Strange Particle Production from Nucleons

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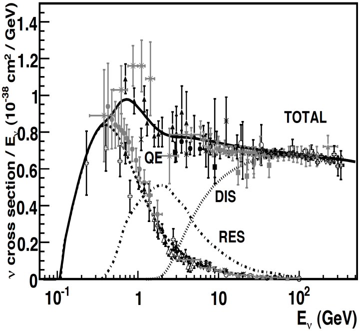
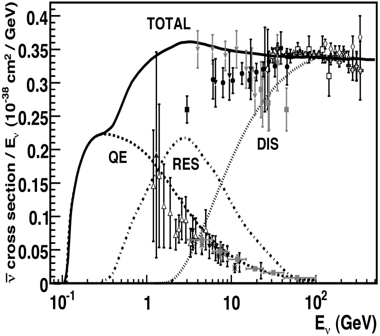
Outline

Introduction

Total σ for $\nu/\bar{\nu}$ CC processes, [G. P. Zeller used NUANCE MC]





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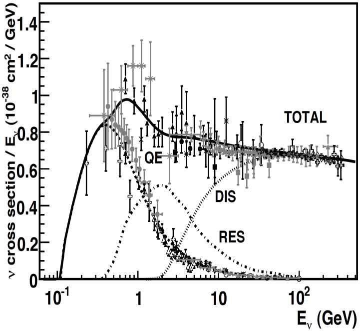

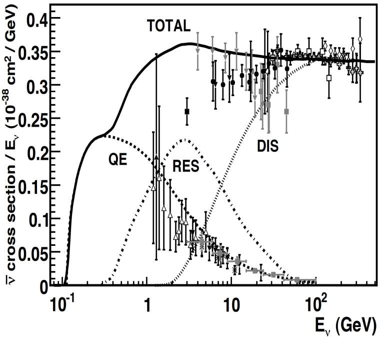

$$\sigma^{Total} = \sigma^{QE} + \sigma^{Inelastic} + \sigma^{DIS}$$
$$\sigma^{Inelastic} = \sigma^{1\pi} + \sigma^{2\pi} + \cdots + \sigma^{YK} + \sigma^{1K} + \sigma^{1Y} + \cdots$$

- MINERνA experiment is planning to study strange particle production with high statistics.
- MiniBooNE,SciBooNE, K2K, T2K, NOνA are taking data in the few GeV region.
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- Monte Carlo generators used in the analysis of the current experiments apply models that are not well suited to describe the strangeness production at low energies.
- In estimation of atmospheric neutrino ΔS backgrounds for nucleon-decay searches.
- LAGUNA plans to use detectors like GLACIER, MEMPHYS or LENA to test physics at the GUT scale.

- R. E. Shrock (Phys. Rev. D 12, 2049, 1975) used a resonant Born model and estimated the charged and neutral $\nu N \rightarrow \mu^- KY$ (10^{-40} cm^2) in the neutrino energy region up to 3 GeV
- A. A. Amer (Phys. Rev. D 18, 2290, 1978) used a harmonic oscillator quark model to estimate cross section for $K^+\Lambda$ production 1.35 - 2.65 10^{-41} cm^2
- H. K. Dewan (Phys. Rev. D 24, 2369, 1981) has studied Associated Production as well as S.C. C.C. reactions $\nu_\mu N \rightarrow \mu^- KY$[1] using Born approximations with hyperon-nucleon transition form factors determined from the Cabibbo theory with SU(3) symmetry.

[1] Y≡ Hyperon ($\Delta S = 0$) and Nucleon ($\Delta S = 1$)

Super Kamiokande set the experimental limit for proton decay.
$\tau > 5.4 \times 10^{33} y$ and $\tau > 2.3 \times 10^{33} y$ for decay modes $p \rightarrow e^+ \pi^0$ and $p \rightarrow K^+ \overline{\nu}$[2]

- K^+ life time 12.8 ns and they decay into
  $K^+ \rightarrow \mu^+ \nu_\mu$ (63.43 %) and
  $K^+ \rightarrow \pi^+ \pi^0$ (21.13 %)
- Main background sources are muon neutrinos produced by cosmic rays interactions
- These neutrinos interact with the detector producing muon in the energy range where search for proton decay is performed.

[2] Journal of Physics: Conference Series 39 (2006) 269271 & PRL83,1529

Weak processes accompanying strange particle

$$\nu_l n \to l^- K^+ n \qquad \bar{\nu}_l n \to l^+ K^- n$$
$$\nu_l p \to l^- K^+ p \qquad \bar{\nu}_l p \to l^+ K^+ p$$
$$\nu_l n \to l^- K^0 p \qquad \bar{\nu}_l p \to l^+ \bar{K}^0 n$$
$$\nu_l n \to l^- K^0 \Sigma^+ \qquad \bar{\nu}_l p \to l^+ K^+ \Sigma^-$$
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Weak processes accompanying strange particle

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\end{aligned}
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$\bar{\nu}$ induced ($|\Delta S| = 1$) charged-current reactions

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\begin{aligned}
\bar{\nu}_\mu + p &\to l^+ + K^- + p \\
\bar{\nu}_l + p &\to l^+ + \bar{K}^0 + n \\
\bar{\nu}_l + n &\to l^+ + K^- + n\,.
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$\Delta S = 1$ processes have no NC contributions as they involve a change

Formalism

The basic reaction for the neutrino induced charged current kaon production is

$$\nu(k) + N(p) \to l(k') + K(p_k) + X(p')$$

where X is I. N $(\Delta S = 1)$ II. Y $(\Delta S = 0)$

$$d^9\sigma = \frac{1}{4ME(2\pi)^5} \frac{d\vec{k}'}{(2E_l)} \frac{d\vec{p}\,'}{(2E'_p)} \frac{d\vec{p}_k}{(2E_K)} \delta^4(k + p - k' - p' - p_k) \bar{\Sigma}\Sigma|\mathcal{M}|^2,$$

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$$\mathcal{M} = \frac{G_F}{\sqrt{2}} j_\mu^{(L)} J^{\mu(H)} = \frac{g}{2\sqrt{2}} j_\mu^{(L)} \frac{1}{M_W^2} \frac{g}{2\sqrt{2}} J^{\mu(H)},$$

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$j_\mu^{(L)}$ is Leptonic Current
& $J^{\mu(H)}$ is Hadronic Current

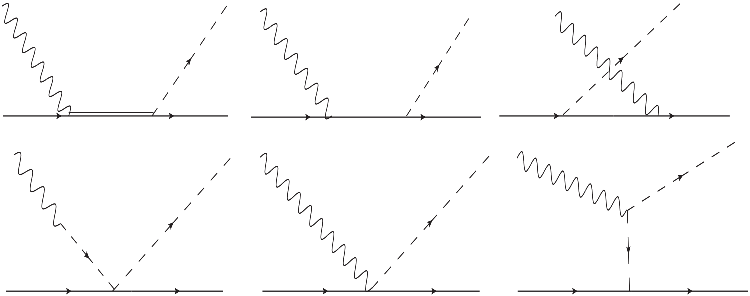
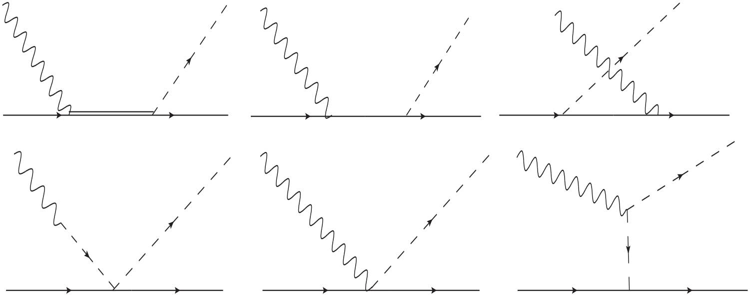


Figure: Feynman diagrams contributing to the $J^{\mu(H)}$



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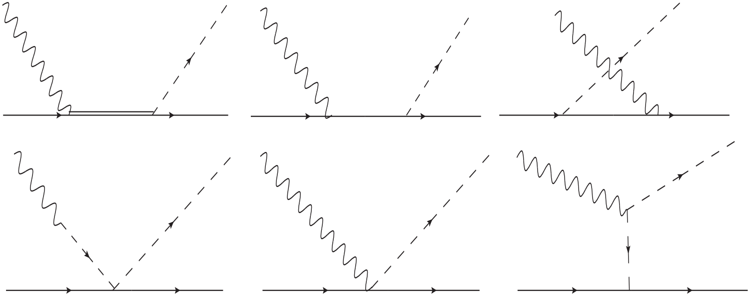
Obtained using Chiral Perturbation Theory (χPT)



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WNN' vertex structure

$$\left\langle Y';\vec{p}'\right|J^{\mu(H)}\left|N;\vec{p}\right\rangle \propto \overline{u}(\vec{p}')\left(V^{\mu}-A^{\mu}\right)u(\vec{p})$$

GENIE (Generates Events for Neutrino Interaction Experiments) MC

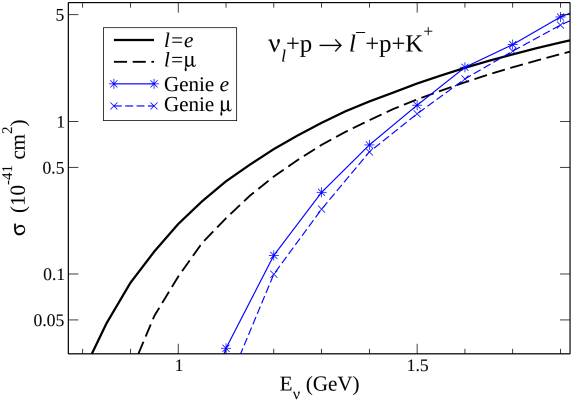
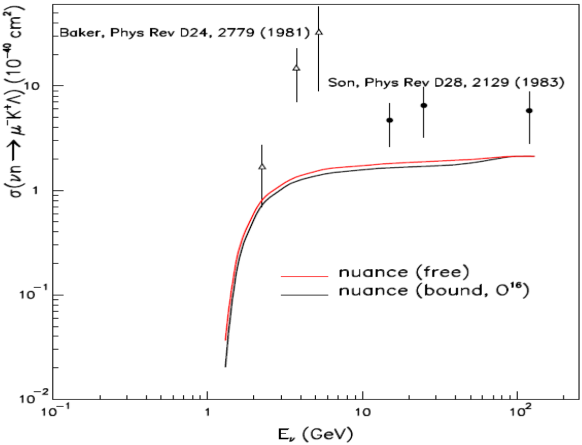


Figure: Comparison of cross-sections for $\nu_l + p \to l^- + K^- + p$

NUANCE Monte Carlo (Baker PRD'1981,83)



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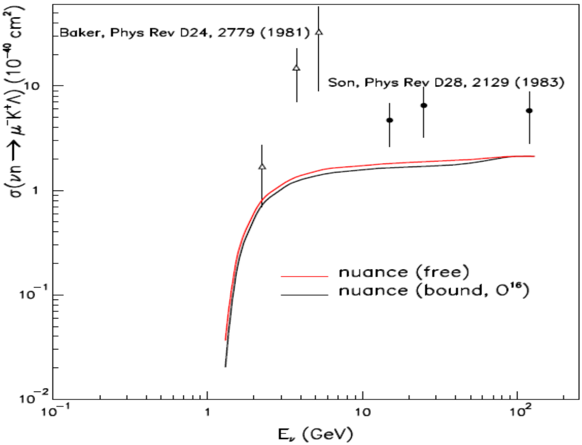
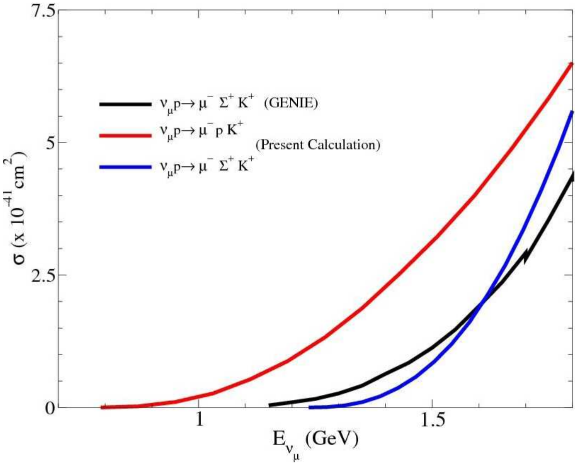


DEVELOPMENT ??

GENIE Cont.



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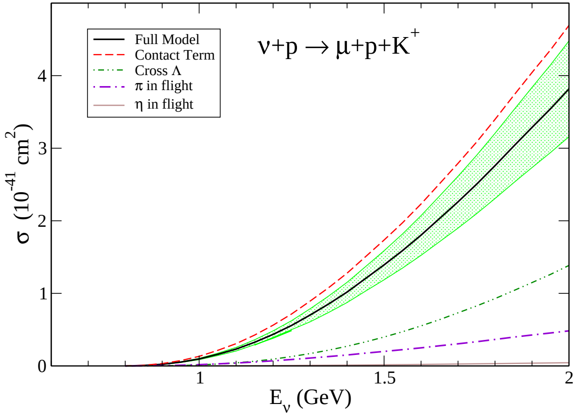
σ for $\nu_\mu + p \to \mu^- + K^+ + p$



Q^2 Distribution

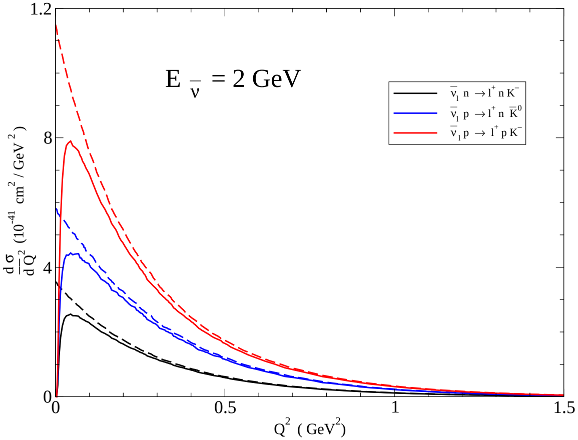
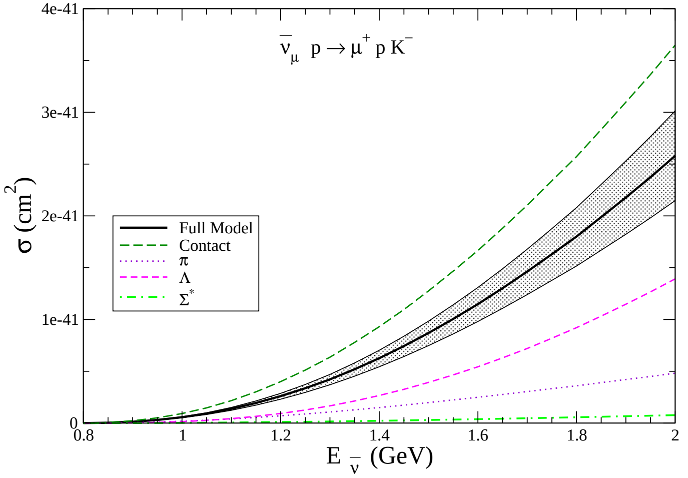
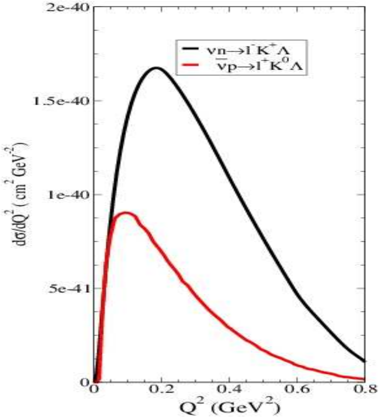


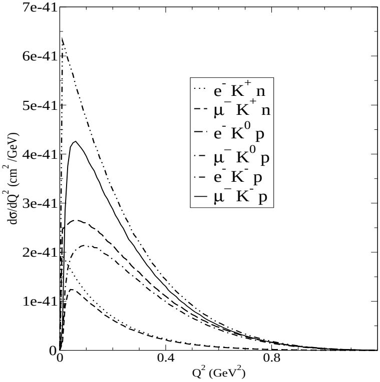
Figure: Differential Cross-section for the processes $\bar{\nu}_\mu N \to \mu^+ N' \bar{K}$ (Solid lines) and $\bar{\nu}_e N \to e^+ N' \bar{K}$ (Dashed lines)

σ for $\bar{\nu}_\mu + p \to \mu^+ + K^- + p$



Preliminary





Flux Convoluted with Cross Section

$<\sigma>$ $(10^{-41} cm^2)$ for $\bar{K}$ production with MiniBooNE $\bar{\nu}_\mu$ flux and neutral current π^0 production (per nucleon) measured at MiniBooNE.

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Process	$<\sigma>$
$\bar{\nu}_\mu + p \rightarrow \mu^+ + K^- + p$	0.11
$\bar{\nu}_\mu + p \rightarrow \mu^+ + \bar{K}^0 + n$	0.08
$\bar{\nu}_\mu + n \rightarrow \mu^+ + K^- + n$	0.04
$\bar{\nu}_\mu + N \rightarrow \bar{\nu}_\mu + N + \pi^0$	$14.8 \pm 0.5 \pm 2.3$

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$<\sigma>$ $(10^{-41}cm^2)$ for $\overline{K}$ production with MiniBooNE $\overline{\nu}_\mu$ flux and neutral current π^0 production (per nucleon) measured at MiniBooNE.

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$<\sigma>$ for MinerVa is $\sim 10^{-41}cm^2$
$<\sigma>$ for T2K is $\sim 1.5 \times 10^{-42}cm^2$
$E_l + E_k < 2.GeV$

Conclusion

- We find the contribution of contact term to be significant in single kaon production as well as in the associated particle production.
- The threshold for associated antikaon production corresponds to the $K - \bar{K}$ channel and it is much higher than for the kaon case (kaon-hyperon).
- The study may be useful in the analysis of antineutrino experiments at MINERνA, NOνA, T2K and others with high statistics and/or higher antineutrino energies.
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- M. Rafi Alam, I. Ruiz Simo, M. Sajjad Athar and M. J. Vicente Vacas, "*Weak Kaon Production off the Nucleon*," **Phys. Rev. D 82**, 033001 (2010)
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- M. R. Alam, I. R. Simo, M. S. Athar, L. Alvarez-Ruso and M. J. V. Vacas, "*Weak production of strange particles off the nucleon*," arXiv:1303.5924 [hep-ph].
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- M. Rafi Alam, I. R. Simo, M. S. Athar and M. J. V. Vacas, "*Strange particle production at low and intermediate energies*," **AIP Conf. Proc. 1405**, 152 (2011)

Thanks

Grazie

backup

Meson-Meson Interaction

$$\mathcal{L}_M^{(2)} = \frac{f_\pi^2}{4}\mathrm{Tr}[D_\mu U (D^\mu U)^\dagger] + \frac{f_\pi^2}{4}\mathrm{Tr}(\chi U^\dagger + U\chi^\dagger),$$

$U(x) = \exp\left(i\frac{\phi(x)}{f_\pi}\right)$
$D_\mu U \equiv \partial_\mu U - i r_\mu U + i U l_\mu$
$u_\mu = i\left[u^\dagger(\partial_\mu - i r_\mu)u - u(\partial_\mu - i l_\mu)u^\dagger\right], \qquad u^2 = U$
$r_\mu = 0, \quad l_\mu = -\frac{g}{\sqrt{2}}(W_\mu^+ T_+ + W_\mu^- T_-)$, with $W^\pm$ the W boson fields and

$$T_+ = \begin{pmatrix} 0 & V_{ud} & V_{us} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}; \quad T_- = \begin{pmatrix} 0 & 0 & 0 \\ V_{ud} & 0 & 0 \\ V_{us} & 0 & 0 \end{pmatrix}.$$

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Meson-Baryon Interaction

$$\mathcal{L}_{MB}^{(1)} = \mathrm{Tr}\left[\bar{B}\left(i\not{D} - M\right)B\right] - \frac{D}{2}\mathrm{Tr}\left(\bar{B}\gamma^{\mu}\gamma_5\{u_\mu, B\}\right) - \frac{F}{2}\mathrm{Tr}\left(\bar{B}\gamma^{\mu}\gamma_5[u_\mu, B]\right)$$

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where M denotes the mass of the baryon octet, and the parameters $D = 0.804$ and $F = 0.463$ can be determined from the baryon semileptonic decays. The covariant derivative of B is given by

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$$D_{\mu}B = \partial_{\mu}B + [\Gamma_{\mu}, B],$$

$$\Gamma_{\mu} = \frac{1}{2}\left[u^{\dagger}(\partial_{\mu} - ir_{\mu})u + u(\partial_{\mu} - il_{\mu})u^{\dagger}\right],$$

Meson-Baryon Interaction Cont.

$$\mathcal{L}_{dec} = \mathcal{C} \left(\varepsilon^{abc} \overline{T}^{\mu}_{ade} u^{d}_{\mu,b} B^{e}_{c} + h.c. \right)$$

$\mathcal{C} \simeq 1$ has been fitted to the $\Delta(1232)$ decay-width.
The spin 3/2 propagator for Σ^* is given by

$$G^{\mu\nu}(P) = \frac{P^{\mu\nu}_{RS}(P)}{P^2 - M^2_{\Sigma^*} + iM_{\Sigma^*}\Gamma_{\Sigma^*}},$$

where $P = p + q$ is the momentum carried by the resonance, $q = k - k'$ and $P^{\mu\nu}_{RS}$ is the projection operator

$$P^{\mu\nu}_{RS}(P) = \sum_{spins} \psi^{\mu}\overline{\psi}^{\nu} = -(\not{P} + M_{\Sigma^*}) \left[g^{\mu\nu} - \frac{1}{3}\gamma^{\mu}\gamma^{\nu} - \frac{2}{3}\frac{P^{\mu}P^{\nu}}{M^2_{\Sigma^*}} + \frac{1}{3}\frac{P^{\mu}\gamma^{\nu} - P^{\nu}\gamma^{\mu}}{M_{\Sigma^*}} \right],$$

The Σ^* width

$$\Gamma_{\Sigma^* \to Y,M} = \frac{C_Y}{192\pi} \left(\frac{\mathcal{C}}{f_\pi} \right)^2 \frac{(W+M_Y)^2 - m^2}{W^5} \lambda^{3/2}(W^2, M_Y^2, m^2)\,\Theta(W - M_Y - m).$$

$$\Gamma_{\Sigma^*} = \Gamma_{\Sigma^* \to \Lambda\pi} + \Gamma_{\Sigma^* \to \Sigma\pi} + \Gamma_{\Sigma^* \to N\bar{K}} \,,$$

Here, m, M_Y are the masses of the emitted meson and baryon. $\lambda(x,y,z) = (x-y-z)^2 - 4yz$ and Θ is the step function.

The Σ^* width

$$\Gamma_{\Sigma^* \to Y,M} = \frac{C_Y}{192\pi}\left(\frac{\mathcal{C}}{f_\pi}\right)^2 \frac{(W+M_Y)^2-m^2}{W^5}\lambda^{3/2}(W^2,M_Y^2,m^2)\,\Theta(W-M_Y-m).$$

$$\Gamma_{\Sigma^*} = \Gamma_{\Sigma^*\to\Lambda\pi} + \Gamma_{\Sigma^*\to\Sigma\pi} + \Gamma_{\Sigma^*\to N\bar{K}}\ ,$$

Here, m, M_Y are the masses of the emitted meson and baryon.
$\lambda(x,y,z) = (x-y-z)^2 - 4yz$ and Θ is the step function.
The factor C_Y is 1 for Λ and $\frac{2}{3}$ for N and Σ.