Coupled Channels Approach to Photo-Production of Mesons off the Nucleon

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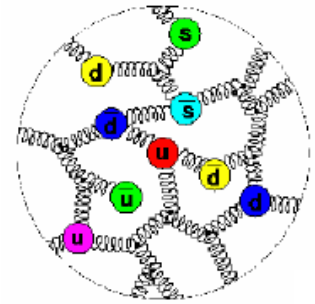
Agenda:

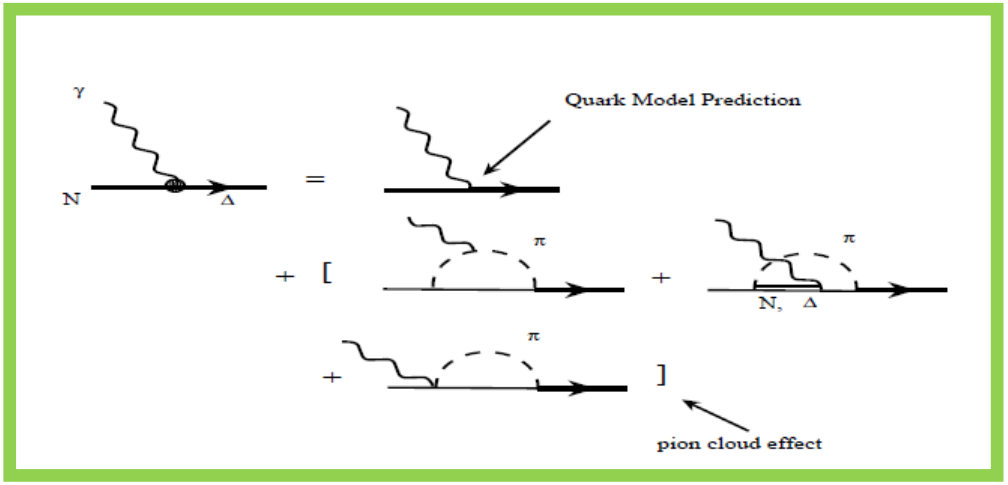
- **Features of meson production on the nucleon**
- **Lagrangian unitary coupled channels approach: the Gießen Model**
- **πN and γN results**
- **η-production on the proton**
- **Recent γN$\rightarrow$KΛ results**
- **Relation to antinucleon-nucleon annihilation**
- **Summary and outlook**

Nucleon Spectroscopy: Quarks and Hadrons

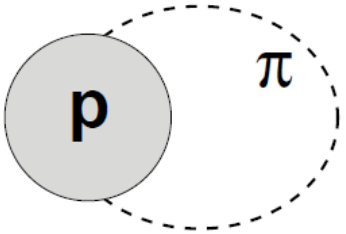
$\ll 0.1$ fm



q, g, $q\bar{q}$



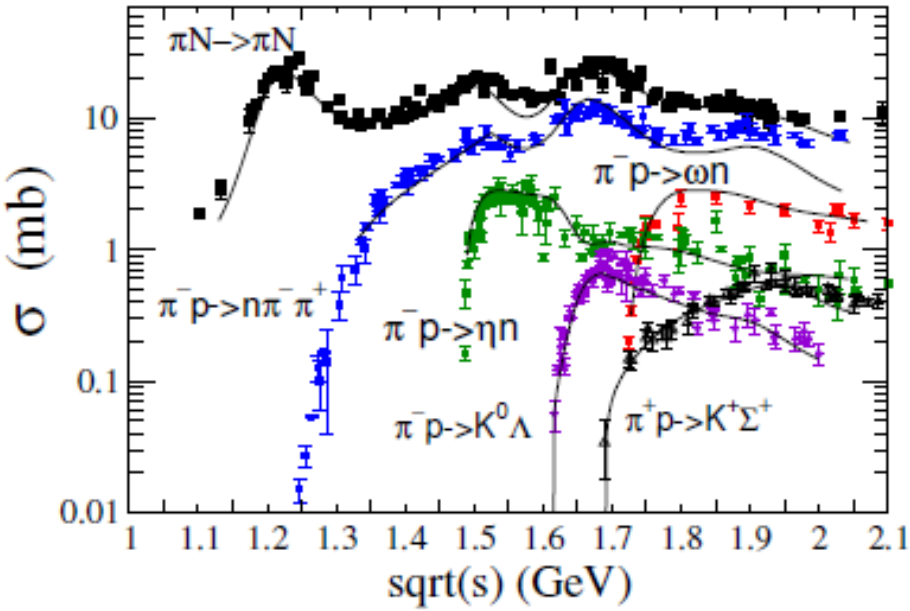
> 1.0 fm



Nucleon and Mesons

- **Reaction dynamics, formation, and spectroscopy of nucleon resonances**
- **Coupling to meson-nucleon continuum states**
- **Dynamical mixing by channel coupling**
- **Meson production: π, ω, η, K ...**

The Gießen Coupled Channels Model

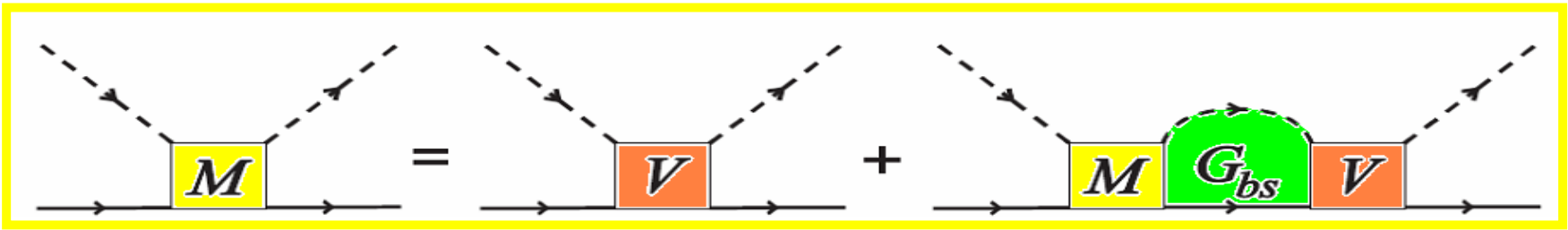


$$Im\,T^{JP}_{\pi N\to\pi N} = \frac{k^2}{4\pi}(\sigma^{JP}_{\pi N\to\pi N} + \sigma^{JP}_{\pi N\to 2\pi N} + \sigma^{JP}_{\pi N\to\eta N} + \sigma^{JP}_{\pi N\to\omega N} + \sigma^{JP}_{\pi N\to K\Lambda} + \sigma^{JP}_{\pi N\to K\Sigma} + \ldots)$$

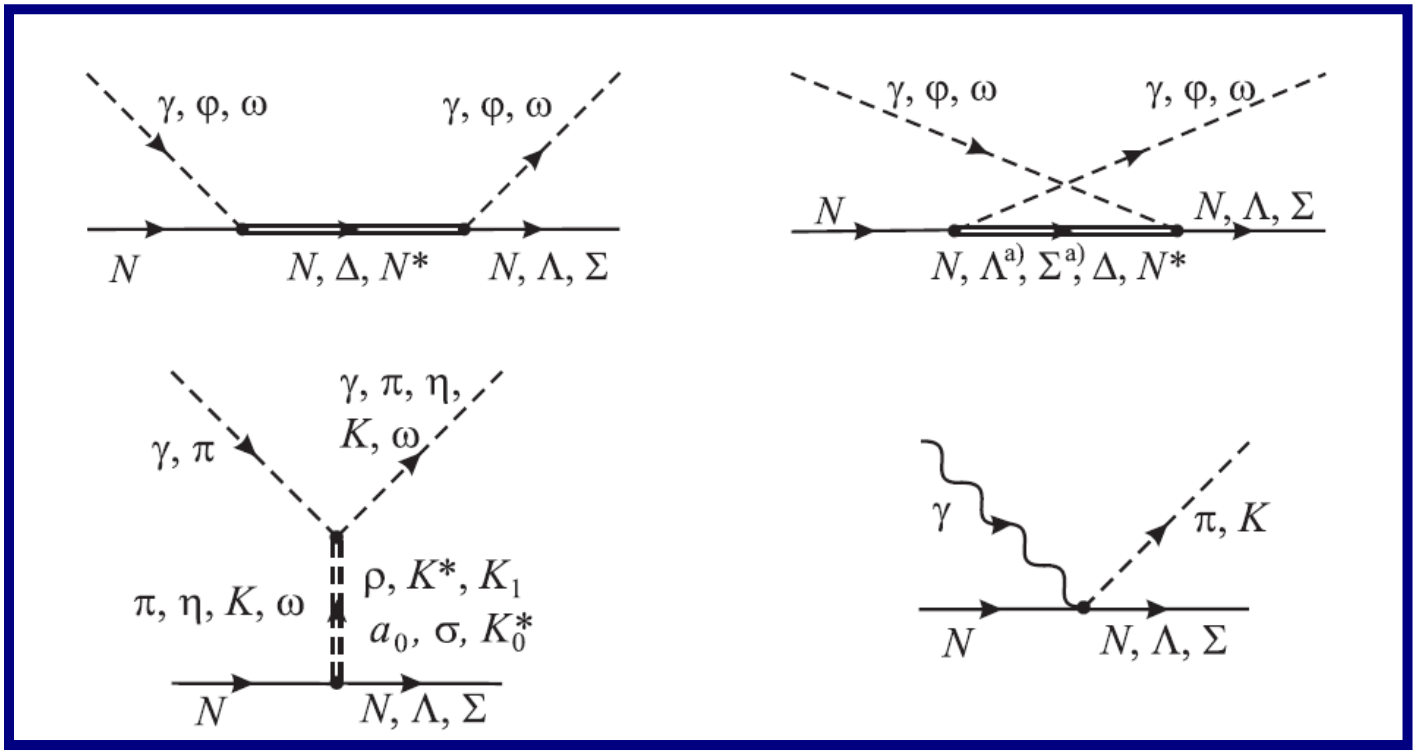
- **Intrinsically a coupled channels problem**
- **Hadro- and photoproduction**
- **Dynamical description of resonances and background**
- **Lagrangian approach obeying gauge invariance**
- **Treatment of high-spin resonance ($j=3/2^{\pm},5/2^{\pm}$)**

The Gießen Model

- Formation and decay of nucleon resonances
- Lagrangian approach: gauge invariance, link to QCD symmetries
- Gauge-independent treatment of high-spin resonances (j=$3/2^{\pm}$,$5/2^{\pm}$)
- Unitary Coupled Channels description
- Simultaneous partial wave analysis of πN and γN data
- Cross-sections, polarization observables…
- Results listed in PDG compilation



The Gießen Model: Unitary CC K-Matrix Approach



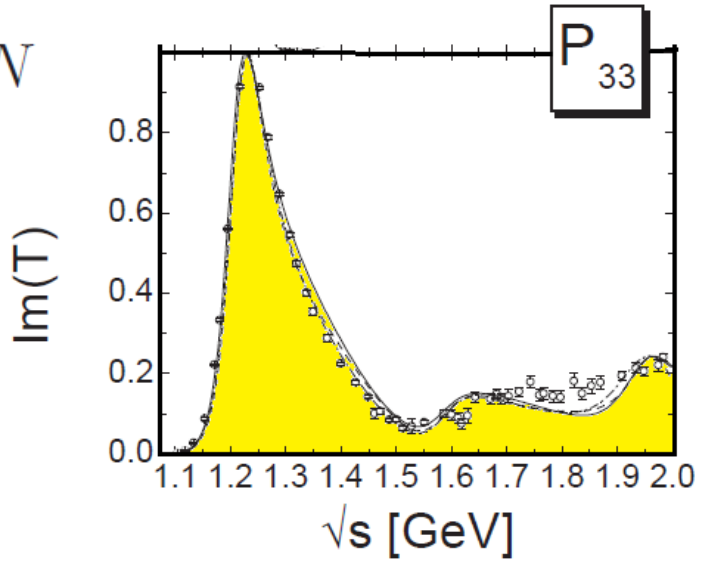
$$\mathcal{T}_{fi}^{IJ\pm} = \left[\frac{\mathcal{K}^{IJ\pm}}{1 - \mathrm{i}\mathcal{K}^{IJ\pm}}\right]_{fi}$$

$$\begin{pmatrix} T_{\gamma\gamma} & T_{\gamma\pi} & T_{\gamma\eta} & T_{\gamma\omega} & \cdots \\ T_{\pi\gamma} & T_{\pi\pi} & T_{\pi\eta} & T_{\pi\omega} & \cdots \\ T_{\eta\gamma} & T_{\eta\pi} & T_{\eta\eta} & T_{\eta\omega} & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

Meson Production on the Nucleon

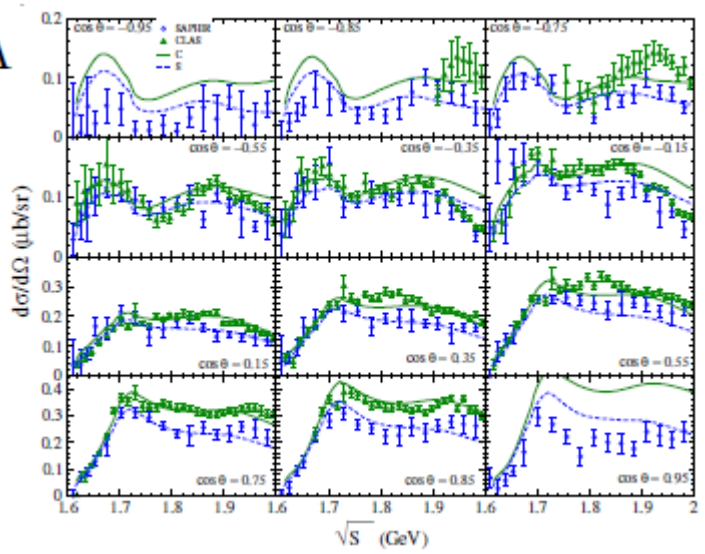
(V. Shklyar, H.L.)

$\pi N \to \pi N$



- **Pion, eta, and omega meson production:**

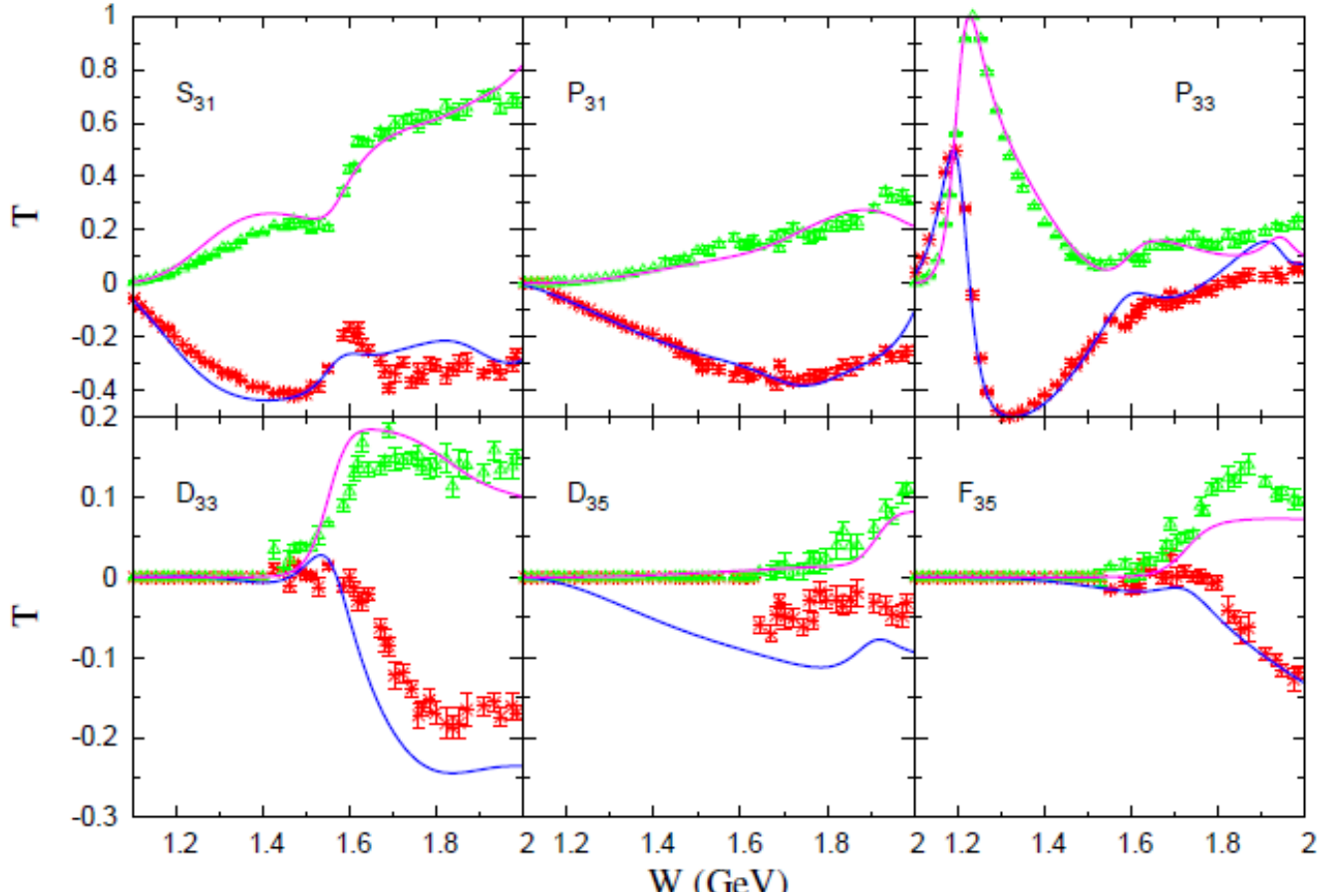
$\gamma p \to K^+ \Lambda$



- **Strangeness production:**

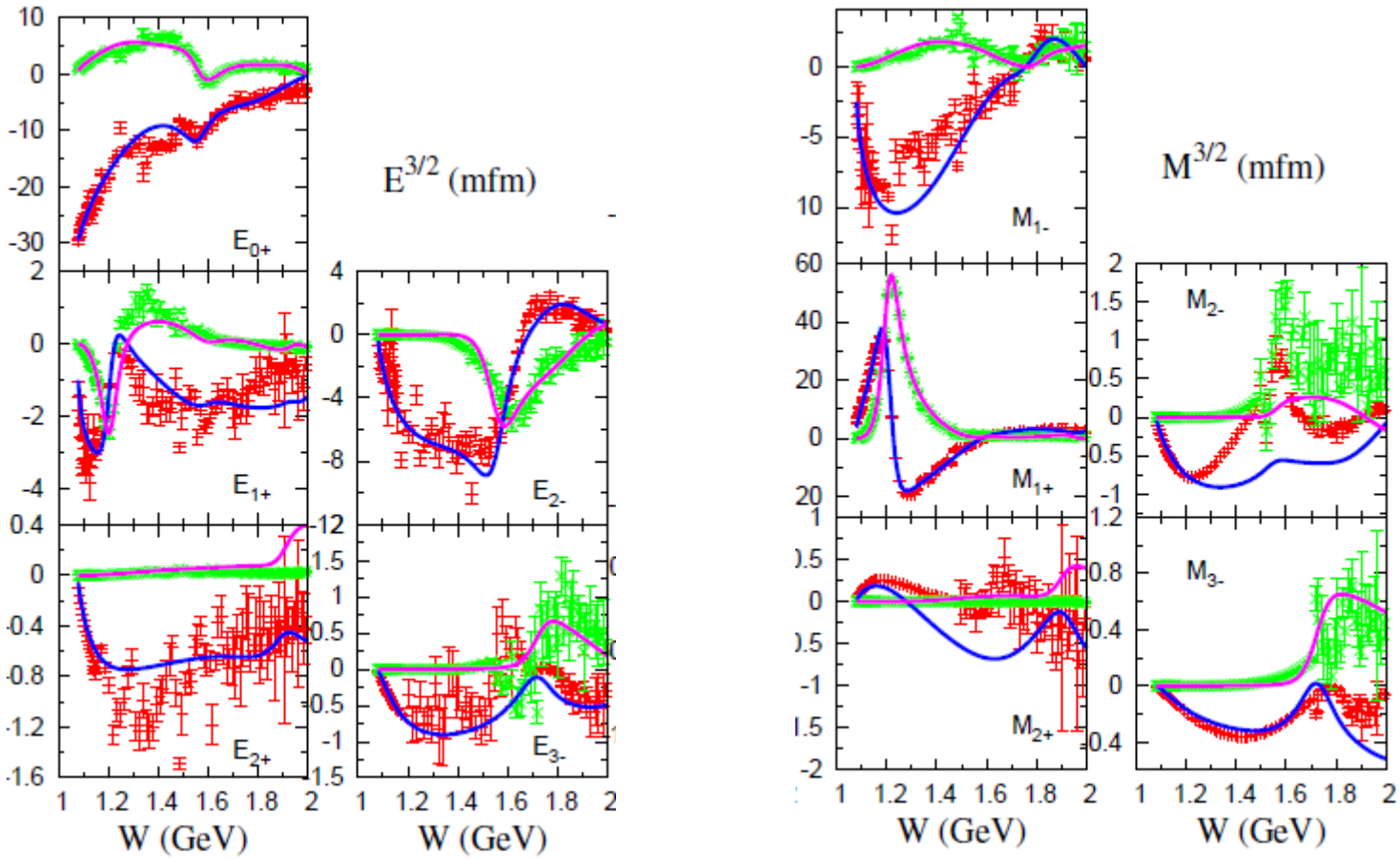
Comparison of elastic πN PW results: GiM vs. GWU/SAID

(Xu Cao, H.L.)



The elastic πN partial waves for $I = 3/2$. The solid lines (magenta) and triangle points (green) are imaginary part of amplitude of our model calculation and GWU/SAID analysis, respectively. The solid line (blue) and star points (red) are the correspondent real part of amplitude.

Comparison of γN→πN PW results: GiM vs. GWU/SAID

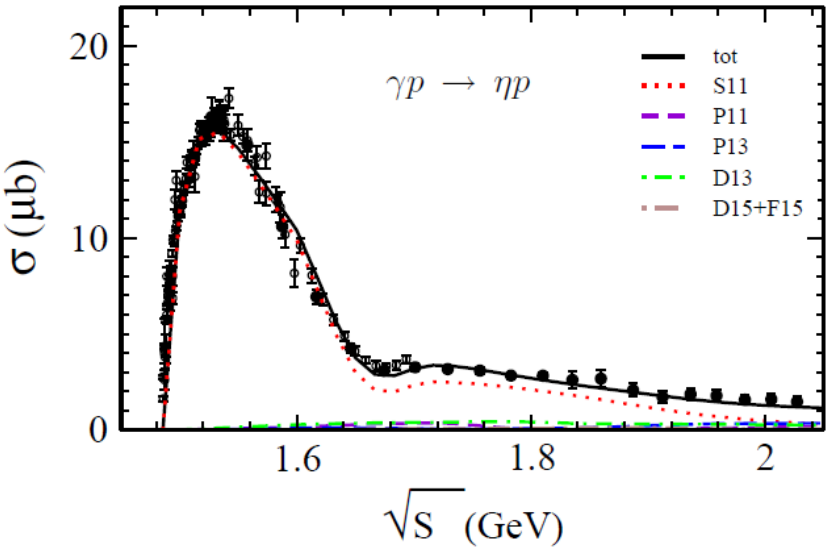


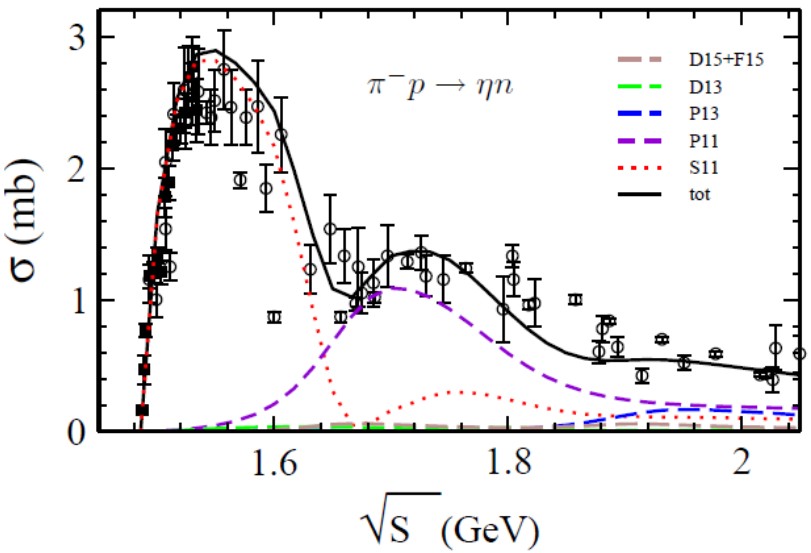
The $\gamma N \to \pi N$ multipoles for $I = 3/2$. The solid lines (magenta) and triangle points (green) are imaginary part of amplitude of our model calculation and SAID analysis, respectively. The solid line (blue) and star points (red) are the correspondent real part of amplitude.

η production on the nucleon

(V. Shklyar, H.L.)

$S_{11}(1535)$ dominates both $\gamma p \to \eta p$ and $\pi^- p \to \eta n$ reactions



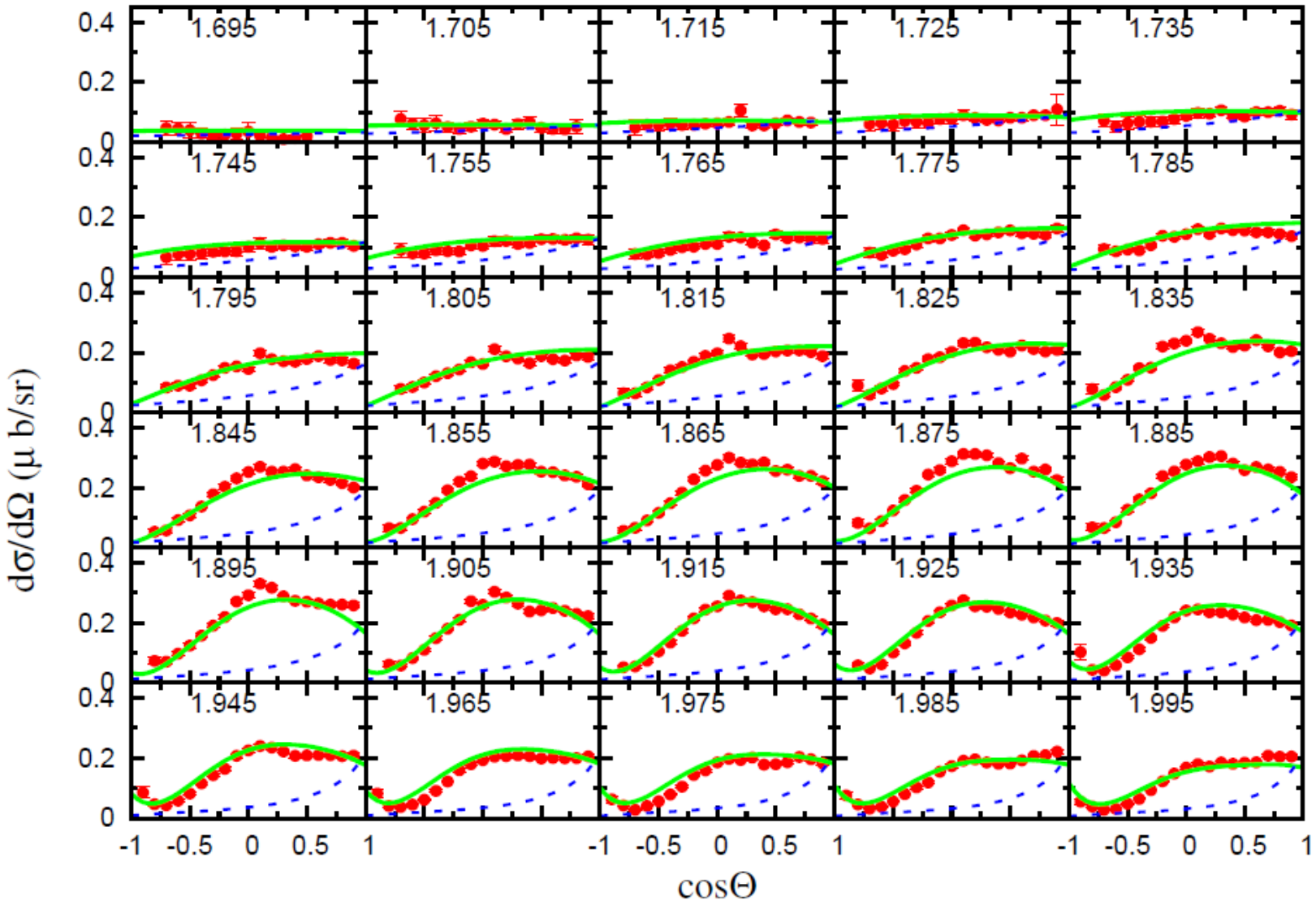


- clearly dominated by $S_{11}(1535)$
- s-wave extends into high energy tail
- destructive interference of $S_{11}(1535)$ and $S_{11}(1650)$
- importance of $P_{11}(1710)$ above ~1600MeV

arXiv:1206.5414

$$\gamma p \to K^+\Sigma^0$$

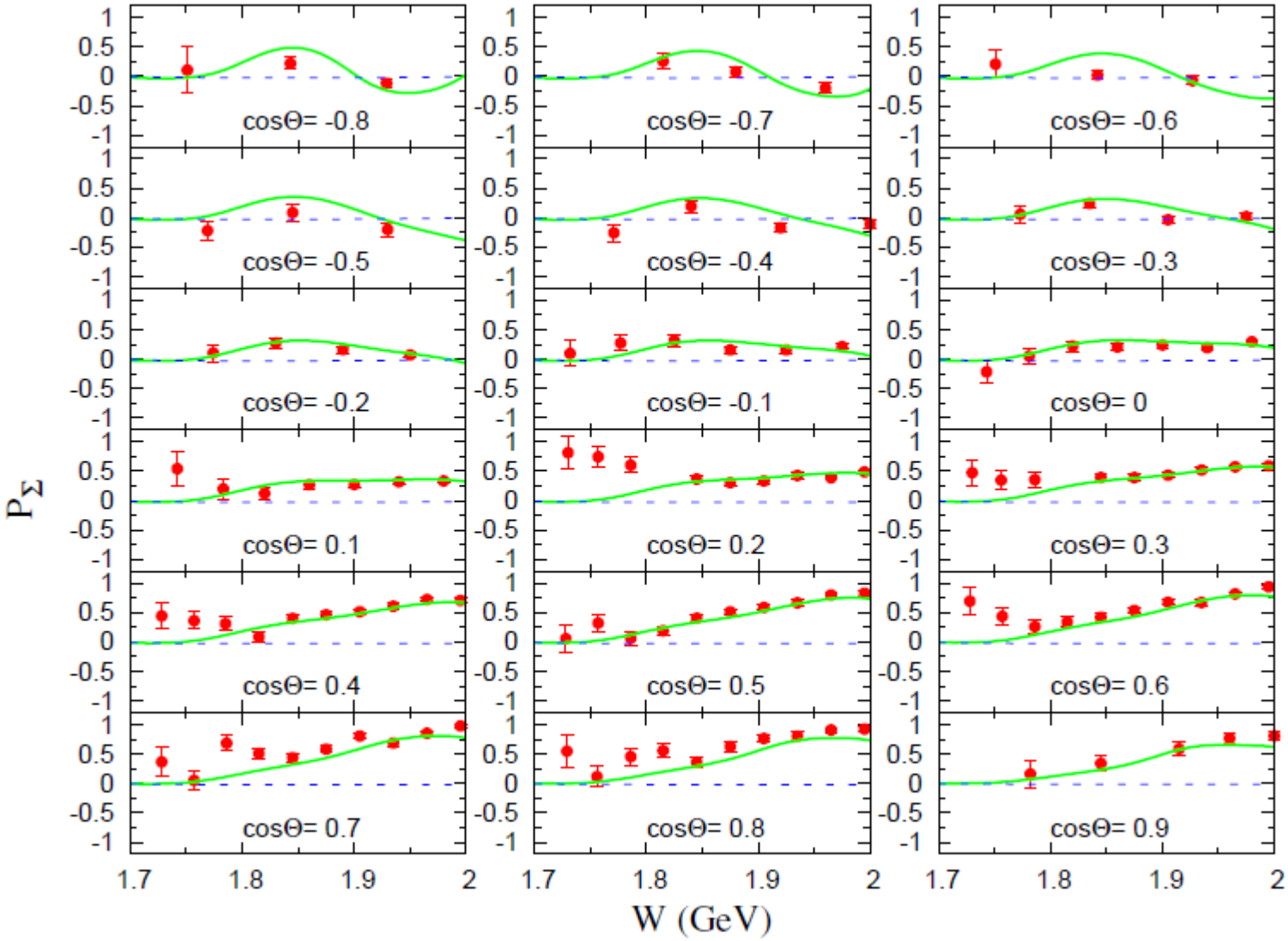
(Xu Cao, H.L.)



GiM CC-results (green), Born terms (dashed) and CLAS data

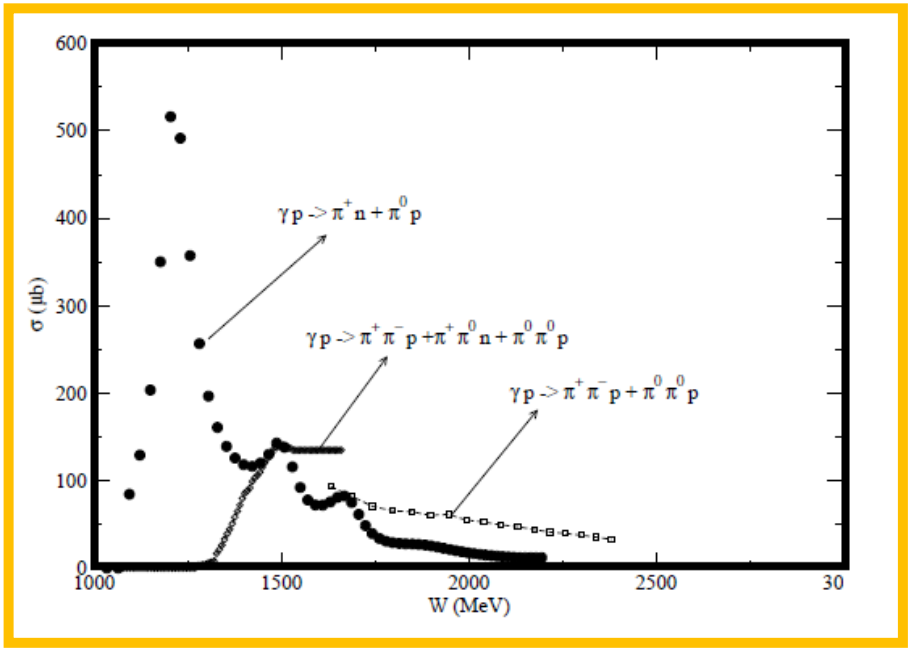
The recoil polarization of $\gamma p \to K^+\Sigma^0$ reaction

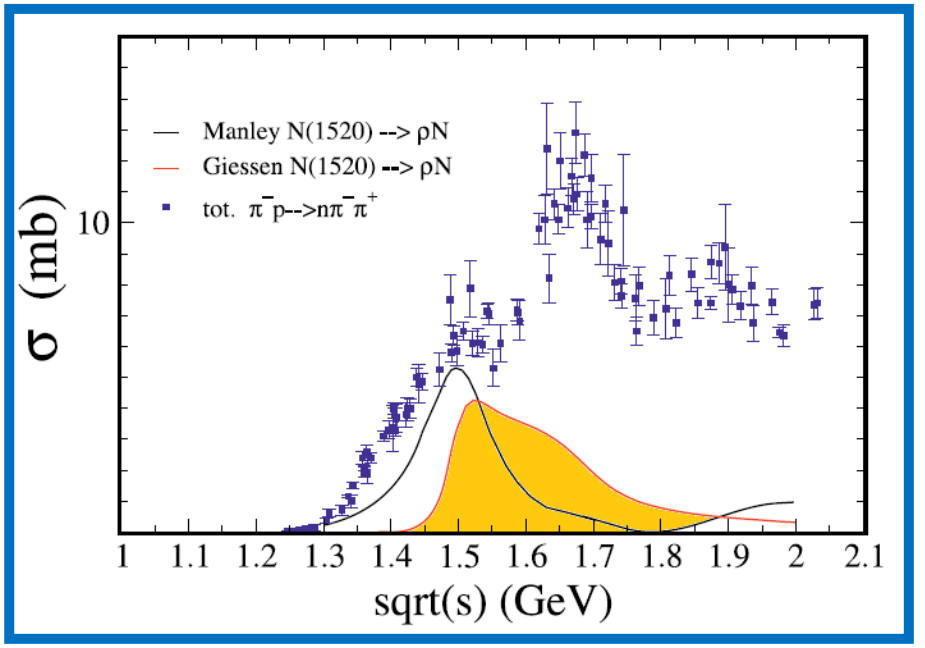
(Xu Cao, H.L.)

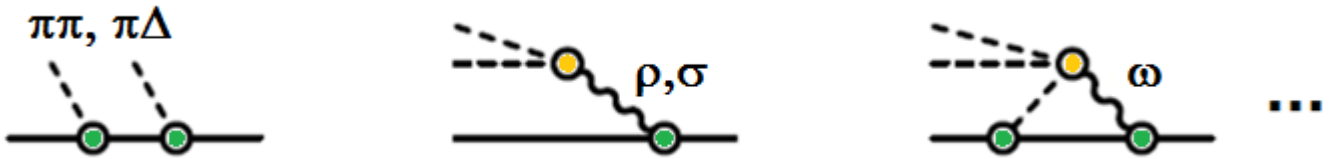


GiM CC-results (green), Born-terms (dashed) and CLAS data

Extension to 2-Pion Dynamics



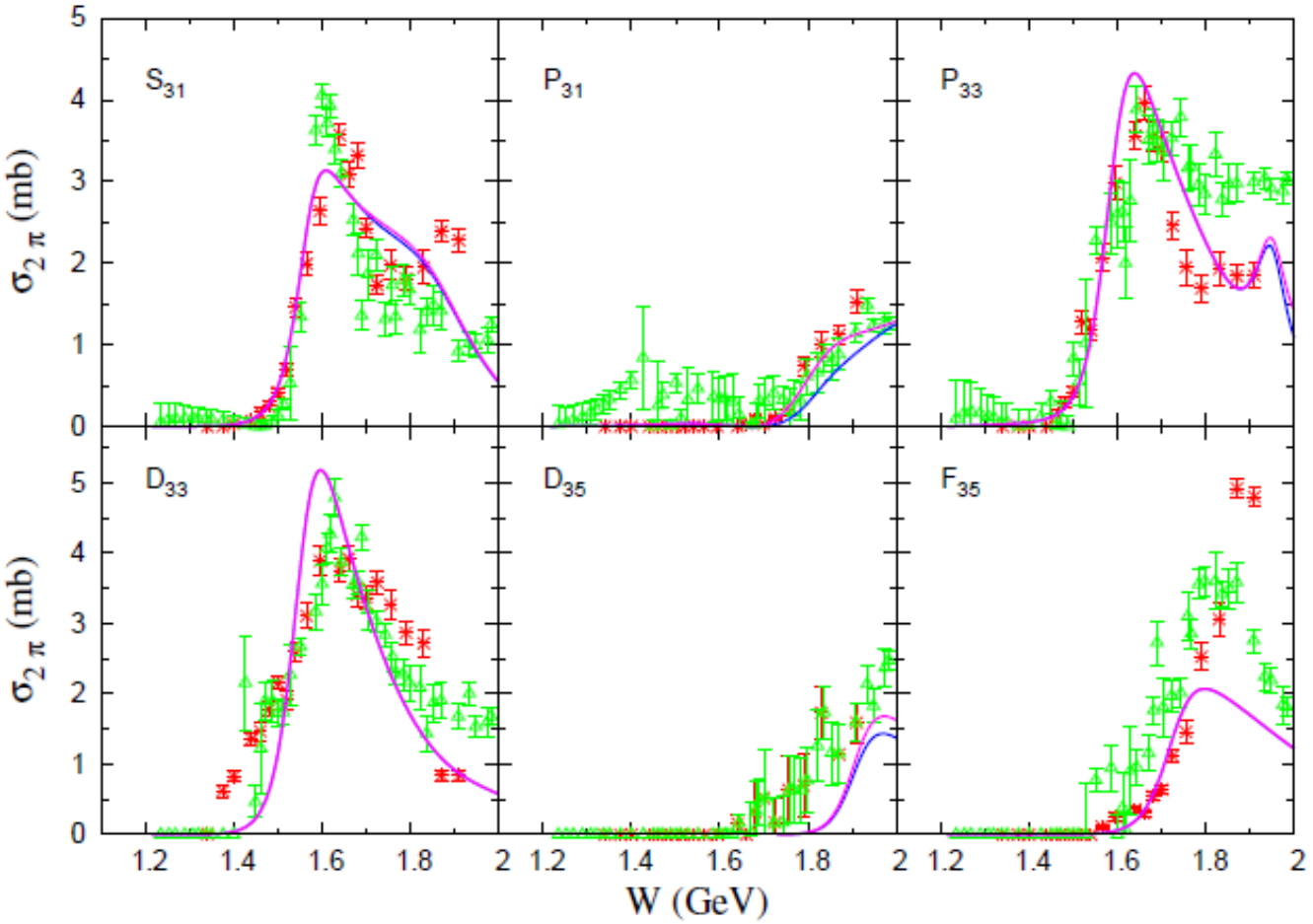




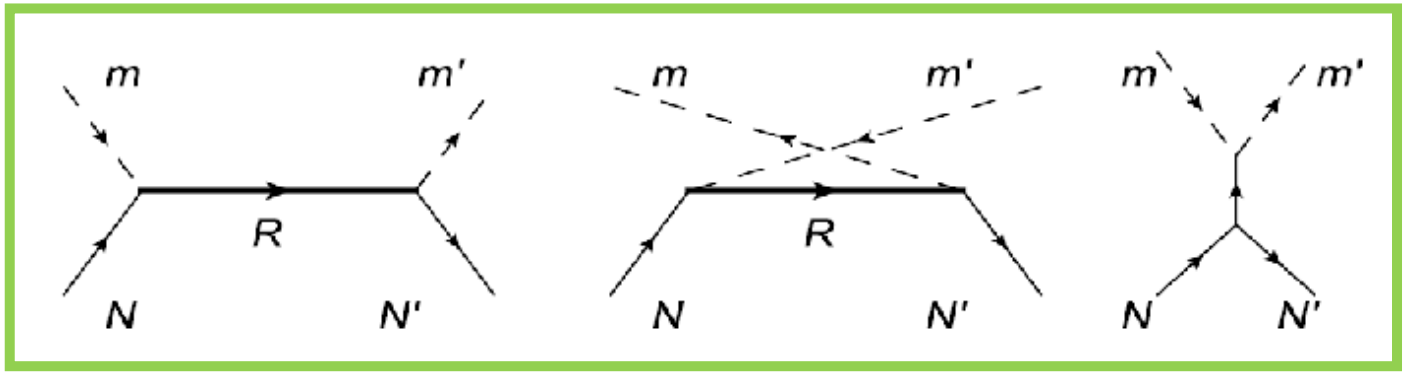
$$T_{\pi\pi N,\gamma N} = T^{dir}_{\pi\pi N,\gamma N} + T^{\pi\Delta}_{\pi\pi N,\gamma N} + T^{\rho N}_{\pi\pi N,\gamma N} + T^{\sigma N}_{\pi\pi N,\gamma N}$$

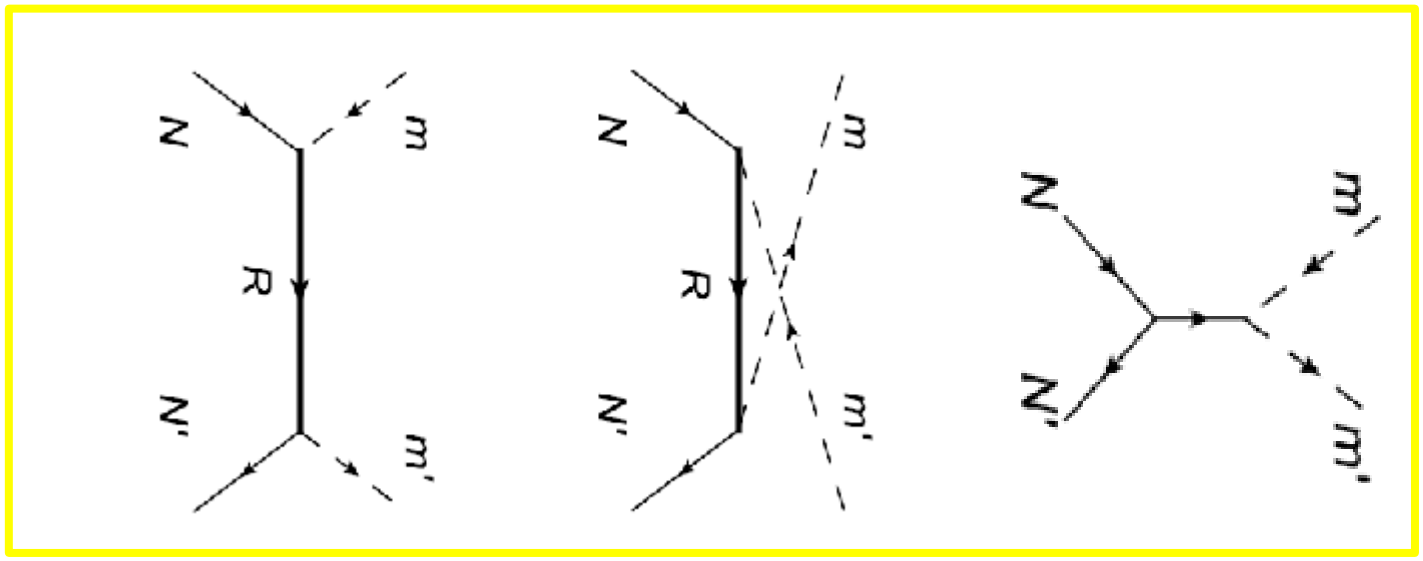
$\pi N \rightarrow 2\pi N$:
I=3/2 partial wave amplitudes

(Xu Cao, H.L.)

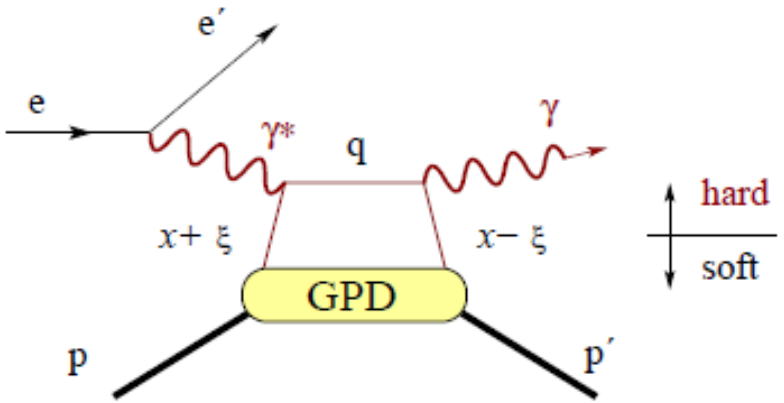


Relation to Antinucleon-Nucleon annihilation

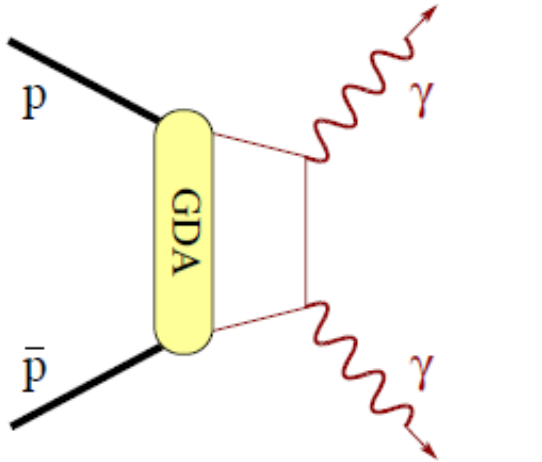




Electromagnetic Studies at PANDA



DVCS



WACS process $\bar{p}p \to \gamma\gamma$

Crossing Relations:

(i) $p + \bar{p} \to \gamma + \gamma' \Leftrightarrow p + \gamma \to p' + \gamma'$

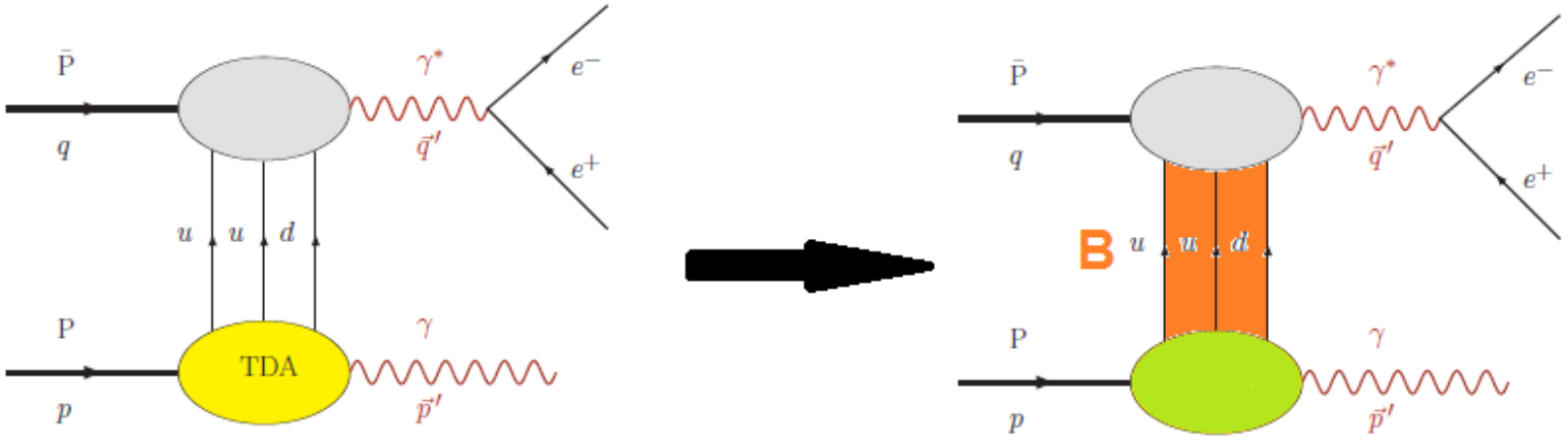
(ii) $p + \bar{p} \to \gamma + m' \Leftrightarrow p + \gamma \to p' + m'$

(iii) $p + \bar{p} \to \bar{m} + m' \Leftrightarrow p + m \to p' + m'$

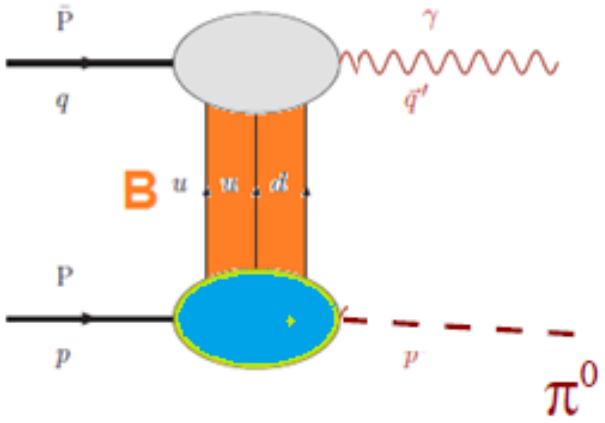
but...a caveat:

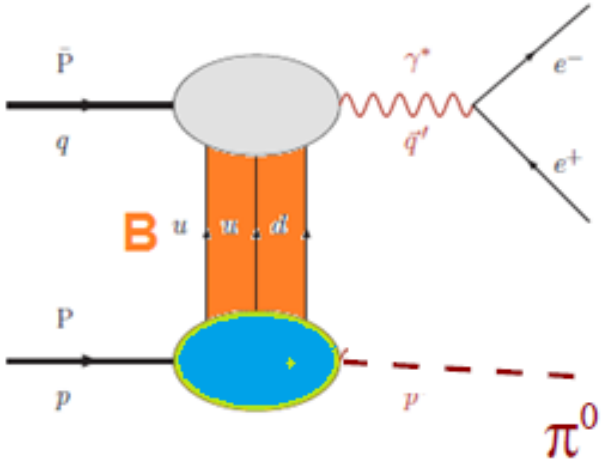
strong $p\bar{p}$ initial state interactions!

Di-Leptons and (γ,π^0) production at PANDA: QCD and Hadronic Scenarios



Di-Lepton and (γ,π^0) production at PANDA: Hadronic Scenario





Vertex:

$\Gamma_{N\bar{N}\gamma}(q)$

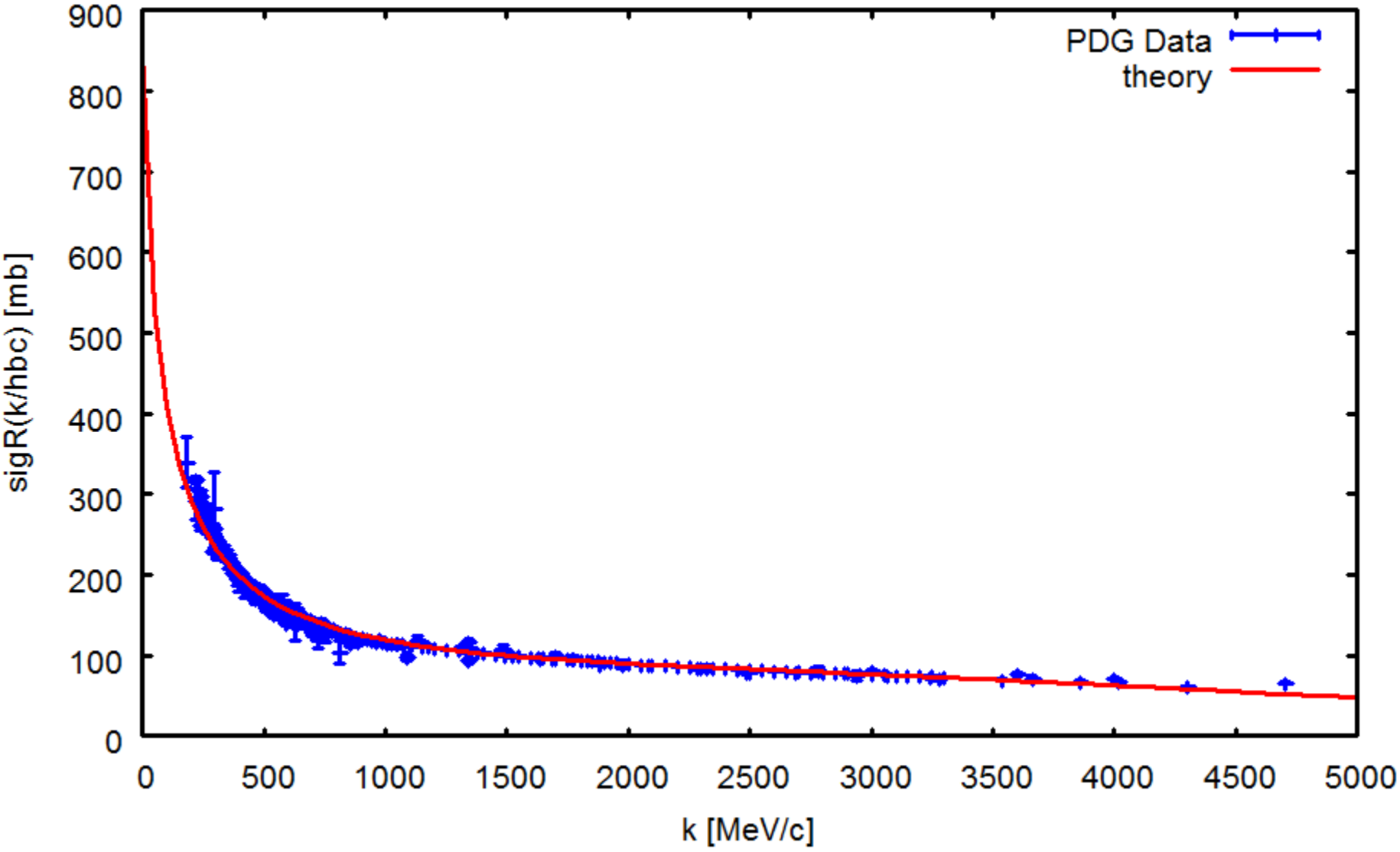
$\Gamma_{N\bar{N}\pi}(q)$

$\Gamma_{N\bar{N}\gamma^*}(q) \underset{VDM}{\leftrightarrow} \Gamma_{N\bar{N}\rho}(q)$

$\Gamma_{N\bar{N}\pi}(q)$

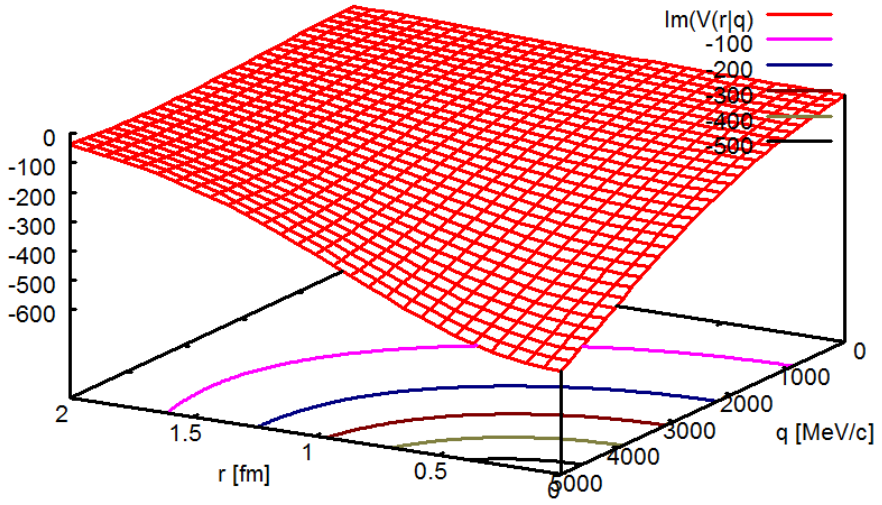
Antiproton-proton scattering: Total X-section

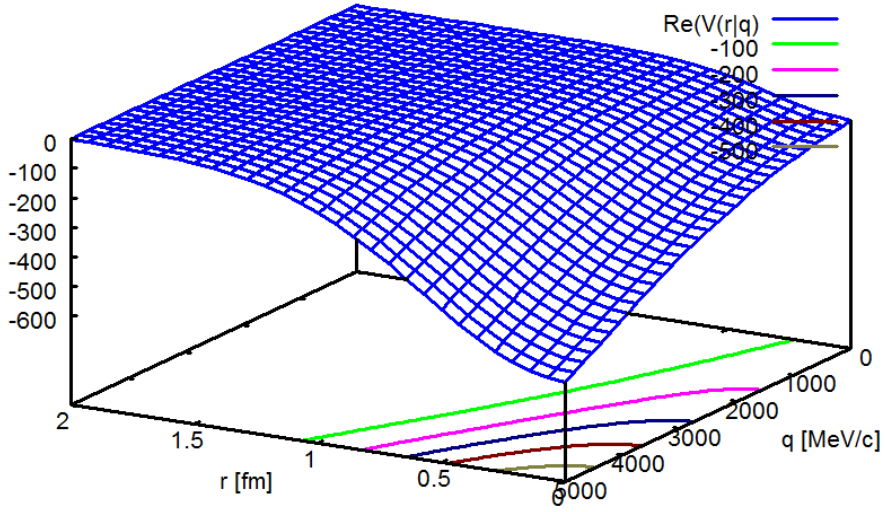
(Stefanie Lourenco, H.L.)



…expressing $\bar{N}N$ interactions by a dispersive self-energy:

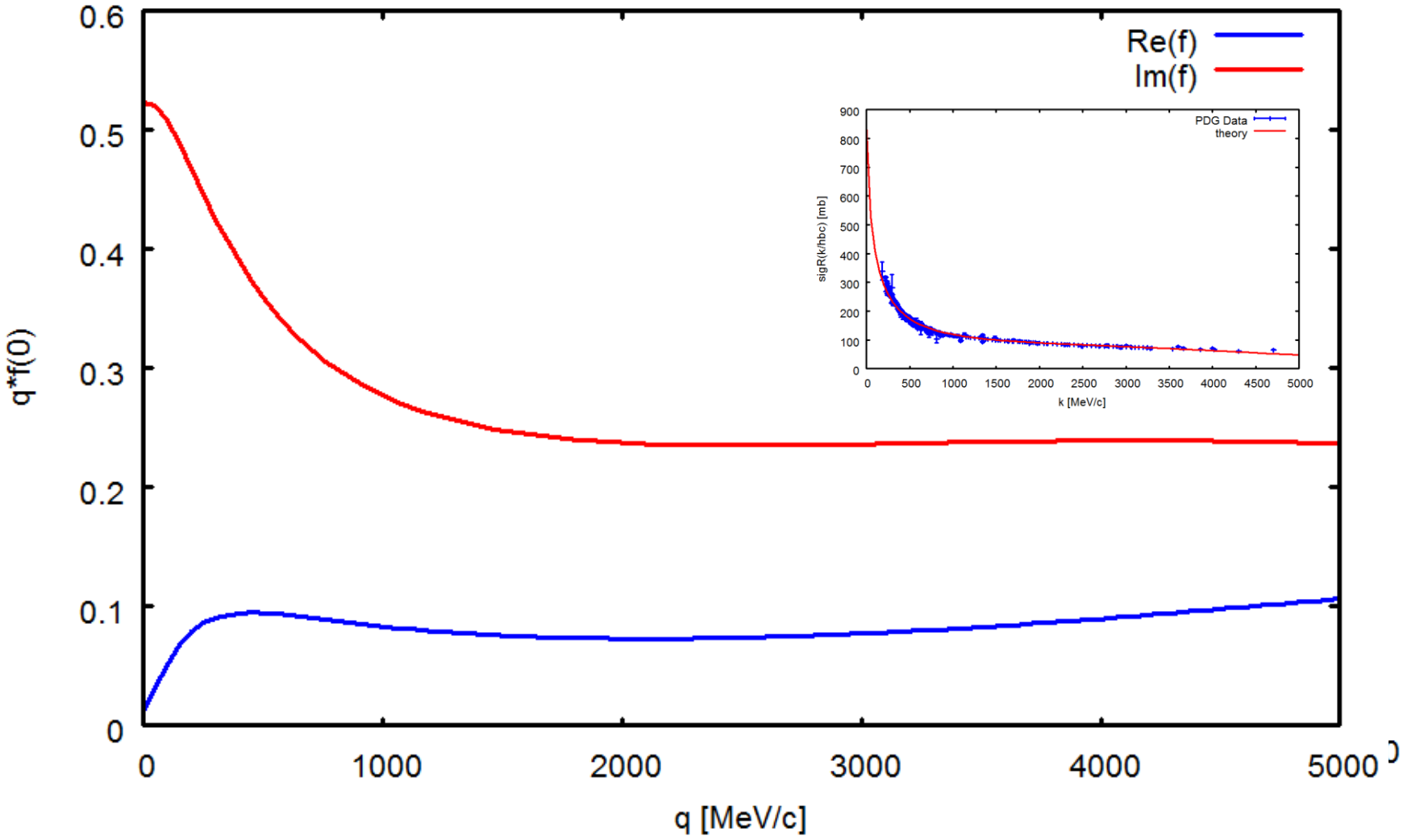
- **Imaginary part:**





- **Real part**

Antiproton-Proton Forward Scattering Amplitude



Summary and Outlook

- Lagrangian CC approach to photo-meson production
- Results for the prodcution of pseudoscalar mesons: π, η, K…
- Two-pion production
- Not discussed: pionic and photonic meson production on nuclei
- Connections to γ,π channels in antinucleon-nucleon annihilation
- Initial state interactions

…with contributions of:

Vitaliy Shklyar, Xu Cao, Stefanie Lourenco, Slawomir Wycech

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