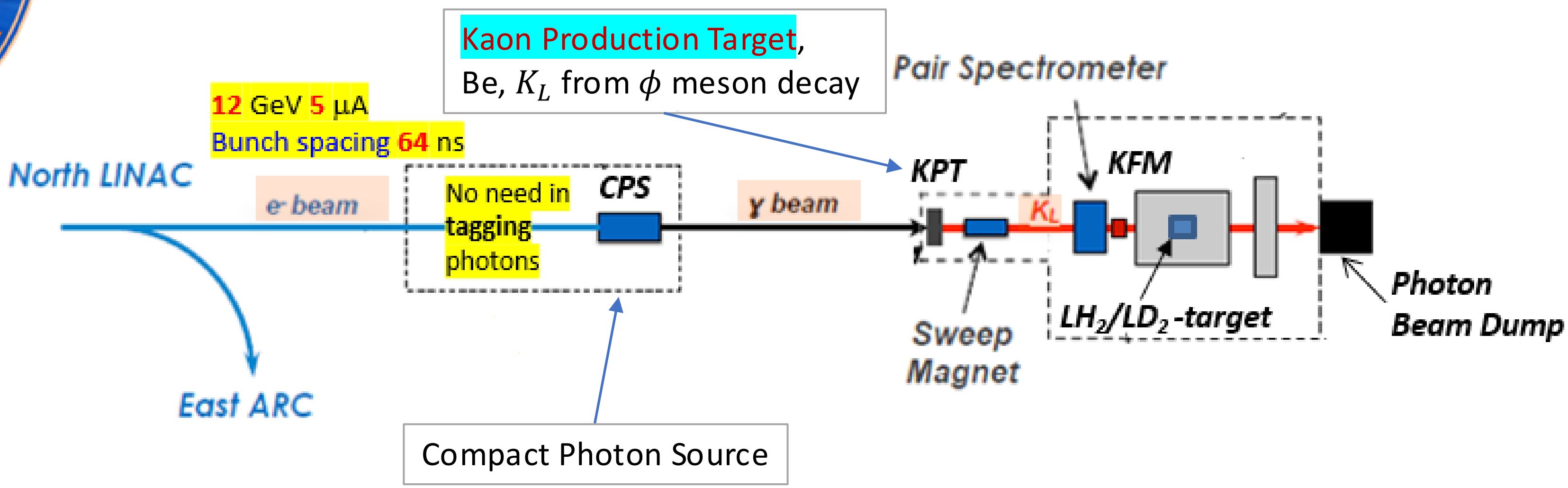
In fit procedure, not include total c-s data.
Avoiding double-counting.
Comparison of theoretical and experimental

Agree well with MC result(by Marshall Scott)



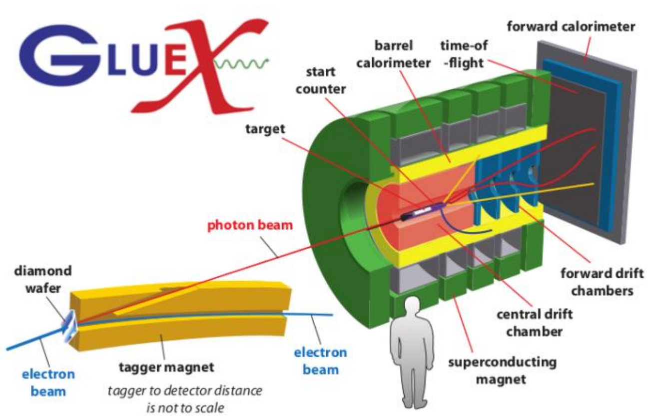


KLF exp. introduction



Production chain：

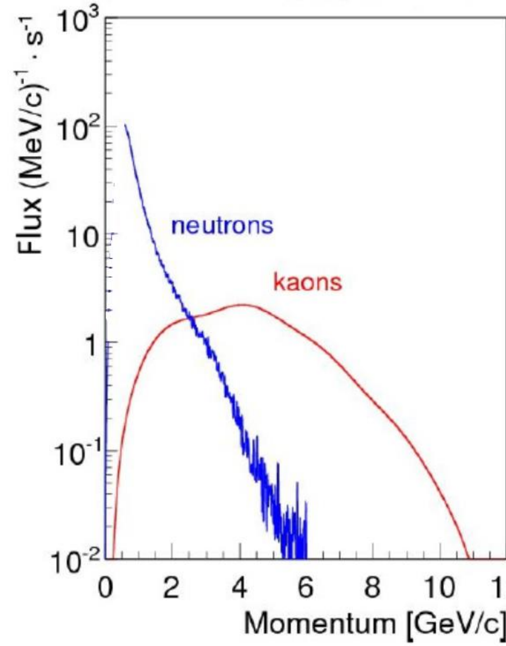
$$e^-(12\text{GeV } 3.1 \times 10^{13}/sec) \rightarrow \gamma(1.5\text{GeV } 4.7 \times 10^{12}/sec)$$
$$\rightarrow K_L(1 \times 10^4 K_L/sec)$$



W = 1490 MeV to 2500 MeV

Unprecedented!!

Property	Value
Electron beam current (μA)	5
Electron flux at CPS (s^{-1})	3.1×10^{13}
Photon flux at Be-target $E_\gamma > 1500$ MeV (s^{-1})	4.7×10^{12}
K_L beam flux at cryogenic target (s^{-1})	1×10^4
K_L beam σ_p/p @ 1 GeV/c (%)	$\sim$1.5
K_L beam σ_p/p @ 2 GeV/c (%)	$\sim$5
K_L beam nonuniformity (%)	< 2
K_L beam divergence (°)	< 0.15
$K^0/\overline{K^0}$ ratio at Be-target	2:1
Background neutron flux at cryogenic target (s^{-1})	6.6×10^5
Background γ flux at cryogenic target (s^{-1}), $E_\gamma > 100$ MeV	6.5×10^5



Neutral flux identification

Except for $\pi\Sigma$, $\pi\Lambda$, also for KN, $\bar{K}N$, $K\Xi$ and $K\pi$

$$T(K^-p \to K^-p) = \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) + \frac{1}{2}T^0(\overline{K}N \to \overline{K}N),$$
$$T(K^-p \to \overline{K^0}n) = \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) - \frac{1}{2}T^0(\overline{K}N \to \overline{K}N),$$
$$T(K^+p \to K^+p) = T^1(KN \to KN),$$
$$T(K^+n \to K^+n) = \frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN),$$

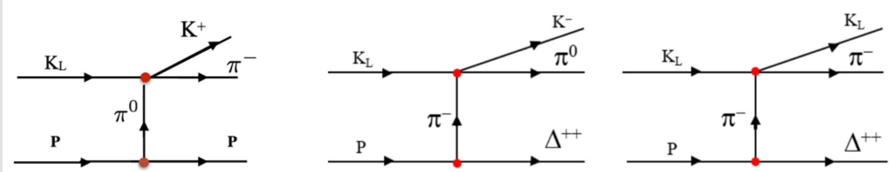
$$T(K_Lp \to K_Sp) = \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) - \frac{1}{2}T^1(\overline{K}N \to \overline{K}N),$$

$$T(K_Lp \to K_Lp) = \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) + \frac{1}{2}T^1(\overline{K}N \to \overline{K}N),$$

$$T(K_Lp \to K^+n) = \frac{1}{\sqrt{2}}\left(\frac{1}{2}T^1(KN \to KN) - \frac{1}{2}T^0(KN \to KN)\right).$$

$$T(K^-p \to K^0\Xi^0) = \frac{1}{2}T^1(\overline{K}N \to K\Xi) + \frac{1}{2}T^0(\overline{K}N \to K\Xi),$$
$$T(K^-p \to K^+\Xi^-) = \frac{1}{2}T^1(\overline{K}N \to K\Xi) - \frac{1}{2}T^0(\overline{K}N \to K\Xi),$$
$$T(K_Lp \to K^+\Xi^0) = -\frac{1}{\sqrt{2}}T^1(\overline{K}N \to K\Xi).$$

$K\pi$ Scattering



$$\frac{1}{3}(T^{1/2} - T^{3/2}) \qquad \frac{1}{3}(T^{1/2} - T^{3/2}) \qquad \frac{1}{3}(T^{1/2} + T^{3/2})$$

K_L: $\tau_{K_L} \approx 5.1 \times 10^{-8}\ s$

K^-: $\tau_{K^-} \approx 1.24 \times 10^{-8}\ s$

Mean lifetime difference: $\frac{\tau_{K_L}}{\tau_{K^-}} \approx 4$

Lab frame, mean fly length:

$$L = \beta\gamma c\tau = \frac{p}{m} c\tau \propto p\tau$$

$\beta = v/c$, $\gamma = 1/\sqrt{1-\beta^2}$

$$\beta\gamma = \frac{p}{m}$$

Lower p beam: smaller v, smaller Lorentz boost, smaller time dilation, easier decay.

Roughly, keeping same fly length $p_{K_L} \sim \frac{1}{4} p_{K^-}$

Reaching the most important lower $\sqrt{s}$

Historical K^-p scattering: momentum-selected secondary beam, ensemble information.

$p_{beam} = 1.2\ \mathrm{GeV}/c$ actually $p_{beam} \in [1.15, 1.25]\ \mathrm{GeV}/c$

Modern KLF K_L beam

Event-by-event tagged K_L beam

Jefferson lab: CEBAF e^- → bremsstrahlung photon →Be target →neutral beam

high precision time measurement: TOF(time-of-flight) → individually tagged

The 8th KLF Collaboration Meeting, 2026年5月6日

https://indico.jlab.org/event/1010/timetable/#20260506

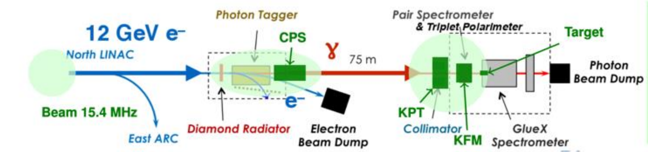
8th KLF Collaboration Meeting

8TH KLF Collaboration

2026年5月6日
CEBAF
US/Eastern 时区

输入您的搜索词

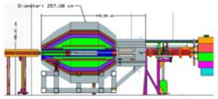
KLF(KLONG) experiment design

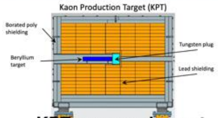


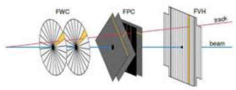
KLF Installation
1. Injector 4 ns → 64 ns
2. CPS - Compact Photon Source
3. KPT - Kaon Production Target
4. KFM - Kaon Flux Monitor
5. LH_2 target of a larger diameter
6. New Start Counter

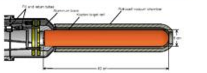
Photon beam e^- 300 nA ⇒ 0.04% RL ⇒ ⌀=5 mm collimator ⇒ ⌀=20 mm LH_2 target

Kaon beam e^- 5 μA ⇒ 10% RL ⇒ ⌀=60 mm, L=40 cm Be target ⇒ L=10 cm W-absorber ⇒ ⌀=60 mm LH_2 target









CPS: new equipment
- Input: 5 μA beam
- 60 kW beam dump
- 10-20% RL radiator
- Output:12kW photon beam
- Responsibility: JLab

KPT: new equipment
- Be target ⌀,L=60,400 mm
- 10 cm W plug for photons
- Shielding
- Beam pipes to LH_2 target
- Responsibility: JLab

KFM: partly recycled
- Flux monitor
- Detectors from Jülich
- Detectors: Uni. of York
- Electronics/support: JLab

Target and Start Counter
- ⌀ 60 mm LH_2 target (JLab)
- New start counter (Osaka Uni)

Resources and Budget

Spent to date
- Capital funding in FY23-25
- Labor of Hall D staff not included
- Purchased (from JLab) labor 75 wks, \$224k
- Purchased material, equipment: \$341k

Manpower for design
- Expect capital funding resuming in FY28
- Current Hall D technical staff: 1.5 ME, 1 MD and 4 MT
- Potential support of KLF from Hall D: 0.5FTE ME next 12 months
- After resolving conceptual design details we can resume the engineering design work (need budget for 1 MD FTE)

Future resourced for building and installing
- See the presentation by Josh Ballard for details
- Total budget about \$1.6 M for materials and \$0.5 M for purchased labor
- Time measured since funding (typically \$750/year) start
- 3.5 years to the end of installation
- 2 years for installation (assuming the existing Hall D technical manpower)
- Highly desirable to purchase more labor to reduce the installation time to 16-18 months (for losing only one running period)

Total time estimate for installation, running, de-installation is about 5-6 years

KLF Citations

- arXiv for the final version of the KLF proposal [C12-19-001]
  - e-Print: 2008.08215 [nucl-ex] 71 citations
- arXiv for the intermediate version of the KLF proposal [PR12-17-001]
  - e-Print: 1707.05284 [hep-ex] PR12-17-001 17 citations
- Four mini-Proceedings for the KLF Workshops:
  - e-Print: 1804.06528 [hep-ph] PKI2018 Workshop mini-Proceedings 2 citation
  - e-Print: 1704.00816 [nucl-ex] HIPS2017 Workshop mini-Proceedings 10 citations
  - e-Print: 1701.07346 [hep-ph] YSTAR2016 Workshop mini-Proceedings 9 citations
  - e-Print: 1604.02141 [hep-ph] KL2016 Workshop mini-Proceedings 20 citations

https://wiki.jlab.org/klproject/index.php/Main_Page

Conclusion

(1) The first theoretical analysis of $K_L p \rightarrow \pi^+\Sigma^0$ and $\pi^+\Lambda$ using effective Lagrangian method, with strict phase convention and isospin-selection.

(2) Further confirm the existence of $\Sigma(1660)1/2^+$.

(3) Due to the limited quality of historical data earlier than 1980, in present, the mass of $\Sigma(1620)1/2^-$ is fitted around 1.55 GeV.

(4) Multichannel fit imposes much stronger constraints on the common resonance parameters and relative phases, resulting almost invisible errorbands. $\Sigma(1620)1/2^-$ is indispensable in $\pi^+\Sigma^0$, but negligible in $\pi^+\Lambda$, maybe channel-dependent.

Expecting more precise measurements of $K_L p$ scattering in wider energy range by **KLF**

Next step

After confirmation of $\Sigma(1660)1/2^{+}$ and $\Sigma(1620)1/2^{-}$ on tree-level, perform coupled-channel analysis considering unitarity and analyticity.
Similar procedure for Λ^{*}, or isolate the Λ^{*} contribution in $K^{-}p \to \pi^{\pm}\Sigma^{\mp}$ scattering.
Directly comparing with $K^{-}p \to \pi^{0}\Sigma^{0}$, then further verify our $I=1$ amplitude.

$$
\begin{aligned}
T(K^{-}p \to \pi^{-}\Sigma^{+}) &= -\frac{1}{2}T^{1}(\overline{K}N \to \pi\Sigma) - \frac{1}{\sqrt{6}}T^{0}(\overline{K}N \to \pi\Sigma), \\
T(K^{-}p \to \pi^{+}\Sigma^{-}) &= \frac{1}{2}T^{1}(\overline{K}N \to \pi\Sigma) - \frac{1}{\sqrt{6}}T^{0}(\overline{K}N \to \pi\Sigma), \\
T(K^{-}p \to \pi^{0}\Sigma^{0}) &= \frac{1}{\sqrt{6}}T^{0}(\overline{K}N \to \pi\Sigma),
\end{aligned}
$$

Thank you for your attention!

燕山大學
YANSHAN UNIVERSITY

Back up

Error propagation

$\vec{x} = (x_1, \ldots, x_i)$ input data vector, $\vec{p} = (p_1, \ldots, p_n)$ parameter vector

Model output: $\vec{y} = f(\vec{x}; \vec{p}) = (y_1, \ldots, y_m)$

a fit by Minuit, given the covariance matrix C of paras, $n \times n$

Numerically calculate the Jacobi matrix J of first derivatives, $m \times n$:

$$J_{ab} = \frac{\partial y_a}{\partial p_b}$$

then obtain the covariance matrix C' of output, $m \times m$

$$C' = JCJ^T$$

Square roots of diagonal elements giving the errors.