Extraction and Interpretation of $\gamma N \to \Delta$ Form Factors at EBAC

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U. Barcelona

In collaboration with

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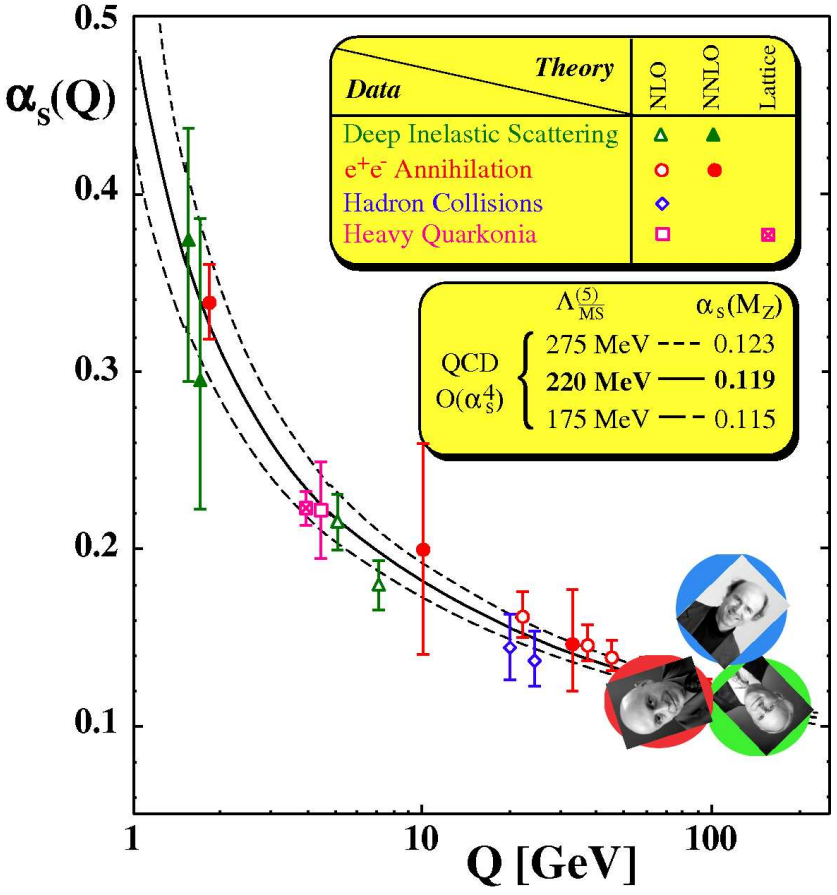
http://ebac-theory.jlab.org

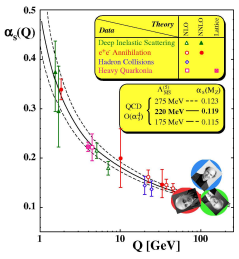
Motivation

- Connection to QCD



Motivation

- Connection to QCD
- Static properties of resonances?



Particle	$L_{2I\cdot 2J}$	Overall status	$N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$N(939)$	P_{11}	****							
$N(1440)$	P_{11}	****	****	*			***	*	***
$N(1520)$	D_{13}	****	****	***			****	****	****
$N(1535)$	S_{11}	****	****	****			*	**	***
$N(1650)$	S_{11}	****	****	*	***	**	***	**	***
$N(1675)$	D_{15}	****	****	*	*		****	*	****
$N(1680)$	F_{15}	****	****	*			****	****	****
$N(1700)$	D_{13}	***	***	*	**	*	**	*	**
$N(1710)$	P_{11}	***	***	**	**	*	**	*	***
$N(1720)$	P_{13}	****	****	*	**	*	*	**	**
$N(1900)$	P_{13}	**	**					*	
$N(1990)$	F_{17}	**	**	*	*	*			*
$N(2000)$	F_{15}	**	**	*	*	*	*	**	
$N(2080)$	D_{13}	**	**	*	*				*
$N(2090)$	S_{11}	*	*						
$N(2100)$	P_{11}	*	*	*					
$N(2190)$	G_{17}	****	****	*	*	*		*	*
$N(2200)$	D_{15}	**	**	*	*				
$N(2220)$	H_{19}	****	****	*					
$N(2250)$	G_{19}	****	****	*					
$N(2600)$	$I_{1\,11}$	***	***						
$N(2700)$	$K_{1\,13}$	**	**						
$\Delta(1232)$	P_{33}	****	****	F					****
$\Delta(1600)$	P_{33}	***	***	o			***	*	**
$\Delta(1620)$	S_{31}	****	****	r			****	****	***
$\Delta(1700)$	D_{33}	****	****	b		*	***	**	***
$\Delta(1750)$	P_{31}	*	*	i					
$\Delta(1900)$	S_{31}	**	**	d		*	*	**	*
$\Delta(1905)$	F_{35}	****	****	d		*	**	**	***
$\Delta(1910)$	P_{31}	****	****	e		*	*	*	*
$\Delta(1920)$	P_{33}	***	***	n		*	**		*
$\Delta(1930)$	D_{35}	***	***			*			**
$\Delta(1940)$	D_{33}	*	*	F					
$\Delta(1950)$	F_{37}	****	****	o		*	****	*	****
$\Delta(2000)$	F_{35}	**		r			**		
$\Delta(2150)$	S_{31}	*	*	b					
$\Delta(2200)$	G_{37}	*	*	i					
$\Delta(2300)$	H_{39}	**	**	d					
$\Delta(2350)$	D_{35}	*	*	d					
$\Delta(2390)$	F_{37}	*	*	e					
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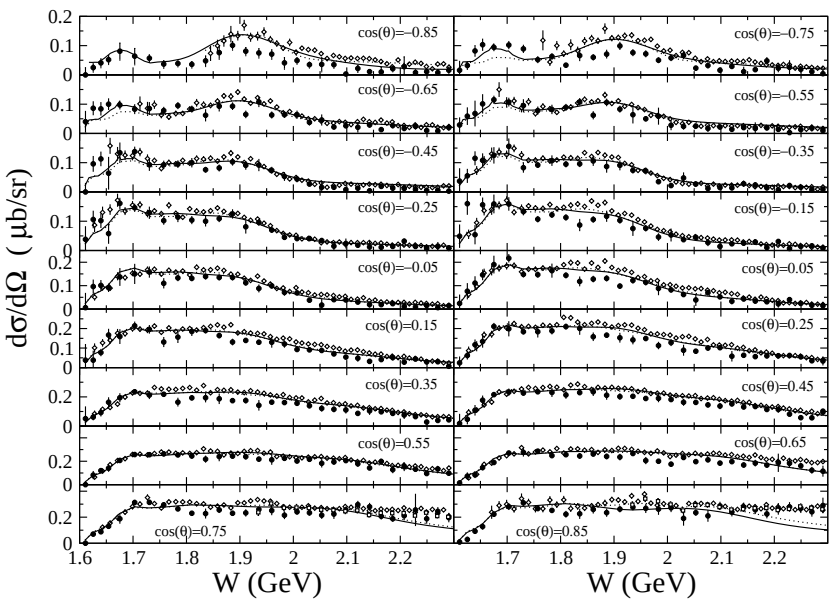
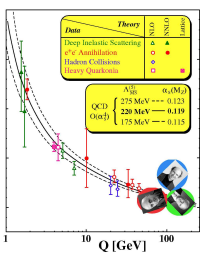
$\Delta(2420)$	$H_{3\,11}$	****	****						*
$\Delta(2750)$	$I_{3\,13}$	**	**						
$\Delta(2950)$	$K_{3\,15}$	**	**						

Motivation

- Connection to QCD
- Static properties of resonances?
- New accurate experimental data





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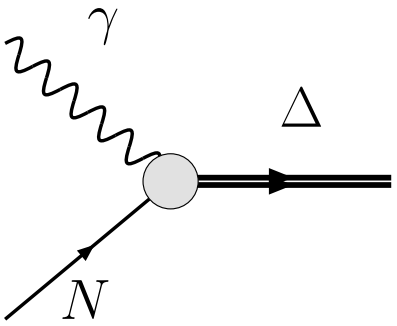
Interpretation



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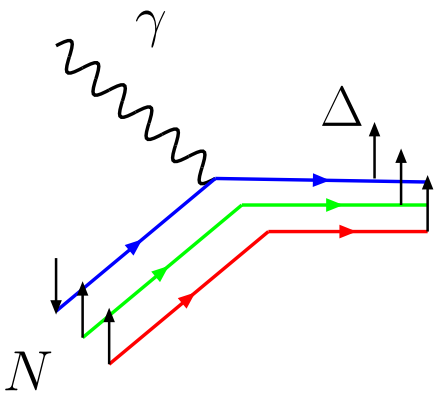
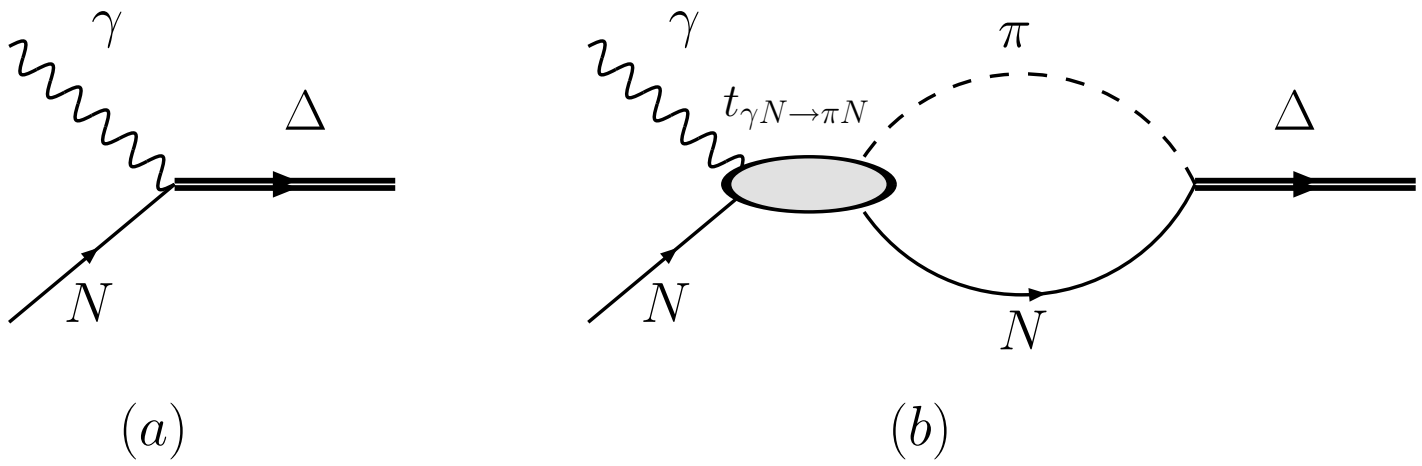


Usual QM spin flip

Interpretation



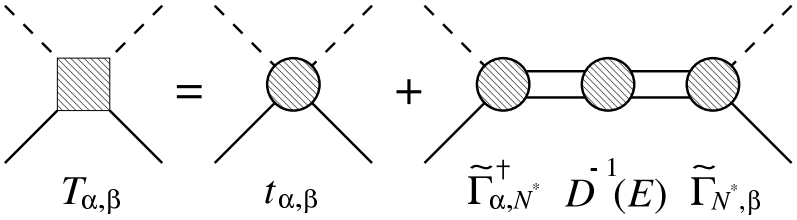
A reaction theory is needed to
properly interpret the extensive amount of data

The main two ingredients are:

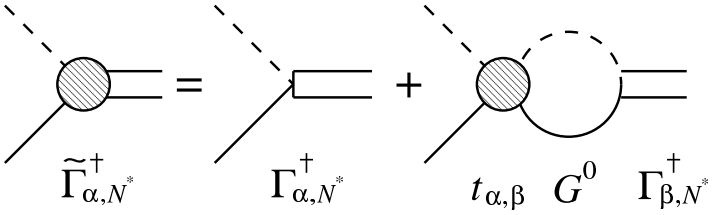
- The bare reaction mechanism
- An account of external dynamics: coupled channel

Theoretical Framework: Coupled Channels

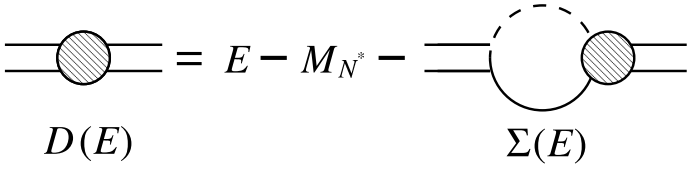
Non-resonant + resonant



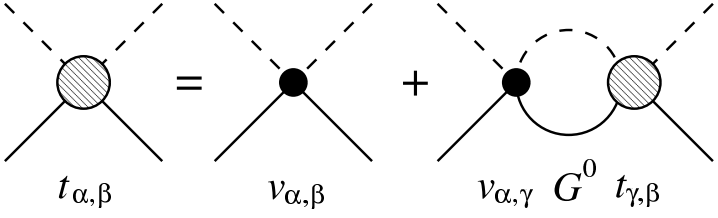
dressed resonant vertexes



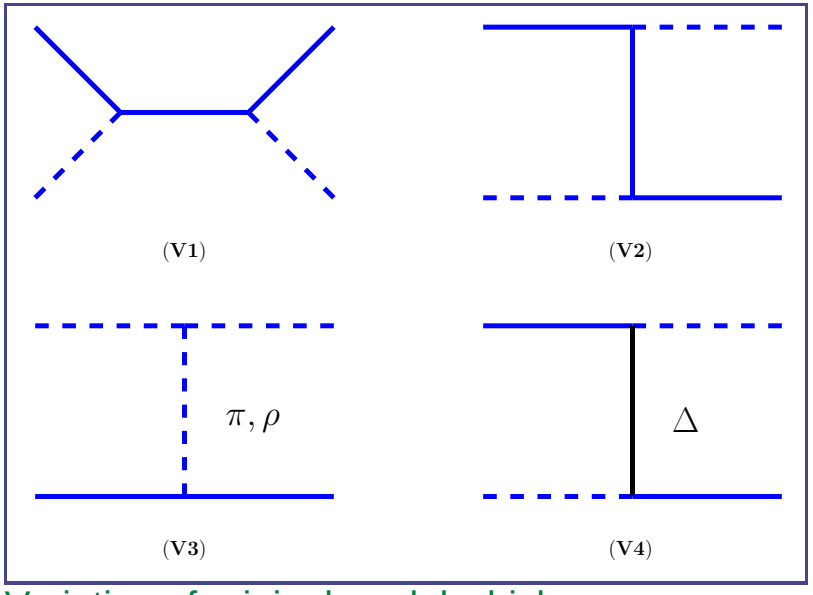
resonant self-energies

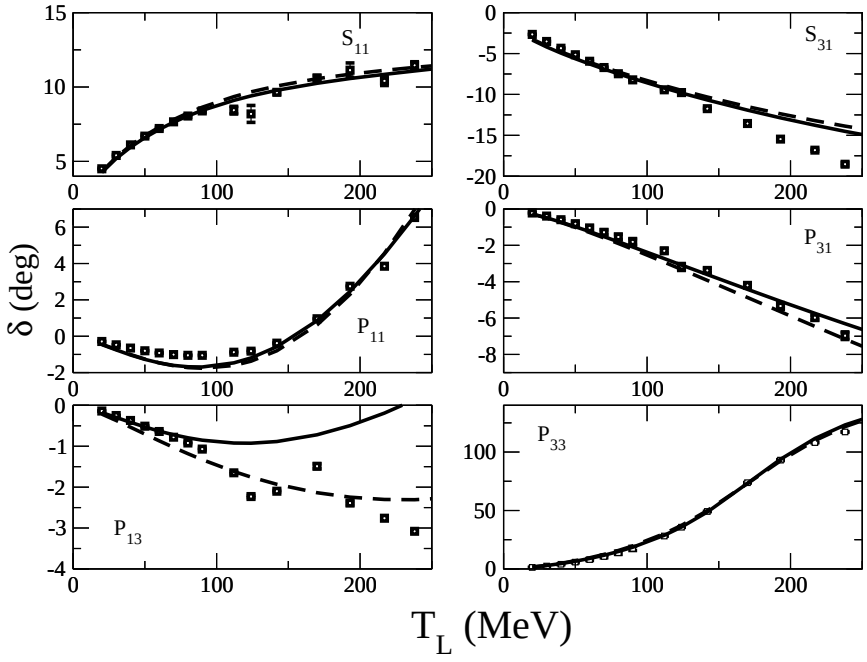


non-resonant tmatrix



Dynamical SL model

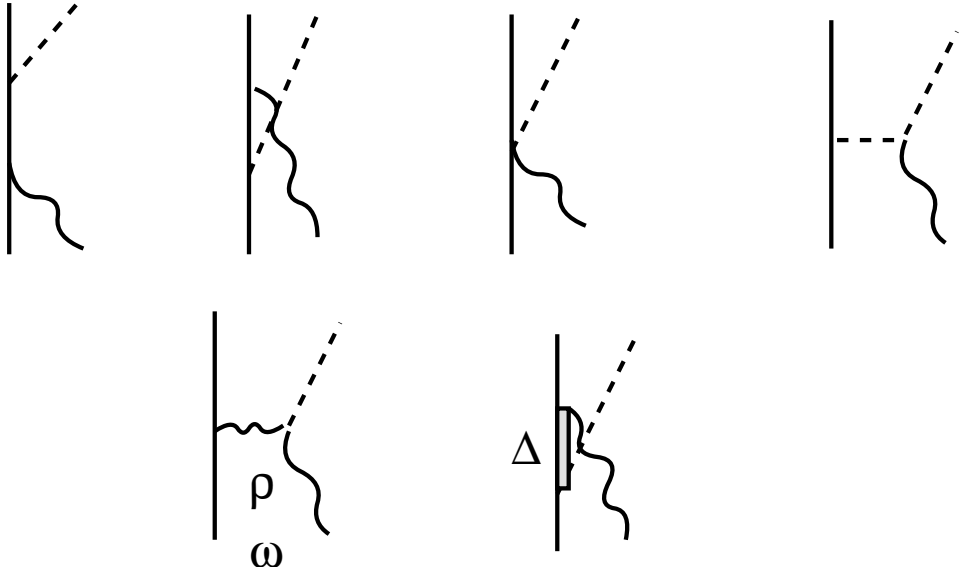




Variation of original model which

improves P_{13} partial wave

Parameter	L2	L
$g_{\rho NN} g_{\rho\pi\pi}$	37.133	38.4329
k_ρ	2.8496	1.825
$\Lambda_{\pi NN}$	3.6177	3.2551
Λ_ρ	7.4639	6.2305
$\Lambda_{\pi N\Delta}$	3.2132	3.29
Bare m_Δ	1296.9	1299.07
$[f_{\pi N\Delta}\sqrt{25/72}]$	1.1664	1.207



Extraction of bare form factors

The photoexcitation of the Δ is described through,

$$\langle \Delta | \mathcal{I}^\mu | N \rangle = e \bar{\Psi}_\nu(p^*) \Gamma^{\nu\mu} \Psi(p)\,, \qquad \Gamma^{\nu\mu} = \sum_i G_i(Q^2)\, \mathcal{K}_i^{\nu\mu}\,.$$

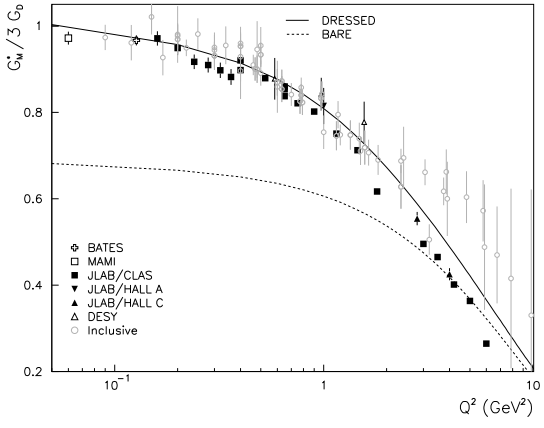
G_E, G_C and G_M are defined from G_i Jones, Scadron (1972)

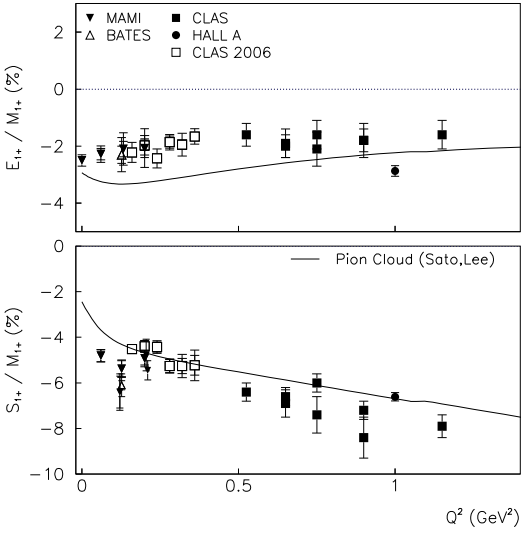
Originally, the form factors were parametrized as:

$$G_\alpha(Q^2) = G_\alpha(0) \left(\frac{1}{1+Q^2/0.71} \right)^2 R_\alpha(Q^2)$$

$$R_\alpha(Q^2) = (1 + aQ^2) \exp(-bQ^2)$$

$$\alpha = E, M, C$$

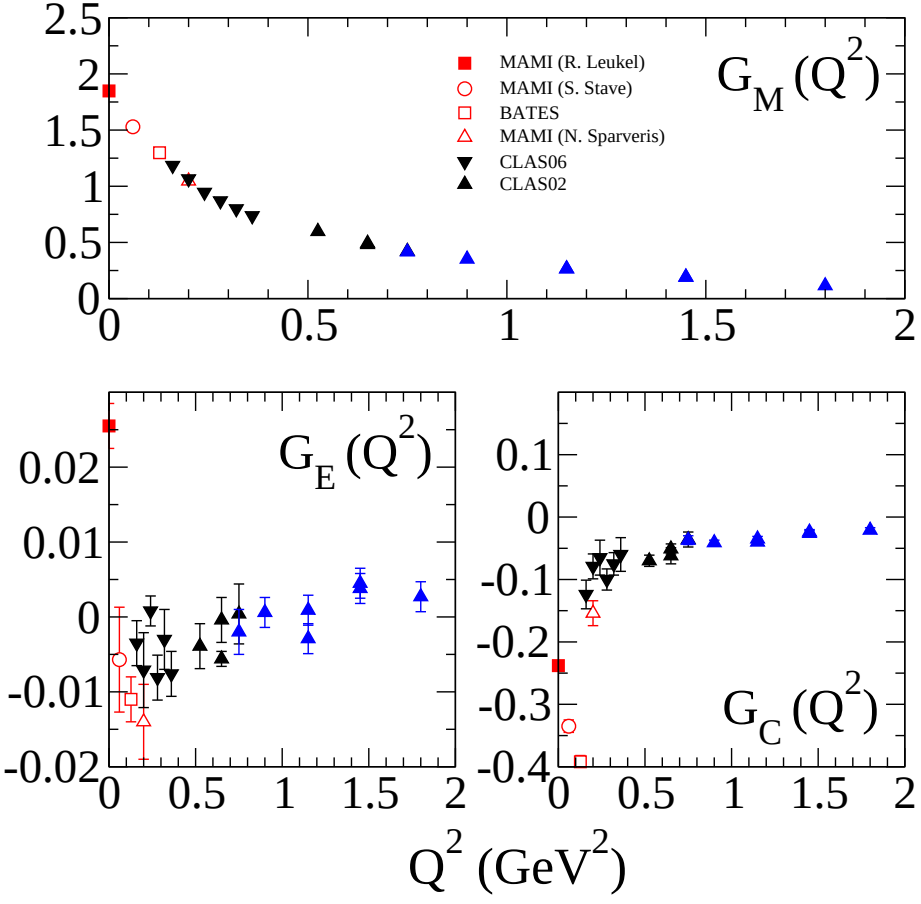




Extraction of bare form factors (II)

Bare form factors do not contain any intermediate meson-baryon states

- No particular behavior assumed for bare FF
- Fit at each Q^2 the electroproduction data fixing $G_\alpha(Q^2)$
- Fits using both L and L2 models for πN



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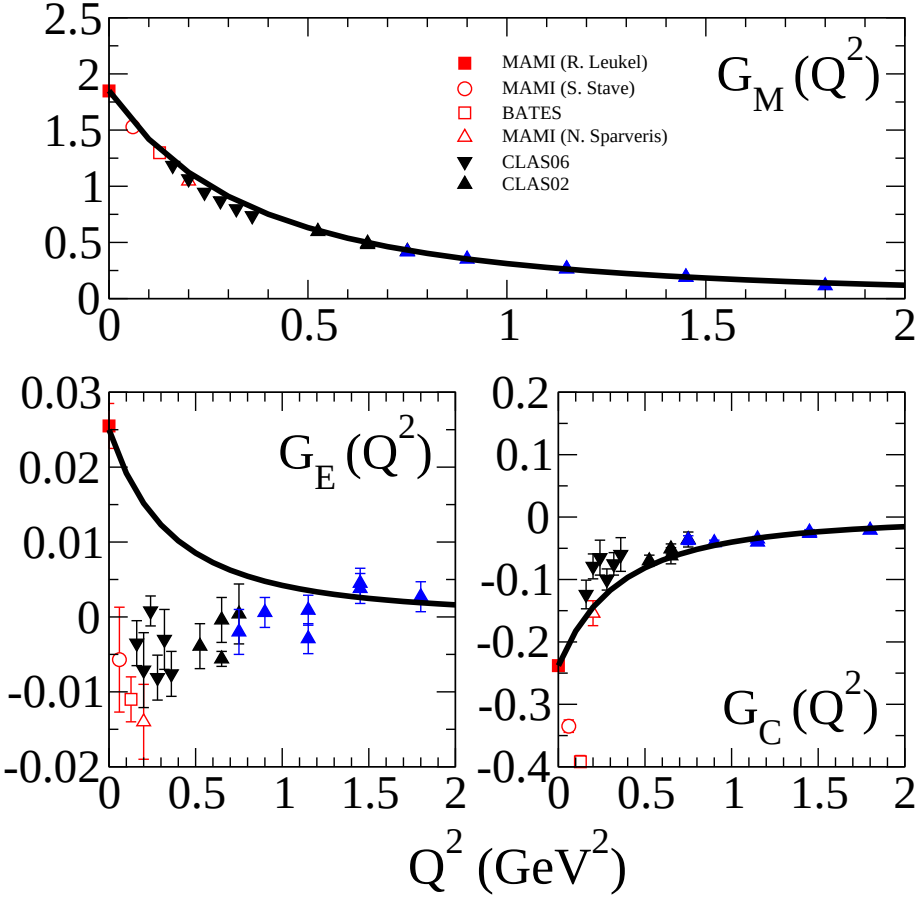
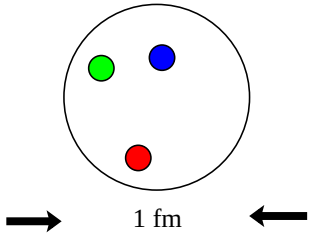


Relativistic Quark Models

few GeV region relativity is important:



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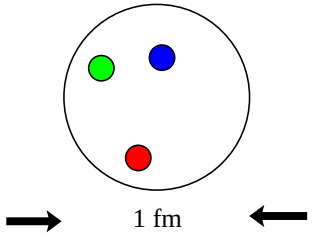
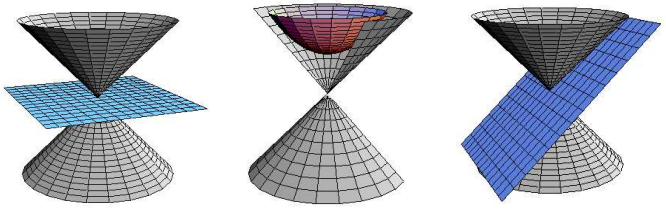


Different ways of implementing relativity into a quark model formalism:



- Instant form
- Point form
- Front form

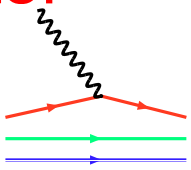
In collaboration with D. O. Riska (U. Helsinki) Plots form A. Krassnigg's PhD thesis

RQM (II)

Common assumptions to the three forms

Single quark current operator

- baryons



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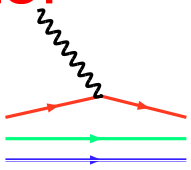


- Ground state wave functions with 2 or 3 parameters

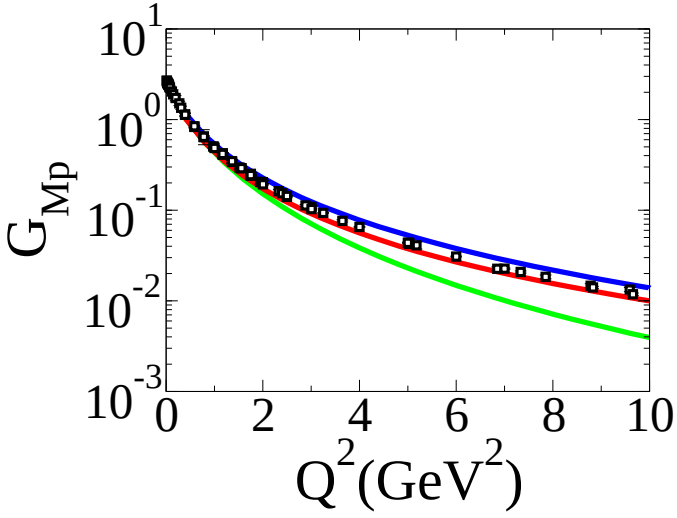
$$\varphi_0^G(\vec{q}) = \frac{1}{(b\sqrt{\pi})^{3/2}} e^{-\vec{q}^2/2b^2}, \qquad \varphi_0^R(\vec{q}) = \mathcal{N}(1+\vec{q}^2/2b^2)^{-a},$$

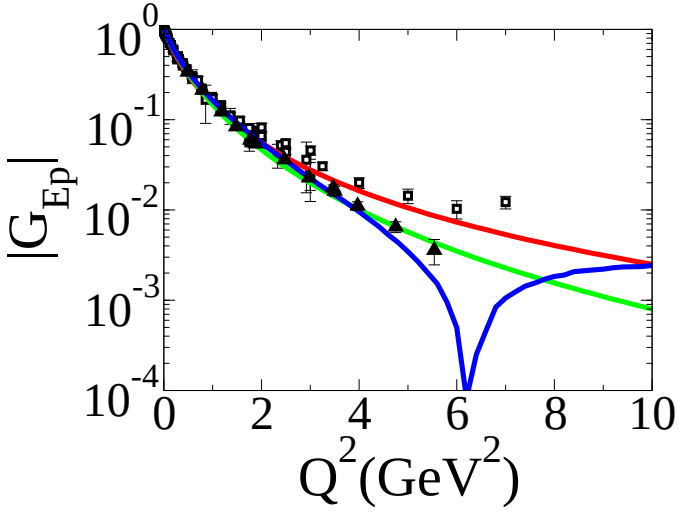
$$\varphi_0(\mathsf{P}) = \mathcal{N}\left(1+\frac{\mathsf{P}^2}{4b^2}\right)^{-a}, \text{with } \mathsf{P} := \sqrt{2(\vec{\kappa}^2+\vec{q}^2)}$$

$SU(6)_{FS}$ is used to build resonances

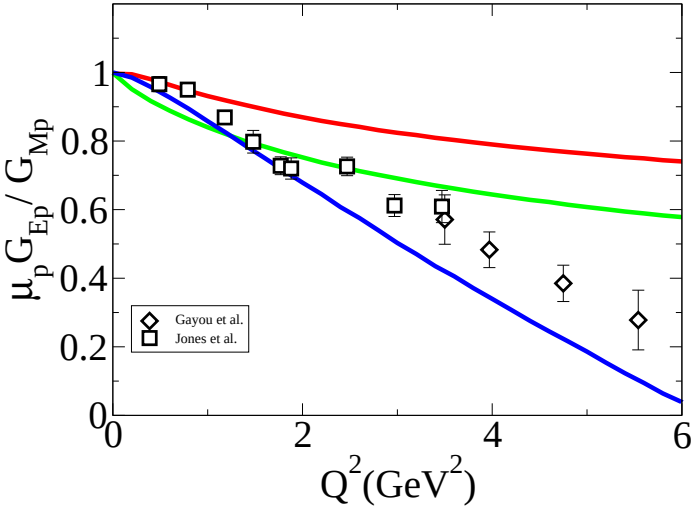
Proton Form Factors

Instant
Point
Front





- **Params fixed to G_{Mp}, G_{Mn}(0)**
  (m_q, 2 parameters for w.f)
- **All forms OK**
  - ∼ Chung & Coester, PRD 44, 229 (91)
  - ∼ Boffi et al. EPJA 14, 17 (02)
- **High Q^2 behavior different**
- **Front form predicts a node**



$\gamma N \longrightarrow \Delta$

The general expression for the transition current operator:

$$\langle \Delta | \mathcal{I}^{\mu}(0) | N \rangle = e \bar{\Psi}_{\nu}(p^*) \Gamma^{\nu\mu} \Psi(p) \, ,$$

has the conventional decomposition:

$$\Gamma^{\nu\mu} = \sum_i G_i(Q^2) \, \mathcal{K}_i^{\nu\mu} \, .$$

The operators $\mathcal{K}_i^{\nu\mu}$ are defined as:

$$\mathcal{K}_1^{\nu\mu} = \frac{Q^{\nu}\gamma^{\mu} - (\gamma \cdot Q) g^{\nu\mu}}{\sqrt{Q^2}} \sqrt{M^* M} \gamma_5 \, ,$$

$$\mathcal{K}_2^{\nu\mu} = \frac{Q^{\nu} P^{\mu} - (P \cdot Q) g^{\nu\mu}}{\sqrt{Q^2}} \gamma_5 \, ,$$

$$\mathcal{K}_3^{\nu\mu} = \frac{Q^{\nu} Q^{\mu} - Q^2 g^{\nu\mu}}{\sqrt{Q^2}} M^* \gamma_5 \, .$$

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$$G_E^* = \frac{M}{3(M^* + M)} \left[\frac{M^{*2} - M^2 - Q^2}{M^*} \frac{\sqrt{M^* M}}{Q} G_1 + \frac{M^{*2} - M^2}{Q} G_2 - 2M^* G_3 \right] ,$$

$$G_M^* = \frac{M}{3(M^* + M)} \left[\frac{(3M^* + M)(M^* + M) + Q^2}{M^*} \times \frac{\sqrt{M^* M}}{Q} G_1 + \frac{M^{*2} - M^2}{Q} G_2 - 2M^* G_3 \right] ,$$

$$G_C^* = \frac{2M}{3(M^* + M)} \left[\frac{2M^* \sqrt{M^* M}}{Q} G_1 + \frac{3M^{*2} + M^2 + Q^2}{2Q} G_2 + \frac{M^{*2} - M^2 - Q^2}{Q^2} M^* G_3 \right] .$$

$\gamma N \longrightarrow \Delta$ (II)

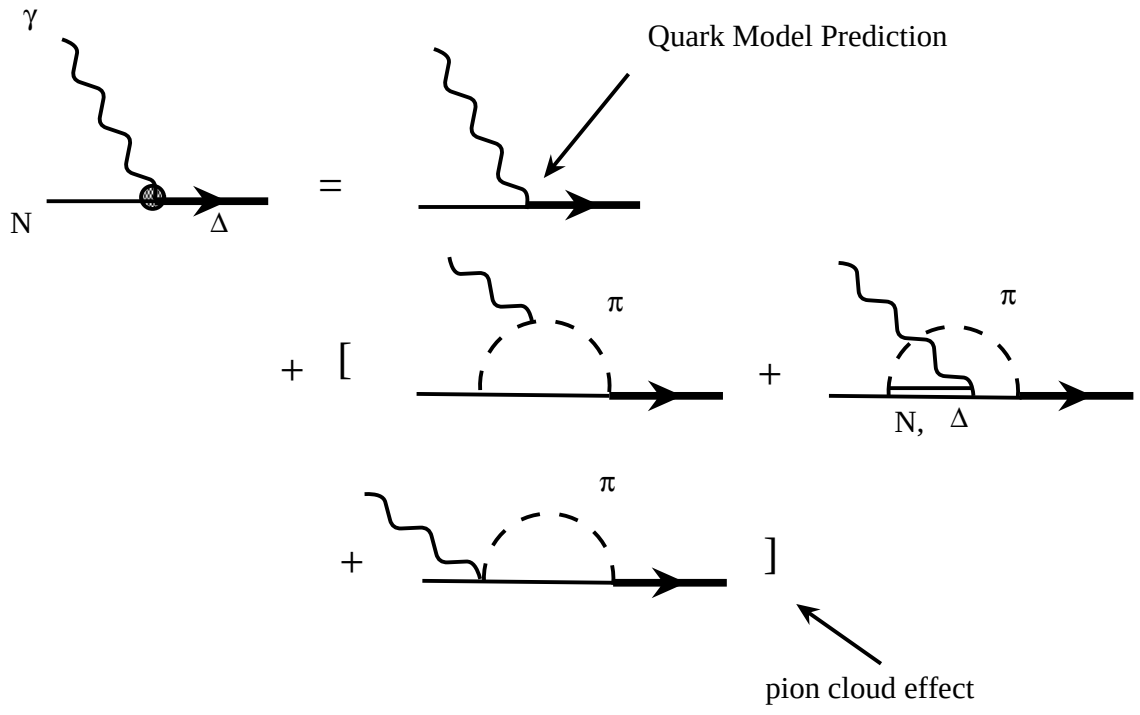
In instant form kinematics the relation between the different spin state matrix elements of the electromagnetic current and the form factors, G_j,

$I_{\alpha',\alpha} = \langle \Delta m_s = \alpha' | I | N m_s = \alpha \rangle$

$$
\begin{aligned}
I^1_{\frac{3}{2},\frac{1}{2}} &= \left[\frac{M^* + M}{\sqrt{Q^2}} G_1 + \frac{M^{*2} - M^2}{2\sqrt{Q^2 M M^*}} G_2 - \sqrt{\frac{M^*}{M}} G_3 \right] \frac{Q_3}{2\sqrt{E(M+E)}} \,, \\
I^1_{\frac{1}{2},-\frac{1}{2}} &= -\frac{\sqrt{3}}{6} \left[\frac{M^* + M}{\sqrt{Q^2}} G_1 + \frac{M^{*2} - M^2}{2\sqrt{Q^2 M M^*}} G_2 - \sqrt{\frac{M^*}{M}} G_3 \right] \frac{Q_3}{\sqrt{E(M+E)}} \\
&+ \frac{\sqrt{3}}{3} \frac{Q_3}{\sqrt{Q^2}} \frac{M+E}{\sqrt{E(M+E)}} G_1 \,, \\
I^0_{\frac{1}{2},\frac{1}{2}} &= -\frac{\sqrt{3}}{3} \left[\frac{Q_3}{\sqrt{Q^2}} G_1 + \frac{Q_3}{\sqrt{Q^2 M M^*}} \frac{E + M^*}{2} G_2 + \frac{Q_3 Q_0}{Q^2} \sqrt{\frac{M^*}{M}} G_3 \right] \frac{Q_3}{\sqrt{E(M+E)}} \,.
\end{aligned}
$$

Meson-cloud effects

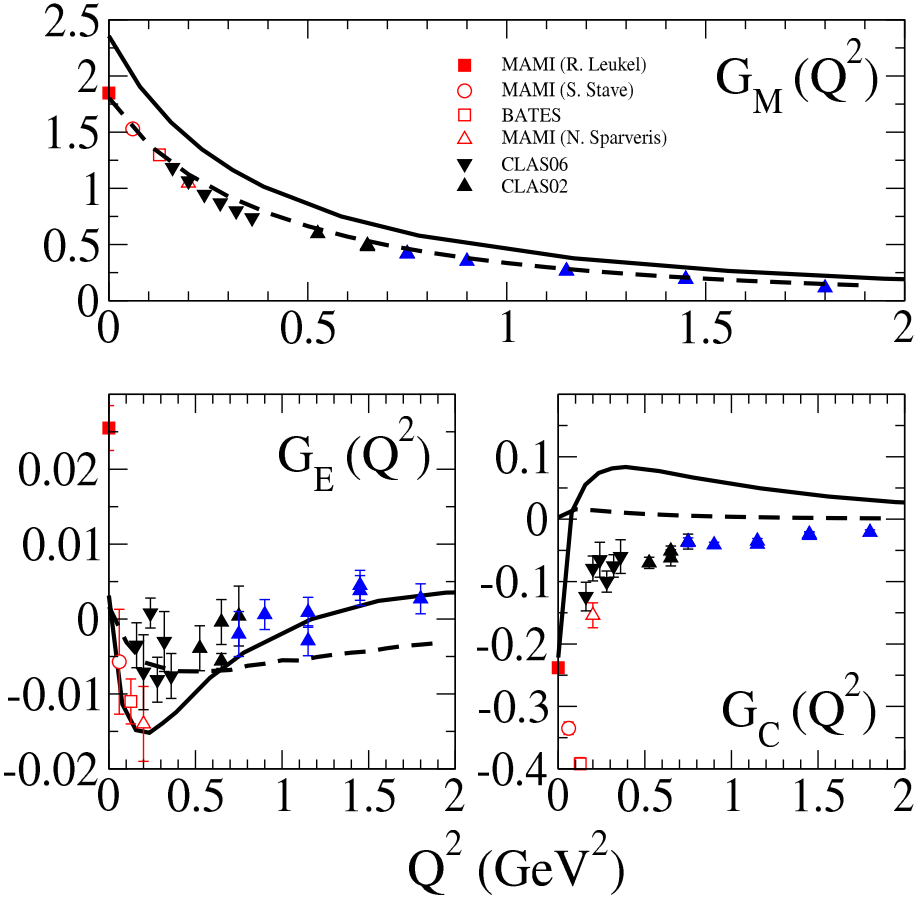
In the dynamical coupled channel formalism, the following meson cloud diagrams can be isolated:



Interpretation of bare form factors

Bare Form factors parametrize the internal structure thus their interpretation should be sought in microscopic theories

- We compare quark model results to the extracted bare form factors
- Capstick-Keister computations done in front form
- Pion cloud effects are more pronounced in G_E and G_C.



Interpretation of bare form factors

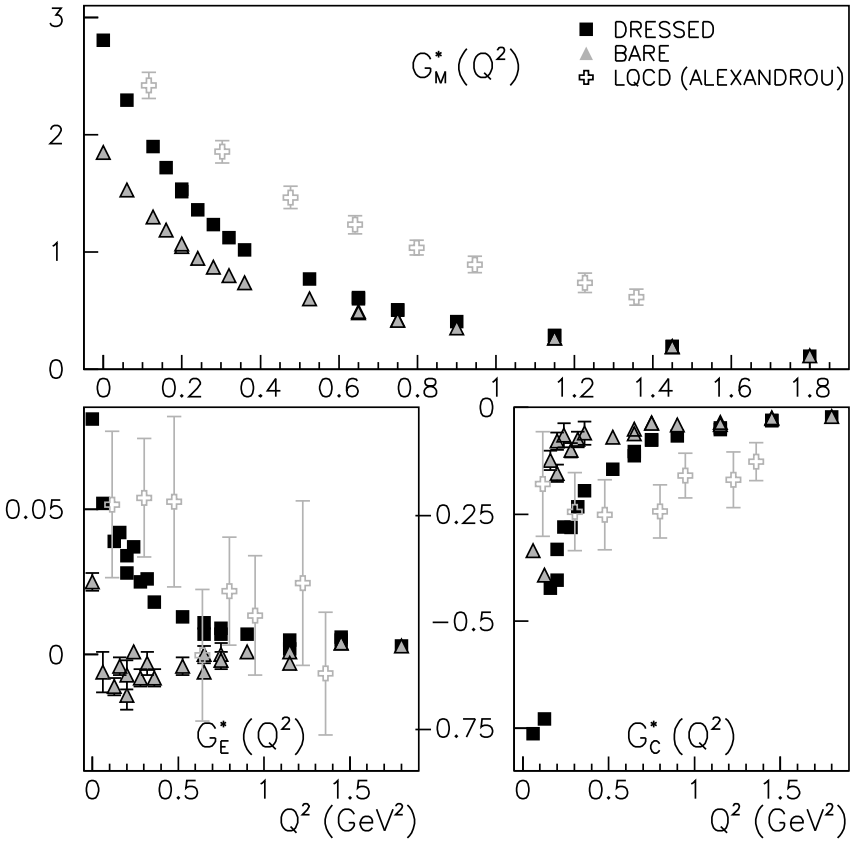
Comparison with QCD should be pursued

In the near future, connection with form factors computed in Lattice-QCD will be done

This, however, may require specifi c LQCD studies

In the fi gure,

- Our extracted bare and dressed form factors
- Recent LQCD analysis



Interpretation of dressed ratios

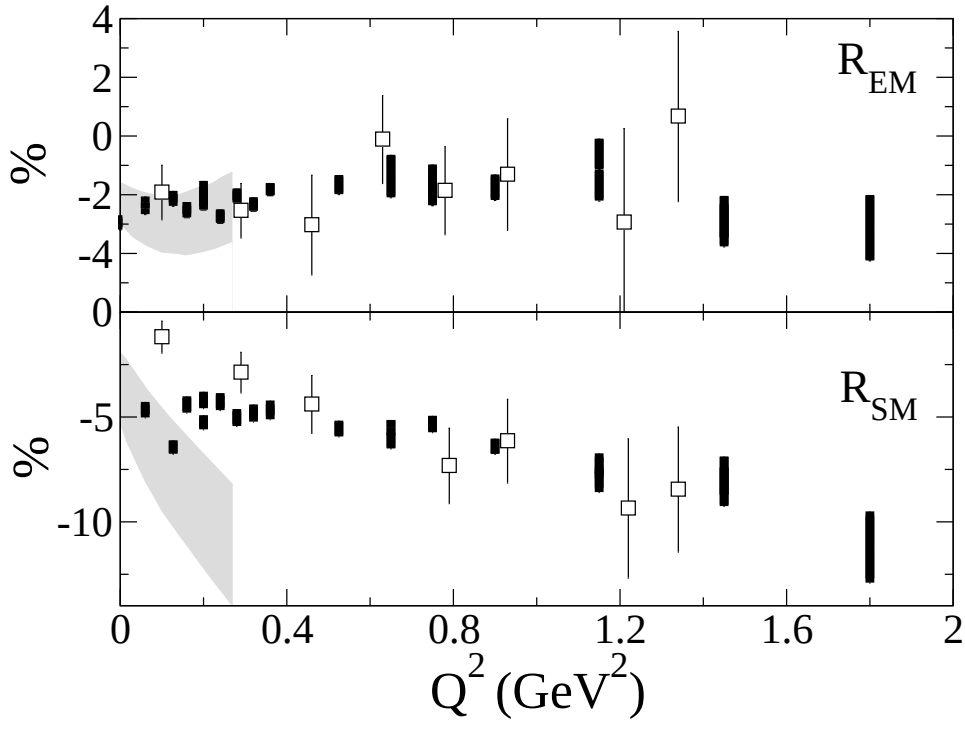
Ratios of form factors are usually plotted

reminder of pQCD predictions:

$R_{EM} \to 1 \qquad Q^2 \to \infty$

$R_{SM} \to \text{constant} \qquad Q^2 \to \infty$

- solid symbols: L and L2 models, together
- squares: LQCD of Alexandrou et al [PRL05]
  - Chiral extrapolation?
- band: EFT of Pascalutsa and Vanderhagen [PRD06]
  - low range of Q^2



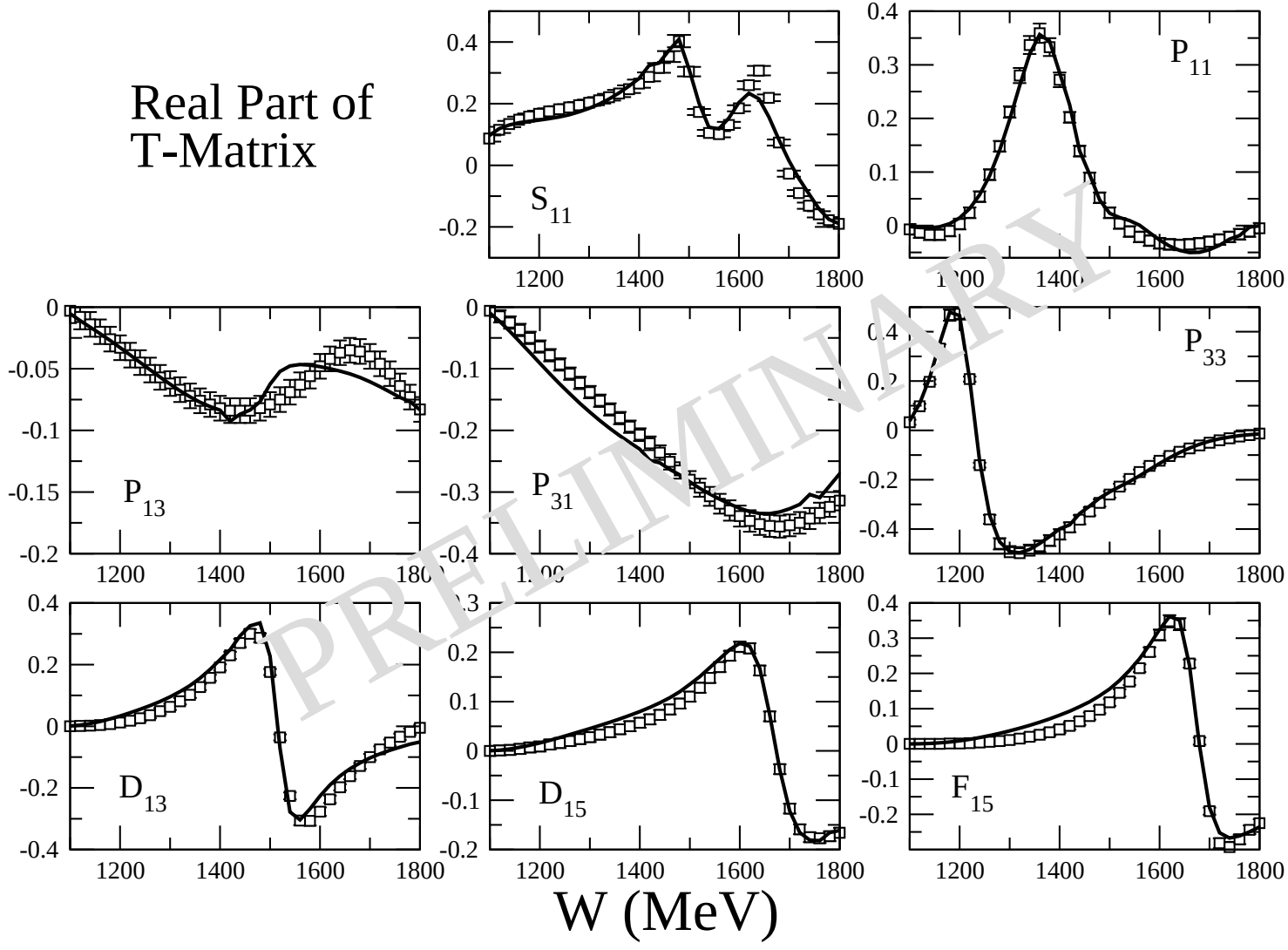
Current efforts

"Dynamical Coupled-Channel Analysis of N* at EBAC"
B. Julia-Diaz, T-S.H. Lee, A. Matsuyama, M. Paris, T. Sato

- First step: Build a well constrained model for $\pi N - \pi N$ including πN, ηN, ($\pi\Delta$, σN, ρN) and explicit $\pi\pi N$ states. (expected $\approx$ Dec 2006)
  - A parallel version of the code has been derived
  - Computing time at several supercomputing facilities:
    - NERSC (LBNL, USA) (startup grant)
    - Marenostrum (BSC, Spain) (production grant)
  - Study of bare/dressed form factors

Preliminary: 5 channel model for πN

Extension of the πN model up to 2 GeV.



Summary

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  - **We have studied model dependence**

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  - Maybe a join effort should be pursued