Dynamical model of meson production reaction in the nucleon resonance region

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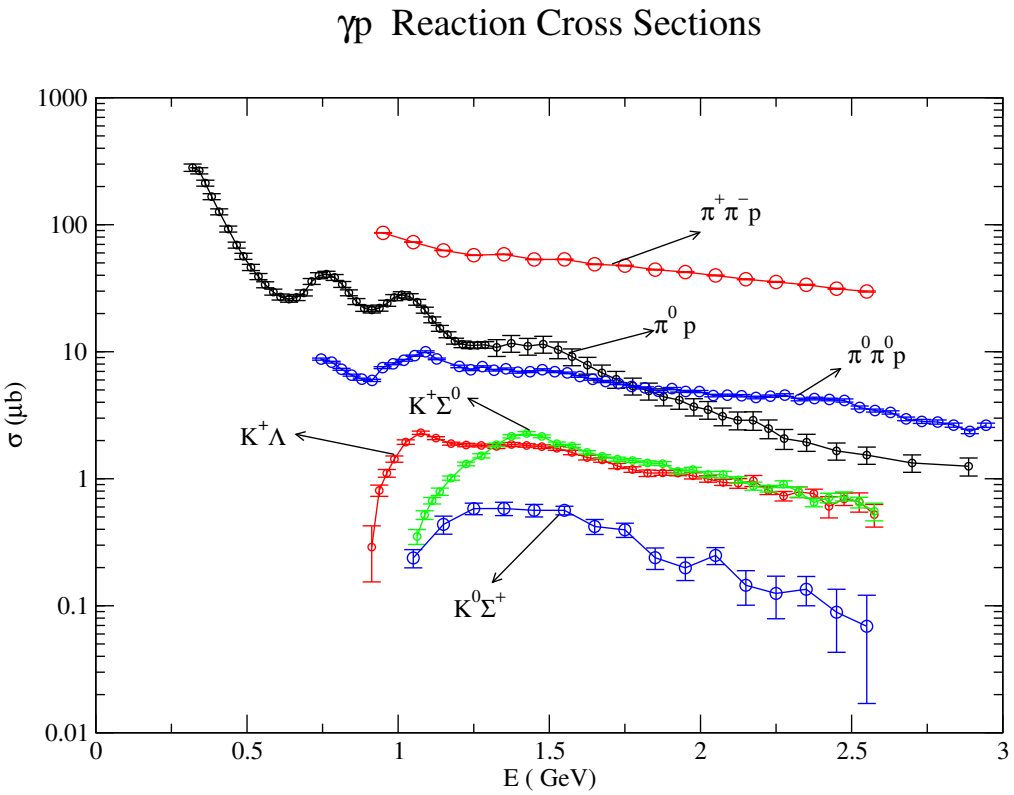
- Objective of N^* Study
- Dynamical model of Meson production reaction
- $\pi\pi N$ cut and $\gamma + N \to \pi + \pi + N$ reaction
- Summary



- Beyond $\Delta_{33}(1232)$ $\sigma_{\pi\pi} > \sigma_{\pi} > \sigma_{KY}$

electromagnetic meson production reaction

Objective:

- Extract N^*, Δ properties from meson production cross section
- Interpret $N*, \Delta$ parameters in terms of hadron models, Lattice QCD

Understand nonperturbative dynamics (confinement, chiral dynamics) of QCD in hadron structure and reactions

Develop reaction theory to extract resonance parameters from meson production cross section

Theoretical approaches

- VPI-GWU, CMB, KSU

  non-resonant amplitudes: separable form, polynomial

- MAID, Jlab-Yeveran, Giessen, KVI, Jlab-Moscow-State

  Meson-exchange mechanism , K-matrix

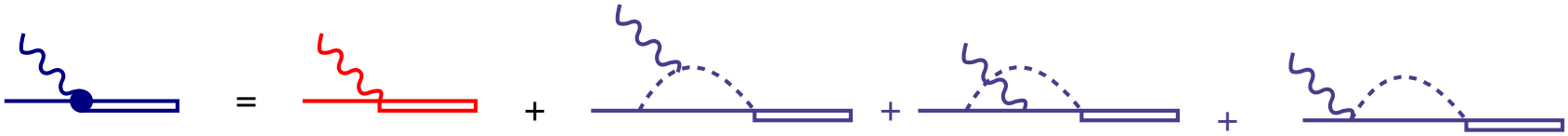
- NTU-ANL,Gross-Surya,SL,Julich, Fuda, Utrecht-Ohio

  dynamical model: coupled channel and off-shell dynamics

$$\rightarrow \quad \gamma N\Delta \ \text{form factor}$$
$$\gamma + p \rightarrow K^+ + \Lambda$$

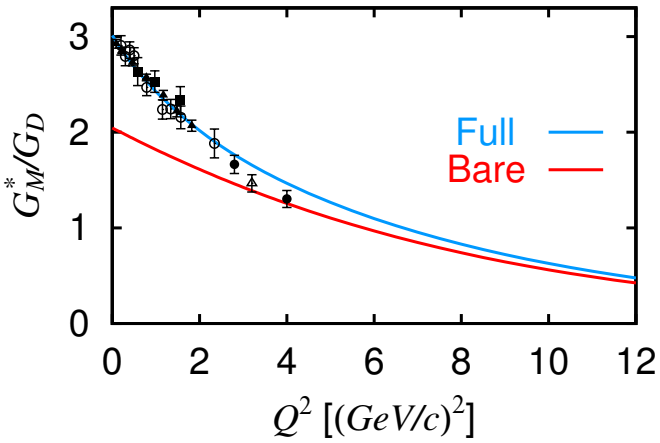
$\gamma N \to \Delta_{33}$ transition form factor

- Amplitude analysis
  $G_M^{exp}(0) \sim G_M^{CQM} \times 1.4$
- Dynamical model
  extract: $G_M^{exp} \sim G_M(full)$
  interpret: role of pion cloud $G_M(full) = G_M^{CQM} +$ pion cloud
  Deformation $G_C(Q^2)$

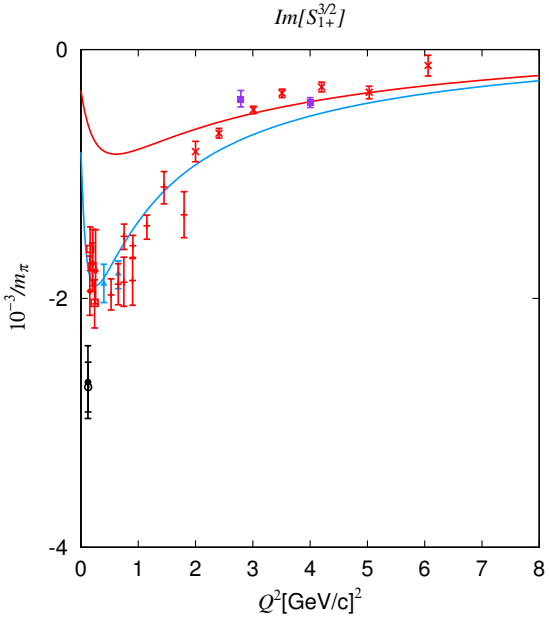


Compare 'exp. data' (amplitude analysis) with prediction of dynamical model

Magnetic Dipole



Coulomb Quadrupole C2

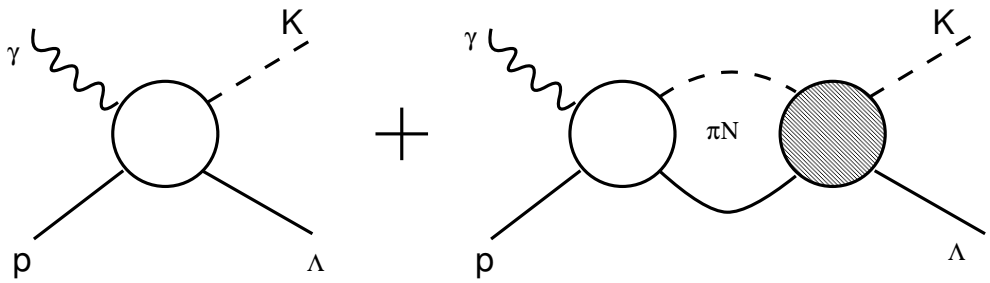


SL-Model(2001) (Full = bare + pion cloud)

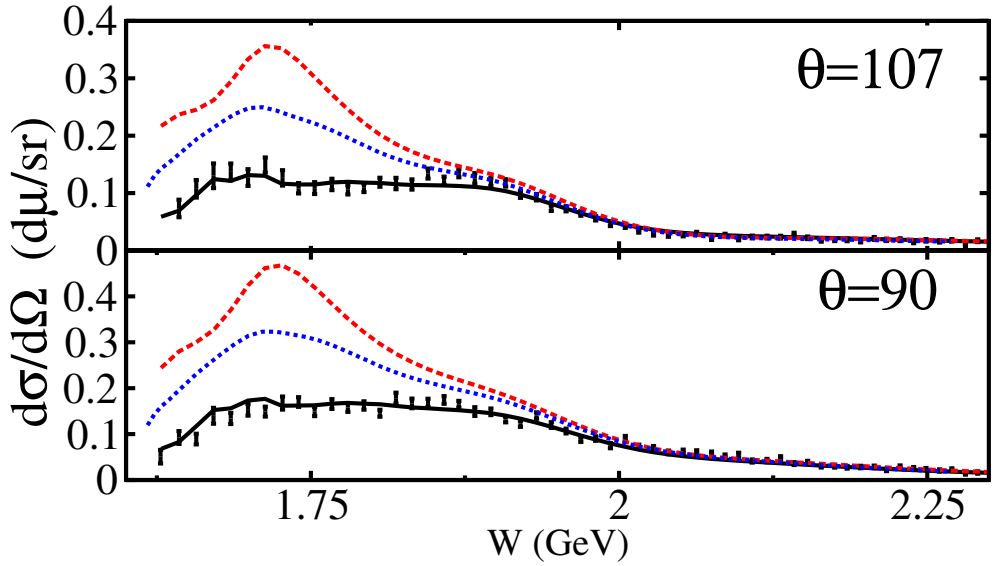
Analysis of N^* form factors:

Coupled channel and off shell physics must be incorporated

Coupled channel effect in $\gamma + p \longrightarrow K^+ + \Lambda$ reaction



Direct Coupled channel



Solid:full, Dashed:no CC, Dotted:no off-shell

B. Julia-Diaz, B. Saghai, T.-S. H. Lee and F. Tabakin

Reaction theory must incorporate

- Unitarity:

$$Im(T)_{MB,\gamma N} = \sum_{M'B'} T^{\dagger}_{MB,M'B'} T_{M'B',\gamma N} + \sum_{\pi\pi N} T^{\dagger}_{MB,\pi\pi N} T_{\pi\pi N,\gamma N}$$

combined analysis of πN and $\pi\pi N$

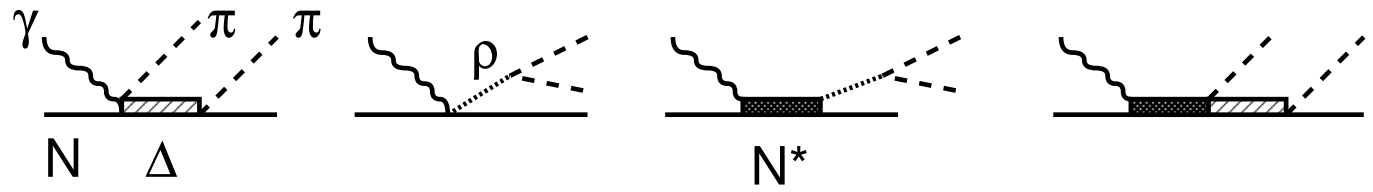
- Off-shell dynamics

crucial in extracting and interpreting N* parameters

$$\gamma + N \longrightarrow \pi\pi N$$

Effective Lagrangian Approach ($\sim$ tree diagram)

- D. Lüke and P.Söding, L. Y. Murphy and J.M. Laget (Δ Kroll-Ruderman)
- Valencia:J.A. Gomez Tejedon and E. Oset J. C. Nacher et al.($N^*(1520), \Delta(1700)$)
- Hiroshima: Ochi, M. Hirata, T. Takaki (ρ,$N^*(1520)$)
- Jlab-Moscow State Univ.: M. Ripani, V.I. Mokeev et al.($+$ FSI and ISI)



coupled channel effects with $\pi\pi N$ unitarity must be examined

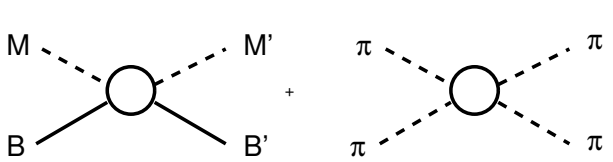
Dynamical model of meson production reaction

ANL-Osaka-Shizuoka approach

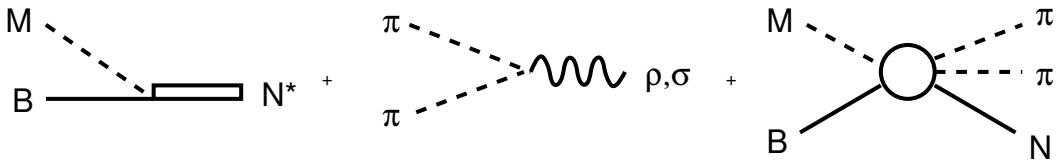
Dynamical model including $\pi\pi N$ channel

Fock space $\gamma N \oplus \pi N \oplus \eta N \oplus \pi\pi N(\pi\Delta, \rho N, \sigma N)$ and N^*, Δ

Interaction Hamiltonian



'potential'



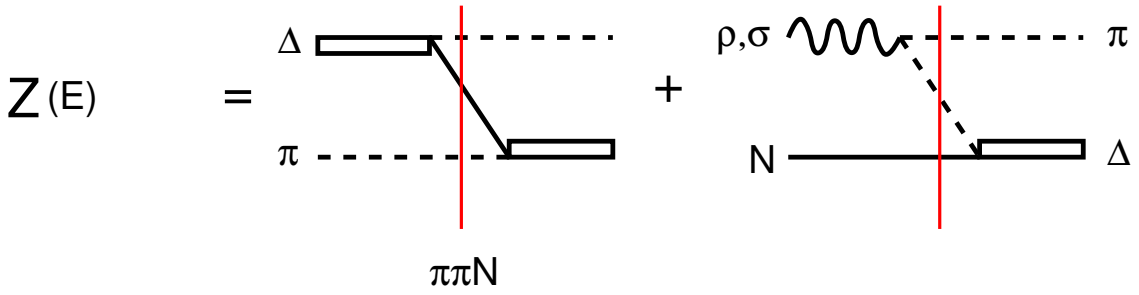
'particle production'

- interaction Hamiltonian (potential and particle production) derived from $L(\pi, \gamma, N, \Delta, , ,)$ using unitary transformation method
- 3-dimensional reduction of scattering equation with hermit (energy independent) interactions

Role of $\pi\pi N$ cut

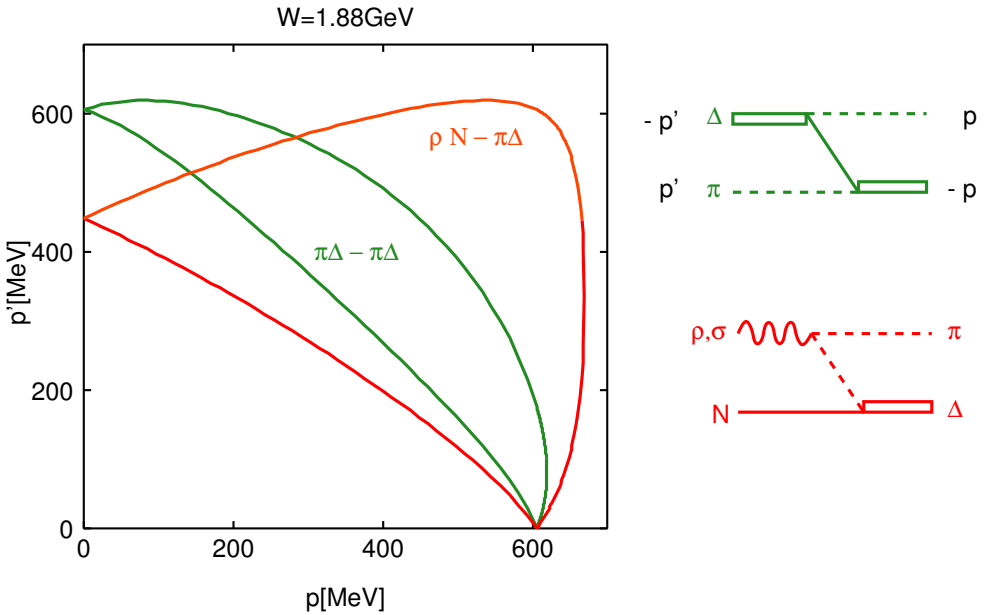
Effective two-body interaction

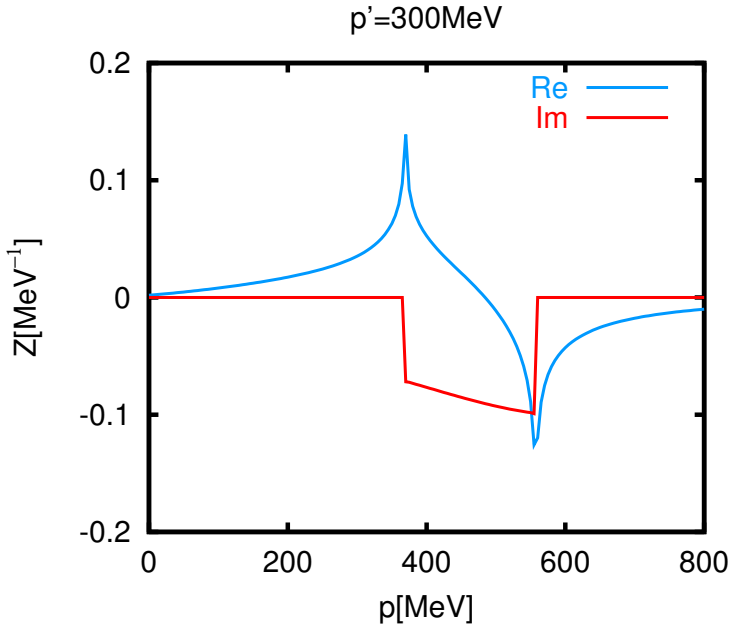
$$V(E) = v + Z(E) \quad \rightarrow \quad t(\text{non-res})$$



Singularity structure of $Z(E)$

$$< \pi\Delta : p' | Z(E) | \pi\Delta : p > \quad l_{\pi\Delta} = 0, j = 3/2$$

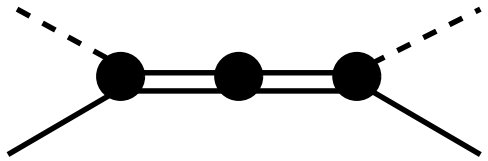




- Rapid momentum dependence of $Z \longrightarrow t$(non-res)
- Numerical complication: Contour rotation method is not valid for $\pi\pi N$ production $\longrightarrow$ Spline-interpolation method (A. Matsuyama for πNN)

Resonance Amplitude

t(Res) =

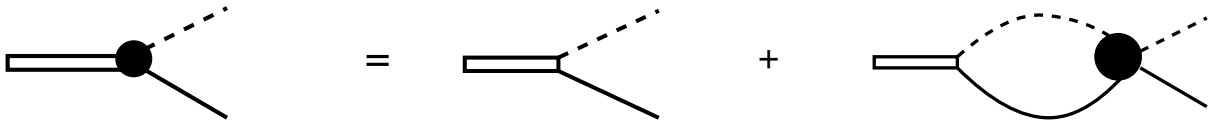


Resonance 'Greens function'

$$G_{N*i,j}^{-1} = (E - m^0)\delta_{i,j} - \Sigma(E)_{i,j}$$

$$< N_i^* | \Sigma(E) | N_j^* >=$$

Resonance 'form factor'



$$\bar{\Gamma}_{N*\to MB}(E) = \Gamma_{N*\to MB} + \sum_{M'B'} t_{MB,M'B}(\text{Non-res}) G_0(E) \Gamma_{N*\to M'B'}$$

- Coupled channel effects

Modified form factor $\bar{\Gamma}$: (example $N^* \to \pi N \to \pi\Delta$)

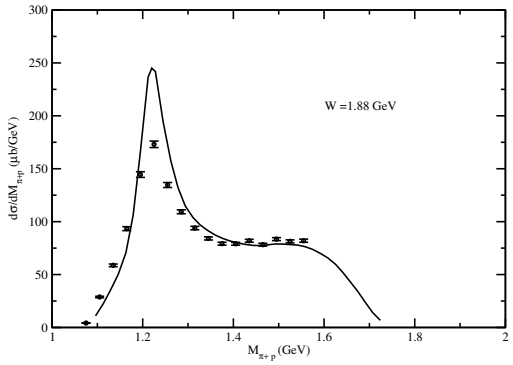
$(\gamma, \pi\pi)$ Reaction and Argonne-Osaka-Shizuoka Model

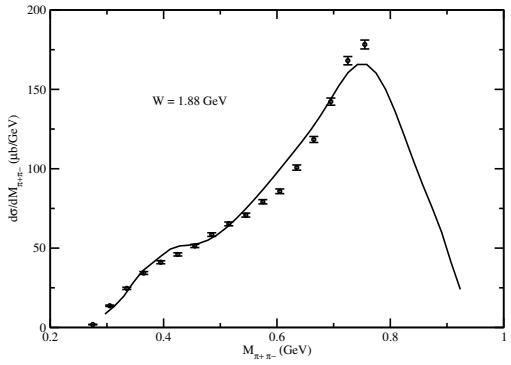
Current status

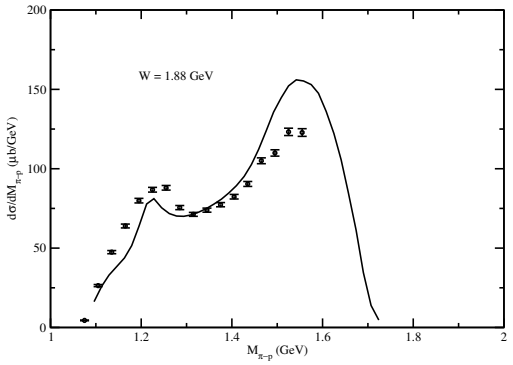
- $\gamma N \oplus \pi N \oplus \eta N \oplus \pi\pi N(\rho N \oplus \pi\Delta \oplus \sigma N)$
- Meson-Baryon coupling constants extend SL model
- $\rho, \sigma \rightarrow \pi\pi$: fit to $\pi\pi$ phase shift(Johnston-Lee)
- $N^*, \Delta \rightarrow Meson + Baryon$: PDG (not yet full dynamical model)

explore effects of $\pi\pi N$ cut

$\gamma + p \longrightarrow \pi^+ + \pi^- + p$ at $W = 1.88$GeV

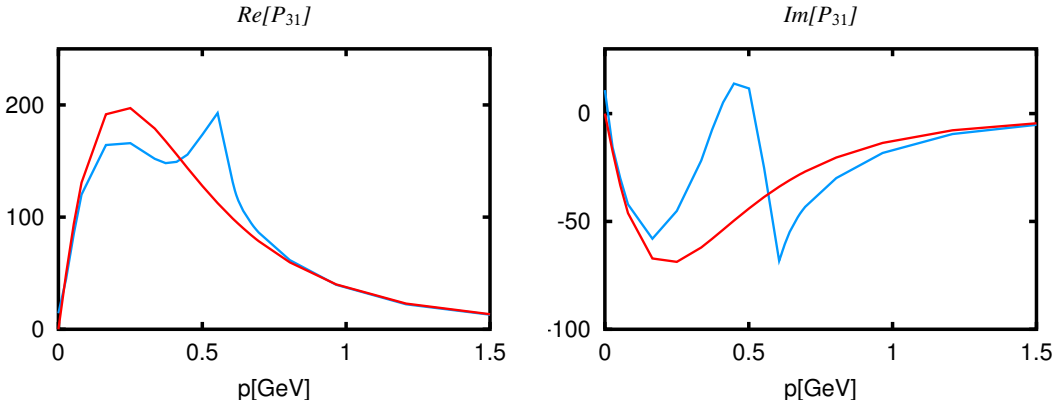




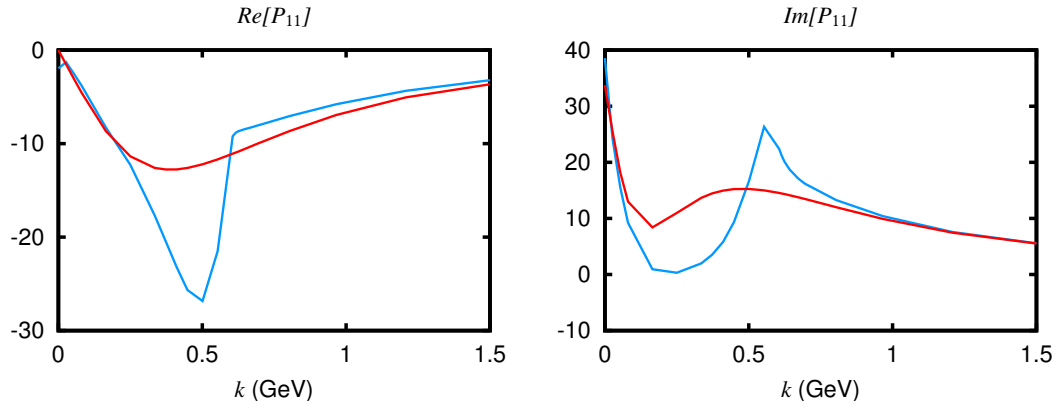


Non-resonant $\gamma N, \pi N \to MB$ amplitudes

$$\pi N \to \pi\Delta(P_{31}) \ (MeV^{-2})$$



$$\gamma N \to \pi\Delta(P_{11}) \ (MeV^{-3/2})$$



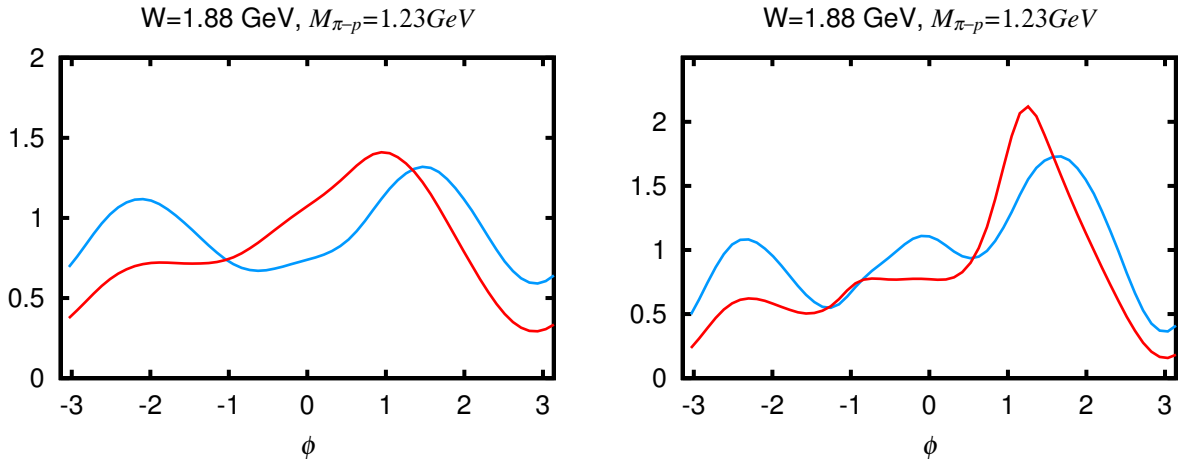
Full, $Z(E) = 0$

- Rapid momentum dependence of partial wave amplitude due to $\pi\pi N$ cuts (consistent with Aaron and Amado's analysis)

Large effects of $\pi\pi N$ cut on differential cross section

Angular Distribution ($\gamma p \to \pi^+\pi^- p$ at W= 1.88GeV) $\quad \frac{d\sigma}{dM_{\pi^- p} d\Omega_{\pi^+} d\Omega_{\pi^- p}}$

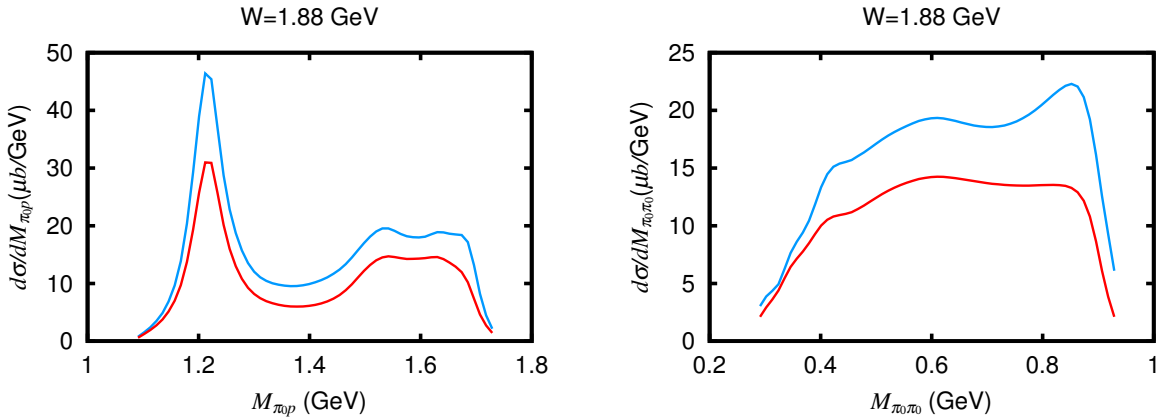
$\phi_{\pi^- p}$ dependence



Full, $Z(E) = 0$

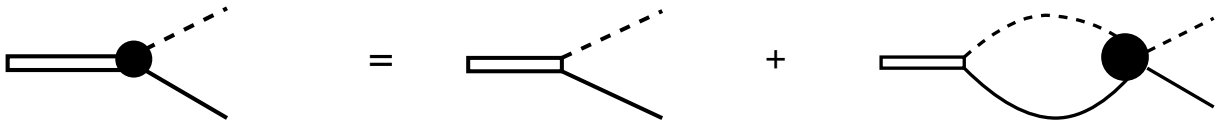
$(\cos\theta_{\pi^+} = 0.183, \phi_{\pi^+} = -\pi, \cos\theta_{\pi^- p} = -0.96, 1.83)$

Invariant mass distribution ($\gamma p \rightarrow \pi^0\pi^0 p$ at W= 1.88GeV)



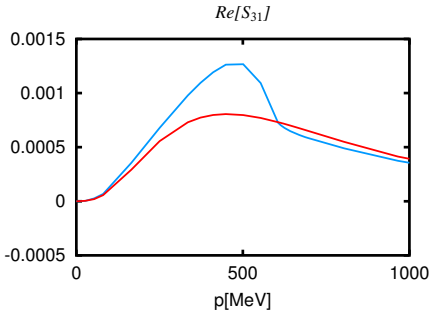
Full $Z(E) = 0$

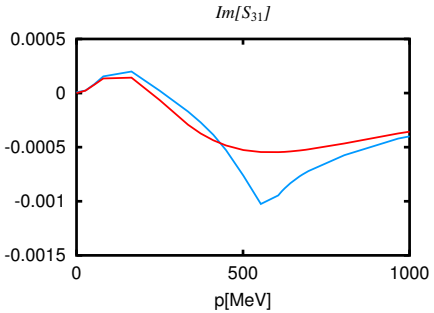
Possible effects of $\pi\pi N$ cut on resonance 'form factor'

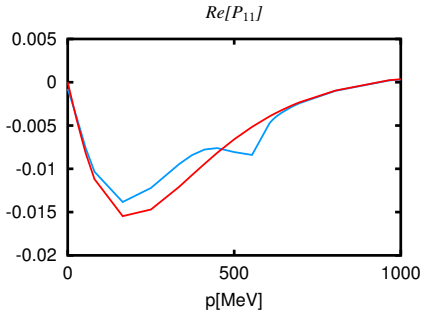


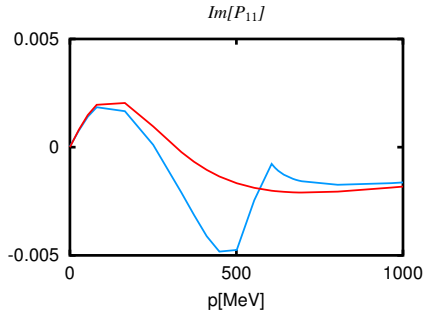
Example : $N^* \longrightarrow \pi N \longrightarrow \pi\Delta$ $\left(_{MeV^{-1/2}}\right)$

$S(31)$ $P(11)$









Simple model $\Gamma(q) = (\frac{q}{m_\pi})^L F(q)_{\text{dipole}}/\sqrt{2\omega}$ Full $Z(E) = 0$

Summary

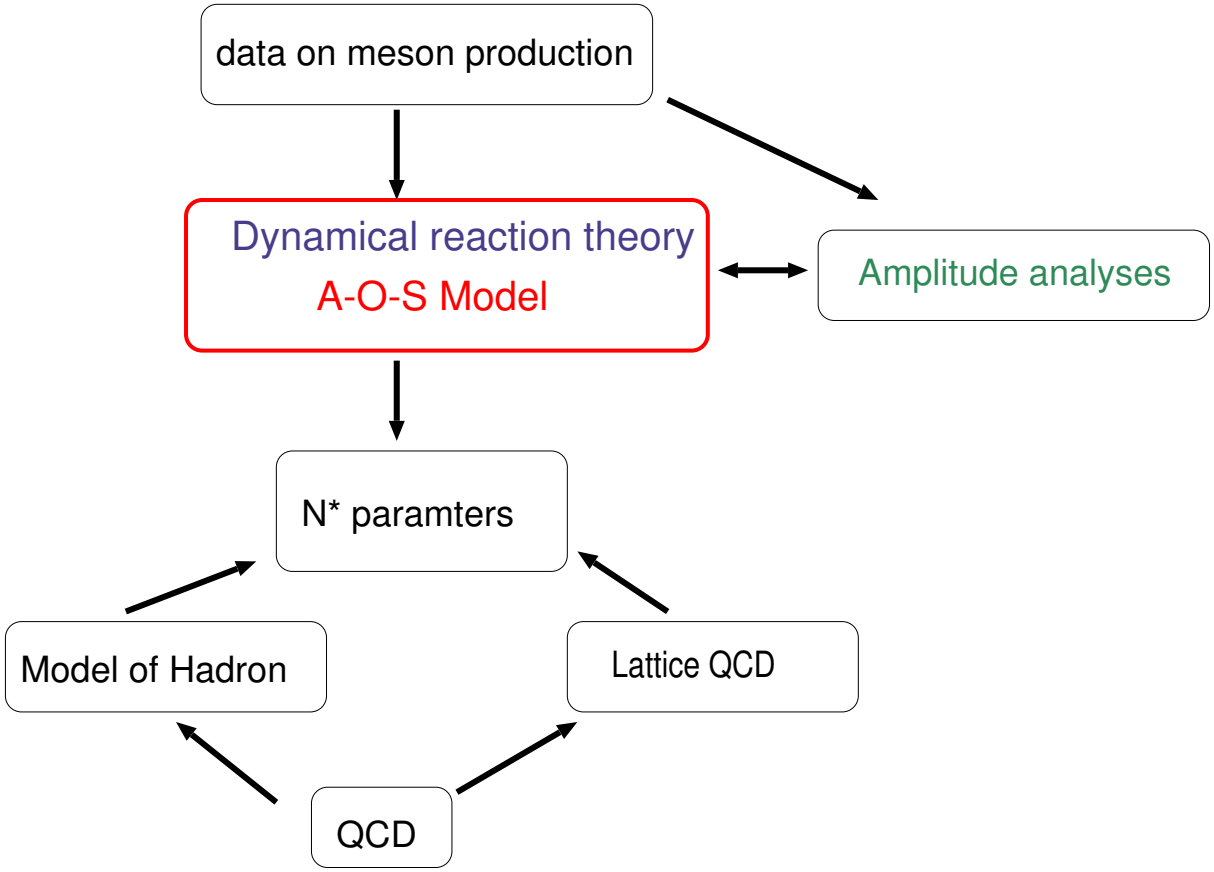
- Dynamical model for analyzing meson production is developped. : Coupled channel + $\pi\pi N$ cut
- Findings: Rapid momentum/energy dependence of Meson production amplitude
- Current analysis of data must be improved by taking into account CC + $\pi\pi N$

ANL-Osaka-Shizuoka(AOS) dynamical model and EBAC

First goal of Excited Baryon Analysis Center

Complete the combined analysis of available data on single pi, eta and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled channel analysis of resonances
(DOE milestone by 2009)

Focus of EBAC: Reaction Theory



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Future

How to constrain reaction model from chiral symmetry

How to compare extracted N* parameters to Lattice QCD

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