Dynamical coupled-channel analysis of $\pi N \rightarrow \pi \pi N$ reaction

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In collaboration with

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Outline of the talk

- ✓ Brief introduction of activities in EBAC @ JLab
- ✓ Motivation for the analysis of $\pi N \rightarrow \pi \pi N$ reaction
- ✓ Dynamical coupled-channel model
- ✓ Results (very preliminary!)
- ✓ Summary

Introduction : activities in EBAC (1)

Excited Baryon Analysis Center (EBAC) @ Jefferson Lab

http://ebac-theory.jlab.org/

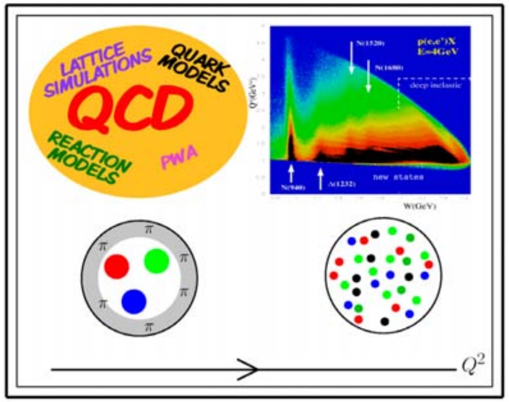
Explore nature of nucleon resonances from analyzing world data of meson production reactions on the nucleon :

$$\pi N,\ \gamma N,\ \gamma^* N \rightarrow \pi N,\ \pi\pi N,\ \eta N,\ \omega N,\ \phi N,\ KY,\ \ldots$$

- ✓ Transition form factors of N*states
- ✓ Pole position of N* states on the complex energy plane
- ✓ Search for new N* states

…

Related to the quark-gluon substructure of N* states



Introduction : activities in EBAC (2)

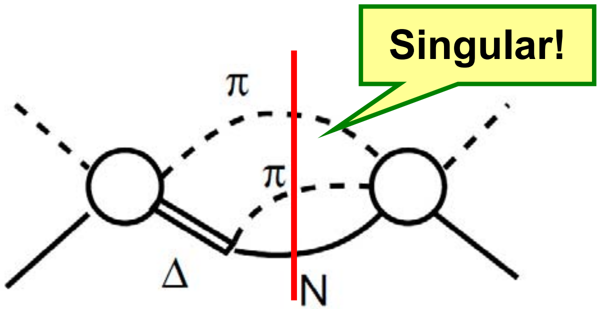
(quark-gluon) structure of N* ⟷ Meson production data

Reaction mechanism

Dynamical coupled-channel model of meson production reactions (MSL model)

A. Matsuyama, T. Sato, T.-S.H. Lee Phys. Rep. 439 (2007) 193

- ✓ Maintain coupled-channel unitarity of πN, ηN, $\pi\Delta$, σN, ρN
- ✓ Can manage 3-body $\pi\pi N$ cut

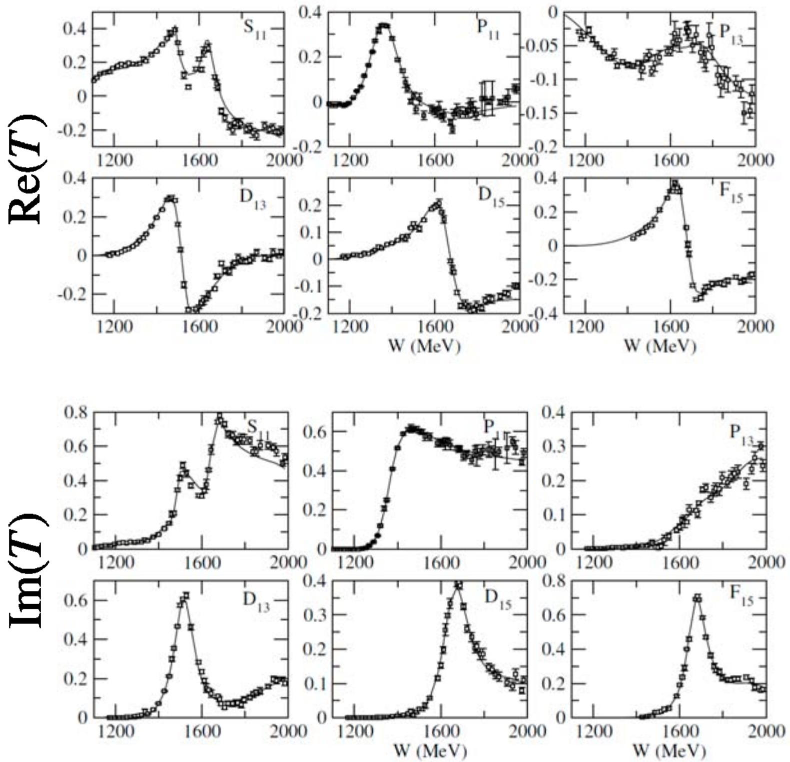


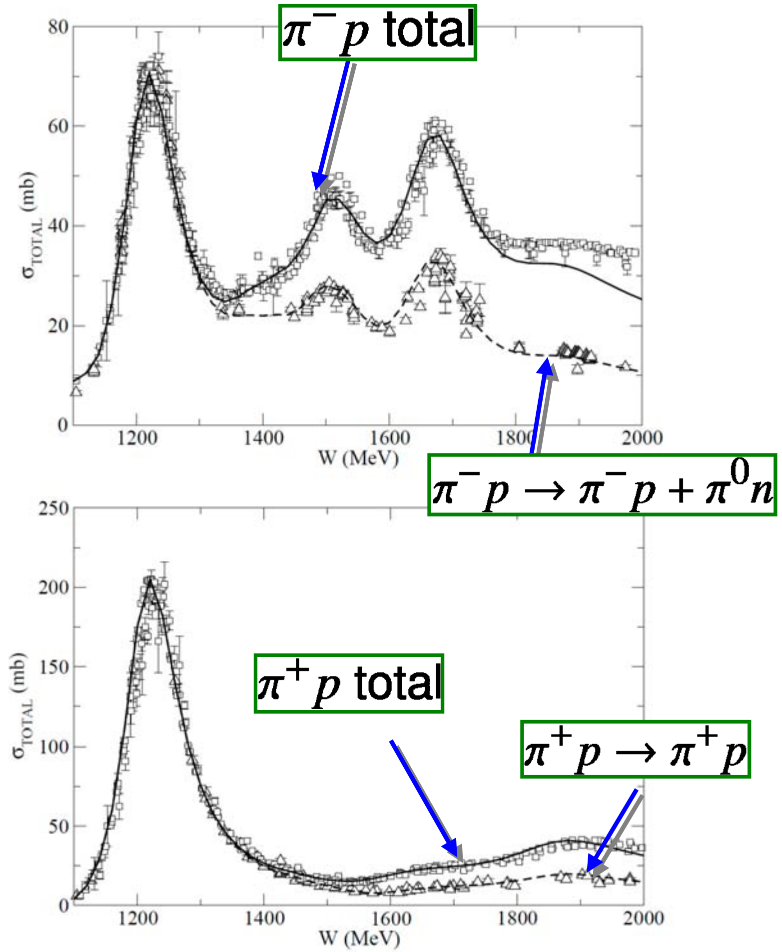
Introduction : activities in EBAC (3)

First stage of model construction has been **completed**.

Julia-Diaz, Lee, Matsuyama, Sato, PRC76 065201 (2007)

Fix all parameters by fitting to the empirical πN partial wave amp. from SAID analysis





Describe well up to W ~ 2 GeV!

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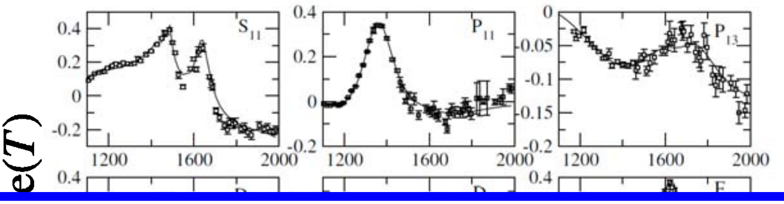
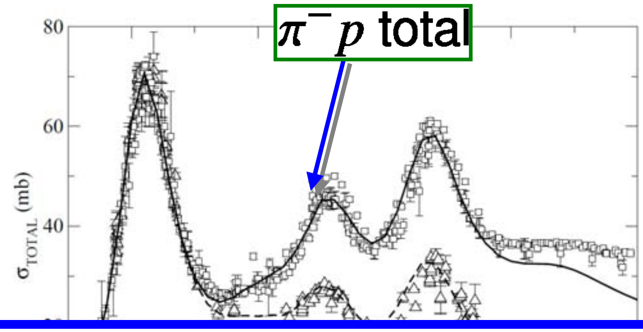
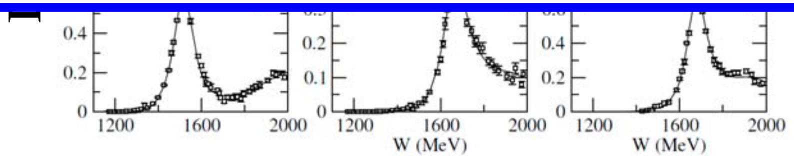
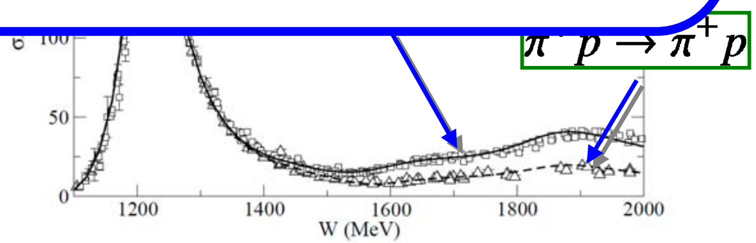




Application to other two-body reactions has been performed:

$\gamma N \rightarrow \pi N$	: Julia-Diaz, Lee, Matsuyama, Sato, Smith, published in PRC (2008)
$\pi N, \gamma N \rightarrow \omega N$	: Paris, submitted to PRC
$\pi N \rightarrow \eta N$	: Durand, Julia-Diaz, Lee, Saghai, Sato, submitted to PRC
$\pi N, \gamma N \rightarrow K Y$	: Julia-Diaz, Kamano, Lee, Sato, Tsushima, in progress





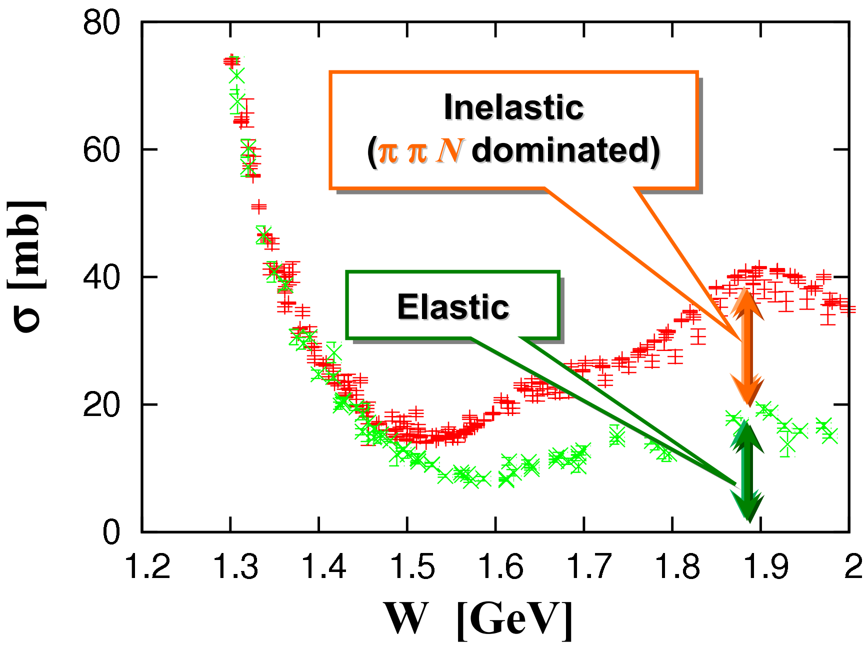
Describe well up to W ~ 2 GeV!

Motivation : why pi pi N reaction?

Above W = 1.5 GeV, cross sections of π N elastic and π π N reactions can be comparable with each other :

$$\sigma(\pi N \to \pi N) \sim \sigma(\pi N \to \pi\pi N)$$

c.f.) $\pi^+ p$ total & elastic cross sections



Expect that

- ✓ large coupled-channel effect can occur between the π N and π π N channels.
- ✓ additional constraints (which may be even severe) on N* parameters could be obtained.

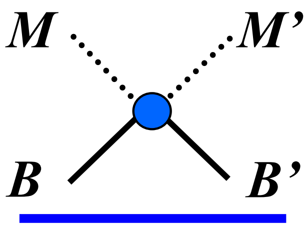
Particularly for

$$N^* \to \pi N,\ \pi\Delta,\ \sigma N,\ \rho N$$

Dynamical coupled-channel model for meson production reactions (1)

Matsuyama, Sato, Lee Phys. Rep. 439 (2007) 193

$T_{MB\rightarrow M'B'}$ =



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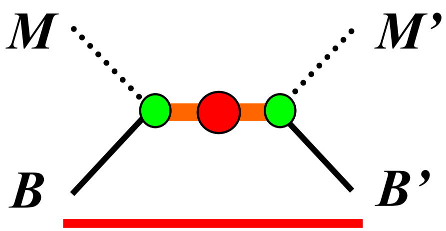
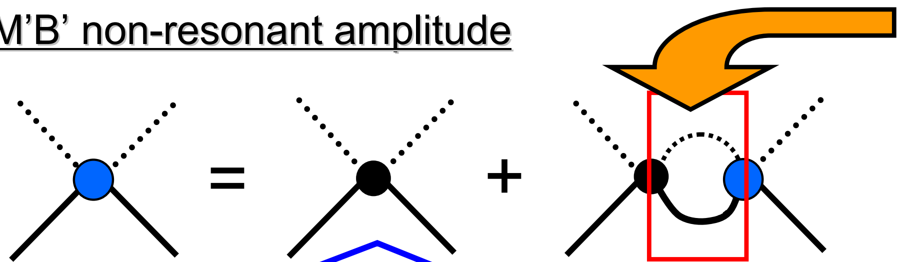


Non-resonant amp. **Rsonant amp.**

MB → M'B' non-resonant amplitude

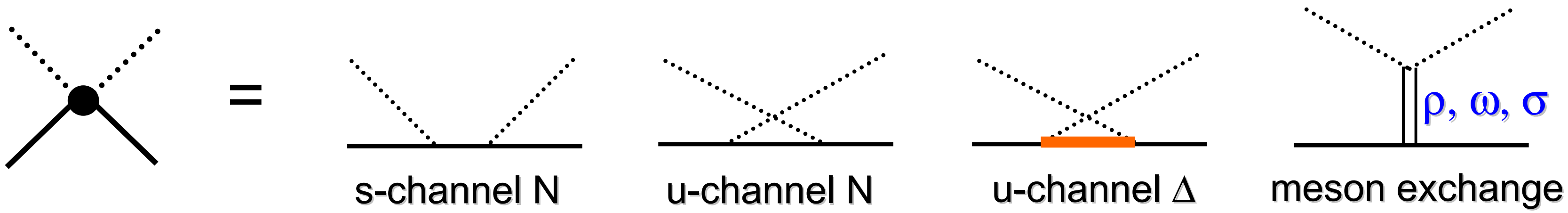


Maintain unitarity of

$\pi N,\ \eta N,\ \pi\Delta,\ \sigma N,\ \rho N$

coupled-channels

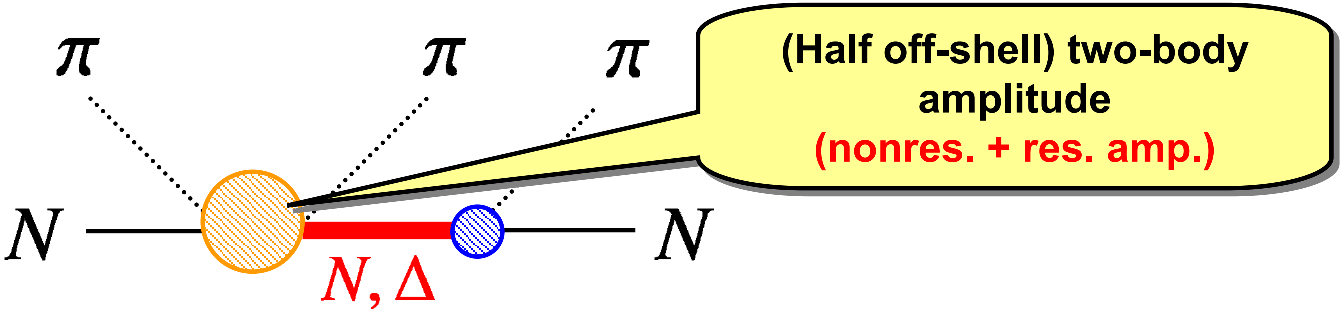
Two-body effective potential (V22)



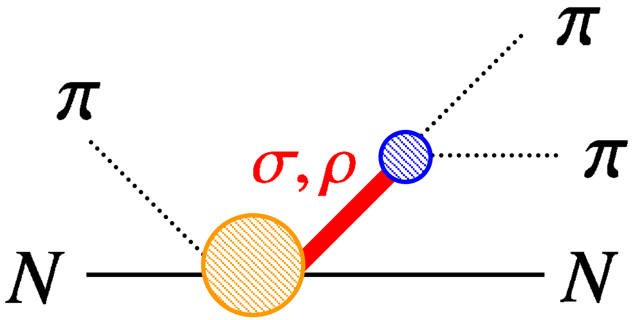
Dynamical coupled-channel model for meson production reactions (2)

$$T_{\pi N \to \pi\pi N}(E) = T^{\pi N}(E) + T^{\pi\Delta}(E) + T^{\sigma N}(E) + T^{\rho N}(E) + T^{\text{direct}}(E)$$

$$T^{\pi N},\ T^{\pi\Delta} =$$



$$T^{\sigma N},\ T^{\rho N} =$$

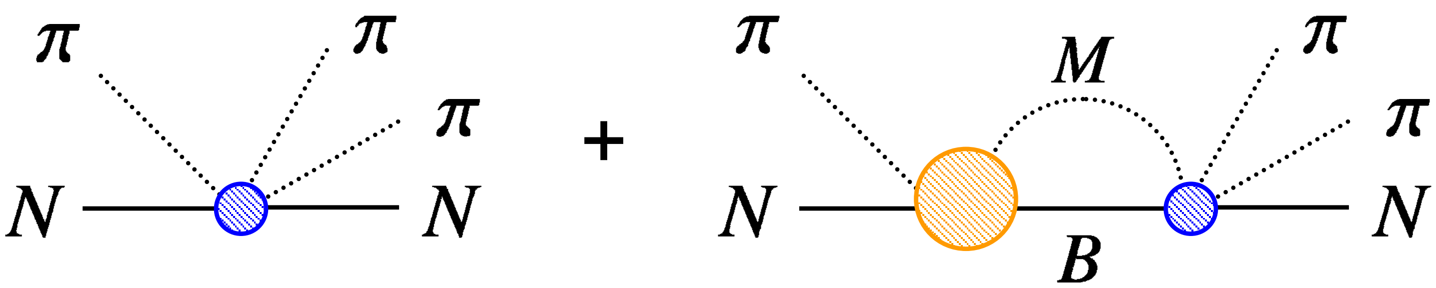


Attach appropriate Green functions (▬) and vertex functions (●) to **πN** (on-shell) → ***MB*** (off-shell) amplitude

Dynamical coupled-channel model for meson production reactions (3)

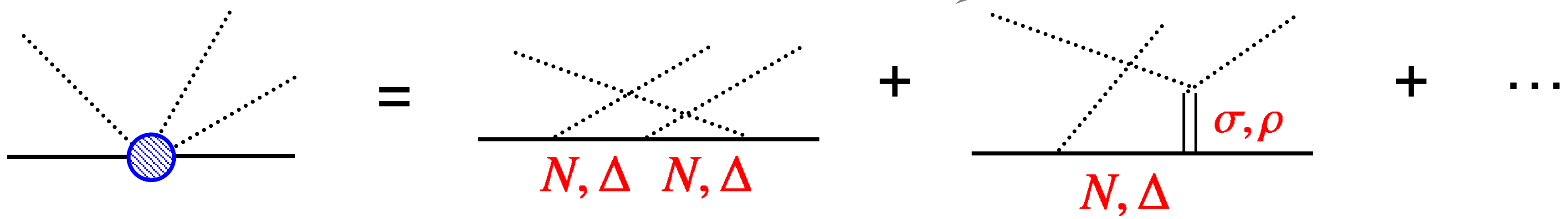
$$T_{\pi N \to \pi\pi N}(E) = T^{\pi N}(E) + T^{\pi\Delta}(E) + T^{\sigma N}(E) + T^{\rho N}(E) + T^{\text{direct}}(E)$$

$$T^{\text{direct}}(E) =$$



Not included in T^{MB}

2 → 3 effective potential (V23)



Treatment of resonance states

All 4-star and most 3-star resonances below 2 GeV are included **assuming** them as **CDD poles** (genuine 3-quark states).

$I = 1/2$

	# of CDD poles	Resonances listed in PDG
S11	2	N(1535) N(1650)
P11	2	N(1440) N(1710)
P13	1	N(1720)
D13	1	N(1520)
D15	1	N(1675)
F15	1	N(1680)
F17	0	

$I = 3/2$

	# of CDD poles	Resonances listed in PDG
S31	1	Δ(1620)
P31	1	Δ(1910)
P33	2	Δ(1232) Δ(1600)
D33	1	Δ(1700)
D35	0	
F35	1	Δ(1905)
F37	1	Δ(1950)

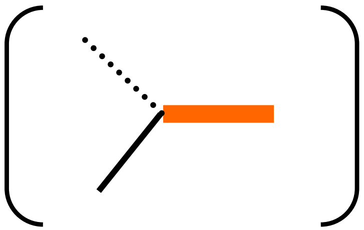
(N, Δ = ** -resonance , N, Δ = *** -resonance)**

Procedures

- ✓ Simultaneous fit of the πN elastic, $\pi N \rightarrow \pi\pi N$, πN total cross sections.
- ✓ Varying only parameters of the bare vertex functions associated with $N^* \rightarrow \pi N,\ \pi\Delta,\ \sigma N,\ \rho N$ decays

Bare vertex for N* → MB with orbital angular momentum L and total spin S

$$\Gamma_{N^*,(MB)_{LS}}(k) = \frac{1}{(2\pi)^{3/2}}\frac{1}{\sqrt{m_N}} C_{N^*,(MB)_{LS}} \left[\frac{\Lambda_{N^*,(MB)_{LS}}{}^2}{\Lambda_{N^*,(MB)_{LS}}{}^2+k^2}\right]^{2+L}\left(\frac{k}{m_\pi}\right)^L$$

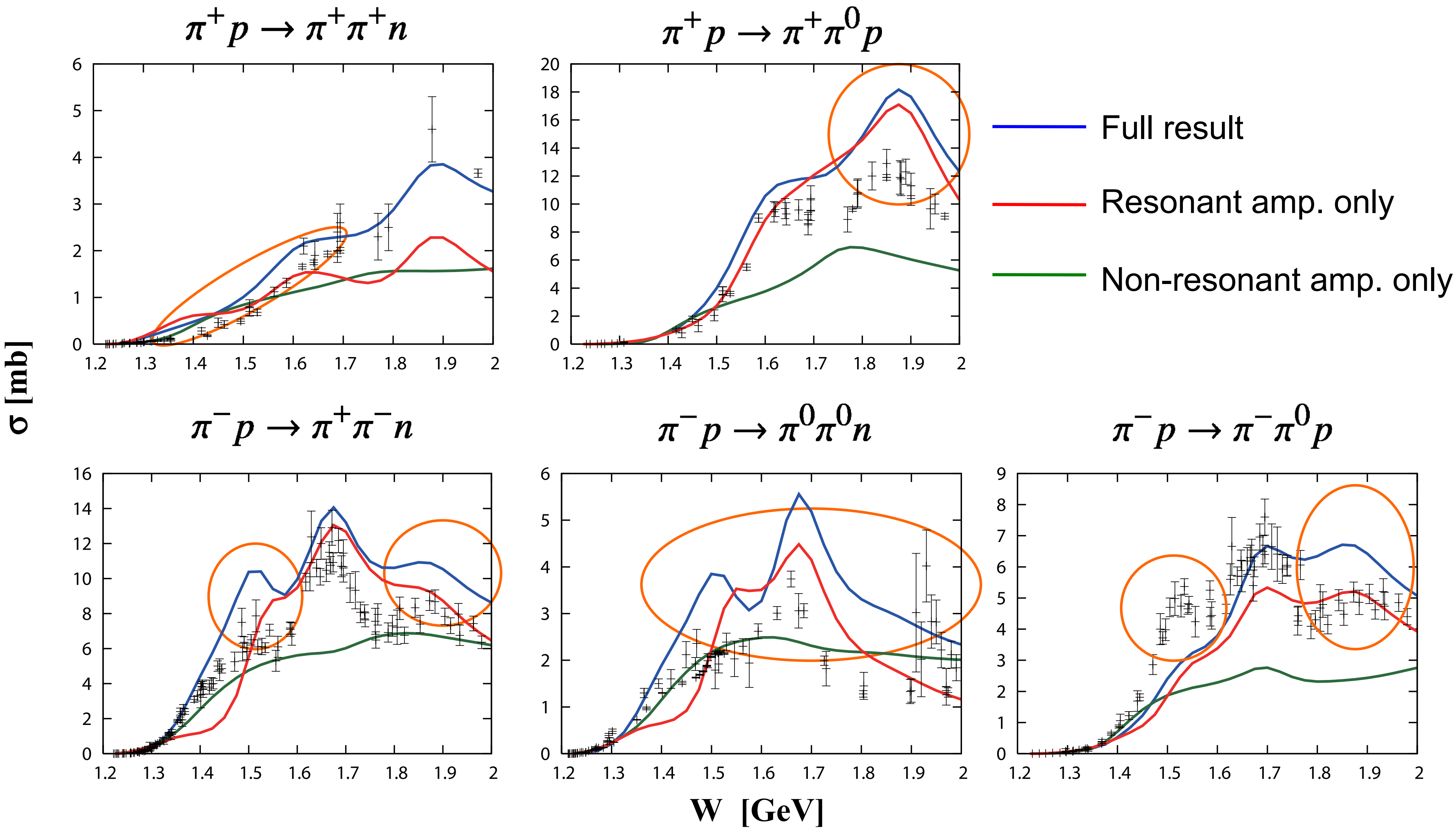


Coupling constant

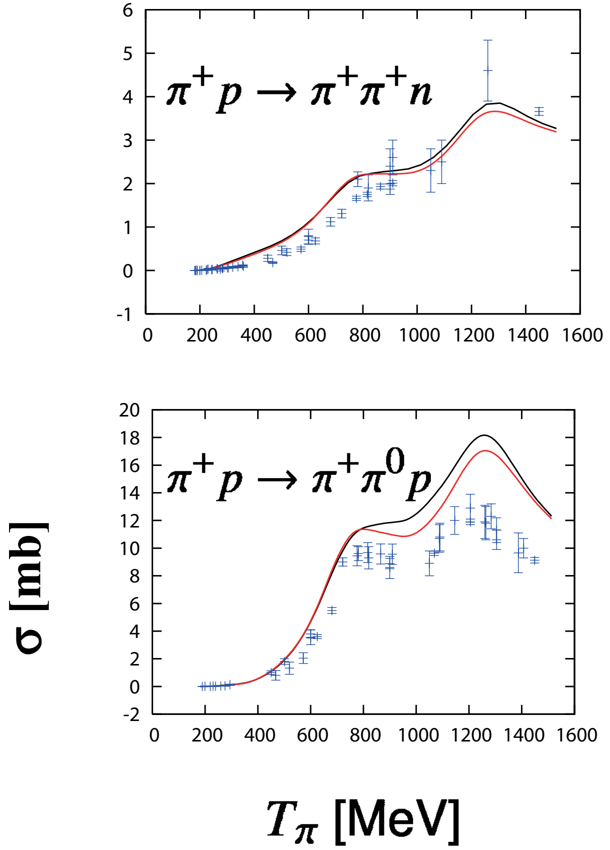
Cutoff

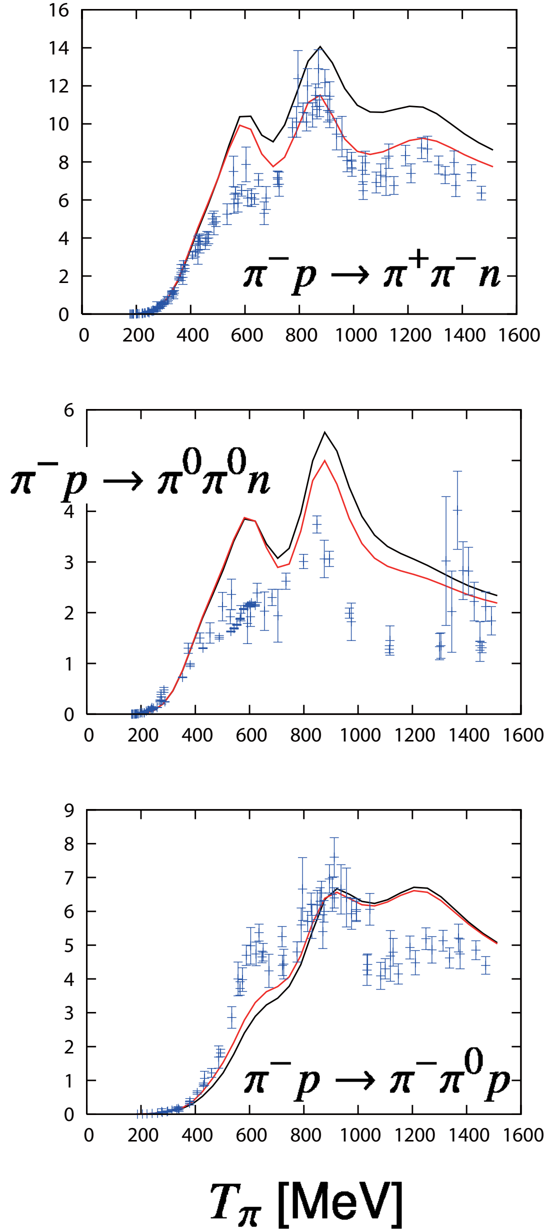
parameters

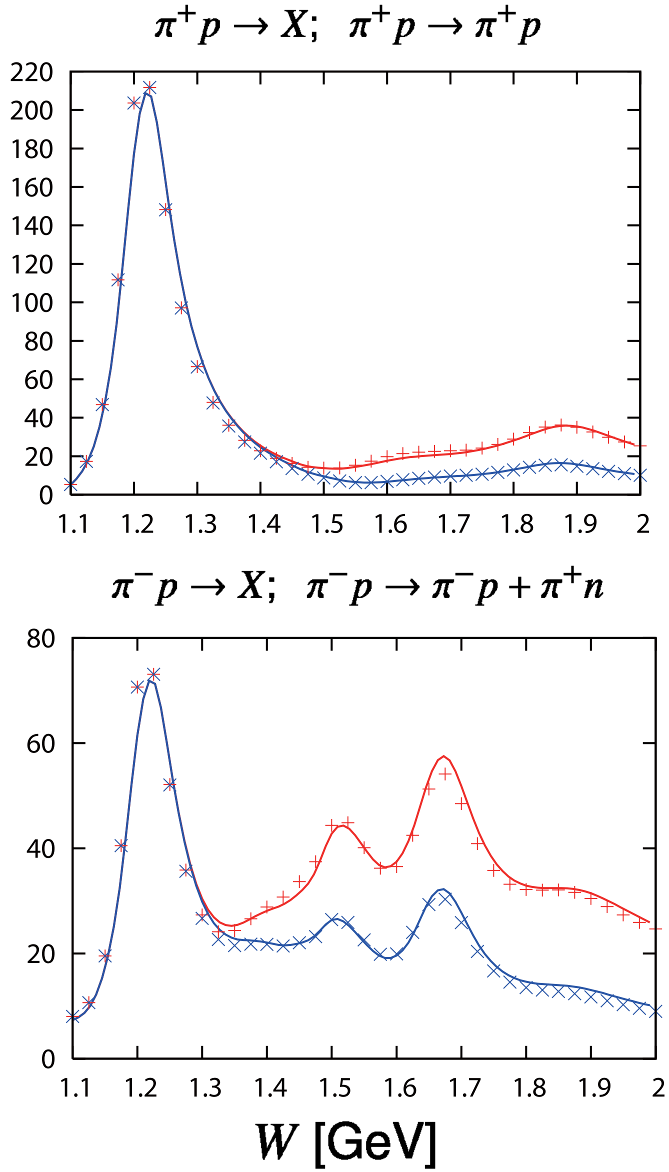
Predicted π N→ π π N total cross sections



First trial of fit



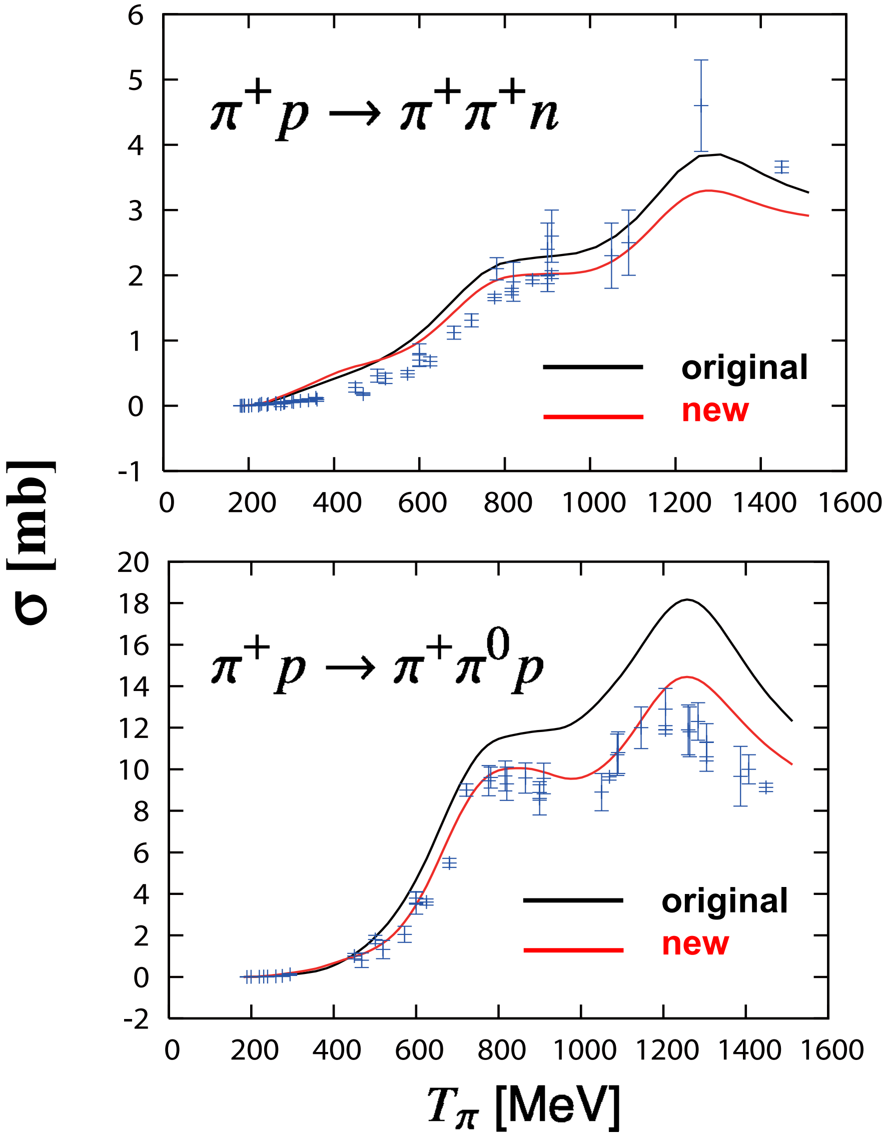


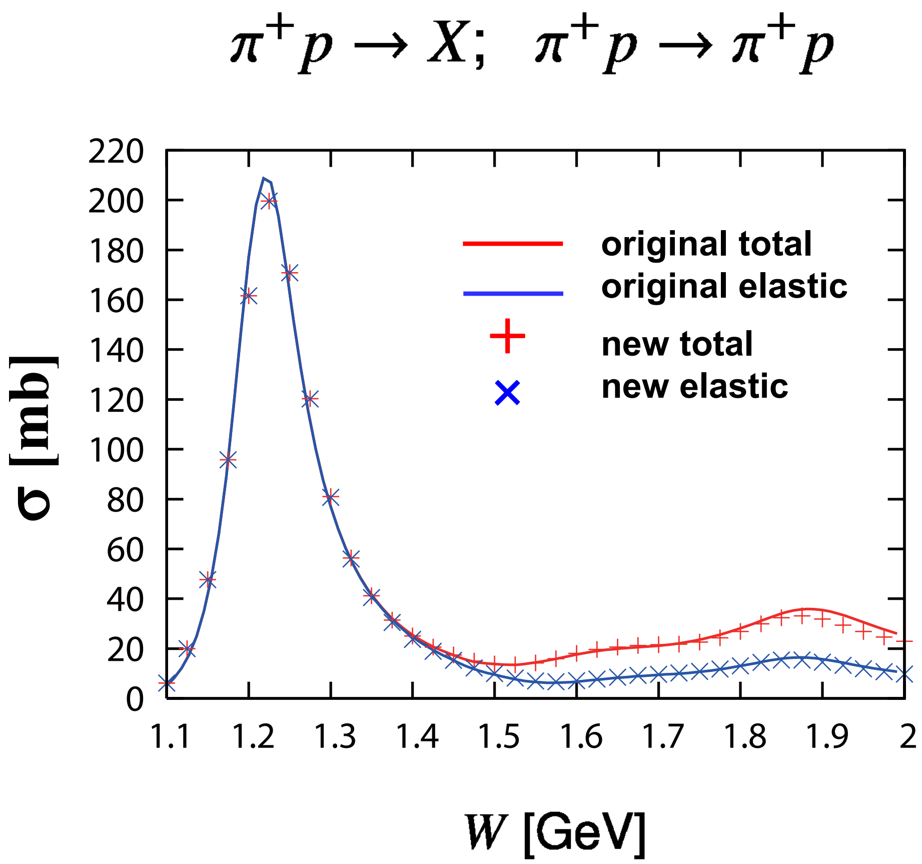


Allow 20-50% variation of the parameters

Current results (preliminary)

Reactions with the initial $\pi^+ p$ state





Change in parameters (preliminary)

Resonance parameters in P33 wave

Parameter	Before		After
$C_{P_{33}\text{1st},(\pi N)_{L=1,S=1/2}}$	1.31	→	1.28
$C_{P_{33}\text{1st},(\pi\Delta)_{L=0,S=3/2}}$	1.08	→	1.25
$C_{P_{33}\text{1st},(\pi\Delta)_{L=1,S=3/2}}$	1.52	→ (blue)	2.316
$C_{P_{33}\text{1st},(\rho N)_{L=1,S=1/2}}$	2.01	→	2.14
$C_{P_{33}\text{1st},(\rho N)_{L=1,S=3/2}}$	−1.25	→	−1.14
$C_{P_{33}\text{1st},(\rho N)_{L=3,S=3/2}}$	0.38	→ (blue)	0.49
$\Lambda_{P_{33}\text{1st},(\pi N)_{L=1,S=1/2}}$	746.20	→	817.80
$\Lambda_{P_{33}\text{1st},(\pi\Delta)_{L=0,S=3/2}}$	846.38	→	758.57
$\Lambda_{P_{33}\text{1st},(\pi\Delta)_{L=1,S=3/2}}$	780.96	→	684.58
$\Lambda_{P_{33}\text{1st},(\rho N)_{L=1,S=1/2}}$	584.98	→	559.30
$\Lambda_{P_{33}\text{1st},(\rho N)_{L=1,S=3/2}}$	500.24	→	558.49
$\Lambda_{P_{33}\text{1st},(\rho N)_{L=3,S=3/2}}$	1369.13	→ (blue)	1074.10

Parameter	Before		After
$C_{P_{33}\text{2nd},(\pi N)_{L=1,S=1/2}}$	1.32	→	1.44
$C_{P_{33}\text{2nd},(\pi\Delta)_{L=0,S=3/2}}$	2.04	→ (red)	4.76
$C_{P_{33}\text{2nd},(\pi\Delta)_{L=1,S=3/2}}$	9.54	→	10.16
$C_{P_{33}\text{2nd},(\rho N)_{L=1,S=1/2}}$	−0.32	→ (red)	−0.13
$C_{P_{33}\text{2nd},(\rho N)_{L=1,S=3/2}}$	1.0358	→	1.0551
$C_{P_{33}\text{2nd},(\rho N)_{L=3,S=3/2}}$	0.77	→ (red)	1.96
$\Lambda_{P_{33}\text{2nd},(\pi N)_{L=1,S=1/2}}$	880.72	→	885.82
$\Lambda_{P_{33}\text{2nd},(\pi\Delta)_{L=0,S=3/2}}$	507.29	→	519.04
$\Lambda_{P_{33}\text{2nd},(\pi\Delta)_{L=1,S=3/2}}$	501.74	→	524.9
$\Lambda_{P_{33}\text{2nd},(\rho N)_{L=1,S=1/2}}$	606.79	→	613.48
$\Lambda_{P_{33}\text{2nd},(\rho N)_{L=1,S=3/2}}$	1043.40	→	1046.90
$\Lambda_{P_{33}\text{2nd},(\rho N)_{L=3,S=3/2}}$	528.27	→	538.18

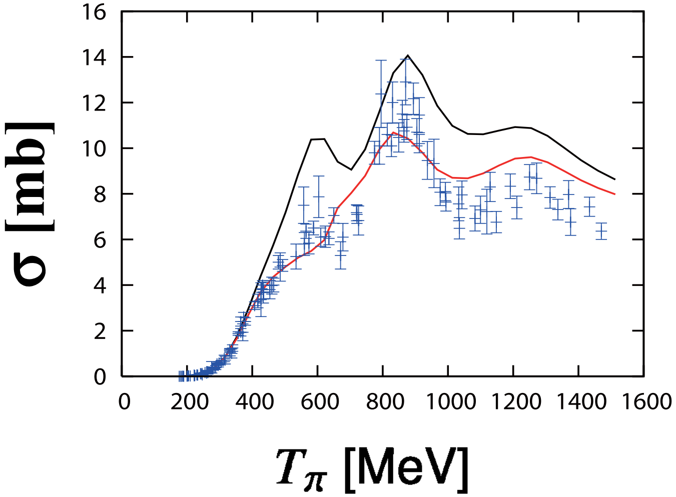
→ (blue) **: 20-100 % change**

→ (red) **: > 100 % change**

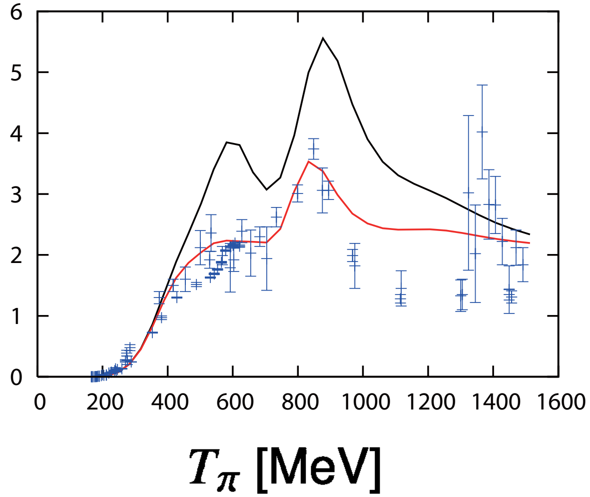
Current results (very preliminary)

Reactions with the initial $\pi^- p$ state

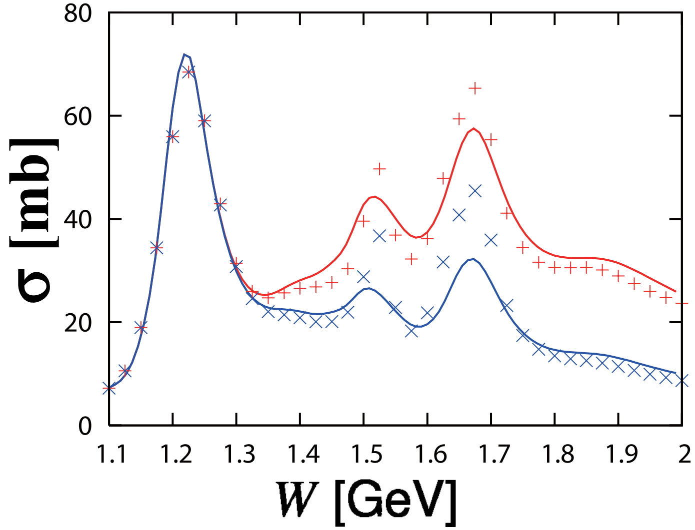
$\pi^- p \to \pi^+ \pi^- n$



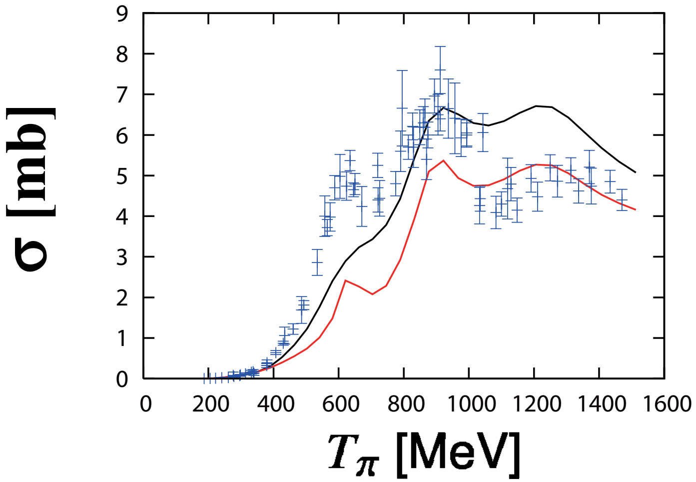
$\pi^- p \to \pi^0 \pi^0 n$



$\pi^- p \to X; \quad \pi^- p \to \pi^- p + \pi^+ n$



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



Please consider these results just as references !

Summary

- ✓ Have performed simultaneous fit of the model to the π N and $\pi\pi$ N channels.
- ✓ Allowing 20-50% variation of parameters results in a little improvement of $\pi N \to \pi\pi N$ total cross sections.
- ✓ Inclusion of $\pi\pi$ N channel to fitting could cause significant rearrangements of the N* parameters
- ✓ Simultaneous consideration of π N and $\pi\pi$ N channel seems inevitable to construct any reliable hadron reaction model below 2 GeV