M. Bayar, **R. Pavao**, S. Sakai and E. Oset

Phys. Rev. C **97** (2018) no.3, 035203

20 August 2019

Effects of a triangle singularity on the production of Λ(1405) through πp and pp reactions

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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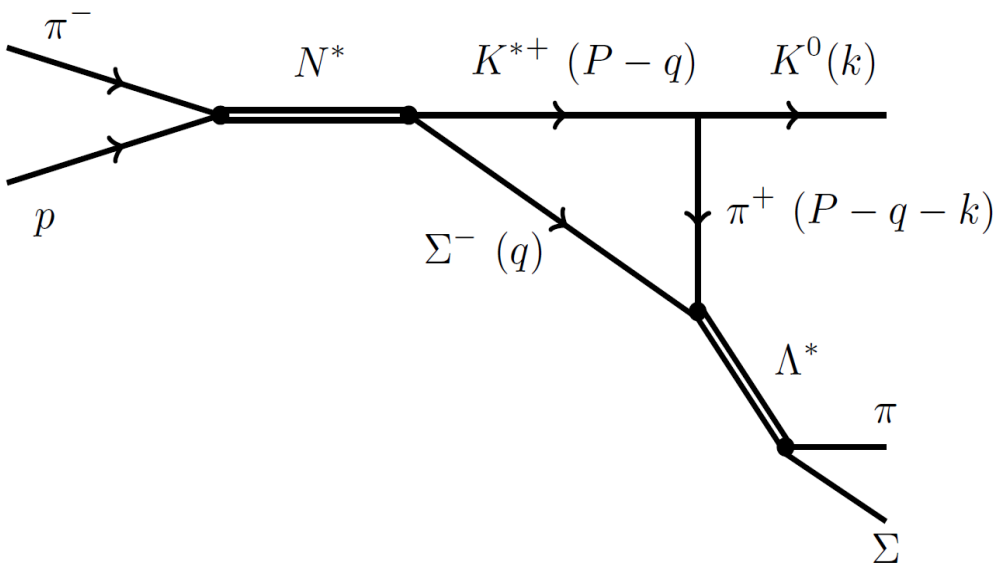
VNIVERSITAT DE VALÈNCIA

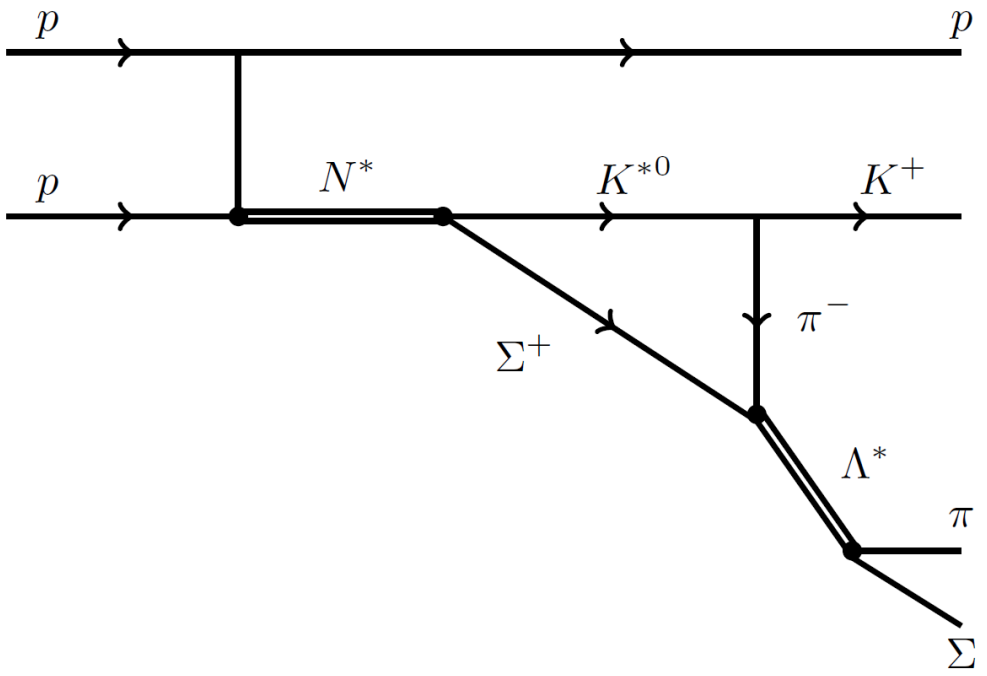
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

Motivation

$$\pi^- p \to K^0 \pi \Sigma$$



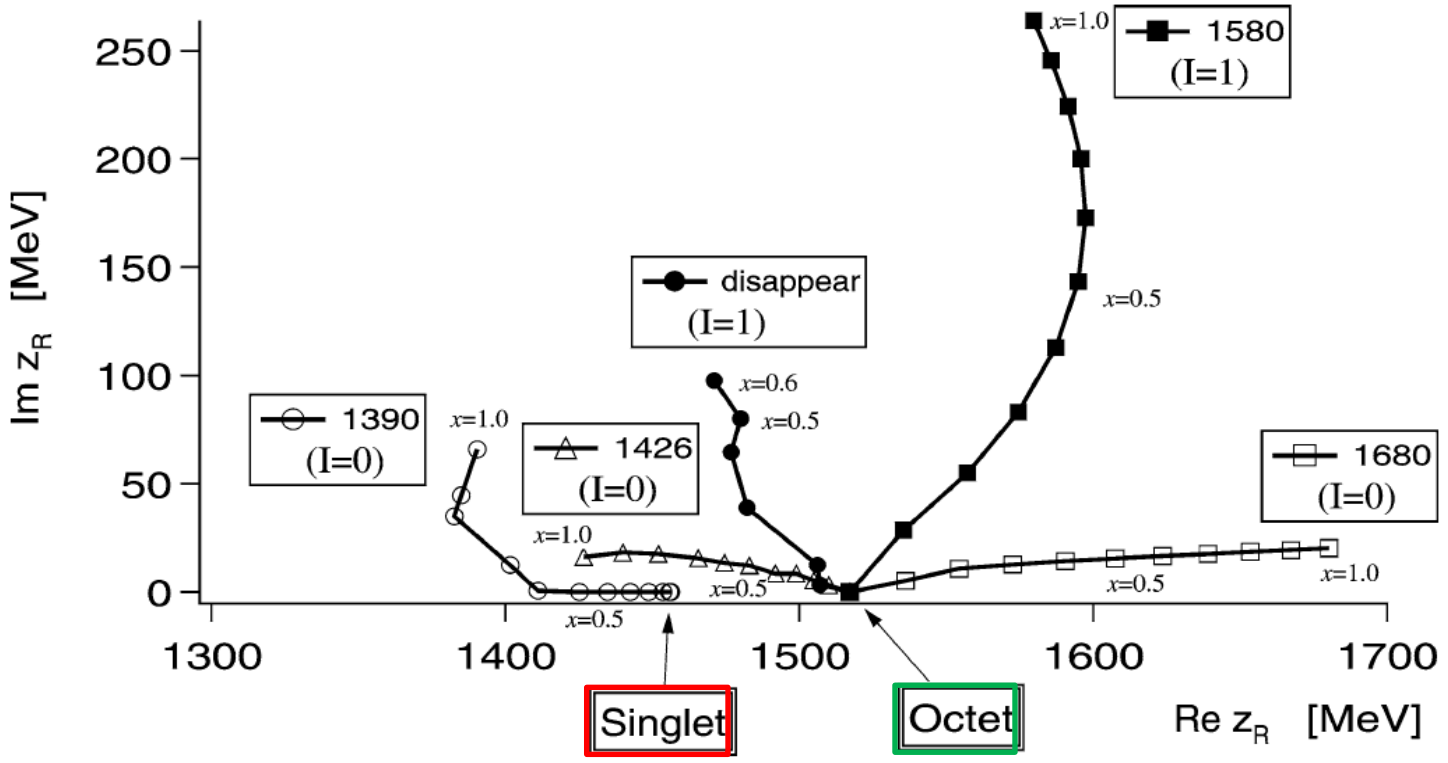
$$pp \to pK^+ \pi \Sigma$$



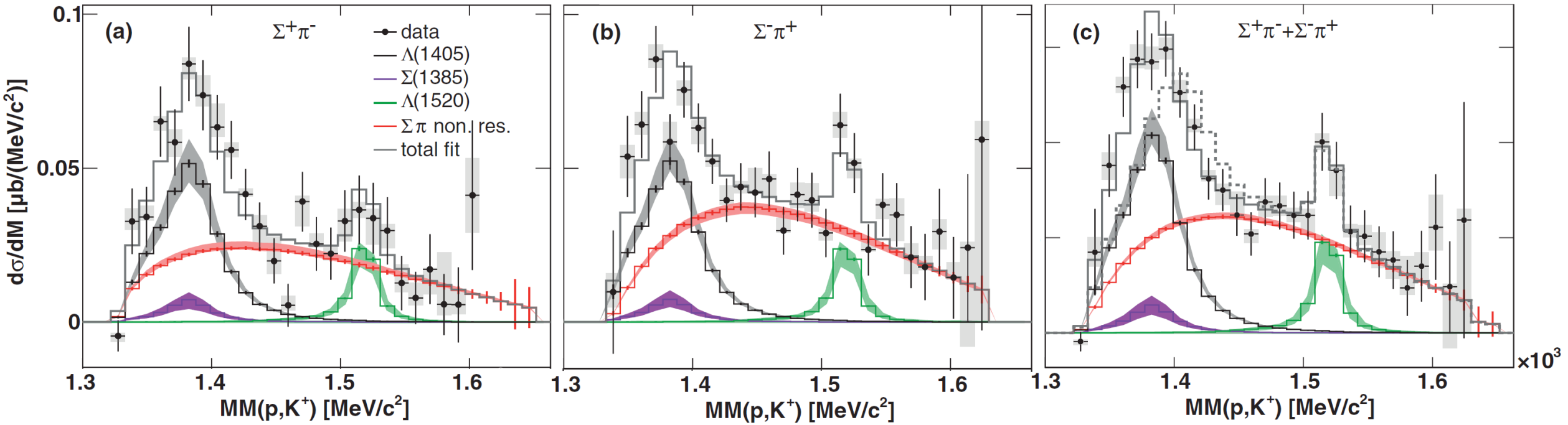
Λ(1405)

Singlet couples more to $\pi\Sigma$ and octet to $\bar{K}N$

Two pole structure of Λ(1405):

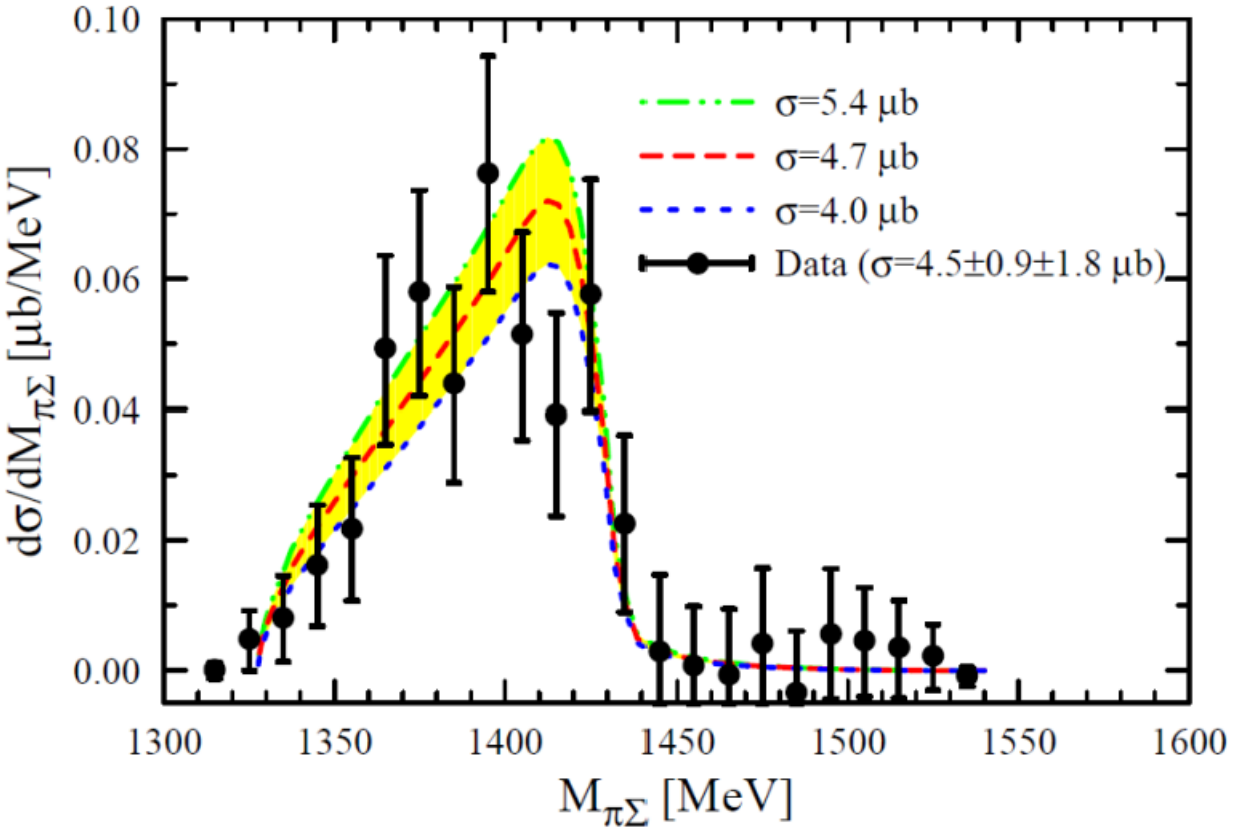


D. Jido, J.A. Oller, E. Oset, A. Ramos and U.G. Meissner, **Nucl. Phys. A 725 (2003) 181**



HADES Collaboration (G. Agakishiev (Dubna, JINR) et al.)
Published in Phys.Rev. C87 (2013) 025201

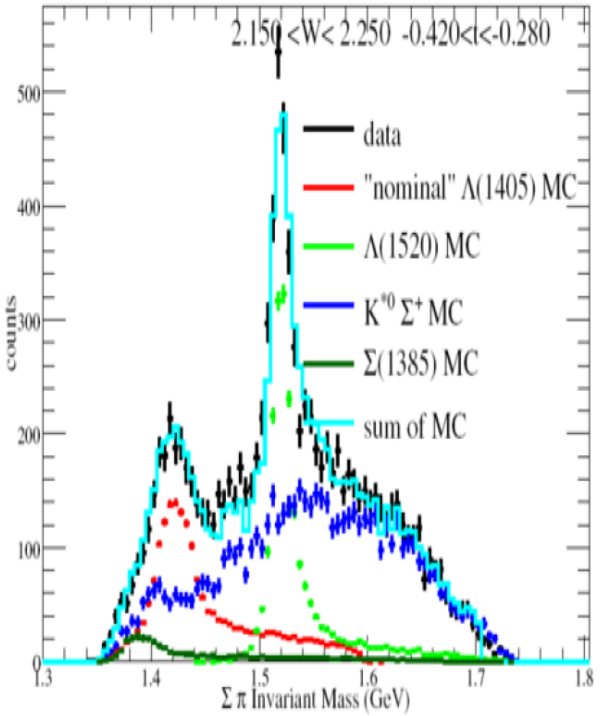
$pp \rightarrow \Lambda(1405)\, K^+ p \rightarrow \pi\, \mathbf{\Sigma}\, K^+ p$



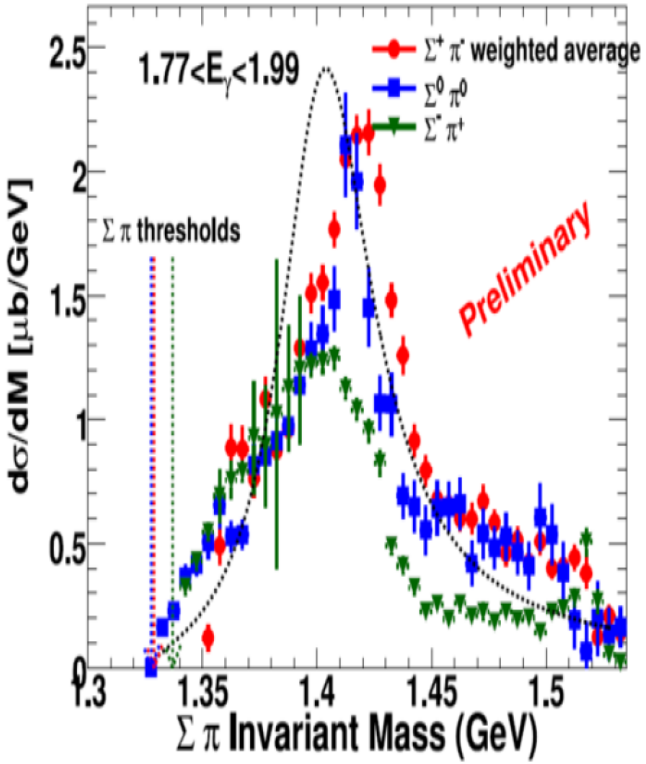
Theory: L.S. Geng and E. Oset, **Eur. Phys. J. A 34 (2007) 405**

pp → Λ(1405) K⁺ p → π Σ K⁺ p

I. Zychor et. al, **Phys.Lett. B660 (2008) 167-171**



(a)



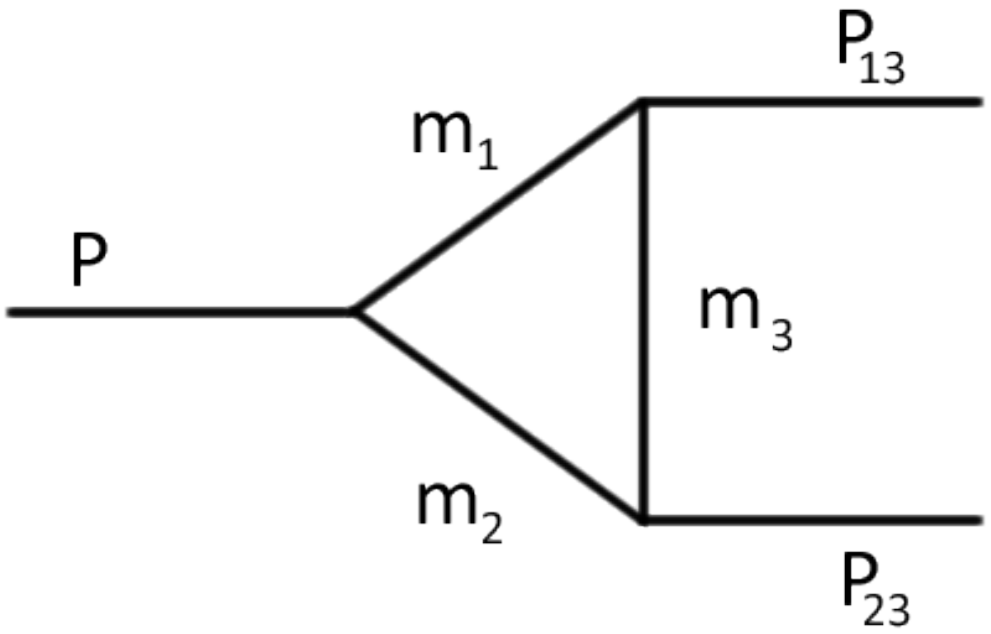
(b)

K. Moriya and R. Schumacher, **Nuclear Physics A 835 (2010) 325–328**

γp → Λ(1405) K⁺ → π Σ K⁺

Formalism

Triangle Singularities

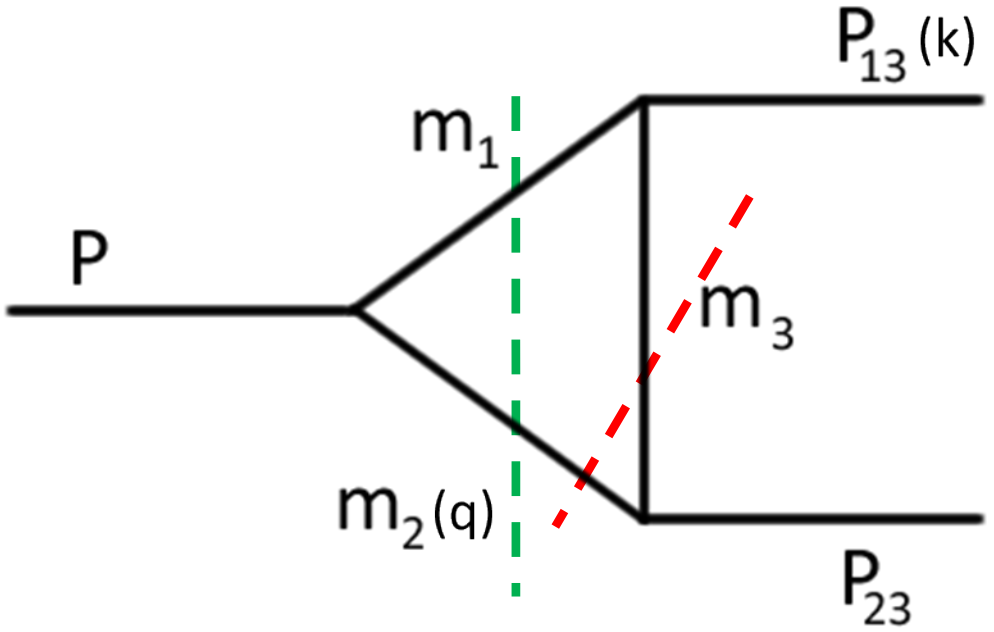


L.D.Landau, **Nucl. Phys. 13 (1959) 181**

$$I = i \int \frac{d^4q}{(2\pi)^4} \frac{1}{(q^2 - m_2^2 + i\epsilon)[(P-q)^2 - m_1^2 + i\epsilon][(P-q-k)^2 - m_3^2 + i\epsilon]}$$

Triangle Singularities

S. Coleman and R.E. Norton, **Nuovo Cimento 38 (1965) 438**



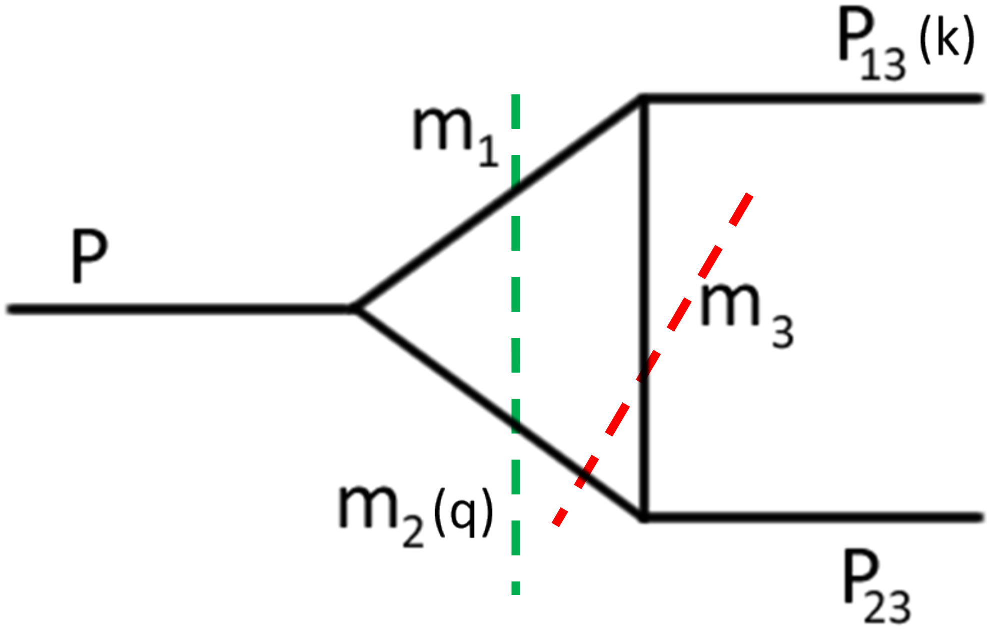
$$P^0 - \omega^*(\vec{q}) - \omega(\vec{q}) = 0 \;\rightarrow q_{\rm on} + i\epsilon$$

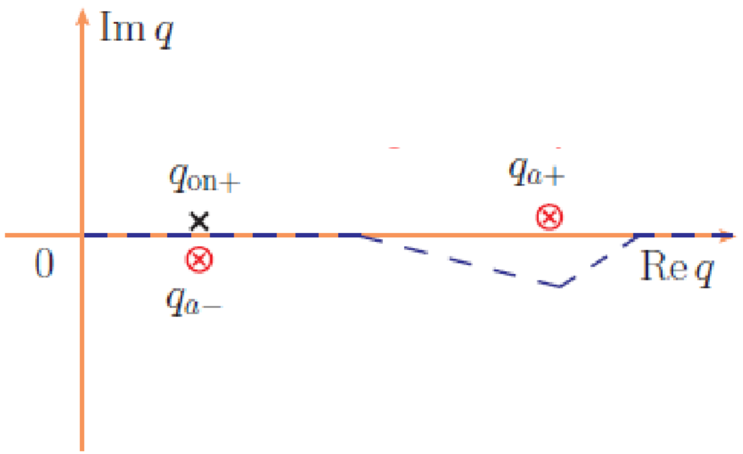
$$P^0 - k^0 - \omega(\vec{q}) - \omega'(\vec{q}+\vec{k}) = 0 \;\rightarrow q_{a-} - i\epsilon$$

M. Bayar, F. Aceti, F-K Guo and E. Oset, **Phys. Rev. D 94 (2016) 074039**

Triangle Singularities

S. Coleman and R.E. Norton, **Nuovo Cimento 38 (1965) 438**





$$P^0 - \omega^*(\vec{q}) - \omega(\vec{q}) = 0 \;\rightarrow\; q_{\rm on} + i\epsilon$$

$$\parallel$$

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M. Bayar, F. Aceti, F-K Guo and E. Oset, **Phys. Rev. D 94 (2016) 074039**

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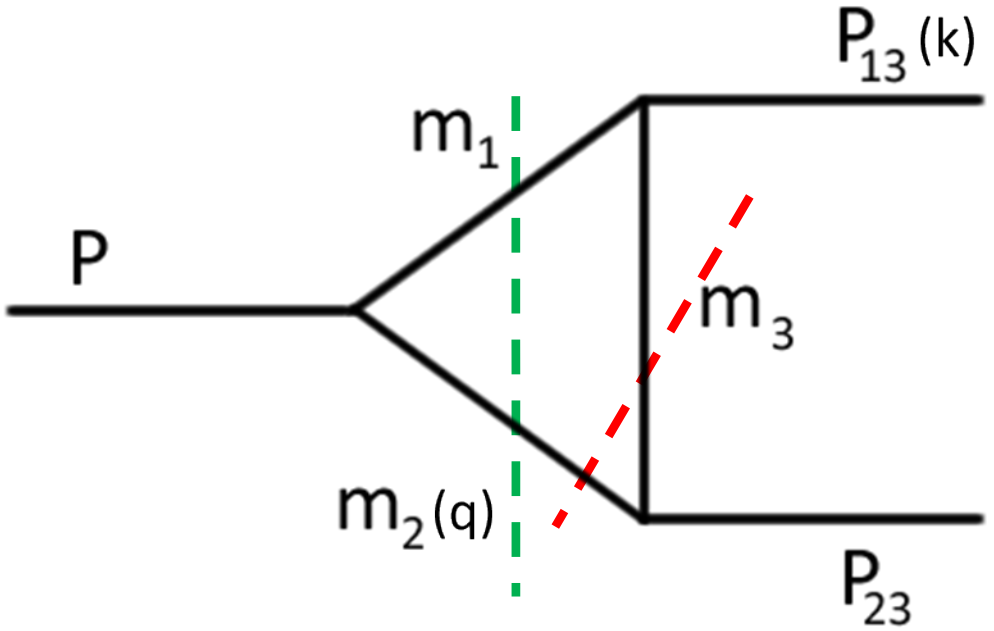
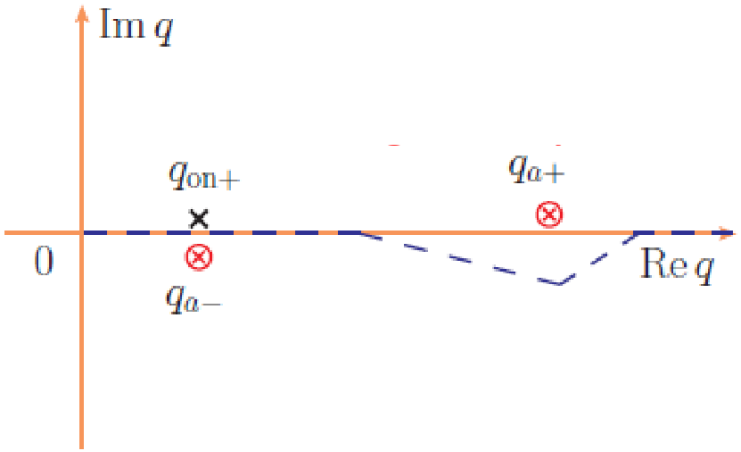


cos(θ)=-1



$$P^0 - \omega^*(\vec{q}) - \omega(\vec{q}) = 0 \;\rightarrow q_{\rm on} + i\epsilon$$

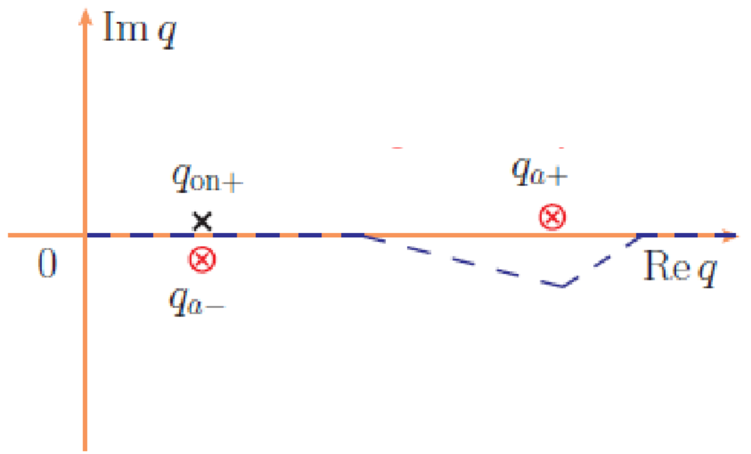
$$\| $$

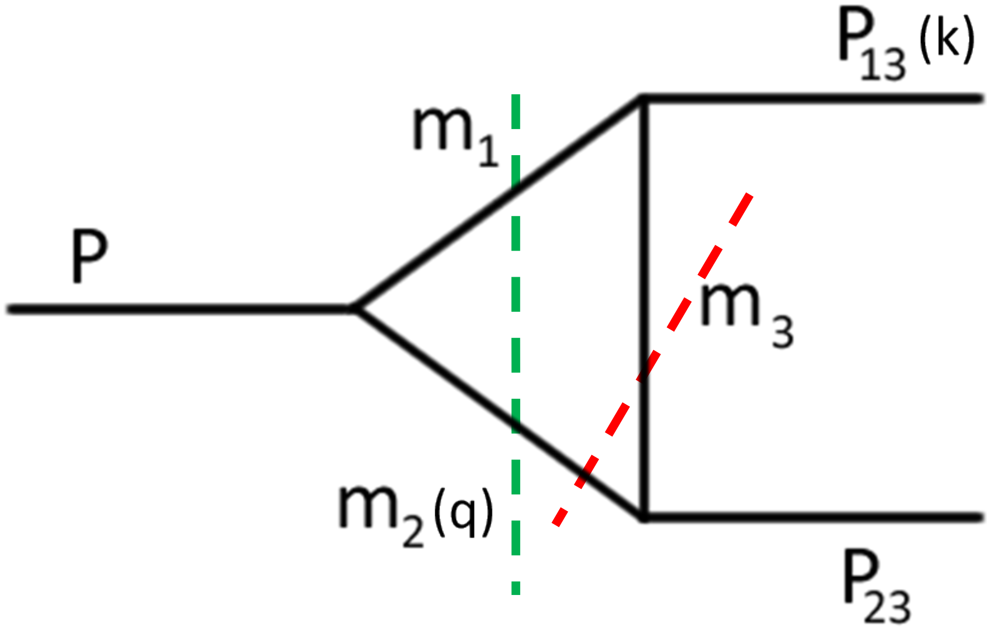
$$P^0 - k^0 - \omega(\vec{q}) - \omega'(\vec{q}+\vec{k}) = 0 \;\rightarrow q_{a-} - i\epsilon$$

M. Bayar, F. Aceti, F-K Guo and E. Oset, **Phys. Rev. D 94 (2016) 074039**

Triangle Singularities

S. Coleman and R.E. Norton, **Nuovo Cimento 38 (1965) 438**





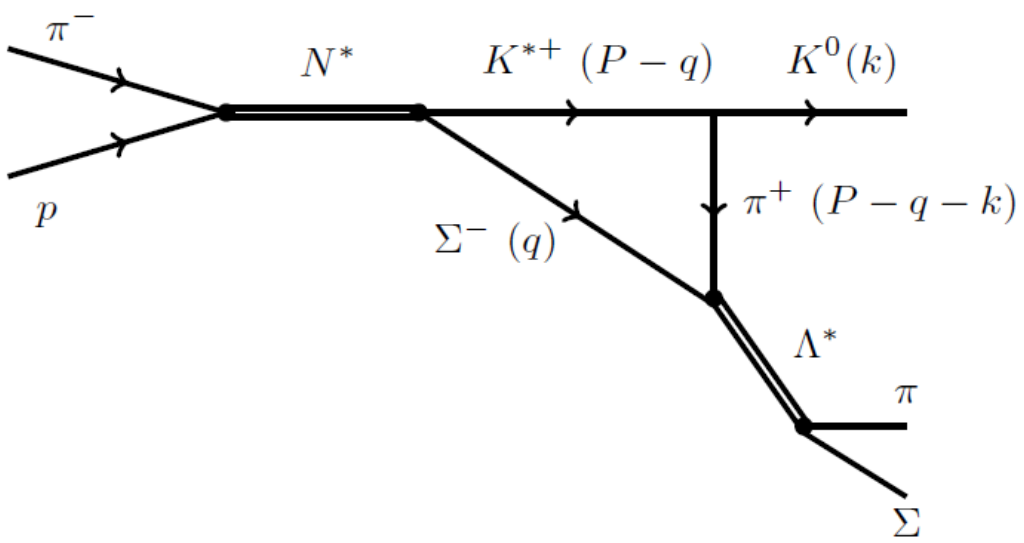
cos(θ)=-1

$$P^0 - \omega^*(\vec{q}) - \omega(\vec{q}) = 0 \;\rightarrow\; q_{\text{on}} + i\epsilon$$

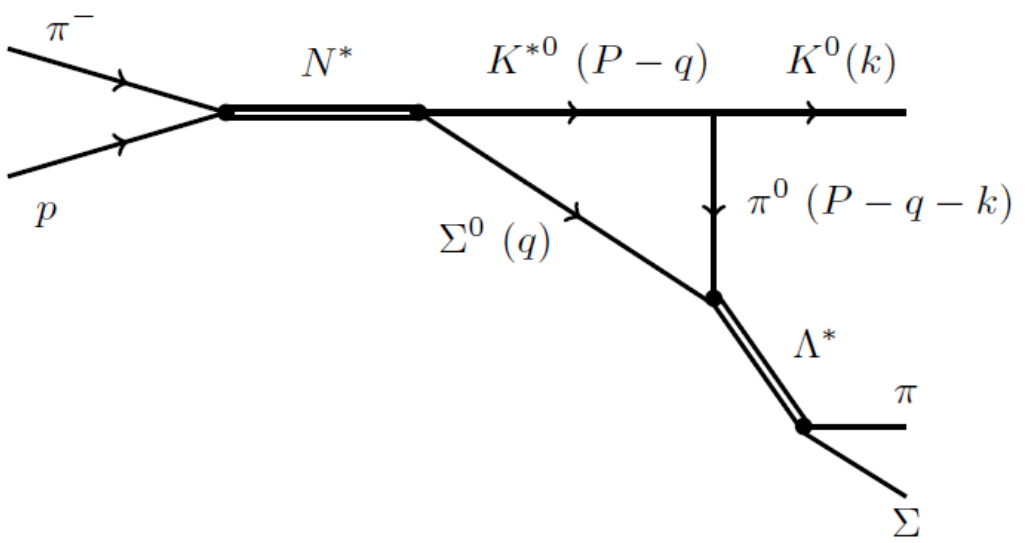
$$P^0 - k^0 - \omega(\vec{q}) - \omega'(\vec{q}+\vec{k}) = 0 \;\rightarrow\; q_{a-} - i\epsilon$$

TS IN 2140 MeV

M. Bayar, F. Aceti, F-K Guo and E. Oset, **Phys. Rev. D 94 (2016) 074039**

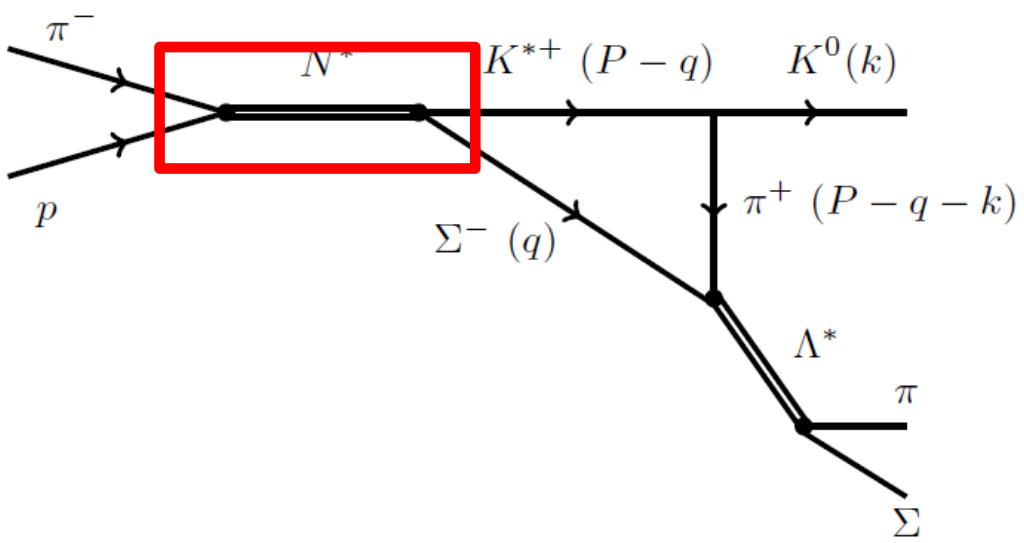


(a)

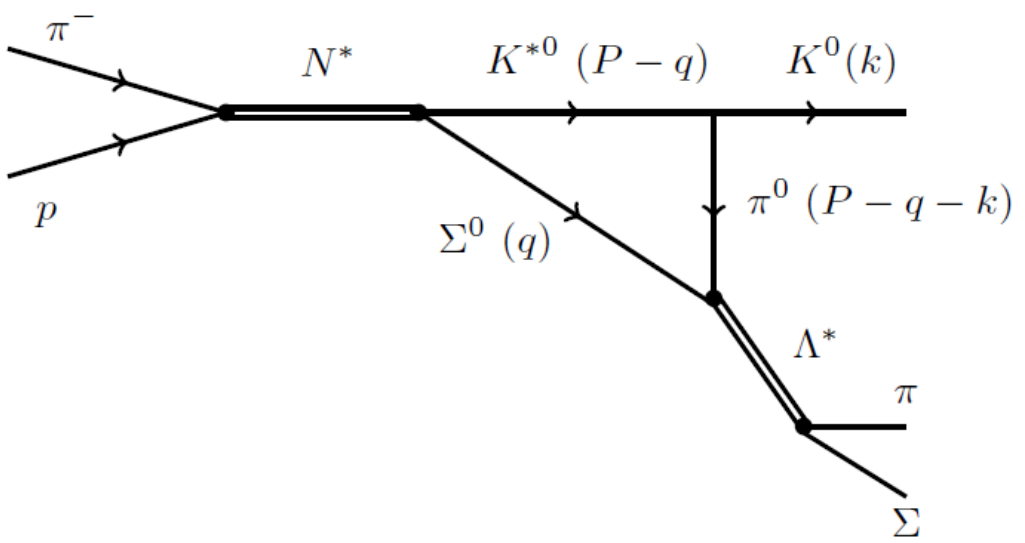


(b)

$\pi\, p \rightarrow \Lambda(1405)\, K \rightarrow \pi\, \mathbf{\Sigma}\, K$

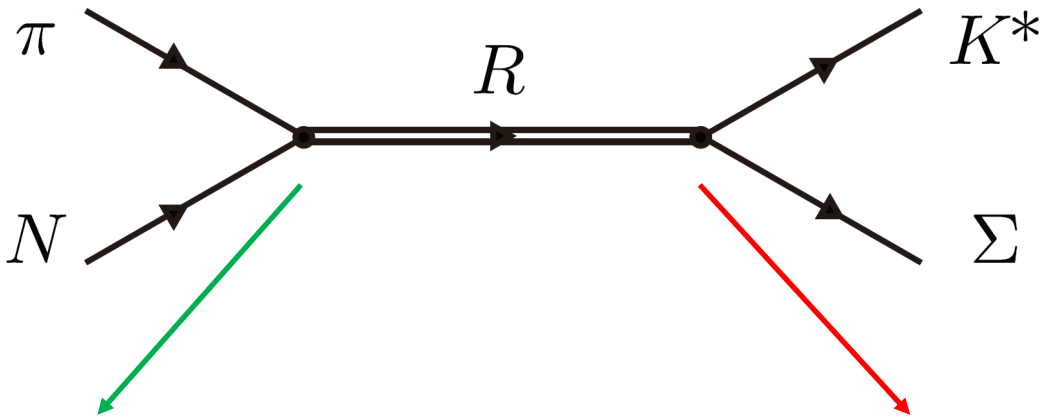


(a)



(b)

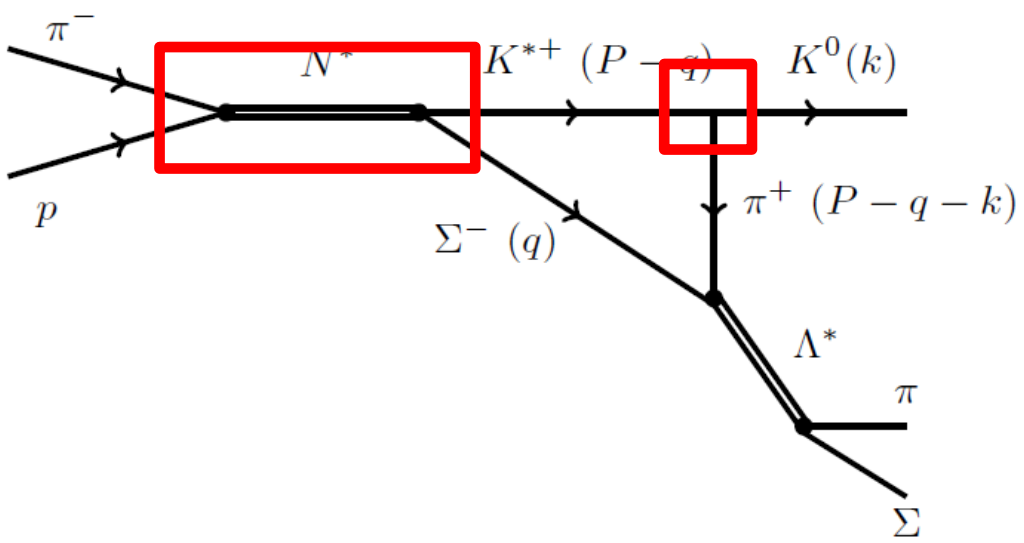
$\pi\, p \rightarrow \Lambda(1405)\, K \rightarrow \pi\, \mathbf{\Sigma}\, K$



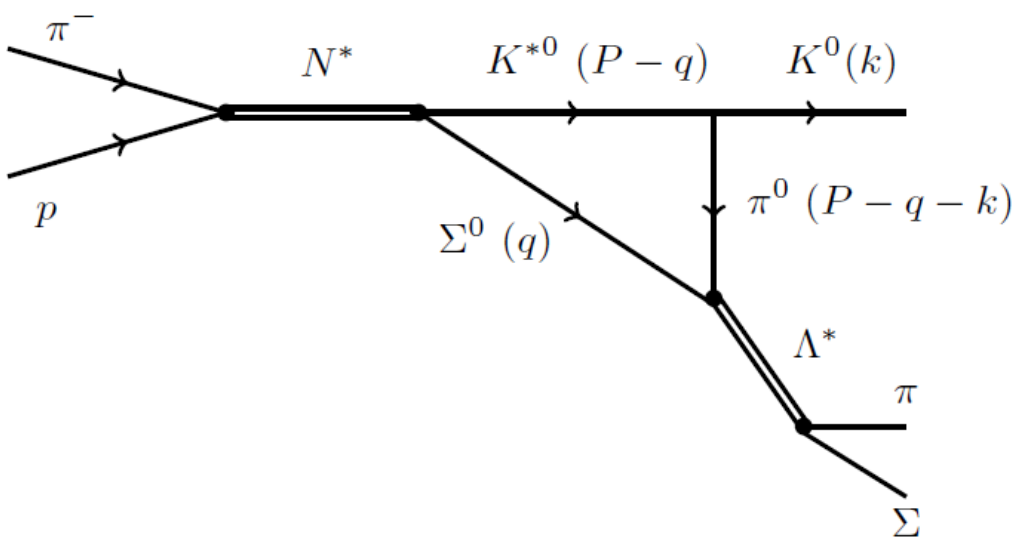
$$-it_{\pi N,N^*} = -ig^{I=\frac{1}{2}}_{\pi N,N^*} \qquad -it_{N^*,K^*\Sigma} = -i\frac{1}{\sqrt{3}} g_{N^*,\Sigma K^*}\ \vec{\sigma}\cdot\vec{\epsilon}_{K^*}$$

$$t_{\pi^- p,\Sigma^0 K^{*0}} = \frac{1}{\sqrt{3}} \frac{g_{\pi^- p,N^*}\ g_{N^*,\Sigma^0 K^{*0}}}{\sqrt{s} - M_{N^*} + i\frac{\Gamma_{N^*}}{2}} \vec{\sigma}\cdot\vec{\epsilon}_{K^*}$$

$$t_{\pi^- p,\Sigma^- K^{*+}} = \frac{1}{\sqrt{3}} \frac{g_{\pi^- p,N^*}\ g_{N^*,\Sigma^- K^{*+}}}{\sqrt{s} - M_{N^*} + i\frac{\Gamma_{N^*}}{2}} \vec{\sigma}\cdot\vec{\epsilon}_{K^*}$$

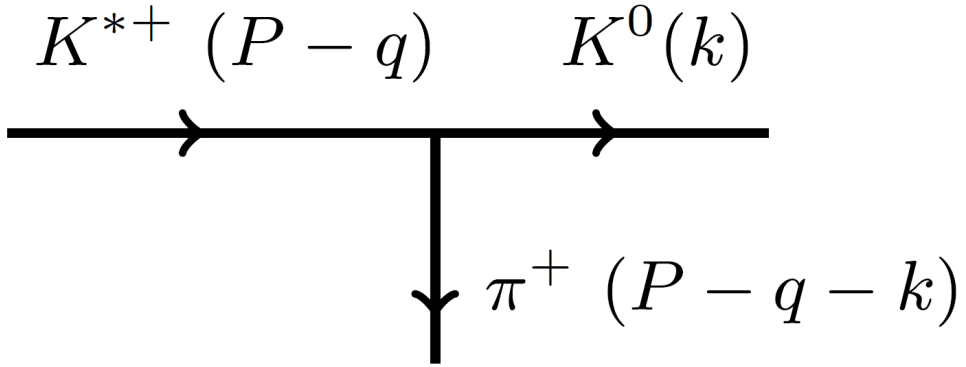


(a)



(b)

$\pi\, p \rightarrow \Lambda(1405)\, K \rightarrow \pi\, \mathbf{\Sigma}\, K$

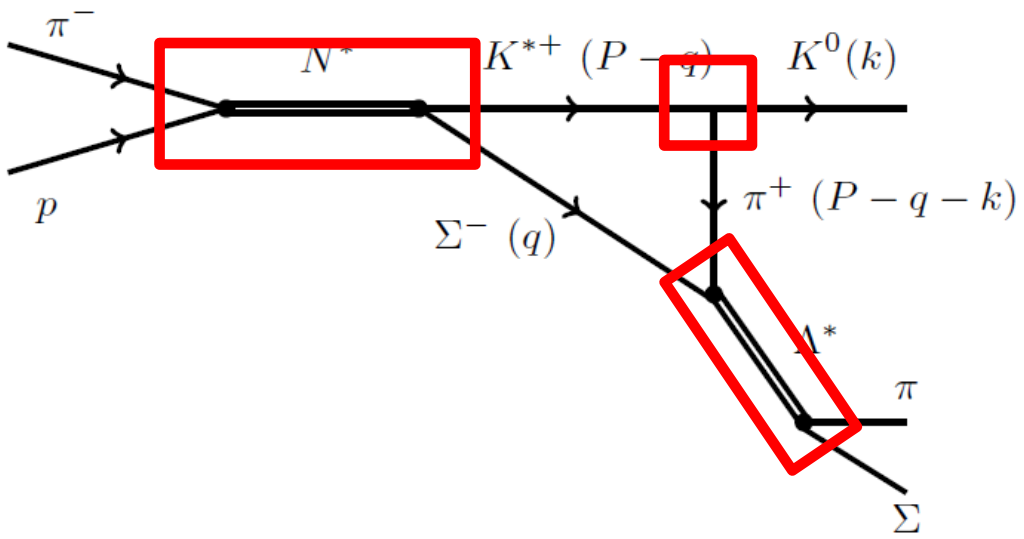


Local Hidden Gauge

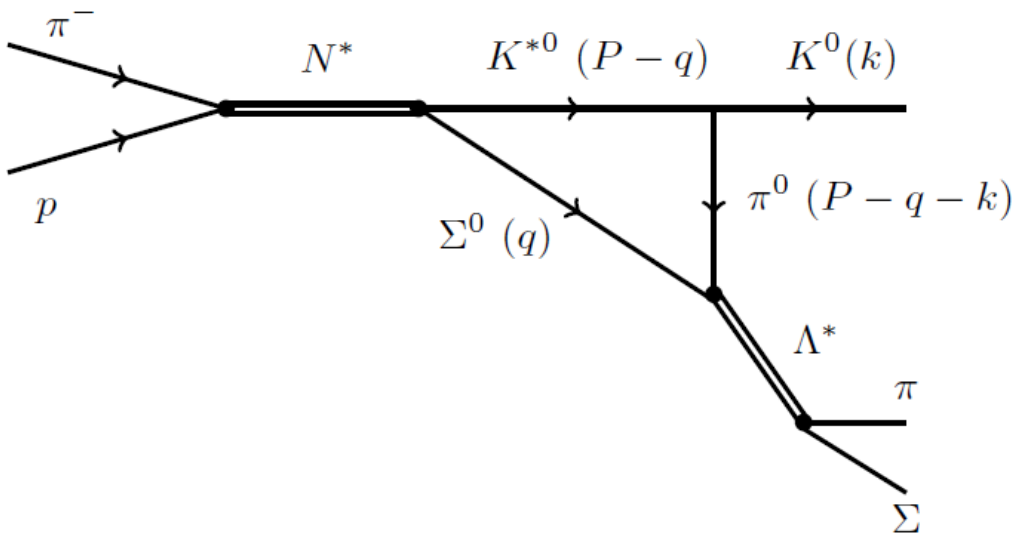
$$\mathcal{L}_{VPP} = -ig\,\langle [\Phi, \partial_\mu \Phi]\, V^\mu \rangle$$

$$-it_{K^{*+},K^0\pi^+} = ig\ \vec{\epsilon}_{K^*} \cdot (\vec{q} + 2\vec{k})$$

$$-it_{K^{*0},K^0\pi^0} = -i\frac{1}{\sqrt{2}} g\ \vec{\epsilon}_{K^*} \cdot (\vec{q} + 2\vec{k}).$$

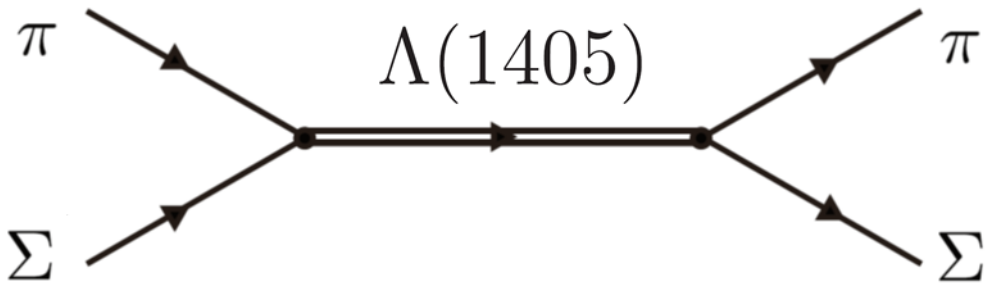


(a)



(b)

$\pi\, p \rightarrow \Lambda(1405)\, K \rightarrow \pi\, \mathbf{\Sigma}\, K$

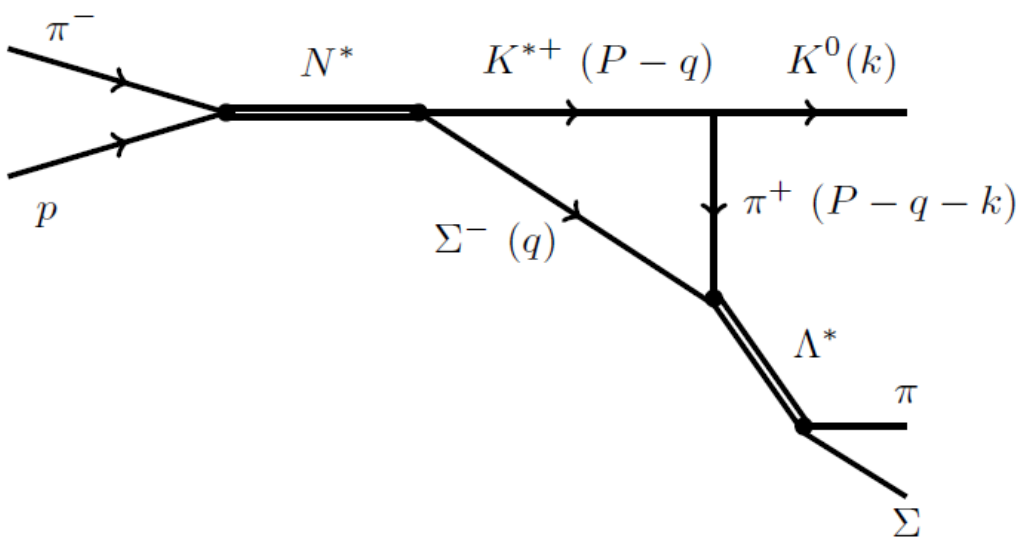


$$t = [1 - VG]^{-1} V,$$

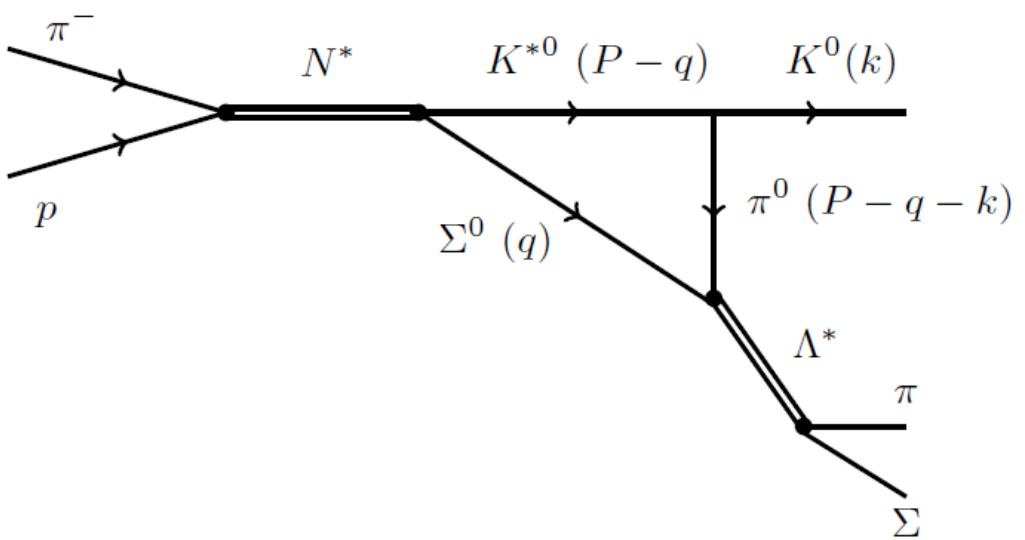
$$\mathcal{L}_1^{(B)} = \left\langle \bar{B} i\gamma^\mu \frac{1}{4f^2} [(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi)B - B(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi)] \right\rangle$$

E. Oset and A. Ramos, **Nucl.Phys. A635 (1998) 99**

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

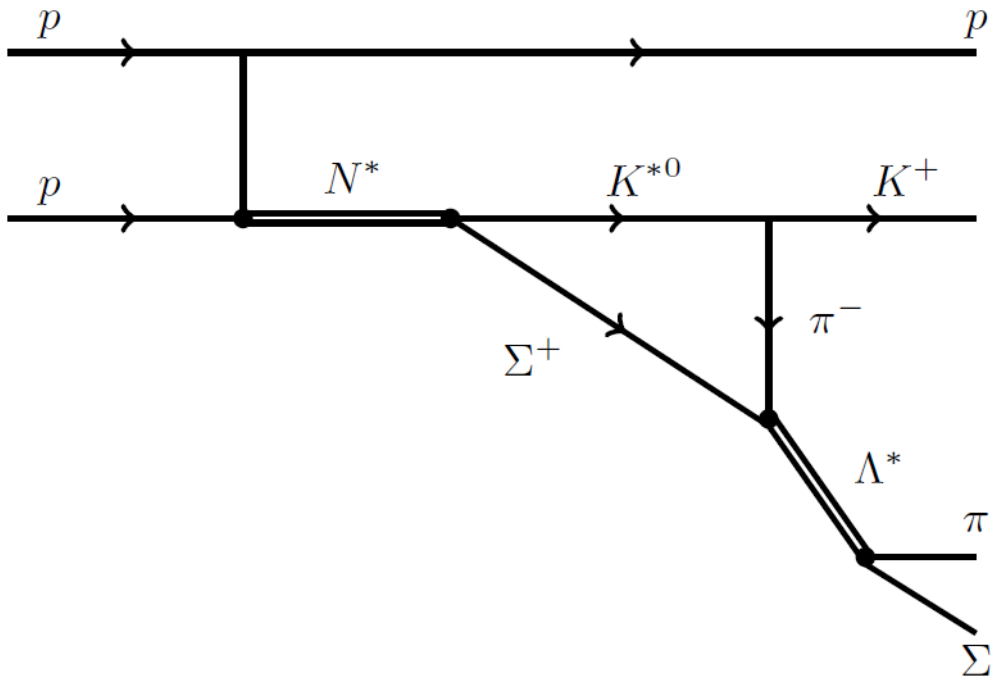


(a)

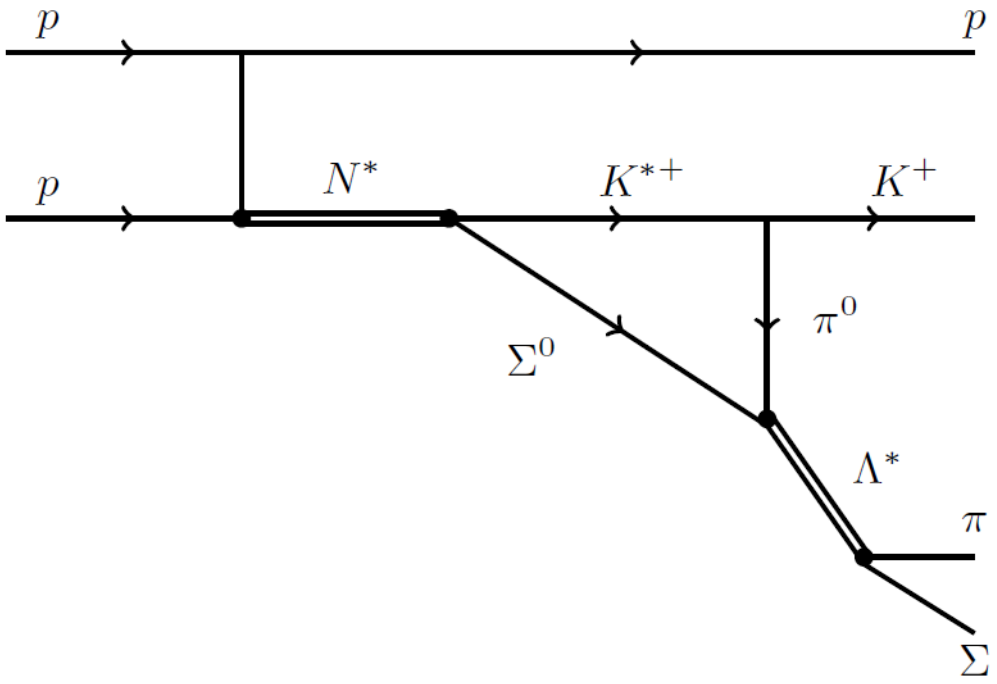


(b)

$$\frac{d\sigma_{K^0\pi\Sigma}}{dm_{\text{inv}}} = \frac{M_p M_\Sigma |\vec{k}||\tilde{\vec{p}}_\pi|}{2(2\pi)^3 s|\vec{p}_\pi|}\overline{\sum\sum}|t_{\pi^- p\to K^0\pi\Sigma}|^2$$

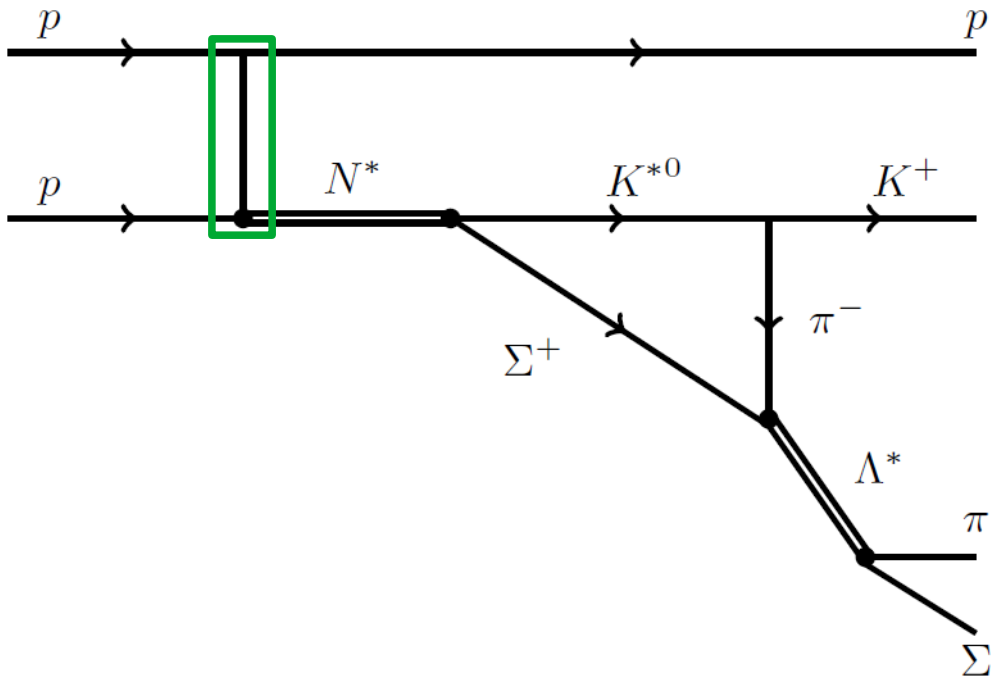


(a)



(b)

pp → Λ(1405) K p → π **Σ** K p



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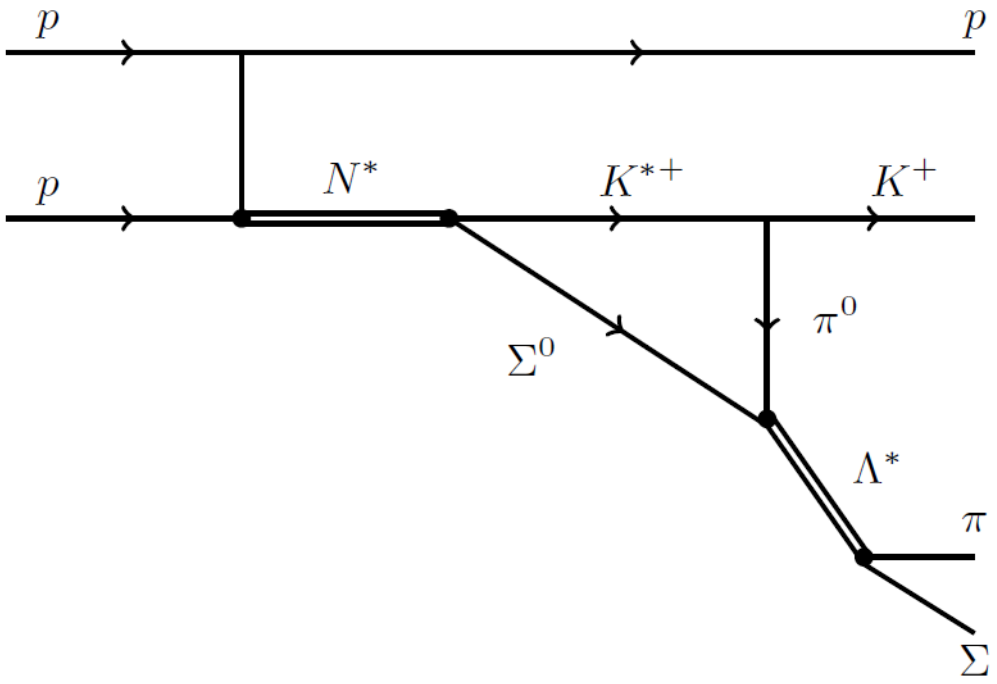
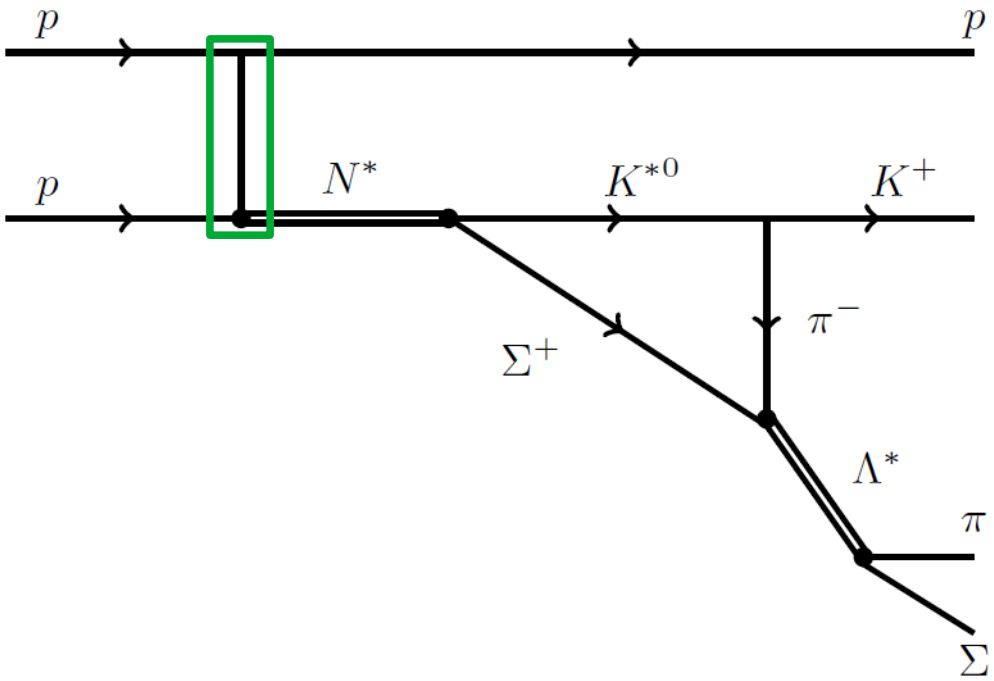
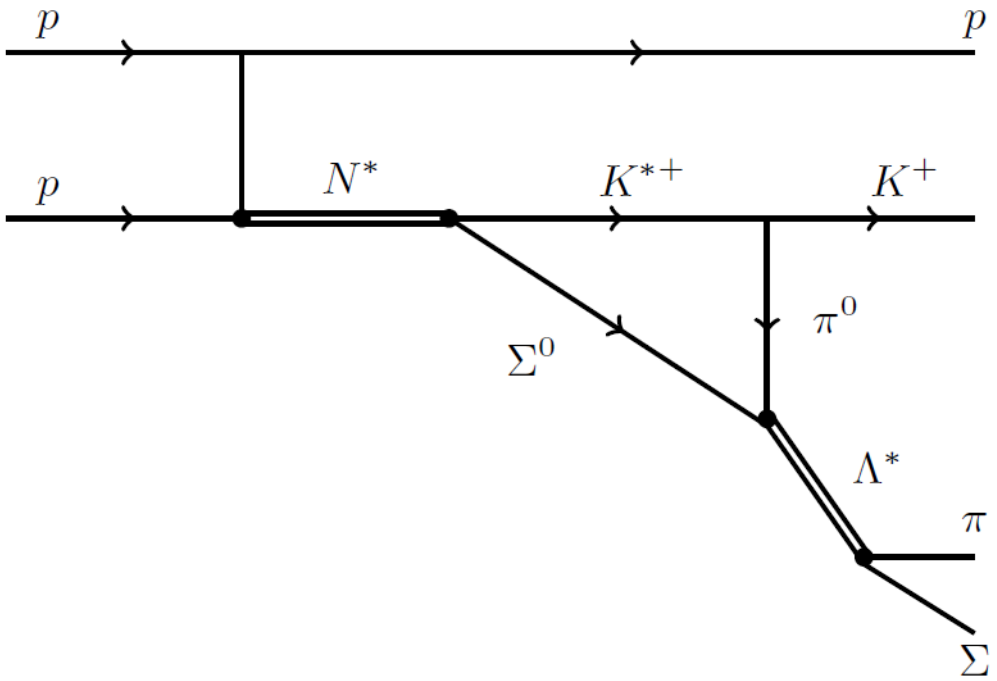


(b)

pp → Λ(1405) K p → π **Σ** K p

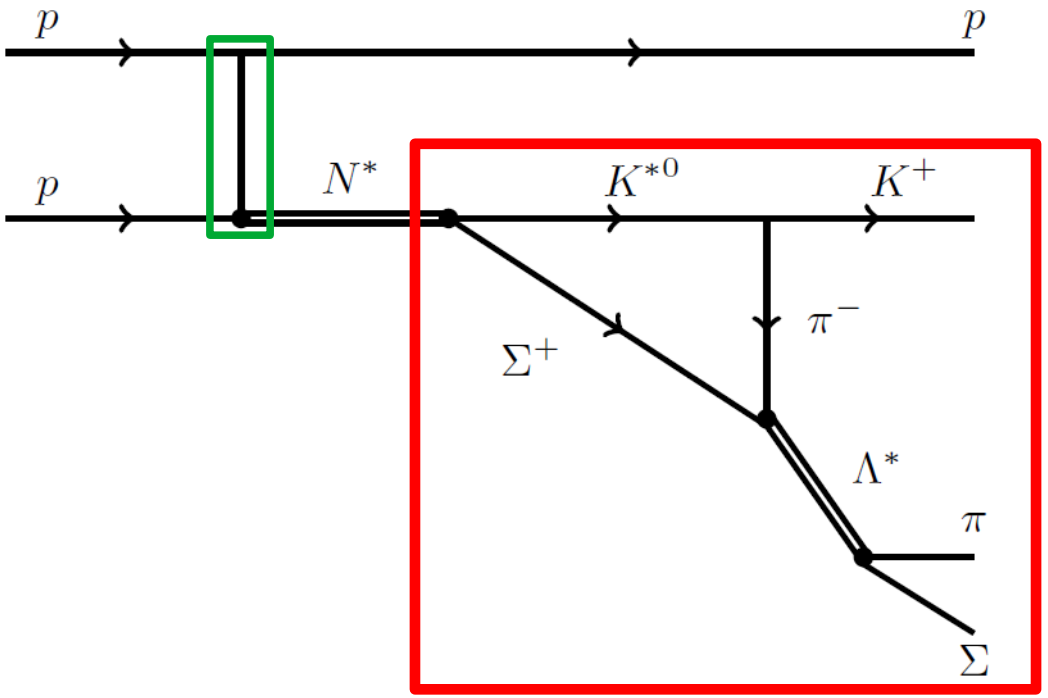


(a)

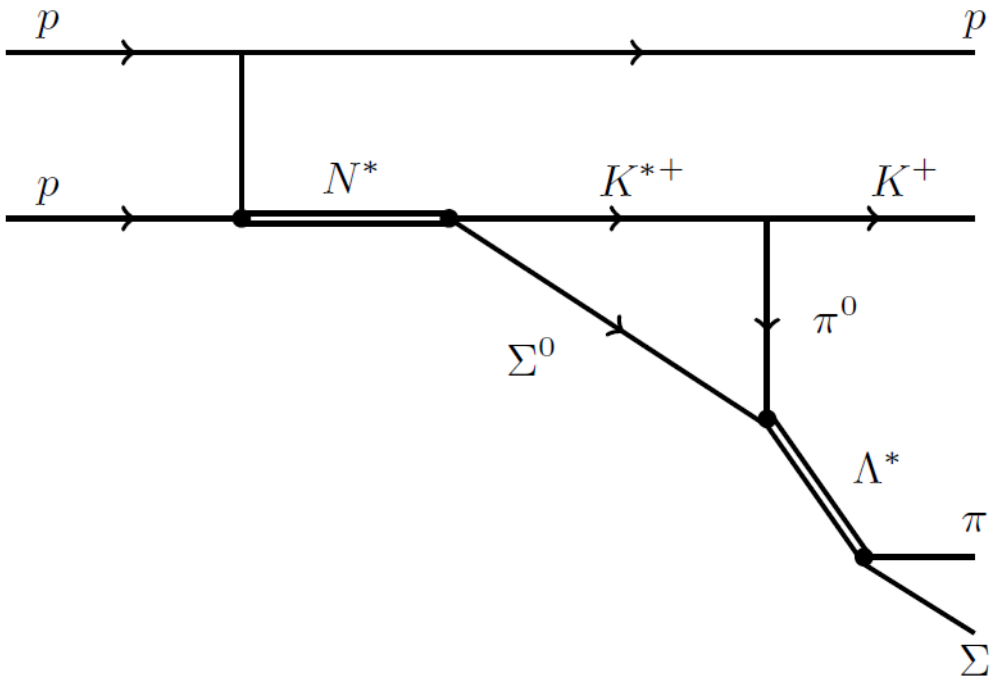


(b)

$$\frac{d^3\sigma_{pK^+\pi\Sigma}}{dt\ dM_{\rm inv}dm_{\rm inv}} = \frac{(2M_p)^3\ 2M_\Sigma}{32p_a^2 s(2\pi)^5}|\vec{p}_K||\vec{\tilde{p}}_\pi|\,|C'|^2\left|\frac{1}{M_{\rm inv}-M_{N^*}+i\frac{\Gamma_{N^*}}{2}}\right|^2\overline{\sum}\sum|t'|^2$$



(a)



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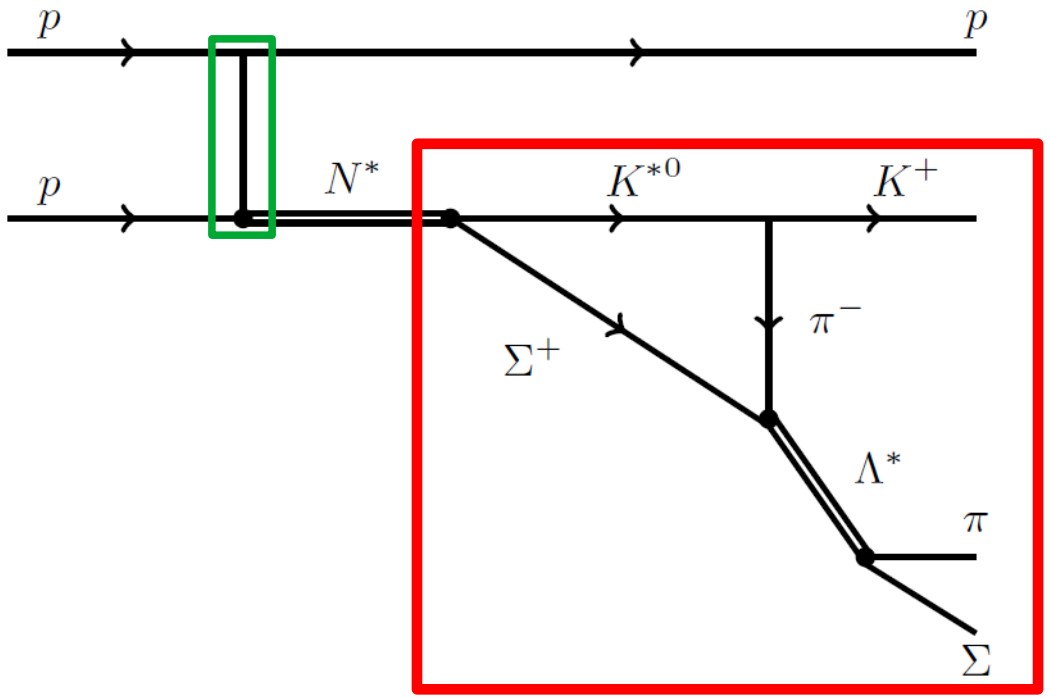
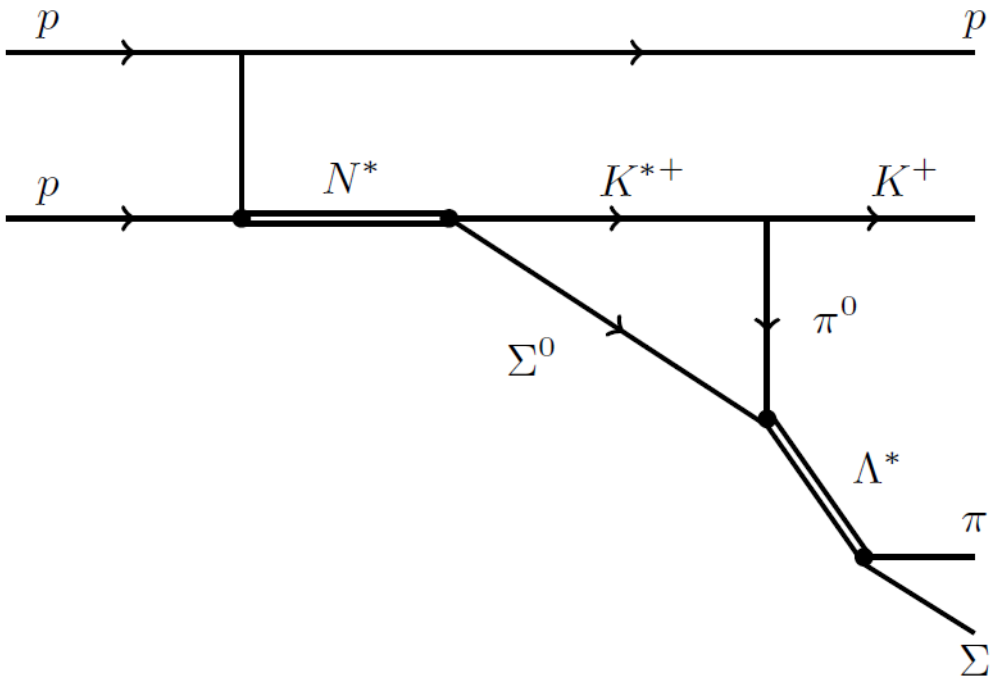


(a)

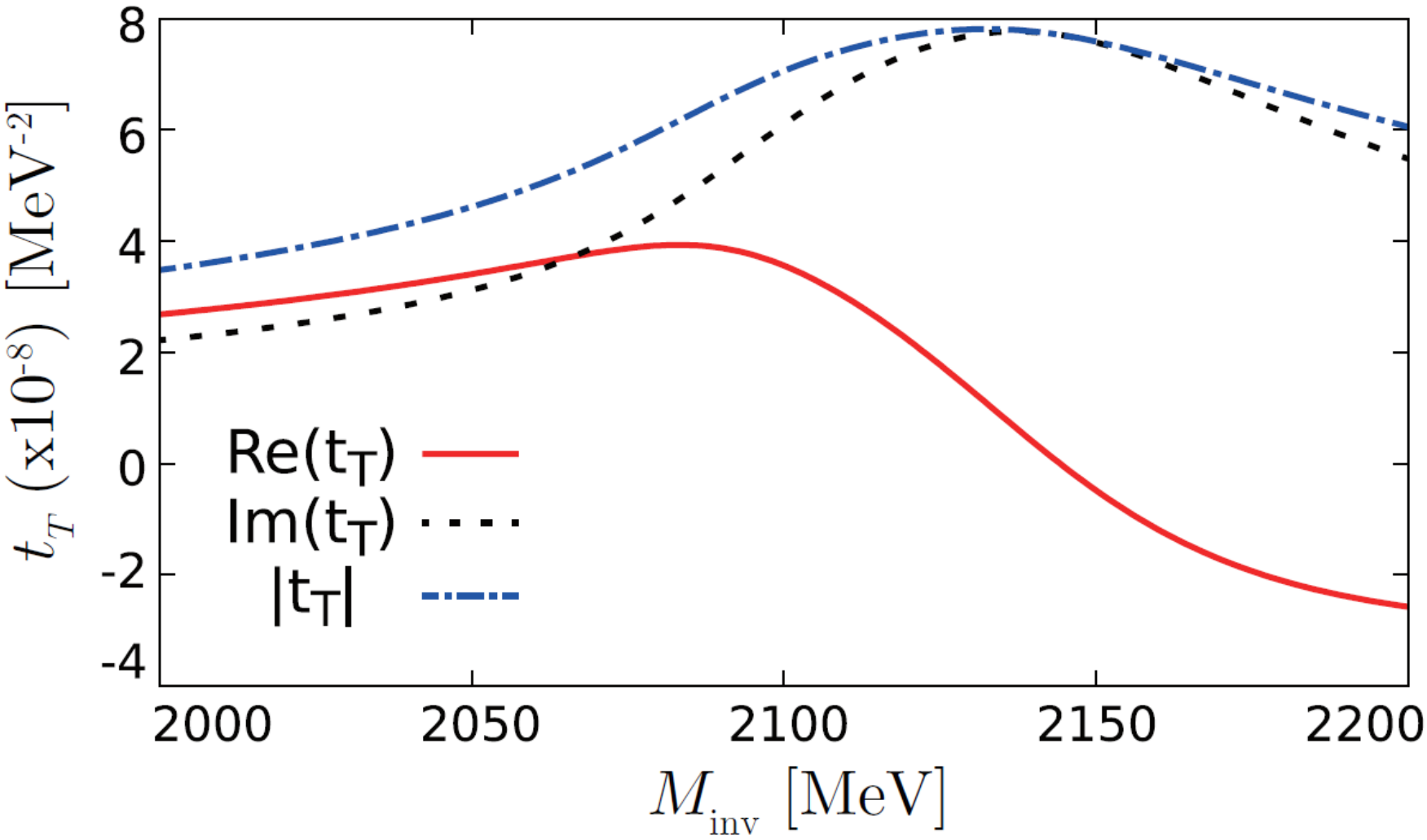


(b)

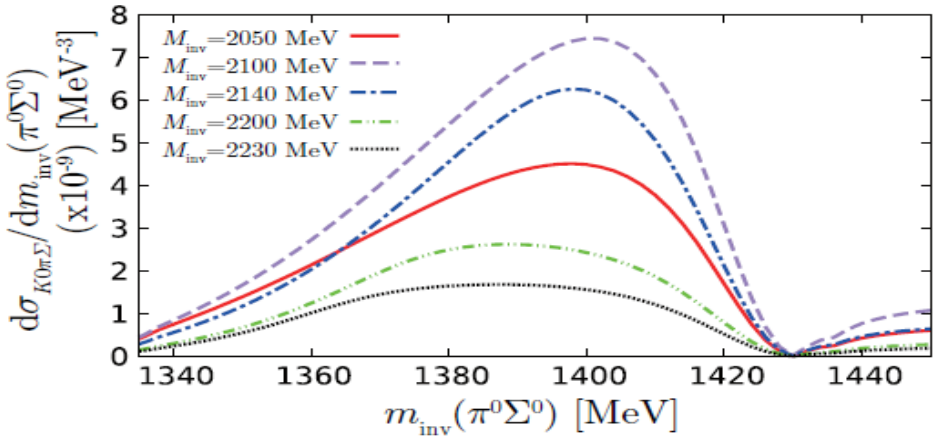
$$\frac{d^2\sigma_{pK^+\pi\Sigma}}{dM_{\rm inv}dm_{\rm inv}} = \frac{C'''' 2|\vec{p}_a||\vec{p}_1|}{|M_{\rm inv} - M_{N^*} + i\frac{\Gamma_{N^*}}{2}|^2}|\vec{\tilde{p}}_\pi||t_{\Sigma^+\pi^-,\Sigma\pi} + \frac{1}{2}t_{\Sigma^0\pi^0,\Sigma\pi}|^2|\vec{k}|^3|t_T|^2$$

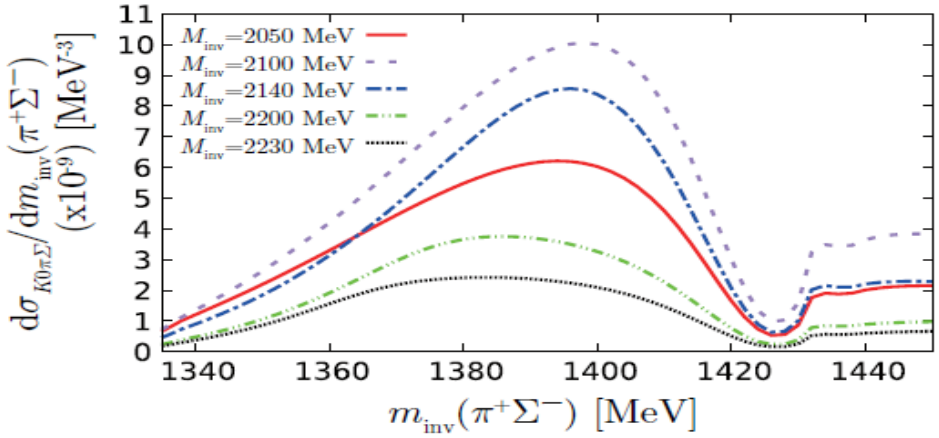
Results

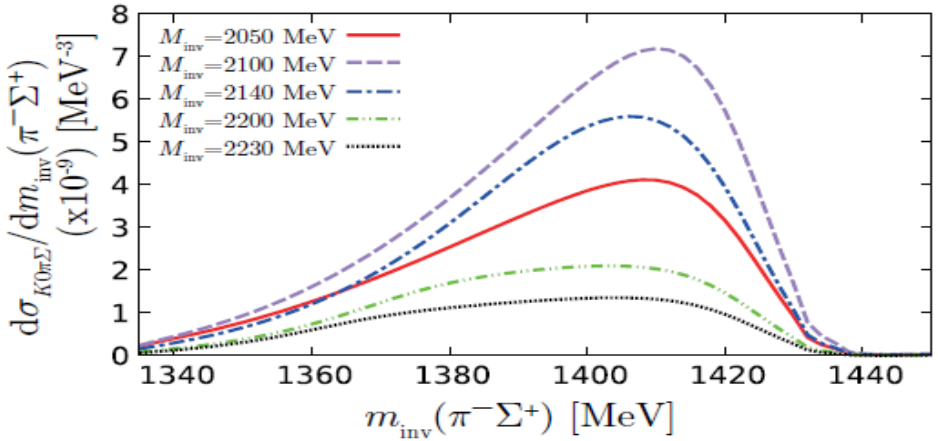
t_T


8
6
4
2
0
-2
-4
2000
2050
2100
2150
2200
t_T (x10^{-8}) [MeV^{-2}]
$M_{\rm inv}$ [MeV]
Re(t$_T$)
Im(t$_T$)
|t$_T$|

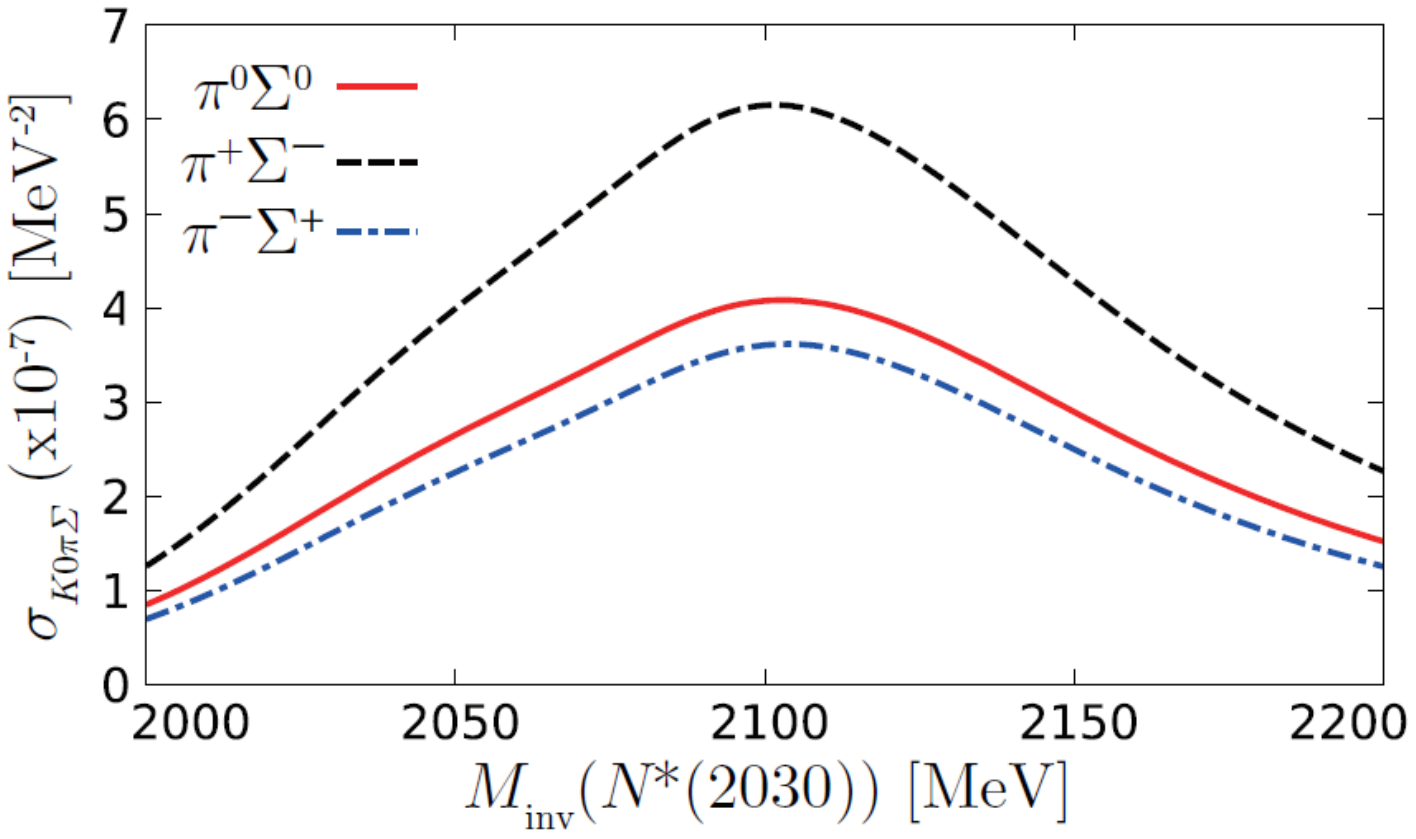
πp


M_{inv}=2050 MeV
M_{inv}=2100 MeV
M_{inv}=2140 MeV
M_{inv}=2200 MeV
M_{inv}=2230 MeV
$d\sigma_{K0\pi\Sigma}/dm_{inv}(\pi^0\Sigma^0)$ (x10^{-9}) [MeV^{-3}]
$m_{inv}(\pi^0\Sigma^0)$ [MeV]

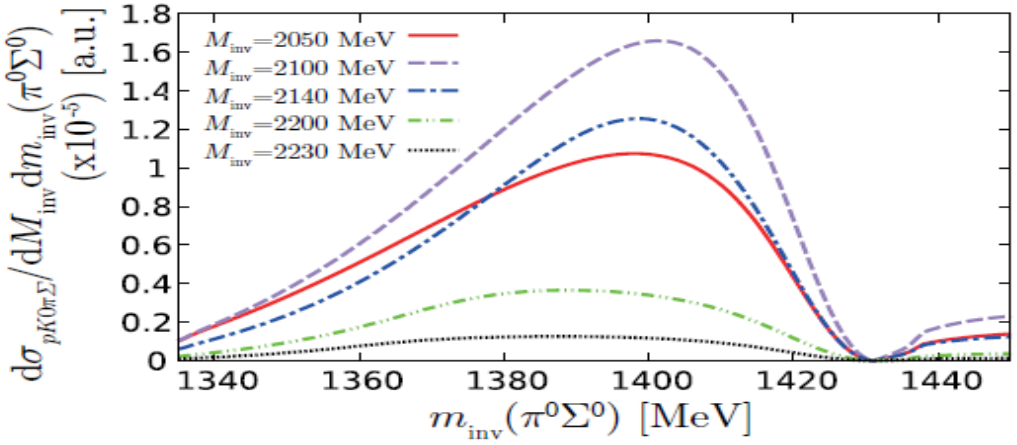

M_{inv}=2050 MeV
M_{inv}=2100 MeV
M_{inv}=2140 MeV
M_{inv}=2200 MeV
M_{inv}=2230 MeV
$d\sigma_{K0\pi\Sigma}/dm_{inv}(\pi^+\Sigma^-)$ (x10^{-9}) [MeV^{-3}]
$m_{inv}(\pi^+\Sigma^-)$ [MeV]

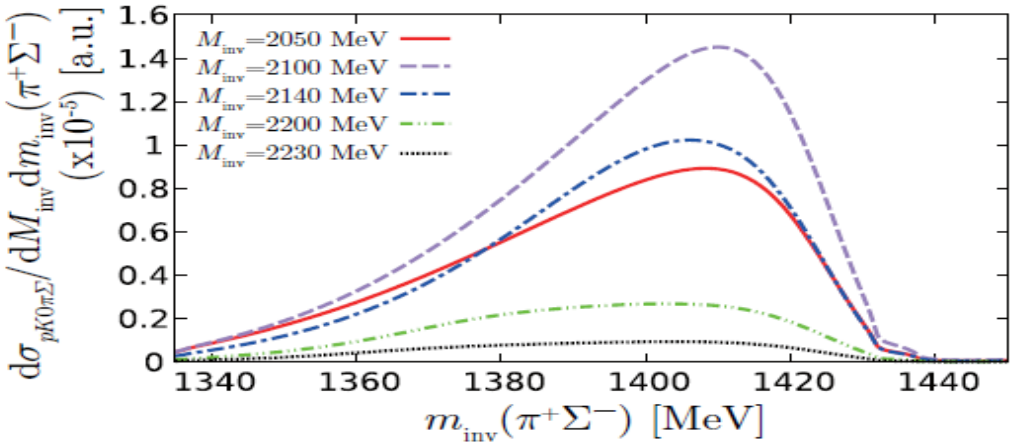

M_{inv}=2050 MeV
M_{inv}=2100 MeV
M_{inv}=2140 MeV
M_{inv}=2200 MeV
M_{inv}=2230 MeV
$d\sigma_{K0\pi\Sigma}/dm_{inv}(\pi^-\Sigma^+)$ (x10^{-9}) [MeV^{-3}]
$m_{inv}(\pi^-\Sigma^+)$ [MeV]

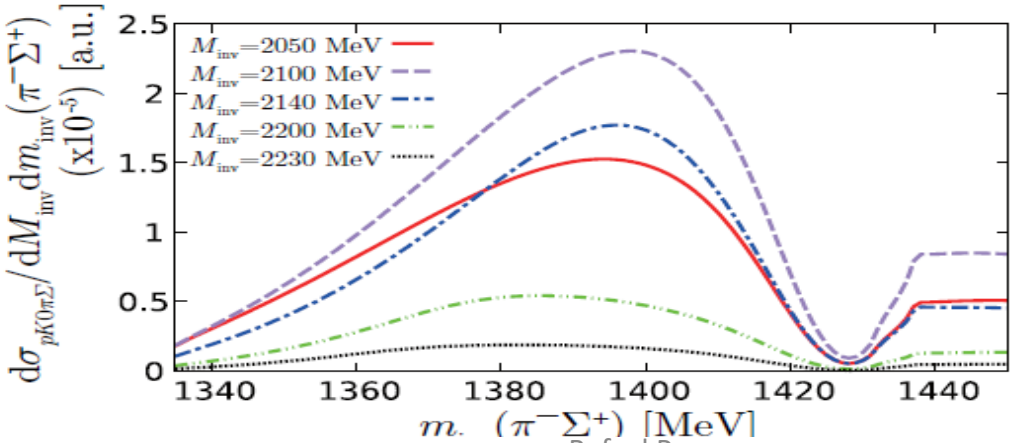
πp


$\pi^0\Sigma^0$
$\pi^+\Sigma^-$
$\pi^-\Sigma^+$
$\sigma_{K0\pi\Sigma}$ (x10^{-7}) [MeV^{-2}]
$M_{\mathrm{inv}}(N^*(2030))$ [MeV]
0
1
2
3
4
5
6
7
2000
2050
2100
2150
2200

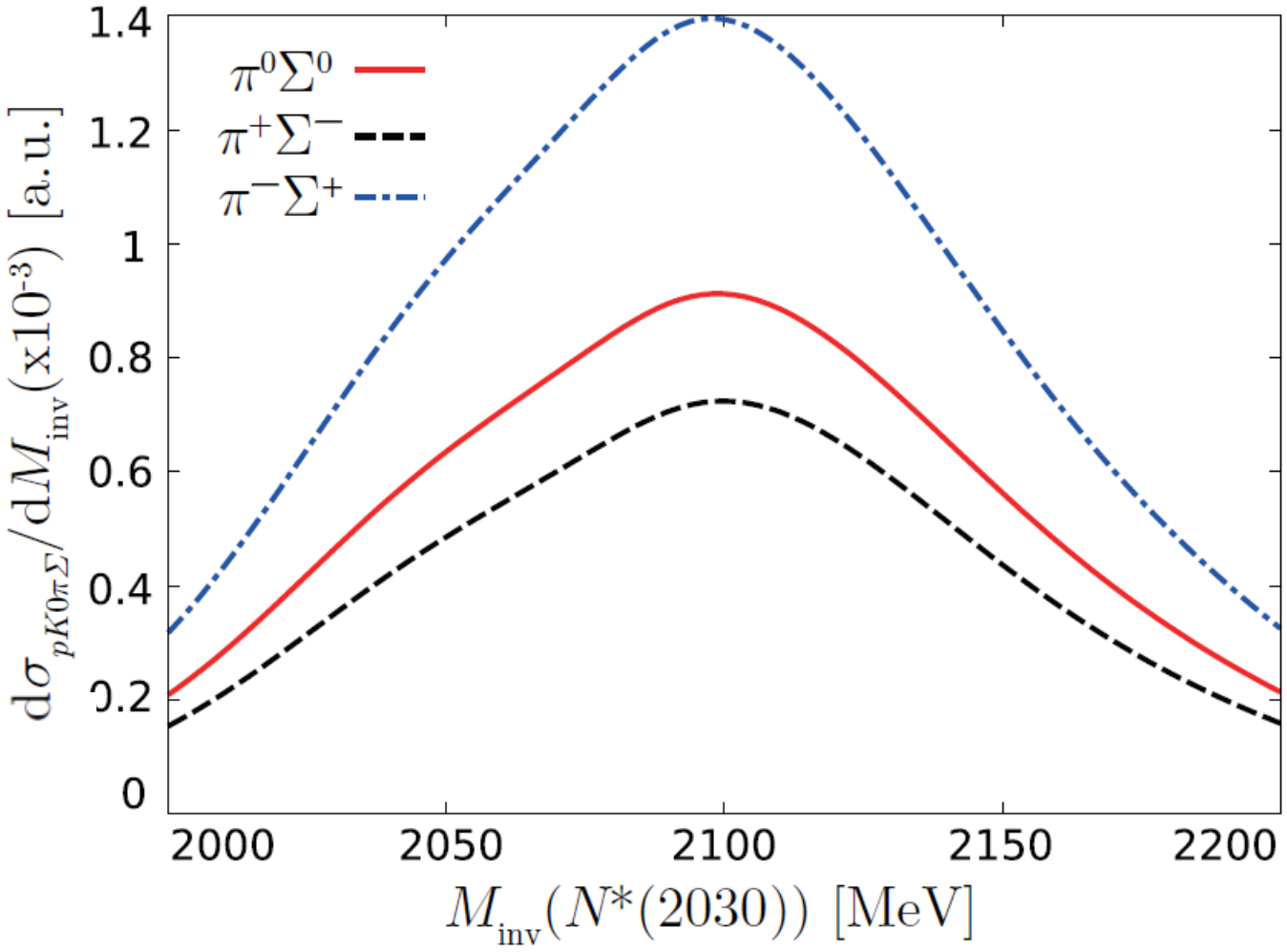
pp


M_{inv}=2050 MeV
M_{inv}=2100 MeV
M_{inv}=2140 MeV
M_{inv}=2200 MeV
M_{inv}=2230 MeV
$d\sigma_{pK^0\pi\Sigma}/dM_{inv}dm_{inv}(\pi^0\Sigma^0)$ (x10^{-5}) [a.u.]
$m_{inv}(\pi^0\Sigma^0)$ [MeV]

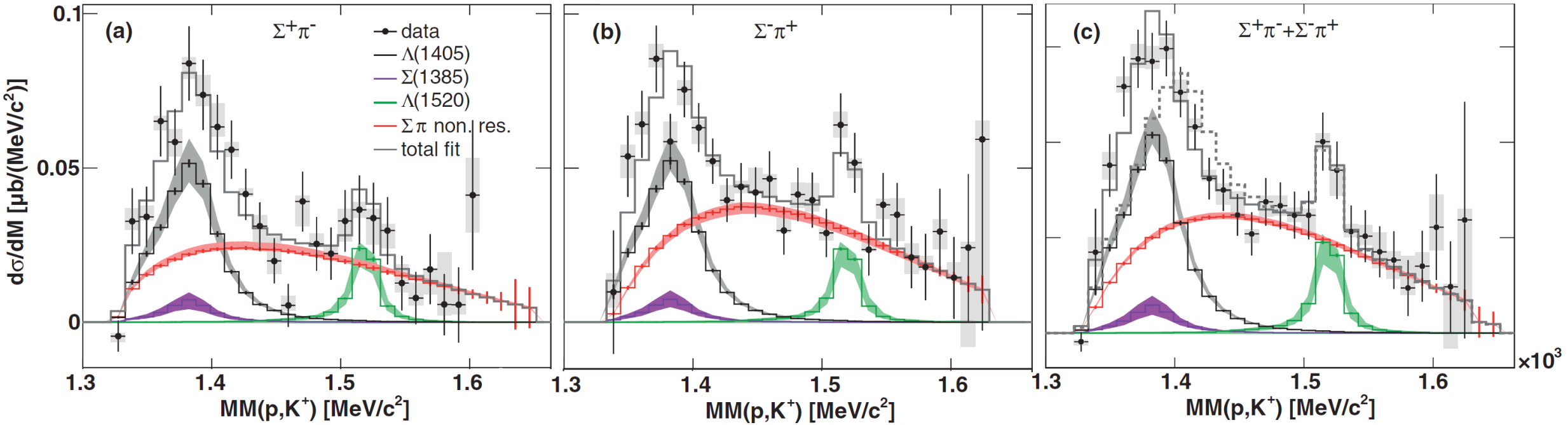

M_{inv}=2050 MeV
M_{inv}=2100 MeV
M_{inv}=2140 MeV
M_{inv}=2200 MeV
M_{inv}=2230 MeV
$d\sigma_{pK^0\pi\Sigma}/dM_{inv}dm_{inv}(\pi^+\Sigma^-)$ (x10^{-5}) [a.u.]
$m_{inv}(\pi^+\Sigma^-)$ [MeV]


M_{inv}=2050 MeV
M_{inv}=2100 MeV
M_{inv}=2140 MeV
M_{inv}=2200 MeV
M_{inv}=2230 MeV
$d\sigma_{pK^0\pi\Sigma}/dM_{inv}dm_{inv}(\pi^-\Sigma^+)$ (x10^{-5}) [a.u.]
$m_{inv}(\pi^-\Sigma^+)$ [MeV]

pp


1.4
1.2
1
0.8
0.6
0.4
0.2
0
$\pi^0\Sigma^0$
$\pi^+\Sigma^-$
$\pi^-\Sigma^+$
$\mathrm{d}\sigma_{pK0\pi\Sigma}/\mathrm{d}M_{\mathrm{inv}}\,(\mathrm{x}10^{-3})$ [a.u.]
2000
2050
2100
2150
2200
$M_{\mathrm{inv}}(N^*(2030))$ [MeV]

Conclusions



HADES Collaboration (G. Agakishiev (Dubna, JINR) et al.)

Published in Phys.Rev. C87 (2013) 025201

$pp \rightarrow \Lambda(1405)\, K\, p \rightarrow \pi\, \mathbf{\Sigma}\, K\, p$

Thank You