Vector meson production and η' N -> η' N scattering

E. Oset, and A. Ramos

-- Meson baryon interaction with chiral Lagrangians. Introducing the η'
--Vector meson Baryon interaction and the local hidden gauge theory
--The interplay of vector meson-baryon and pseudoscalar meson-baryon states. Particular case of the η' N.
-- Results for different reactions involving η'.

Chiral Lagrangian for pseudoscalar meson- baryon interaction

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

$$\Phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix}$$

Octet X Octet

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

Introducing the singlet $\mathrm{diag}(\eta_1/\sqrt{3}, \eta_1/\sqrt{3}, \eta_1/\sqrt{3})$

Because of the structure $\Phi \partial_{\mu} \Phi - \partial_{\mu} \Phi \Phi$ the singlet does not contribute

η – η’ mixing

$$\eta = \cos\theta_P\, \eta_8 - \sin\theta_P\, \eta_1$$
$$\eta' = \sin\theta_P\, \eta_8 + \cos\theta_P\, \eta_1$$

$\theta_P = -14.34^{\circ}$

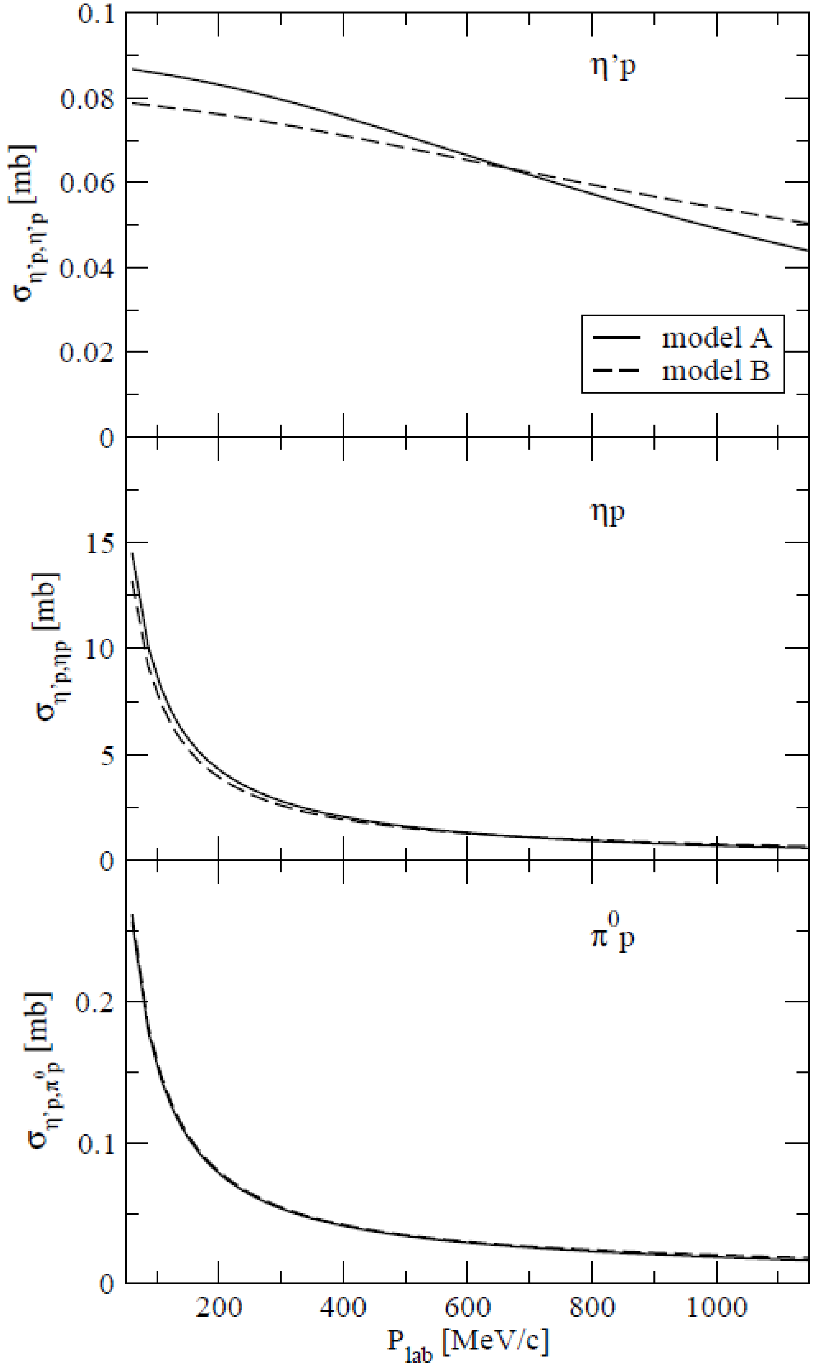
$$T = [1 - V\, G]^{-1}\, V$$

$$V_{ij} = -C_{ij}\frac{1}{4f_i f_j}(2\sqrt{s} - M_i - M_j)\left(\frac{M_i + E_i}{2M_i}\right)^{1/2}\left(\frac{M_j + E_j}{2M_j}\right)^{1/2}$$

$$\begin{aligned} G_l &= i2M_l \int \frac{d^4q}{(2\pi)^4}\frac{1}{(P-q)^2 - M_l^2 + i\epsilon}\frac{1}{q^2 - m_l^2 + i\epsilon} \\ &= \frac{2M_l}{16\pi^2}\left\{a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s}\ln\frac{m_l^2}{M_l^2} + \right. \\ &\qquad + \frac{\bar{q}_l}{\sqrt{s}}\left[\ln(s - (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}) + \ln(s + (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}) \right. \\ &\qquad\quad \left.\left. - \ln(-s + (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}) - \ln(-s - (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s})\right]\right\} \end{aligned}$$

channel (threshold)	Model A [Eq. (8)] [fm]
$(\pi N)_{I=1/2}$ (1077)	0.179 fm $= 0.125\ m_\pi^{-1}$
$(\pi N)_{I=3/2}$ (1077)	-0.121 fm $= -0.085\ m_\pi^{-1}$
$\pi^- p$ (1078)	0.079
$\pi^- n$ (1079)	−0.123
$\pi^0 p$ (1073)	−0.023
ηp (1486)	$0.195 + \mathrm{i}\,0.141$ (0.241)
$\eta' p$ (1896)	$-0.0078 + \mathrm{i}\,0.025$ (0.026)

$|a_{\eta' N}| \sim 0.1$ fm   P. Moskal *et al.*, Phys. Lett. B **482**, 356 (2000)



η'p
ηp
π^0p
model A
model B
$\sigma_{\eta'p,\eta'p}$ [mb]
$\sigma_{\eta'p,\eta p}$ [mb]
$\sigma_{\eta'p,\pi^0 p}$ [mb]
P_{lab} [MeV/c]
0.1
0.08
0.06
0.04
0.02
0
15
10
5
0
0.2
0.1
0
200
400
600
800
1000

Experimental information

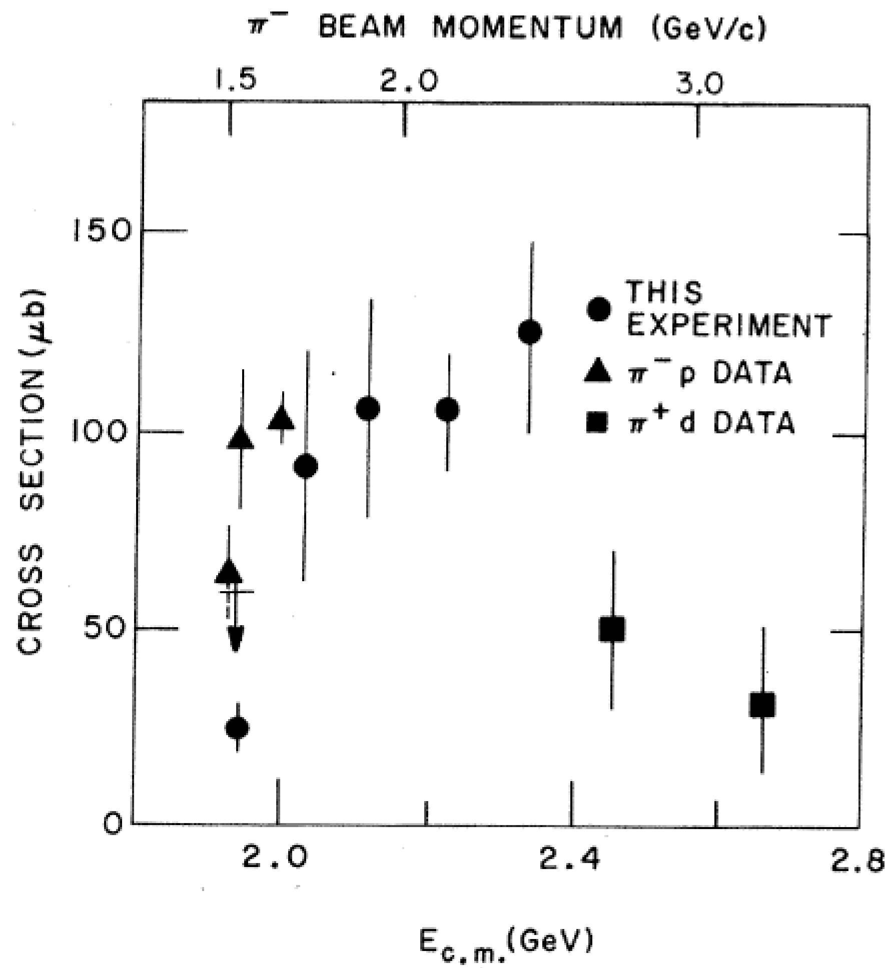


FIG. 9. Cross section for $\pi^+ n \to p \eta'$; the charge-symmetric data and $\pi^+ d$ data from other experiments are also shown (Ref. 27).

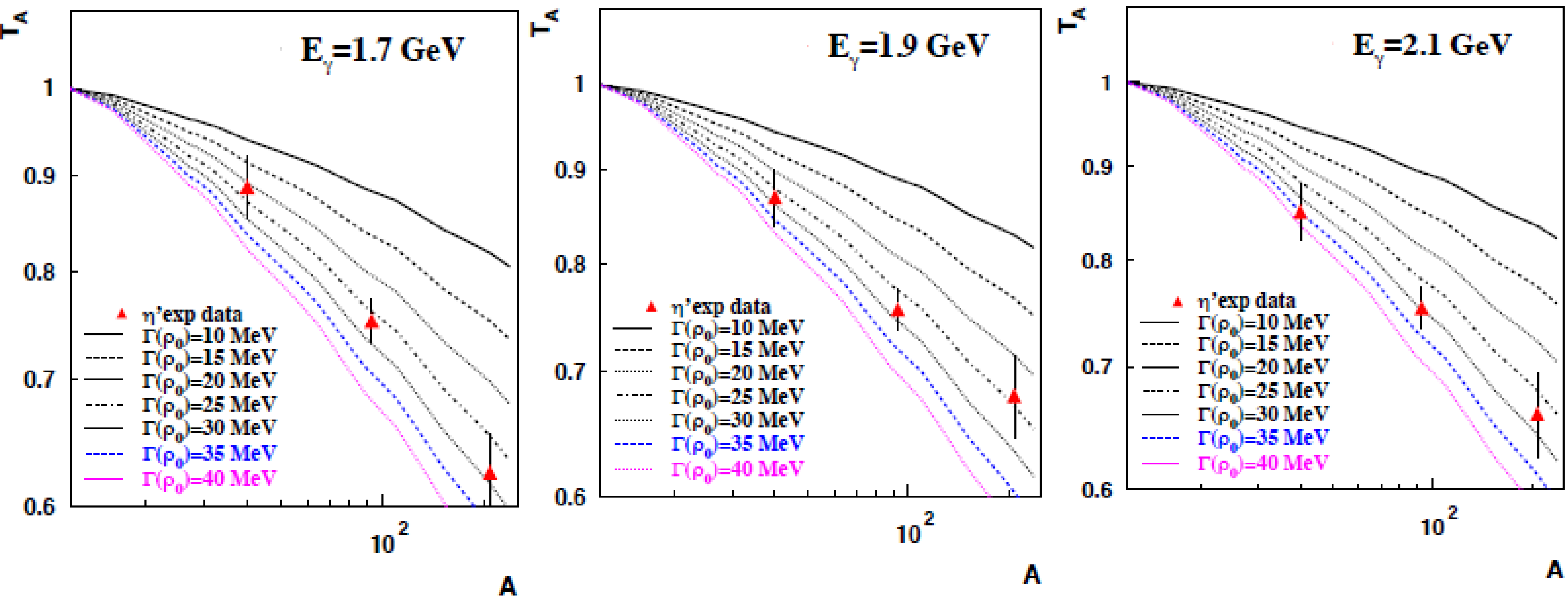
M. Nanova, V. Metag ….

η′ in-medium width

η′ transparency ratio compared with theoretical calculations *A. Ramos and E. Oset*

$$T_A = \frac{\sigma_{\gamma A \to V X}}{A \sigma_{\gamma N \to V X}}$$

⇒in-medium width:



comparison to data $\Gamma(\rho_0, <|\vec{p}_{\eta'}|> \approx 0.9$ GeV/c$) \approx$ 25-30 MeV

η′ is broadened in the medium

$$\Rightarrow \quad \sigma_{\eta' N} = \frac{\Gamma_{inel}}{\rho \cdot \beta \cdot \hbar \cdot c} = 14 \text{ mb}$$

But this could come also from η′ absorption by two nucleons.

Hidden gauge formalism for vector mesons, pseudoscalars and photons

Bando et al. PRL, 112 (85); Phys. Rep. 164, 217 (88)

$$\mathcal{L} = \mathcal{L}^{(2)} + \mathcal{L}_{III} \tag{1}$$

with

$$\mathcal{L}^{(2)} = \frac{1}{4} f^2 \langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + \chi^\dagger U \rangle \tag{2}$$

$$\mathcal{L}_{III} = -\frac{1}{4} \langle V_{\mu\nu} V^{\mu\nu} \rangle + \frac{1}{2} M_V^2 \langle [V_\mu - \frac{i}{g} \Gamma_\mu]^2 \rangle, \tag{3}$$

where $\langle ... \rangle$ represents a trace over $SU(3)$ matrices. The covariant derivative is defined by

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu, \tag{4}$$

with $Q = diag(2, -1, -1)/3$, $e = -|e|$ the electron charge, and A_μ the photon field. The chiral matrix U is given by

$$U = e^{i\sqrt{2}\phi/f} \tag{5}$$

$$\phi \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix}, \quad V_\mu \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu . \tag{6}$$

In $\mathcal{L}_{III}$, $V_{\mu\nu}$ is defined as

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu] \tag{9}$$

and

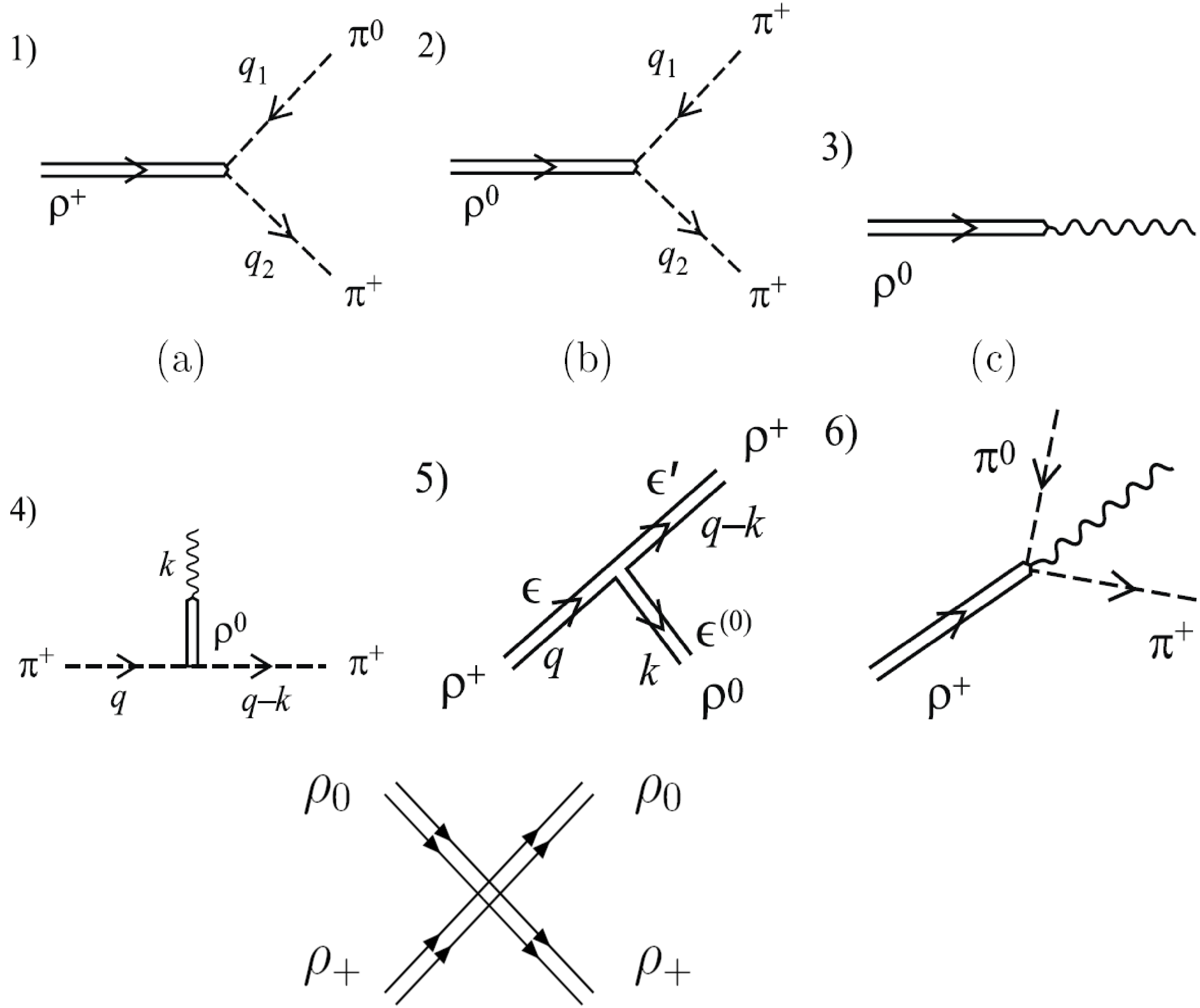
$$\Gamma_\mu = \frac{1}{2}[u^\dagger(\partial_\mu - ieQA_\mu)u + u(\partial_\mu - ieQA_\mu)u^\dagger] \tag{10}$$

with $u^2 = U$. The hidden gauge coupling constant g is related to f and the vector meson mass (M_V) through

$$g = \frac{M_V}{2f}, \tag{11}$$

$$\mathcal{L}_{V\gamma} = -M_V^2 \frac{e}{g} A_\mu \langle V^\mu Q \rangle$$
$$\mathcal{L}_{V\gamma PP} = e\frac{M_V^2}{4gf^2} A_\mu \langle V^\mu (Q\phi^2 + \phi^2 Q - 2\phi Q \phi) \rangle$$
$$\mathcal{L}_{VPP} = -i\frac{M_V^2}{4gf^2} \langle V^\mu [\phi, \partial_\mu \phi] \rangle$$

$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2} \langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu \rangle \ , \qquad \mathcal{L}_{III}^{(3V)} = ig\langle (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu \rangle \ ,$$



1)
π^0
q_1
ρ^+
q_2
π^+
2)
π^+
q_1
ρ^0
q_2
π^+
3)
ρ^0
(a)
(b)
(c)
4)
k
ρ^0
π^+
q
$q-k$
π^+
5)
ρ^+
ϵ'
$q-k$
ϵ
$\epsilon^{(0)}$
ρ^+
q
k
ρ^0
6)
π^0
π^+
ρ^+
ρ_0
ρ_0
ρ_+
ρ_+

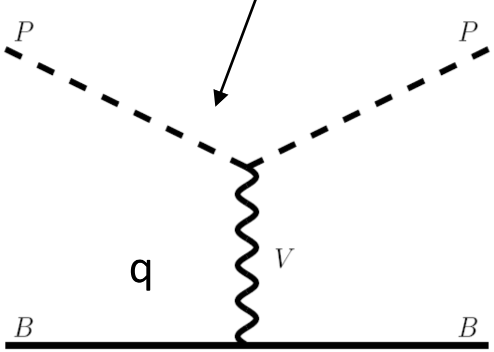
Extension to the baryon sector

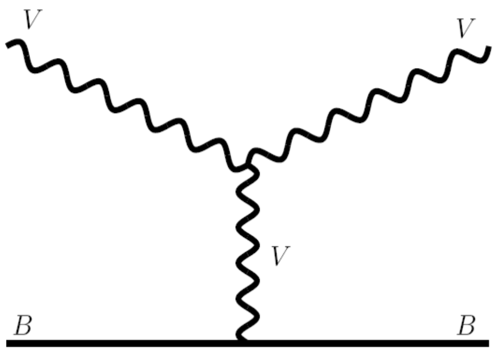
$$\mathcal{L}_{BBV} = -\frac{g}{2\sqrt{2}}\left(tr(\bar{B}\gamma_\mu[V^\mu, B] + tr(\bar{B}\gamma_\mu B)tr(V^\mu)\right)$$

Vector propagator $1/(q^2-M_V^2)$

In the approximation $q^2/M_V^2= 0$ one recovers the chiral Lagrangians Weinberg-Tomozawa term. For consistency, for vectors we take $q/M_V=\vec{0}$

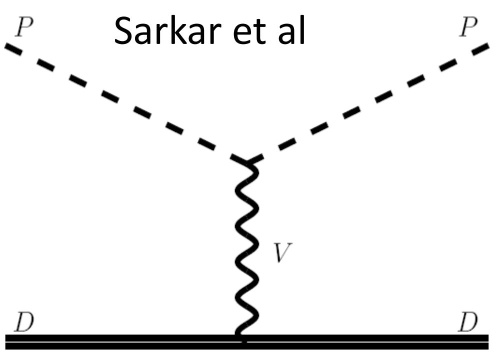
> 200 works

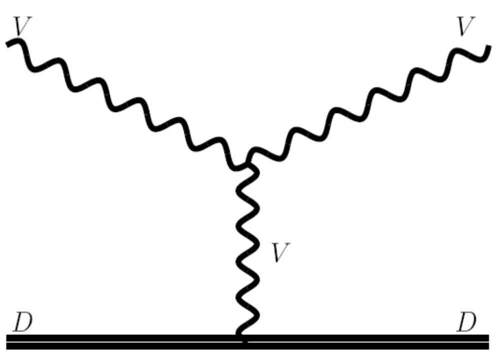




New: A. Ramos, E. O.
Eur. Phys. J A, 2010

Kolomeitsev et al
Sarkar et al





New: J. Vijande, P. Gonzalez. E.O
PRC,2009
Sarkar, Vicente Vacas, B.X.Sun, E.O
Eur. Phys. J. A, 2010

Vector octet – baryon octet interaction

$$\mathcal{L}_{III}^{(3V)} = ig\langle V^\nu \partial_\mu V_\nu V^\mu - \partial_\nu V_\mu V^\mu V^\nu \rangle$$
$$= ig\langle V^\mu \partial_\nu V_\mu V^\nu - \partial_\nu V_\mu V^\mu V^\nu \rangle$$
$$= ig\langle (V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu) V^\nu \rangle \ ,$$

$$\mathcal{L}_{VPP} = -ig\ tr\left([P, \partial_\mu P] V^\mu\right)$$

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

V^ν cannot correspond to an external vector.

Indeed, external vectors have only spatial components in the approximation of neglecting three momenta, $\varepsilon^0 = k/M$ for longitudinal vectors, $\varepsilon^0=0$ for transverse vectors. Then ∂_ν becomes three momentum which is neglected. →

V^ν corresponds to the exchanged vector. → complete analogy to VPP

Extra $\varepsilon_\mu \varepsilon^\mu = -\varepsilon_i \varepsilon_i$ but the interaction is formally identical to the case of PB→PB

In the same approximation only γ^0 is kept for the baryons → the spin dependence is only $\varepsilon_i \varepsilon_i$ and the states are degenerate in spin 1/2 and 3/2

$$V_{ij} = -C_{ij}\,\frac{1}{4f^2}\,(k^0 + k'^0)\ \vec{\epsilon}\vec{\epsilon}'$$

K^0 energy of vector mesons

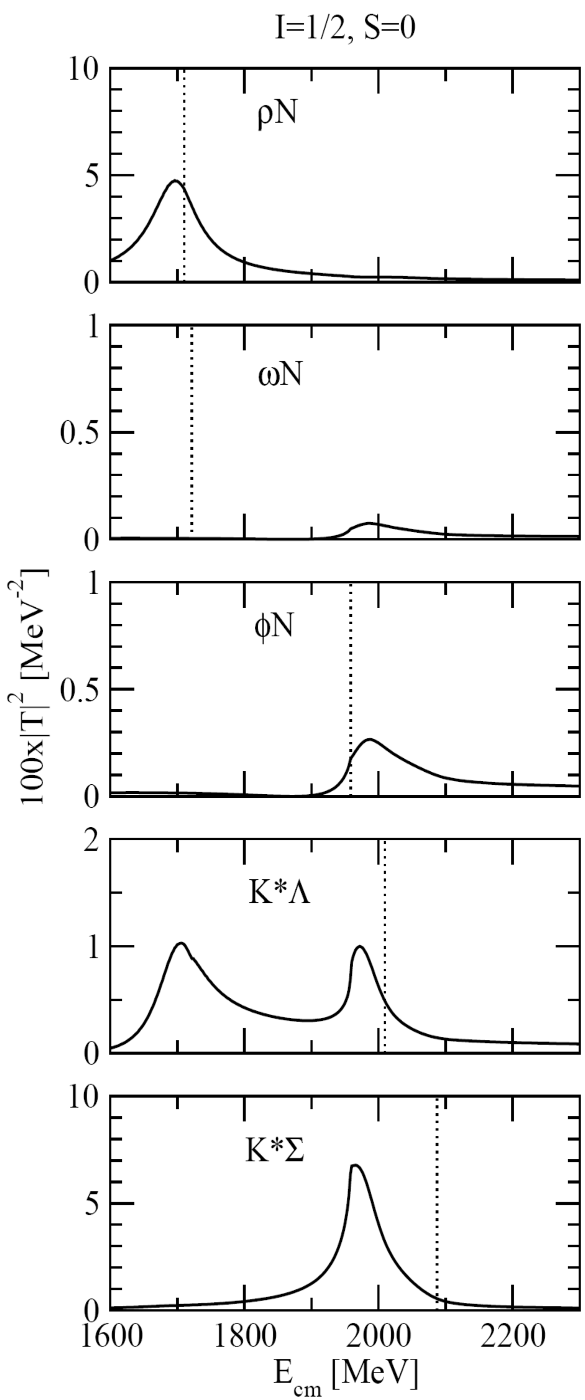
We solve the Bethe Salpeter equation in coupled channels Vector-Baryon octet.

$T = (1-GV)^{-1} V$

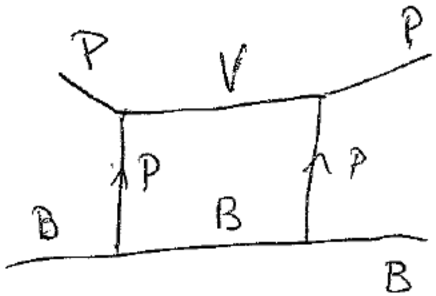
with G the loop function of vector-baryon

Apart from the peaks, poles are searched In the second Riemann sheet and pole positions and residues are determined.

The G function takes into account the mass distribution of the vectors (width).
Decay into pseudoscalar-baryon not yet considered.

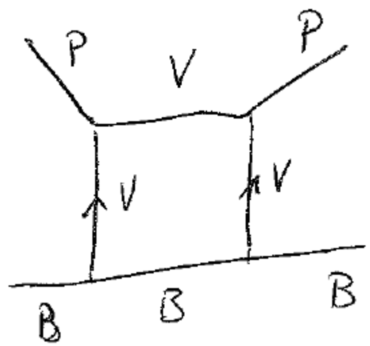


VECTOR MESONS IN $\eta' N$ INTERACTION



Normal VPP coupling

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

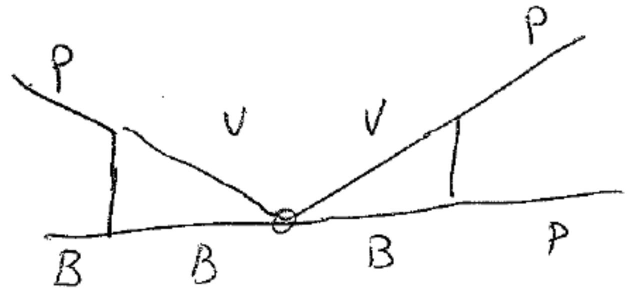


Anomalous VVP coupling

$$\mathcal{L}_{VVP} = \frac{G}{\sqrt{2}} \epsilon^{\mu\nu\alpha\beta} \langle \partial_\mu V_\nu \partial_\alpha V_\beta P \rangle$$

- Normal coupling has no contribution for singlet
- Anomalous coupling gives contribution for singlet

In addition we consider $VB \to VB$ interaction



$t_{VB \to VB}$

↓

contains resonance close to $\rho' N$ threshold

B. Borasoy , Phys. Rev D 61 (1999) 014011

There is an extra term for coupling of the singlet η_0 baryons

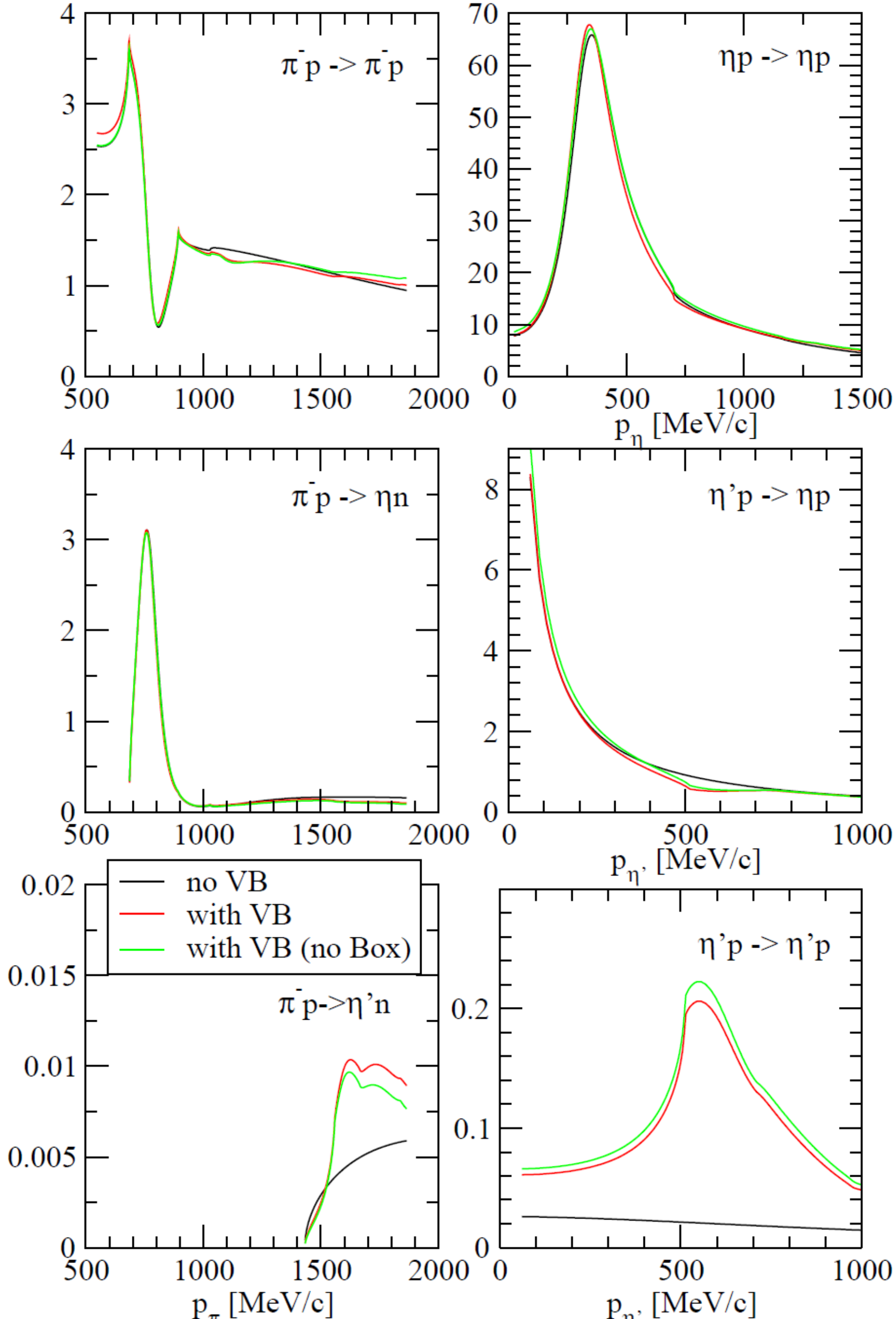
$$\mathcal{L}_{\phi B} = \lambda_1 \eta_0^2 (-2M \langle \bar{B} B \rangle)$$

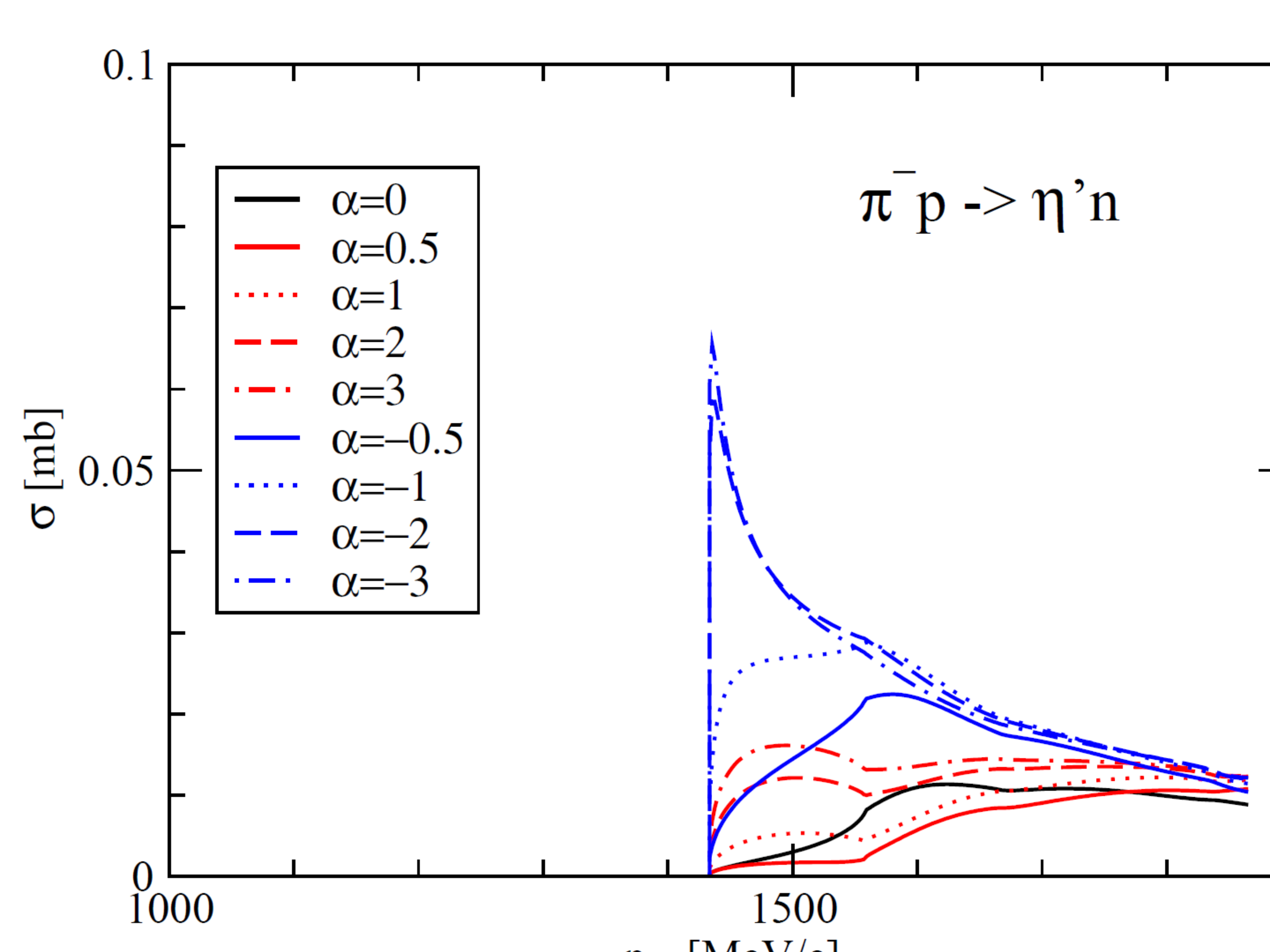
This leads to a scattering amplitude

$$t_{0,ij} = \frac{\alpha}{4f^2} 2 m_{\eta'} \tilde{C}_{ij}$$

C_{ij}	η N	η’ N
η N	$\sin^2\Theta_P$	$-\sin\Theta_P \cos\Theta_P$
η’ N	$-\sin\Theta_P \cos \Theta P$	$\cos^2\Theta_P$

Effect of introducing vector mesons-baryon



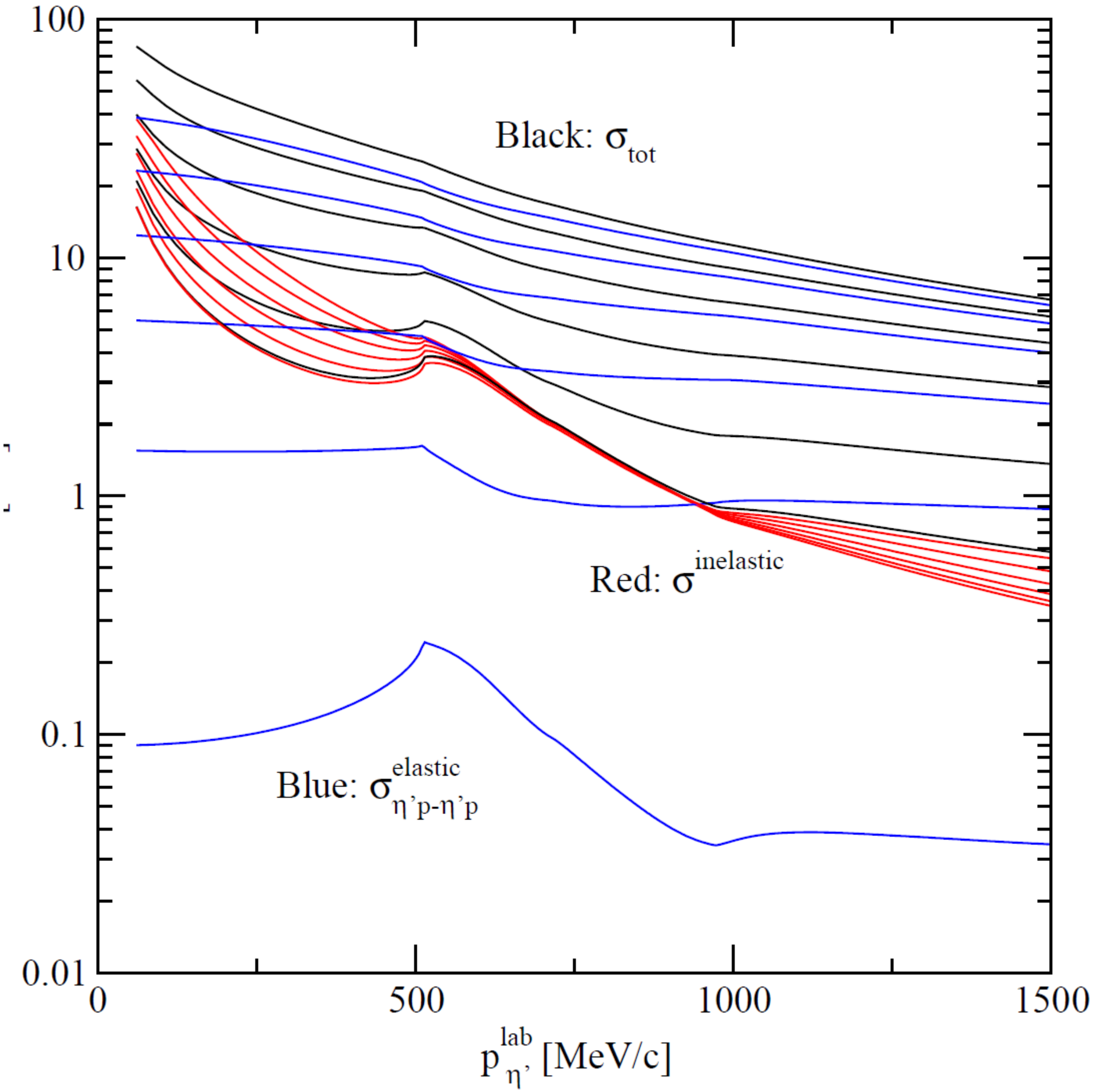


0.1
0.05
0
σ [mb]
1000
1500
α=0
α=0.5
α=1
α=2
α=3
α=−0.5
α=−1
α=−2
α=−3
π⁻p -> η'n

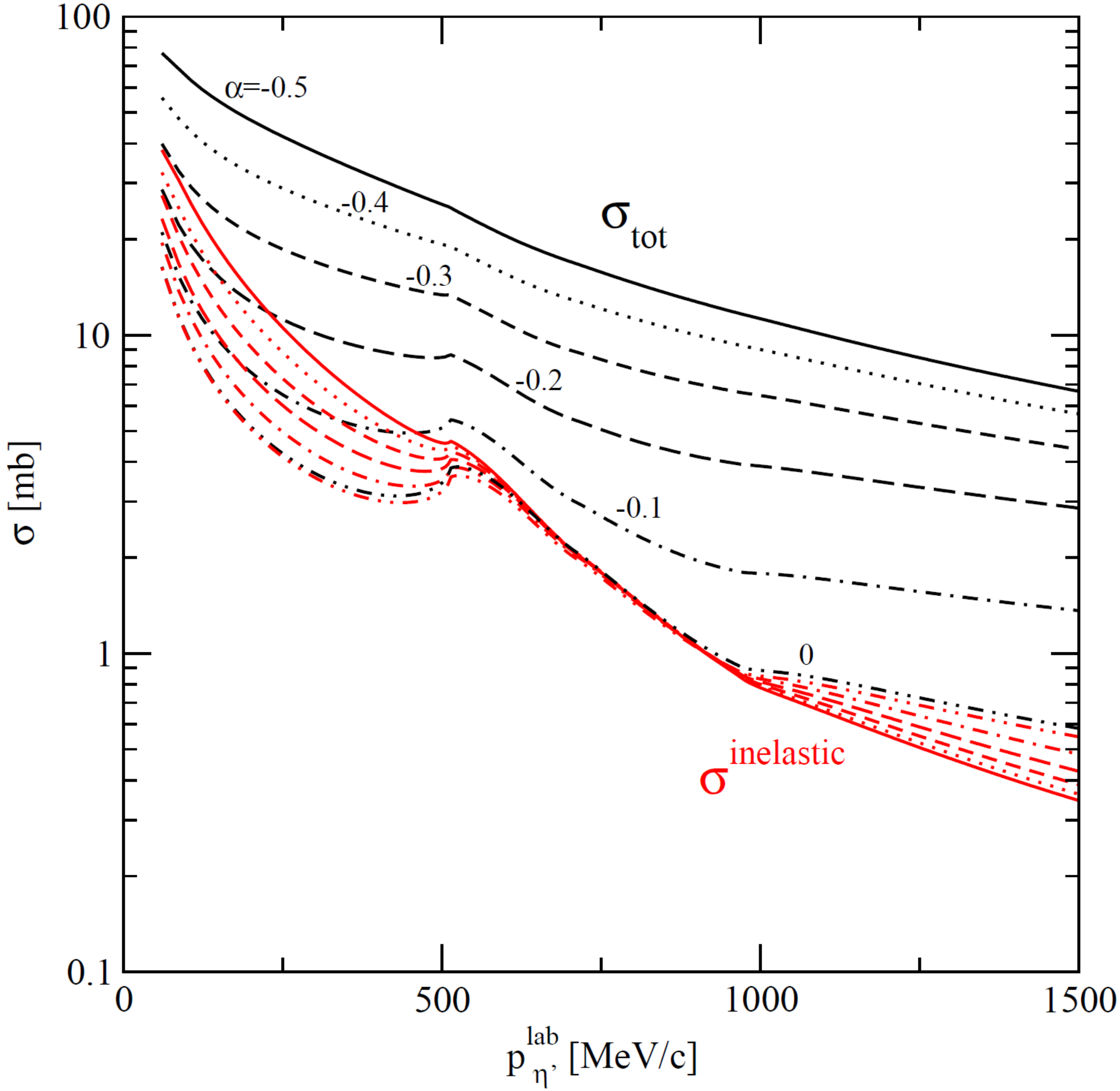
eta' p

model	Re(a)	Im(a)	$\lvert a \rvert$
only PB	-0.0029	0.0141	0.0144
PB-VB	0.0180	0.0197	0.0266
PB-VB(anom=0)	-0.0025	0.0144	0.0146
adding singlet term:			
alpha=-3	5.8721	7.6120	9.6137
alpha=-2	3.5086	1.3138	3.7465
alpha=-1	1.2062	0.1829	1.2200
alpha=-0.5	0.5204	0.0599	0.5238
alpha=-0.4	0.4076	0.0473	0.4103
alpha=-0.3	0.3015	0.0373	0.3038
alpha=-0.2	0.2015	0.0296	0.2037
alpha=-0.1	0.1071	0.0238	0.1098
alpha=0.0	0.0180	0.0197	0.0266
alpha=0.5	-0.3624	0.0161	0.3628

Empirical data demand alpha around -0.1



100
10
1
0.1
0.01
0
500
1000
1500
Black: σ_{tot}
Red: $\sigma^{inelastic}$
Blue: $\sigma^{elastic}_{\eta' p-\eta' p}$
$p^{lab}_{\eta'}$ [MeV/c]



100
10
1
0.1
0
500
1000
1500
σ [mb]
p_η'^lab [MeV/c]
α=-0.5
-0.4
-0.3
-0.2
-0.1
0
σ_tot
σ^inelastic

Summary:

The η’ N interaction sets new theoretical challenges

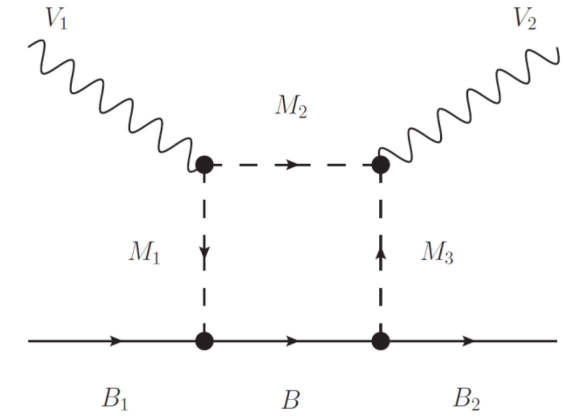
The mixing with vector baryon states that generate a resonance N*
with spin $1/2^-$ or $3/2^-$ around 1900 MeV has been proved.

Pure contribution of the singlet, beyond the Weinberg-Tomozawa term
has also been shown to be very important.

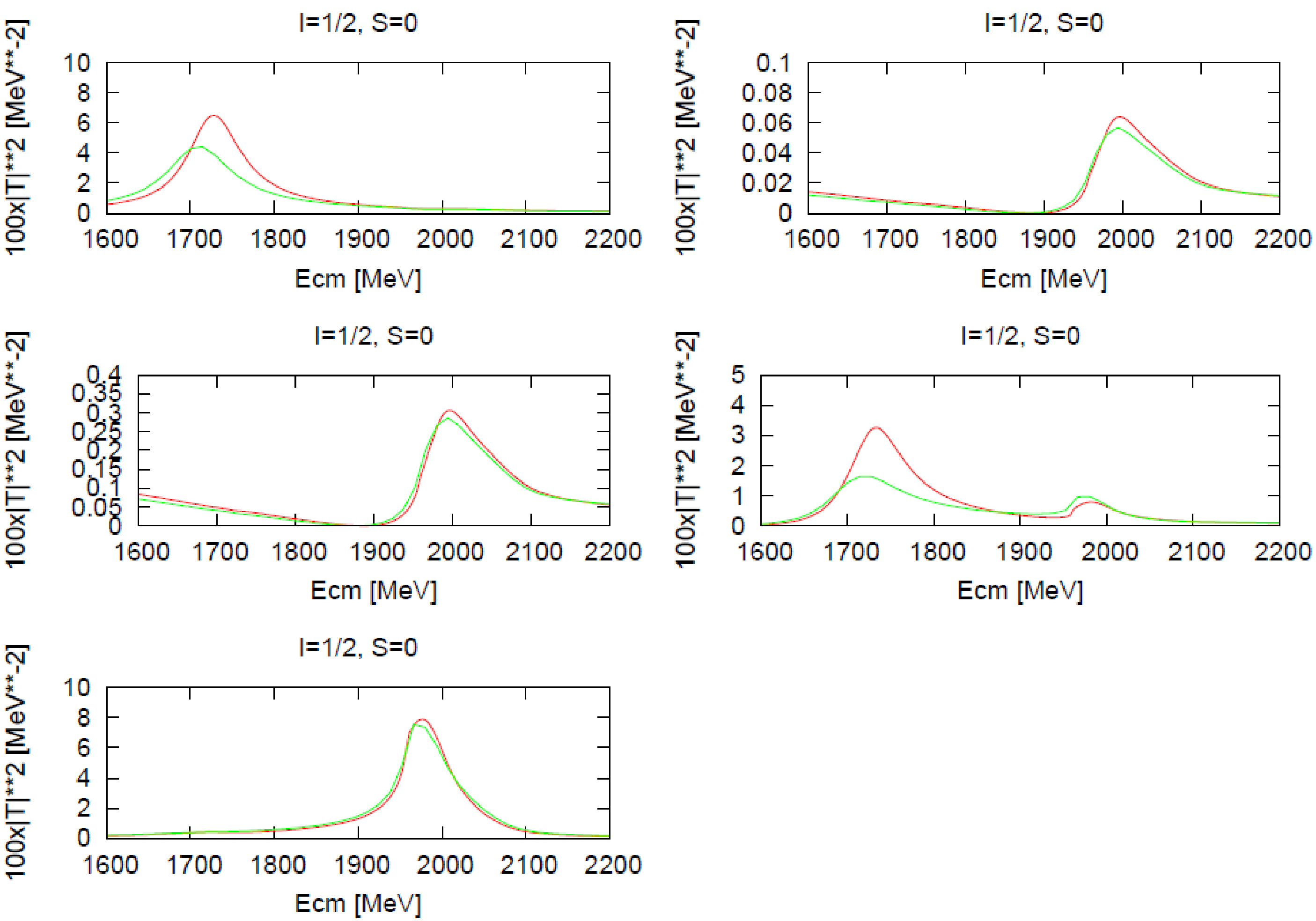
Puzzle remaining, the empirical data of the scattering length and the
“in principle” data on inelastic cross section from the
transparency ratio cannot be made compatible.

Signal of a strong η’ NN -> NN absorption mechanism?
Missing mechanisms that increase the inelastic cross
section without modifying the elastic one? Maybe but
optical theorem relates them.....

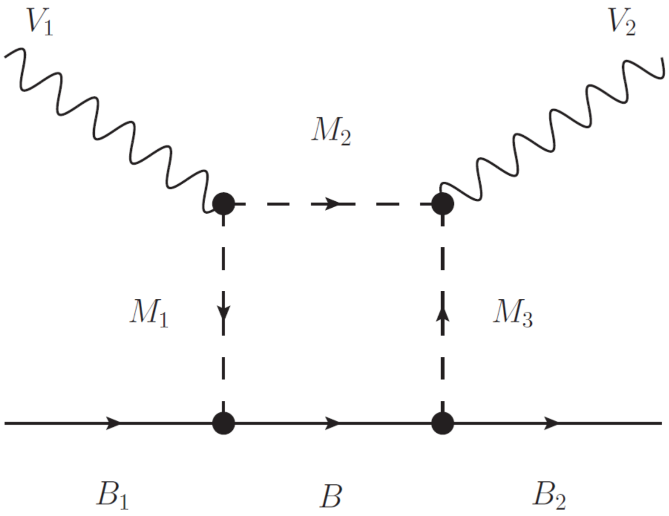
Improvements needed to account for the width:



J. Garzon



This work allows one to introduce PB and VB in the same set of coupled channels: Technically not trivial since the exchanged pseudoscalar could be placed on shell and has pathologies to be used as a potential.



Box diagran no problem:
We separate L=0 and L=2 contributions

Put L=0 part, $V_{PB,}$ in the coupled channels defining

Im V_{box}(L=0)= V_{PB} Im G_{PB} V_{PB}

Box with L=2 and intermediate decuplet added to VB→VB

Since the N*(1650) appears generated from VN (mostly ρN), and N*(1535) from PB (mostly K Λ, KΣ) hopes appear to extend theoretically the theory to higher energies for πN scattering.
Could parameters of the N*(1535) become of natural size?
This could solve a problem about the nature of the N*(1535) stated by Hyodo Jido, Hosaka.